

Review

Human-Centric Collaboration and Industry 5.0 Framework in Smart Cities and Communities: Fostering Sustainable Development Goals 3, 4, 9, and 11 in Society 5.0

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Abstract: The necessity for substantial societal transformations to meet the Sustainable Development Goals (SDGs) has become more urgent, especially in the wake of the COVID-19 pandemic. This paper examines the critical role of disruptive technologies, specifically Industry 5.0 and Society 5.0, in driving sustainable development. Our research investigation focuses on their impact on product development, healthcare innovation, pandemic response, and the development of nature-inclusive business models and smart cities. We analyze how these technologies influence SDGs 3 (Good Health and Well-Being), 4 (Quality Education), 9 (Industry, Innovation, and Infrastructure), and 11 (Sustainable Cities and Communities). By integrating these concepts into smart cities, we propose a coordinated framework to enhance the achievement of these goals. Additionally, we provide a SWOT analysis to evaluate this approach. This study aims to guide industrialists, policymakers, and researchers in leveraging technological advancements to meet the SDGs.

Keywords: sustainable development goals (SDGs); disruptive technologies; smart cities; industry 5.0; society 5.0; human centric



Citation: Adel, A.; HS Alani, N. Human-Centric Collaboration and Industry 5.0 Framework in Smart Cities and Communities: Fostering Sustainable Development Goals 3, 4, 9, and 11 in Society 5.0. *Smart Cities* **2024**, *7*, 1723–1775. <https://doi.org/10.3390/smartcities7040068>

Academic Editor: Pierluigi Siano

Received: 18 May 2024

Revised: 1 July 2024

Accepted: 3 July 2024

Published: 5 July 2024



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1. Introduction

The Sustainable Development Goals (SDGs), established by the United Nations in September 2015, outline a global agenda for fostering prosperity, protecting the planet, and improving the lives of people worldwide. Adopted by 193 member states, these 17 goals and 169 associated targets are designed to prompt action in vital areas essential to both humanity and the environment. While substantial research has been conducted on the role of disruptive technologies in advancing the SDGs, there is a significant gap in understanding the integrated impact of Industry 5.0 and Society 5.0 technologies within smart cities and communities. Our research uniquely addresses this gap by proposing a comprehensive framework that integrates these technologies to enhance the achievement of SDGs 3, 4, 9, and 11. This commitment underscores the critical role of corporate participation in addressing global challenges through sustainable practices and solutions [1].

Figure 1 presents a temporal distribution of publications or activities related to the Sustainable Development Goals (SDGs) over several dates in April 2024. Each colored segment in the bars corresponds to a specific SDG, illustrating the focus and volume of efforts directed towards each goal throughout the month. This visualization highlights the dynamic engagement across different SDGs, reflecting how priorities or emphasis may shift over time. Such trends are critical for understanding the progress in addressing global challenges and can aid policymakers, researchers, and stakeholders in evaluating the impact of their initiatives and adjusting their strategies accordingly.

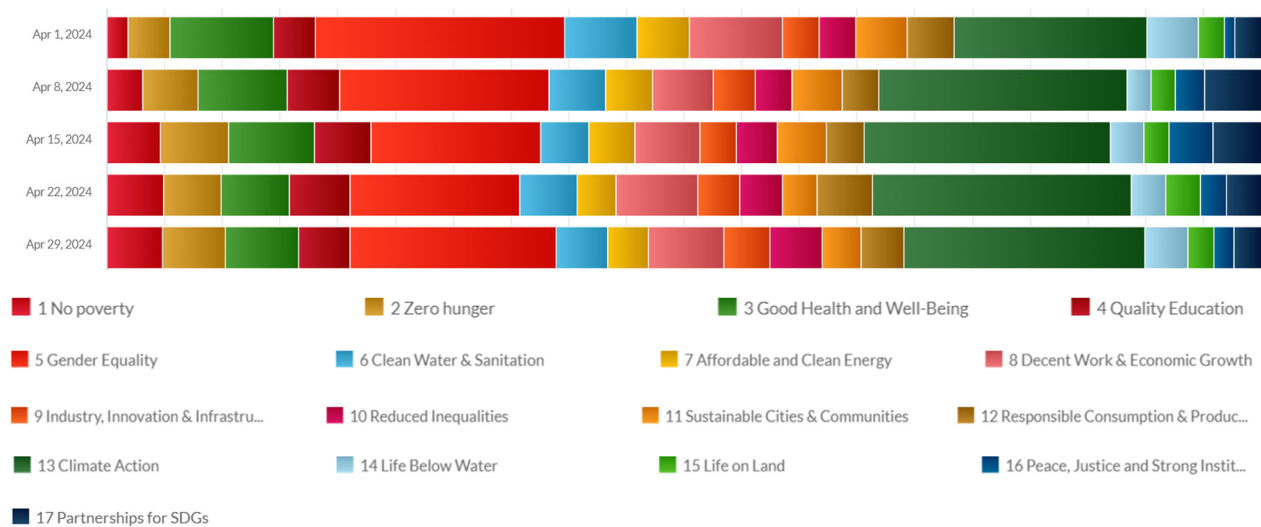


Figure 1. Distribution of recent publications by Sustainable Development Goal [1].

This study explores the pivotal role of disruptive technologies in advancing the Sustainable Development Goals (SDGs). By examining how these technologies influence the achievement of SDGs, the research sheds light on their potential to significantly accelerate progress towards these goals. Disruptive technologies, known for their revolutionary impact, have the capability to transform various sectors by introducing more efficient, scalable, and sustainable solutions. The study provides a qualitative analysis of the interactions between these technologies and the SDGs, mapping out the specific areas where their influence is most pronounced. Through a comprehensive analysis, it identifies the direct impacts of disruptive technologies on each SDG, highlighting the ways in which they can foster a quicker and more effective realization of sustainable development objectives. This analysis not only clarifies the mechanisms through which these technologies operate but also underscores the integrated nature of technological advancement and sustainable development.

Disruptive technologies, characterized by their ability to radically change business models, industry landscapes, and societal structures, are at the forefront of shaping the future of smart cities and communities [2]. As we transition into Industry 5.0, these technologies are set to play a pivotal role in enhancing the efficiency, sustainability, and livability of urban environments [3]. Industry 5.0, which builds on the automation and connectivity of Industry 4.0, emphasizes the reintegration of human touch and craftsmanship enhanced by advanced technologies, promoting a balance between automated industrial production and human creativity [4]. This evolution holds immense potential for smart cities and communities, driving innovations that are not only technologically advanced but also socially inclusive.

The core of Industry 5.0 within smart cities revolves around the use of disruptive technologies, such as the Internet of Things (IoT), artificial intelligence (AI), robotics, big data analytics, and blockchain [5]. IoT devices are instrumental in smart cities, providing a backbone for connected infrastructure. They allow for real-time data collection from various sources, such as sensors on roads, buildings, and vehicles, facilitating efficient resource management, urban planning, and emergency response systems. AI and machine learning algorithms leverage this data to optimize traffic flows, reduce energy consumption, predict maintenance issues, and enhance public safety through predictive policing and emergency management. Robotics, enhanced by AI, plays a crucial role in Industry 5.0 by performing tasks that can be hazardous, such as maintenance of high-voltage equipment or sewer systems, thus ensuring safety and efficiency [6]. Moreover, robots equipped with AI are increasingly used in personalized healthcare within communities, supporting the aging population and enhancing the quality of life. Big data analytics in smart cities processes

vast amounts of data generated by urban activities to provide insights that drive cost reductions, improve services, and make cities more adaptable to the needs of their residents. For example, analyzing traffic and mobility data helps in designing better transportation systems that reduce congestion and pollution. Blockchain technology offers transformative potential in governance and accountability, enabling transparent and secure transactions [7]. It can be used for everything from voting systems to real estate transactions, ensuring integrity and reducing fraud. In smart cities, blockchain technology could revolutionize utility management and billing, property registration, and even citizen identity systems.

In the wake of the COVID-19 pandemic, the urgency to achieve the Sustainable Development Goals (SDGs) has intensified, necessitating substantial societal and technological transformations. This study uniquely integrates the concepts of Industry 5.0 and Society 5.0, leveraging disruptive technologies such as AI, IoT, robotics, and blockchain within the framework of smart cities and communities. Unlike previous studies that address these paradigms in isolation, our interdisciplinary approach provides a comprehensive framework for sustainable development.

The integration of these technologies within the framework of Industry 5.0 can significantly enhance the capacity of smart cities to not only manage their resources more effectively but also improve the quality of life for their inhabitants [8]. By fostering an environment where technology and human ingenuity coexist harmoniously, Industry 5.0 aims to create more inclusive and sustainable urban areas.

This study aims to investigate the transformative potential of Industry 5.0 and Society 5.0 technologies in achieving the Sustainable Development Goals (SDGs) and to provide a comprehensive analysis of how disruptive technologies can be harnessed to drive sustainable development across various sectors. Our specific research goals are as follows:

1. **Goal 1:** To analyze the integration of Industry 5.0 technologies, such as AI, IoT, robotics, and blockchain, within the ITSD framework and their impact on SDGs 3, 4, 9, and 11.
2. **Goal 2:** To develop a comprehensive framework that combines these technologies with human-centric design and sustainability principles, providing a pathway for smart cities and communities.
3. **Goal 3:** To identify the challenges and barriers associated with the adoption and integration of these technologies and propose strategies to overcome them.

Based on these goals, we put forward the following hypotheses:

Hypothesis 1: *The integration of Industry 5.0 technologies within the ITSD framework significantly enhances the achievement of SDGs 3 (Good Health and Well-Being), 4 (Quality Education), 9 (Industry, Innovation, and Infrastructure), and 11 (Sustainable Cities and Communities).*

Hypothesis 2: *The ITSD framework, incorporating human-centric design and sustainability principles, provides a resilient foundation for addressing contemporary global challenges and future societal needs.*

Hypothesis 3: *The primary challenges to the adoption of Industry 5.0 technologies include high initial costs, complexity of integration, cybersecurity risks, and ethical concerns, which can be mitigated through continuous monitoring, feedback mechanisms, and strong partnerships among stakeholders.*

Our study focuses on four key SDGs: SDG 3 (Good Health and Well-Being), SDG 4 (Quality Education), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 11 (Sustainable Cities and Communities). These goals were selected due to their critical importance in fostering resilient and inclusive societies. By examining the integration of disruptive technologies in these areas, we seek to demonstrate their potential to create significant positive impacts.

Specifically, the research explores how technologies such as artificial intelligence, the Internet of Things (IoT), robotics, big data analytics, and blockchain can revolutionize

product development, healthcare innovation, pandemic response, and the development of smart cities. The study also addresses the concept of nature-inclusive business models, emphasizing the need for environmentally sustainable practices in technology integration.

A key component of this work is the development of a coordinated framework that outlines how these disruptive technologies can be systematically integrated into smart cities and communities. This framework aims to provide a strategic roadmap for policymakers, industrialists, and researchers to follow, ensuring that technological advancements are aligned with sustainable development objectives.

Furthermore, the study includes a SWOT analysis to evaluate the strengths, weaknesses, opportunities, and threats associated with this integrated approach. The findings from this analysis are intended to guide stakeholders in identifying and mitigating potential challenges, thereby enhancing the efficacy of efforts to achieve the SDGs through technological innovation.

The structure of the remainder of this paper is organized as follows: The next section clarifies the research method, followed by a comprehensive literature review. Subsequent sections examine the impact of disruptive technologies on the Sustainable Development Goals and discuss smart cities and communities as products of integrated disruptive technologies. Further, the paper explores how disruptive technologies are integrated within Industry 5.0 to support SDG achievement. The paper concludes with a comprehensive discussion and conclusion on the findings.

2. Research Method

The research methodology employed in this review paper involves a systematic and comprehensive analysis of the existing literature, case studies, and empirical data related to the integration of disruptive technologies within the framework of Industry 5.0 and Society 5.0 to achieve Sustainable Development Goals (SDGs). The goal of this approach is to provide a holistic understanding of the key components, challenges, and potential solutions associated with leveraging these technologies for sustainable development. The following steps outline the research methodology and selection criteria process for the sources used in this review paper, as shown in Figure 2.

Literature Search

A thorough search of scholarly databases, online repositories, and professional journals was conducted to identify relevant articles, books, reports, and conference proceedings addressing the topics of Industry 5.0, Society 5.0, and their role in achieving SDGs. To ensure a comprehensive literature search, a systematic search query was designed using relevant keywords and phrases related to disruptive technologies, Industry 5.0, Society 5.0, and sustainable development. An electronic search on various platforms, including Google Scholar, ACM Digital Library, ScienceDirect, IEEE Xplore, Scopus, and Springer, was conducted. The following search queries were utilized to gather sources for this review:

- a. (("Industry 5.0" OR "Society 5.0" OR "disruptive technologies") AND ("Sustainable Development Goals" OR "SDGs") AND ("artificial intelligence" OR "AI" OR "machine learning" OR "ML") AND ("smart cities" OR "healthcare innovation" OR "product development"))
- b. (("human-machine collaboration" OR "advanced technologies in industry") AND ("pandemic response" OR "nature-inclusive business models") AND ("IoT" OR "Internet of Things") AND ("urban planning" OR "smart communities"))
- c. (("Industry 5.0" OR "Society 5.0") AND ("blockchain" OR "big data analytics") AND ("challenges" OR "ethical considerations" OR "data privacy"))
- d. (("disruptive technologies" OR "AI" OR "robotics") AND ("sustainable development" OR "SDGs") AND ("implementation" OR "case studies"))
- e. (("Industry 5.0" OR "Society 5.0") AND ("future research directions" OR "emerging trends" OR "research opportunities") AND ("policy implications" OR "stakeholder collaboration"))

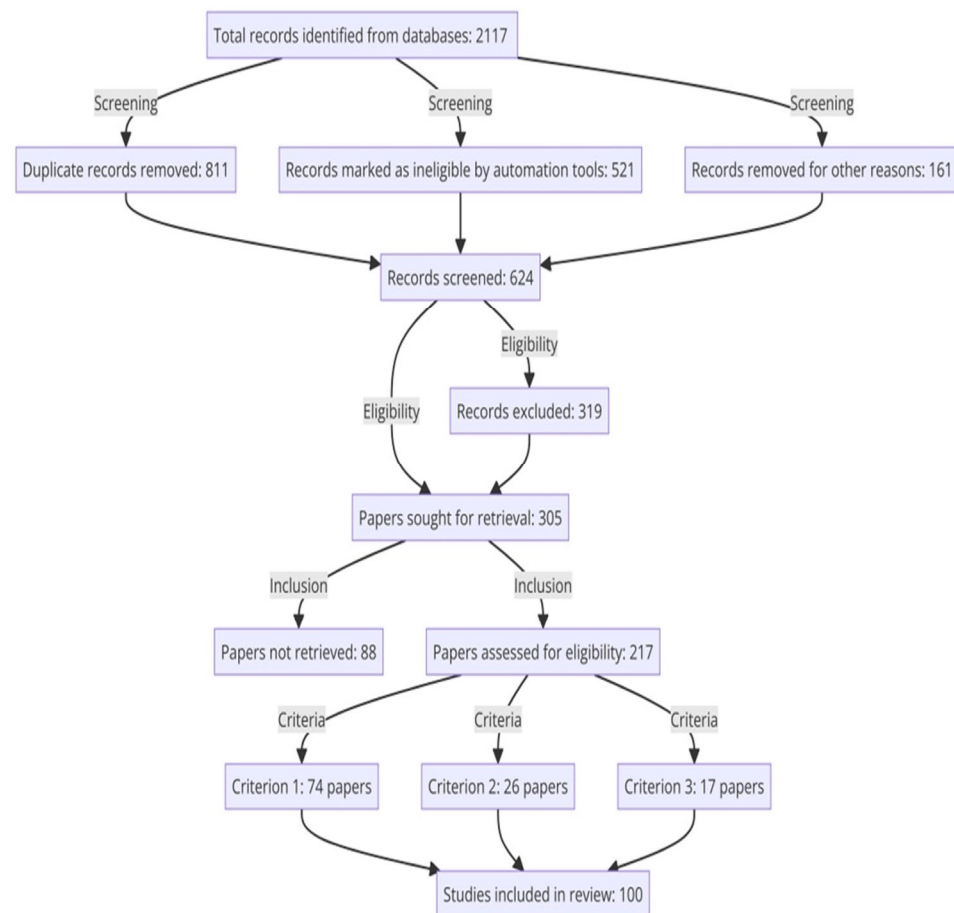


Figure 2. Selection criteria process.

3. Literature Review

The progression of industrial paradigms has significantly influenced the course of human advancement. Industry 1.0 introduced mechanized labor using water and steam power. Industry 2.0 ushered in mass production powered by electricity. The digital age began with Industry 3.0 through the incorporation of computers and automation, which further developed into the cyber-physical systems of Industry 4.0. Now, on the brink of a new era, we are experiencing the rise of Industry 5.0, a paradigm that aims to seamlessly blend human creativity with machine capabilities [5]. Industry 5.0, characterized by resilience, sustainability, and human-centricity, is a technological-organizational framework that emphasizes human well-being and sustainable society [8]. The integration of Industry 5.0 and Society 5.0 in smart cities and communities is seen as a key driver for achieving Sustainable Development Goals (SDGs) 3, 4, 9, and 11 [9]. However, there is a need to ensure that Industry 5.0 is truly human-oriented, with a focus on empowering workers and creating sustainable and resilient production systems [10]. The human-centric approach of Industry 5.0 is further emphasized in the proposed human-centric Industry 5.0 collaboration architecture, which aims to integrate innovative technologies with human actors [11]. The transition from Industry 4.0 to Society 5.0, with a focus on sustainability and human well-being, is further explored [12–16]—(see Table 1).

Table 1. Comparison of related studies and their contribution.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
Unlocking the Future: Fostering Human–Machine Collaboration and Driving Intelligent Automation through Industry 5.0 in Smart Cities [5]	The paper explores various technological advancements that will shape the future of smart cities, including cyber–physical systems, fog computing, unmanned aerial vehicles, renewable energy, machine learning, deep learning, cybersecurity, and digital forensics. The paper highlights the role of Industry 5.0 in enabling advanced cybersecurity measures, fostering human–machine collaboration, driving intelligent automation in urban services, and refining data management and decision-making in smart cities. The paper reviews existing smart city frameworks and evaluates how Industry 5.0 technologies could augment these frameworks, while also addressing the technological challenges faced by smart cities and proposing Industry 5.0-enabled solutions.	The methodology of the study is an exhaustive survey and literature review to analyze future technologies, including Industry 5.0, and their implications for smart cities. The paper explores technological advancements across various domains and examines the specific role of Industry 5.0 in the smart city context.	Human–Machine Collaboration: Enhanced collaboration between humans and machines, improving productivity and decision-making. Intelligent Automation: Increased automation in urban services, driven by AI and IoT technologies. Cybersecurity and Data Management: Improved cybersecurity measures and refined data management. Socio-Economic Benefits: Addressing urban challenges, such as privacy, security, and inequality, through technological advancements.	There are significant challenges and limitations from social, technological, and ethical perspectives in shifting from a high industrial performance strategy (Industry 4.0) to a human-centric strategy (Industry 5.0) The integration of digital technologies raises ethical, health, and safety concerns, which become more pronounced with the centralization of human roles in production processes.	Data privacy concerns and the lack of comprehensive, universally accepted solutions. Cybersecurity challenges in safeguarding smart city infrastructure and services. Achieving interoperability and standardization between diverse systems and devices. Effective data management strategies to handle vast data volumes. Ensuring the reliability and continuous availability of IT services addressing the digital divide and ensuring digital inclusion. Developing updated legal and regulatory frameworks to keep up with technological change. Achieving sustainability of large-scale IT infrastructure.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives [8]	Industry 5.0 is a technological-organizational framework that combines principles and technologies to design resilient, sustainable, and human-centric operations and supply chains.	The methodology employed involved conducting a cluster analysis of the existing literature focused on supply chain resilience, sustainability, and human-centric approaches.	The outcomes measured in the article centered on developing an Industry 5.0 framework that integrates the concepts of resilience, sustainability, and human-centricity.	The study's findings are mainly based on specific case studies and industry examples, which might not be easily generalizable to other sectors or broader contexts.	Implications of Industry 5.0 for future operations and supply chains remain underexplored.
	The key technological principles of Industry 5.0 are collaboration, coordination, communication, automation, data analytics, and identification.	From this analysis, a framework of Industry 5.0 was developed and further explored through the perspectives of the viable supply chain model, the reconfigurable supply chain, and business ecosystems.	This framework aimed to assess the viability of applying Industry 5.0 principles in enhancing the adaptability and efficiency of supply chains while prioritizing sustainability and human-centered approaches.	There is a limitation in the availability and quality of data that can be used to support the framework proposed. This affects the robustness and applicability of the conclusions drawn.	Open research areas on Industry 5.0 are discussed, suggesting further study is needed.
	Industry 5.0 covers four areas: organization, management, technology, and performance assessment, and spans three levels: society, network, and plant.	This approach allowed for a contextualized understanding of Industry 5.0 within these operational frameworks.	The effectiveness of this framework was evaluated through its ability to provide a cohesive structure that supports the operational and strategic alignment of these three perspectives within business ecosystems.		
	Industry 5.0 frames a new triple bottom line of resilient value creation, human well-being, and sustainable society.				

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
Realization of Sustainable Development Goals with Disruptive Technologies by Integrating Industry 5.0, Society 5.0, Smart Cities and Villages [9]	- Disruptive technologies, particularly Industry 5.0 and Society 5.0, can directly influence progress on SDGs 3, 8, 9, and 11. - Integrating Industry 5.0 and Society 5.0 to form smart cities and villages can further support the achievement of the SDGs due to the synergies between these concepts. - The integration of these technological developments and societal transformations can provide a favorable framework for making progress on the SDGs.	The methodology used in the study is a comprehensive qualitative analysis to: - Examine the impacts of disruptive technologies on each of the 17 Sustainable Development Goals (SDGs) - Map the outcomes of disruptive technologies to their direct influence on SDGs 3, 8, 9, and 11 - Analyze the contribution of disruptive technologies to SDGs and map them to the transformative scenarios of Industry 5.0 and Society 5.0 - Examine the impact of the technology-powered society, giving rise to smart cities and villages, on attaining the SDGs - Develop an integrated framework to identify the influence of disruptive technologies on the SDGs	The main or primary outcomes measured in the study are the influence of disruptive technologies on Sustainable Development Goals 3 (Good Health and Well-Being), 8 (Decent Work and Economic Growth), 9 (Industry, Innovation and Infrastructure), and 11 (Sustainable Cities and Communities)	The limitations of research are often linked to the search criteria, such as keywords, which might exclude relevant studies or include less pertinent ones. Future research could benefit from broader criteria to ensure comprehensive analysis. Integrating new technologies into existing systems, particularly in human-centric and sustainable ways, is complex and requires ongoing adaptation and development.	Map how disruptive technologies can support each individual SDG. Understand the actual benefits offered by disruptive technologies in progressing towards the SDGs.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
Is Industry 5.0 a Human-Centred Approach? A Systematic Review [10]	Industry 5.0 aims to address the human challenges of Industry 4.0 by placing the worker's well-being at the center of the production process. Industry 5.0 intends to capture the value of innovative digital technologies through human-machine interaction, where the operator works alongside and with the assistance of machines. The future perspectives for human-centricity in Industry 5.0 are to empower human operators by enhancing their individual capabilities and skills, and to achieve a balance and collaboration between humans and machines.	The methodology used in this study was a systematic literature review (SLR). The authors searched three electronic databases (Science Direct, Scopus, and Web of Science) using keywords related to Industry 5.0 and human-centricity, with Boolean operators. The search was conducted in English without any time restriction. The authors then performed a screening process, first based on titles and abstracts, and then by full-text reading, to select eligible studies. The inclusion criteria were: full-text available, published in English, research articles, review articles, and conference papers that explore Industry 5.0 and/or human-centricity, as well as related topics like sustainability and resilience. Articles focused solely on technological advancement without human-centricity or only suggesting Industry 5.0 as a future perspective were excluded.	This is a systematic literature review involves evaluating the extent to which Industry 5.0 initiatives incorporate human-centric principles. This systematic review assessed various case studies, policies, and practices to determine how well they align with the goal of enhancing human factors such as worker well-being, job satisfaction, and ergonomic considerations within the technological advancements of Industry 5.0.	There are limited number of real industrial cases. The study highlights the scarcity of real-world industrial applications of Industry 5.0 concepts and ideologies, making it challenging to fully validate the proposed frameworks and ideas in practical settings. Future studies may need to conduct experiments in laboratory settings to expedite the research process. However, this approach might produce results that are not entirely reflective of real-world industrial environments, potentially leading to findings that lack practical applicability.	The need to develop real and achievable strategies and methodologies to put the human factor at the center of production, without neglecting the human factor and implementing the ideologies of Industry 5.0. It is perhaps too early to speak of Industry 6.0 when Industry 5.0 is in its early stages of development. It is unclear whether Industry 6.0 will be devoted to environmental-oriented aspects if Industry 5.0 is human-oriented.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
The I5arc approach for human-AI collaboration [11]	The main findings of this paper are focused on proposing a human-centric collaboration architecture for Industry 5.0, which aims to integrate innovative technologies like AI with human actors in a more value-driven way. The key objectives of this architecture are to make production resilient, sustainable, and human-centric, going beyond the technology-centric focus of Industry 4.0. - The proposed methodology addresses the need for a human-AI collaborative process design, with the goal of developing advanced AI-driven co-creation and collaboration tools.	The methodology described, known as the I5arc process innovation cycle, focuses on enhancing human-AI collaboration in manufacturing environments. It introduces a cycle that integrates human insights and AI capabilities through a structured framework. This framework is built around six key domains aimed at improving processes by assessing, designing, and implementing collaborative tasks using a language specific to plant collaboration. It also addresses the acceptance and societal impacts of human-AI interaction, ensuring the collaboration is economically, technically, and socially beneficial. The methodology is visually supported by diagrams that detail the roles of various agents, including humans and AI, in the innovation cycle.	The measured outcomes of the described Industry 5.0 research are focused on enhancing human-AI collaboration in plant-level processes. This includes the development of a user-oriented PKB (phenotype knowledge base) ontology for better design and regulation, universal semantic descriptions for real-time collaboration, and AI techniques for optimization within manufacturing environments. The approach integrates technological and societal factors into a comprehensive innovation lifecycle and supports the creation of roles like plant knowledge engineer, enhancing job opportunities and workplace safety through remote operations.	The limitations of the I5arc approach for human-AI collaboration include technological complexity: Integrating various innovative agents such as AI, IoT, and robots can present technical challenges, especially in terms of interoperability, data privacy, and security.	The main research gap focuses on how to develop a human-AI collaborative process design and innovation approach to support advanced AI-driven co-creation and collaboration tools in industrial plants.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
From the Dark Side of Industry 4.0 to Society 5.0: Looking “Beyond the Box” to Developing Human-Centric Innovation Ecosystems [12]	The article aims to design a comprehensive framework based on the quintuple helix model to support the design and implementation of “Super Smart Societies” (S5.0), which are based on human-centricity, sustainability, and resilience. The article provides prescriptions on how different stakeholders (government, university, industry, civil society, and environment) can address the goals of S5.0. - The article acknowledges the adverse effects of adopting an overly technocentric perspective in the context of Industry 4.0 and proposes a shift towards a future where technology empowers people and innovation benefits both business and society.	The methodology involves developing a conceptual framework based on the quintuple helix model and providing prescriptive recommendations on how different stakeholders can address the goals of Society 5.0.	Framework development: Establishing a comprehensive framework based on the quintuple helix model, supporting the design and implementation of Society 5.0. Human–AI collaboration: Enhancing collaboration between humans and AI to drive intelligent automation in smart cities. Technological Integration: Combining technocentric and human-centric innovations for sustainable socioeconomic growth. Societal Impact: Addressing global challenges like digital divide, job market transformation, and environmental impacts through human-centric approaches.	The S5.0–5H model does not cover all the dynamics of the 5H framework, indicating a gap in representing the interconnections that may dynamically change within an ecosystem.	Guidelines on how to combine technocentric and human-centric innovations to trigger Society 5.0 are still missing. The comprehensive framework based on the Quintuple Helix Model to support the design and implementation of Society 5.0 is not yet developed.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
An Investigation upon Industry 4.0 and Society 5.0 within the Context of Sustainable Development Goals [13]	The Sustainable Development Goals (SDGs) 9, 10, 11, 12, 13, and 14 had a low influence ($R^2 = 0.172$) on the application of Industry 4.0 and Society 5.0.	The methodology of the study involved: A survey with 30 questions conducted with 335 academicians at Kafkas University	The study assessed the feasibility of implementing Industry 4.0 technologies and the Society 5.0 philosophy in Turkey.	Small sample size (335 academicians)	Limited research on the topic of Society 5.0.
	The participants were heavily influenced by current events and trends when responding to the survey questions.	Data analysis using exploratory factor analysis, confirmatory factor analysis, and structural equation modeling	The study measured the impact of implementing Society 5.0 on various SDGs in Turkey. The findings indicated that SDGs related to infrastructure (SDGs 9–14) had a low-density effect.	Potential bias due to participants being “heavily affected by order of the day”	Low influence of Industry 4.0 and Society 5.0 on certain Sustainable Development Goals (SDGs).
	Turkey does not have a leading philosophy or approach when it comes to Society 5.0 and Industry 4.0, and has been focusing on outdated processes.		The study utilized SEM to test the hypotheses and model. The analysis revealed that the hypothesis relating to SDG social impact on feasibility was not supported	Lack of a leading philosophy in Turkey regarding Society 5.0 and Industry 4.0, with a focus on outdated processes	Potential biases in participant responses due to current events.
			The confirmatory factor analysis showed good coherence for the feasibility scale and acceptable coherence for the SDGs scale.		Lack of a leading philosophy on Society 5.0 and Industry 4.0 in Turkey.

Table 1. Cont.

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From Industry 4.0 towards Industry 5.0: A Review and Analysis of Paradigm Shift for the People, Organization and Technology [14]	Industry 5.0 complements Industry 4.0 by focusing on the worker and their important role in the production process, which was emphasized during the COVID-19 pandemic. Industry 5.0 is a transformative model that integrates social and environmental principles and aims to make industrial systems more resilient to future shocks. There has been a shift in research aims from sustainability in Industry 4.0 to human-centricity in Industry 5.0, as the lack of human perspective was a major disadvantage of Industry 4.0.	The methodology used in this study was: Literature search in the Scopus database for papers related to Industry 4.0/5.0 and the three key enablers: people, organization, and technology Exclusion of literature reviews and state-of-the-art papers Analysis of the 50 most cited papers from the “Industry 4.0 & Organization” and “Industry 4.0 & Technology” categories Use of manufacturing industry analyses, such as the analysis of Industry 4.0 implementation in the German manufacturing industry and the analysis of Croatian manufacturing companies, to obtain a practical, real-life perspective	The study tested the stated hypotheses and model using structural equation modeling (SEM) through the Smart PLS program. The reliability tests confirmed that the model’s reliability was appropriate for testing. The q2 values indicated a low-level impact between SDGs of Social Effect and Feasibility, and a low-density impact between SDGs of Infrastructure and Feasibility. The R2 value of 0.172 also indicated a low-density impact.	The study was conducted only with academicians at Kafkas University, Turkey, limiting the generalizability of the results to a broader population. It was challenging to obtain information from the general public due to the topic’s current nature and technological elements. The study’s narrow scope, focusing primarily on the technological aspects of Industry 4.0 and Society 5.0, may overlook other critical factors such as cultural, political, and environmental impacts	Lack of research on the role of humans in the future factory. Lack of research on appropriate organizational models for Industry 4.0. Lack of research on approaches for long-term value creation. Lack of research on the outcomes of Industry 4.0 on society.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
Human-centric artificial intelligence architecture for industry 5.0 applications [15]	The proposed architecture is designed to comply with three key desired characteristics for manufacturing environments in Industry 5.0: safety, trustworthiness, and human centrality. The feasibility of the proposed architecture was validated through three real-world use cases, which showed how AI can be used to achieve particular goals in manufacturing and confirmed the interplay between the architecture modules to deliver a human-centric experience aligned with Industry 5.0. Ongoing and future work will focus on human intention recognition to enhance worker safety, active learning approaches for cybersecurity, and machine learning and active learning for human fatigue monitoring to enhance worker well-being.	The methodology used in this study is the development of a modular architecture for manufacturing systems that integrates key technologies like AI, simulated reality, and decision-making, designed to comply with the principles of safety, trustworthiness, and human centrality. The feasibility of this architecture was validated through three real-world use cases.	The paper emphasizes the enhancement of human-machine collaboration through the integration of Industry 5.0 technologies. This includes assessing the efficiency and effectiveness of human-centric AI systems in industrial settings The study measures outcomes related to the implementation of AI-driven process improvements. This includes evaluating the success of AI in optimizing manufacturing processes and its impact on productivity and efficiency. The study also measures the tangible benefits of the proposed AI systems. This includes economic gains, technical advancements, and social impacts such as improved job satisfaction and safety.	One limitation noted is the challenge of integrating AI systems with existing manufacturing processes and workflows. This includes technical hurdles and resistance to change from the workforce. The quality and availability of data required for training AI models is another limitation. Issues such as incomplete, biased, or low-quality data can impact the performance of AI systems.	The study identifies a gap in the existing research on human-centric AI, particularly in understanding the interactions between humans and AI in manufacturing settings. There is a need for more in-depth studies on how AI can be designed and implemented to support and enhance human roles rather than replace them.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0 [16]	Industry 5.0 is a concept that aims to create a human-centric, sustainable, and resilient manufacturing system. Society 5.0 is a concept for a highly intelligent, data-driven, and cyber-physical society that aims to improve human quality of life and environmental sustainability. Both Industry 5.0 and Society 5.0 build on the technological advances of Industry 4.0 to achieve these goals.	The authors used a combination of database searches, including Scopus, Web of Science, and Science Direct, to retrieve peer-reviewed articles on Industry 4.0, Society 5.0, and Industry 5.0. They used a specific search query focused on publications from 2015 onwards. The results were then converted to CSV format and analyzed using the VOSviewer software. The authors also developed their own algorithm that utilizes APIs from scientific databases to search and retrieve relevant publications.	Identification of Key Technologies: Recognizing essential technologies like edge computing, digital twins, collaborative robots, and blockchain that facilitate the transition. Human-Centric Design: Emphasizing the need for human-centric approaches in technological advancements. Impact on Various Sectors: Evaluating the implications for supply chain management, intelligent healthcare, and cloud manufacturing. Future Research Directions: Highlighting promising areas for further research to achieve Industry 5.0 and Society 5.0.	Conducting studies in industrial environments can be challenging due to the difficulty of gaining openness and acceptance of new ideas and technologies from operators and top managers	Lack of adequate literature specifically addressing Industry 5.0 and Society 5.0 simultaneously. Inclusion of research works from 2022 that have not yet finished, so the developments discussed may not be fully up-to-date.

Table 1. Cont.

Title	Main Findings	Methodology	Outcome Measured	Limitations	Research Gap
Our Proposed Study	This study integrates Industry 5.0 and Society 5.0 technologies within smart cities to enhance the achievement of Sustainable Development Goals (SDGs) 3 (Good Health and Well-Being), 4 (Quality Education), 9 (Industry Innovation and Infrastructure), and 11 (Sustainable Cities and Communities).	The methodology employed in this study includes a systematic literature review to gather and analyze existing research on Industry 5.0, Society 5.0, and their roles in achieving SDGs.	The primary outcomes measured include the enhancement of SDGs 3, 4, 9, and 11 through the implementation of Industry 5.0 and Society 5.0 technologies.	Ethical concerns related to data privacy and the use of AI and other disruptive technologies.	Long-term sustainability and scalability of the integrated technologies need to be addressed.
	The research proposes a comprehensive framework that leverages disruptive technologies such as AI, IoT, robotics, and blockchain to drive sustainable development.	Case studies are examined to provide real-world examples and validate the proposed framework.	The study assesses improvements in healthcare innovation, education quality, industrial innovation, and the development of sustainable cities.	High initial costs associated with the implementation of advanced technologies.	Further research is required to explore the socio-economic impacts of these technologies on different communities.
	By integrating these technologies, the study aims to enhance product development, healthcare innovation, pandemic response, and the creation of nature-inclusive business models within smart cities.	A SWOT analysis is conducted to assess the strengths, weaknesses, opportunities, and threats of integrating disruptive technologies in smart cities.	It measures the effectiveness of the proposed framework in achieving these goals and provides insights into the practical applications of disruptive technologies in smart cities.	Potential resistance from stakeholders due to the complexity and novelty of the proposed solutions.	The study highlights the necessity for ongoing adaptation and development to keep pace with technological advancements and changing societal needs.
	The study provides a SWOT analysis to evaluate the strengths, weaknesses, opportunities, and threats associated with this integrated approach, offering guidance for policymakers, industrialists, and researchers.				

To clearly illustrate the unique contributions of our research in comparison to existing studies, we present the following table. This table highlights the objectives, methodologies, key findings, and novel contributions of similar research papers, thereby positioning our study within the current academic landscape and emphasizing its originality and impact.

3.1. Selection Criteria

The inclusion and exclusion criteria for the study are detailed in Table 2. This table provides a comprehensive overview of the specific parameters used to determine the eligibility of sources for the research. The inclusion criteria ensure that only relevant and high-quality data are considered, while the exclusion criteria help eliminate any sources that do not meet the necessary standards or relevance to the study objectives.

Table 2. Inclusion and exclusion Criteria.

Inclusion Criteria	Exclusion Criteria
Sources discussing disruptive technologies and their components, including AI, ML, robotics, AR/VR, IoT, and advanced analytics.	Sources that do not directly address the topics of Industry 5.0, Society 5.0, or sustainable development.
Sources addressing the integration of these technologies within Industry 5.0 and Society 5.0 with a focus on sustainable development.	Sources that are outdated or do not reflect the current state of knowledge in the field.
Sources presenting case studies, examples, or best practices related to the successful implementation of disruptive technologies in various sectors.	Sources lacking empirical evidence or rigorous analysis.
Sources discussing the challenges and ethical considerations associated with these technologies.	Sources that are not peer-reviewed or from reputable sources.
Sources providing insights into future research directions and opportunities in the field.	Sources that focus solely on theoretical aspects without practical applications.

3.2. Data Extraction

Relevant information from the selected sources was extracted and organized according to the key topics and subtopics outlined in the review paper's scope based on the inclusion/exclusion criteria of Table 2. This process involved summarizing key findings, identifying common themes and trends, and noting any contradictions or gaps in the existing literature.

3.3. Synthesis and Analysis

The extracted data was synthesized and analyzed to develop a comprehensive understanding of the integration of disruptive technologies in Industry 5.0 and Society 5.0 to achieve SDGs. This involved comparing different perspectives, assessing the strengths and weaknesses of various approaches, and identifying opportunities for further research and development in the field.

3.4. Presentation of Findings

The findings of the review paper are presented in a structured and coherent manner, following the proposed outline, and addressing each topic in detail. The results are supported by evidence from the selected sources and are discussed in the context of their implications for policymakers, industrialists, and researchers.

By employing this research methodology and selection criteria, this review paper aims to provide a rigorous and comprehensive analysis of the integration of disruptive technologies within Industry 5.0 and Society 5.0 to achieve the Sustainable Development Goals, contributing to the ongoing discourse and informing future research and practice in the field.

4. Industry 5.0 Technologies and Their Impact on Sustainable Development Goals

4.1. SDG 3 (Good Health and Well-Being)—Disease Prediction Management in Society 5.0

As we transition into Society 5.0, a concept that integrates advancements in technology with the needs of human society, there is a growing emphasis on how these innovations can enhance public health systems. Sustainable Development Goal 3 (SDG 3), which focuses on ensuring healthy lives and promoting well-being at all ages, stands as a critical objective in this new societal framework [17]. Society 5.0 leverages technologies, such as artificial intelligence (AI), big data analytics, and the Internet of Things (IoT), to support public health decision-making, ultimately leading to more effective and personalized healthcare solutions [18,19].

Figure 3 provides a structured overview of several interconnected aspects related to healthcare, technological advancements, and societal structures within the context of Society 5.0.



Figure 3. Comprehensive overview of healthcare research, data analytics, and technologies in Industry 5.0.

1. Future Research Areas:
 - **Telemedicine:** Highlighting the importance of remote healthcare services.
 - **Data Integration:** Emphasizing the need for integrating various data sources to improve healthcare outcomes.
 - **Industry 5.0: Human–Machine Collaboration:** Discussing the collaboration between humans and advanced technologies to enhance healthcare services.
2. Healthcare Data Analytics Process:
 - **Four Types of Analytics:** Descriptive (what happened), diagnostic (why it happened), predictive (what might happen), and prescriptive (what should be done).
 - **Data Workflow:** This includes data source (e.g., EMR and personal data), data cleaning (pre-processing, deleting, and updating records), data analytics (classification, detection, and association), and data application (prevention applications and prediction strategies).
3. Industry 5.0 Technologies in Healthcare:
 - A variety of technologies are listed, such as cobots, wearable tech, AR/VR, AI, 3D printing, smart sensors, blockchain, big data analytics, cloud computing, and more, indicating their application in healthcare to enhance treatment, diagnostics, and patient management.

4. Society 5.0 Stakeholders:

- Lists key stakeholders in Society 5.0, including local governments, financial institutions, tech companies, hospitals, NGOs, international bodies, regional governments, world governments, police, transportation, law, and education. These stakeholders play critical roles in shaping policies, driving innovation, and ensuring the effective implementation of Society 5.0 initiatives.

5. Emergency Services during Disasters:

- Details essential services that must remain operational during disasters to ensure public safety and welfare, such as Emergency Medical Services, Fire Services, Disaster Response Support Units, Communications Services, and Military and Police Support.

In Society 5.0, big data plays a transformative role in public health management. By collecting vast amounts of data from diverse sources, including electronic health records, social media, and even wearable technology, health professionals can gain a more comprehensive understanding of population health trends. This integration of big data allows for real-time surveillance of disease outbreaks and quicker responses to public health emergencies [20]. For instance, during the COVID-19 pandemic, big data was crucial in tracking the spread of the virus, monitoring the effectiveness of public health interventions, and facilitating the strategic deployment of resources.

AI and machine learning algorithms are at the forefront of revolutionizing healthcare in Society 5.0. These technologies are used to predict disease outbreaks, personalize treatment plans, and optimize healthcare delivery [16]. AI systems can analyze large datasets to identify patterns and predict outbreaks before they occur, allowing for preemptive actions that can save lives and reduce healthcare costs. Moreover, AI is instrumental in managing chronic diseases; it can monitor patients' conditions in real time and adjust treatments as needed [21]. This proactive approach in healthcare not only improves patient outcomes but also enhances the efficiency of health systems.

The IoT has enabled the development of connected healthcare devices that monitor patients' health statuses in real-time. Devices such as smartwatches and fitness trackers collect data on vital signs like heart rate and activity levels, which can be analyzed to detect potential health issues before they become severe [22]. Remote health monitoring has become particularly important for elderly populations, allowing for continuous care without the constant need for physical hospital visits. This technology fosters a preventive health culture that aligns with the goals of SDG 3 by reducing the incidence of severe health episodes and improving the general well-being of the population [23].

Society 5.0 also sees the emergence of digital health platforms that integrate various healthcare services. These platforms facilitate the efficient distribution of healthcare resources, enhance the accessibility of medical care, and improve communication between different health providers and patients. For example, telemedicine platforms have expanded access to medical consultations, particularly in rural or underserved areas, ensuring that geographical location is no longer a barrier to receiving high-quality healthcare. Such platforms also enable better resource management by predicting patient inflows and optimizing staff allocations and medical inventory [24].

While the benefits of integrating technologies in public health decision-making are manifold, they also raise significant ethical and privacy concerns. The collection and analysis of large volumes of personal health data necessitate stringent data protection measures to prevent misuse and ensure privacy [25]. Furthermore, the reliance on AI and automated systems must be balanced with ethical considerations to avoid biases in healthcare delivery and ensure equitable access to medical services [26].

The continued integration of advanced technologies in healthcare within the framework of Society 5.0 offers tremendous potential to further the aims of SDG 3 [27]. Research and development are ongoing to explore newer technologies like blockchain for secure medical data exchange and augmented reality for enhanced medical training and patient

care procedures [28]. The challenge lies in ensuring these technologies are implemented in a way that is both ethically sound and socially beneficial, promoting not just health and well-being but also fairness and inclusivity in healthcare access [29].

Society 5.0 provides a robust framework for supporting public health decision-making through advanced technologies [30]. Harnessing the power of AI, big data, and IoT enhances the capability of health systems to predict, manage, and prevent health issues, driving progress towards achieving SDG 3 [31]. However, to fully realize this potential, it is imperative to address the ethical and privacy concerns associated with these technologies, ensuring that the pursuit of technological advancement does not overshadow the need for human-centered values and equitable health access for all [32].

The interconnected nature of SDGs was the primary investigation by [33], and it emphasizes the pivotal role of SDG 3 (Good Health and Well-Being) in relation to other goals. It advocates for an integrated policy approach, acknowledging that various social, environmental, and economic factors influence health outcomes. Moreover, the investigated emerging technologies in the broader context of SDGs, such as emerging technologies like artificial intelligence (AI) and blockchain, are not just tools, but transformative forces. AI, for instance, can optimize healthcare delivery and disease prediction, enhancing SDG 3's reach. Blockchain, on the other hand, offers robust data management for improved transparency and efficiency in food security (SDG 2) and resource management (SDG 6), directly supporting the health outcomes of SDG 3.

Comparing the conceptual approach proposed by [33] with the comprehensive bibliometric analysis investigated by [34], the latter study focused on the quantitative aspect of research publications that addressed SDG 3 between 2015 and 2019. This thorough approach evaluates the scope, trends, and impacts of the academic discourse surrounding SDG 3 and its intersection with other SDGs. This data-driven insight into the proliferation of research on SDG 3 provides a robust understanding of which areas are receiving the most attention, which institutions are leading in research, and how global collaboration patterns are forming.

The role of responsible investment instruments in financing SDG 3, as explored in a comprehensive study by [35], is a beacon of hope. It investigates how emerging technologies can be leveraged to enhance the efficiency and impact of these investments. Blockchain can ensure transparency and accountability in financing, while AI and big data analytics improve decision-making through precise data management. FinTech innovations expand access to capital by enabling diverse funding channels. IoT and wearable technologies offer real-time health data, improving project monitoring and outcomes. These technologies collectively facilitate efficient resource allocation, risk management, and outcome tracking, which are crucial for maximizing the impact of investments in global health initiatives.

The significant impact of disruptive technologies on achieving SDGs within the European Union's healthcare sector is evaluated [36]. Technologies such as AI, blockchain, and telemedicine are pivotal in transforming healthcare systems. AI enhances diagnostic accuracy and treatment personalization, directly supporting SDG 3 (Good Health and Well-being). Blockchain ensures data integrity and security, fostering trust in health data management. Telemedicine expands access to healthcare, which is significant for remote areas, aligning with SDG 10 (Reduced Inequalities). Together, these technologies foster more inclusive, efficient, and effective healthcare services, crucial for sustainable health and well-being across the EU.

To shed more light on sustainable health behaviors, which are pivotal for achieving SDG 3, many studies, such as [37], critique the role of such behavior. The research promotes health and well-being across all ages. While the viewpoint underscores the importance of integrating health education and lifestyle changes into public health strategies, it may overlook broader socio-economic and environmental determinants of health that can limit individual choices and behaviors. Additionally, focusing on personal responsibility in health might shift attention away from systemic issues and the need for comprehensive health services and infrastructure. Addressing these limitations could enhance the potential

of sustainable health behaviors to contribute more effectively to the broader objectives of SDG 3 and other interlinked SDGs.

The main findings from [37] suggest that robust public health policies can improve long-term health. However, the critique might center on the lack of specific strategies to effectively integrate these health policies across different SDGs. The study highlighted in [37] could benefit from addressing how these health initiatives interact with environmental, educational, and economic policies. By exploring these cross-sectoral impacts more deeply, the discussion would provide a more holistic approach to understanding and achieving the broader spectrum of the Sustainable Development Goals through health-focused actions.

To focus more on long-term health and its relation to SDG 3, the main findings from [38] suggest that robust public health policies can improve long-term health. However, the critique might center on the lack of specific strategies to effectively integrate these health policies across different SDGs. The investigation in [38] could benefit from addressing how these health initiatives interact with environmental, educational, and economic policies. By exploring these cross-sectoral impacts more deeply, the discussion would provide a more holistic approach to understanding and achieving the broader spectrum of Sustainable Development Goals through health-focused actions.

Technological advancements have been investigated in many cultures. The Society 5.0 initiative in Japan is one of the pioneer examples of addressing social challenges like aging and economic competitiveness, with an emphasis on creating a sustainable society that integrates health and well-being into its core development strategies [39]. It discusses Japan's Society 5.0 initiative, which envisions a smart, technology-integrated society addressing significant socio-economic challenges such as aging populations and economic stagnation. The initiative focuses on leveraging advancements in digital technology, big data, and artificial intelligence to enhance societal functions and improve quality of life, ensuring inclusivity and sustainability. It aims to integrate cyber-physical systems into everyday life to solve existing social problems and to promote a more efficient and equitable society.

We can use other examples from developing countries, such as the Sahel region in Africa. The work undertaken by [40] aims to comprehensively assess the progress and challenges associated with SDG 3, which is focused on ensuring good health and well-being, specifically within the Sahel region. Their work intends to highlight the disparities in health outcomes within the region, identify key obstacles to achieving SDG 3, and suggest strategic interventions to enhance health equity. However, the study in [40] might benefit from a more detailed exploration of local and cultural factors influencing health behaviors and outcomes. Additionally, while [40] focuses on regional challenges, it could further strengthen its analysis by integrating more comparative data from similar regions to draw broader, more generalizable conclusions.

Despite significant advancements in healthcare technologies, there remains a substantial gap in research focusing on the integration of Industry 5.0 and Society 5.0 concepts to enhance health outcomes. Specifically, the potential of AI, IoT, and robotics to improve pandemic response, healthcare delivery, and personalized medicine within the framework of smart cities is underexplored. Our study addresses this gap by examining how these technologies can be strategically deployed to achieve SDG 3, thereby improving public health and well-being.

4.2. SDG 4 (Quality Education)—Education Management in Smart Communities

The drive towards achieving Sustainable Development Goal 4 (SDG 4), which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all, aligns perfectly with the evolution of smart communities [41]. These communities, characterized by their use of technology to improve the quality of life of their residents, are at the forefront of innovating education management systems that cater to diverse populations [42]. This comprehensive exploration discusses how smart communities are uniquely positioned to meet the diverse targets of SDG 4 through integrated technological solutions and collaborative educational frameworks [43].

The existing literature on smart education technologies often overlooks the comprehensive application of disruptive technologies within Industry 5.0 and Society 5.0 to enhance educational outcomes. There is a lack of research on how AI, IoT, and advanced analytics can be utilized to create adaptive learning environments, support lifelong learning, and bridge educational inequalities in smart city contexts. This study fills this gap by proposing innovative solutions to integrate these technologies, aiming to achieve SDG 4 and improve the quality of education.

Figure 4 presents a structured approach to addressing educational challenges brought forth by the COVID-19 pandemic, with a focus on aligning innovative solutions to Sustainable Development Goal (SDG) Target 4, which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities.

COVID-19 Problems: The top section of the figure identifies critical issues impacting education due to the pandemic. Key challenges include school closures, which have disrupted learning for millions; the transition to online learning, which has exposed and exacerbated digital divides [44]; and a lack of access to digital tools, particularly affecting underprivileged students.

Innovative Solutions: The middle section details various innovative strategies implemented to mitigate these educational disruptions. These include AI-driven personalized learning platforms that adapt educational content to the learning styles and paces of individual students and hybrid learning models that combine online and face-to-face education. Virtual reality (VR) classrooms are introduced to make learning more engaging, while mobile learning applications ensure education is accessible on various digital devices [45]. Additional solutions include community learning hubs that provide essential support and digital literacy training for teachers to enhance their ability to effectively utilize online learning tools.

SDG 4 Targets: The bottom section illustrates how these innovative solutions contribute directly to achieving specific targets under SDG 4. For instance, technology enhancements in education (Target 4.1) include the integration of VR and AR to transform traditional learning environments. Early childhood education (Target 4.2) benefits from digital tools that enhance learning environments and provide interactive content [46]. Higher education and vocational training (Target 4.3) are made more accessible and relevant through online platforms and industry collaborations [47]. Skills for employment (Target 4.4) are bolstered by aligning education with labor market needs and integrating data analytics to identify and address skill gaps. The specifics and targets of SDG 4 and its different components are outlined in the following sub-sections [48].

4.2.1. SDG Target 4.1: Primary and Secondary Education

Smart communities leverage technology to democratize access to education, ensuring that primary and secondary education is not only universally available but also of high quality. Digital platforms can provide personalized learning experiences that adapt to the needs of individual students, ensuring effective learning outcomes [49]. For instance, AI-driven educational programs can assess a student's learning style and pace, adapting the educational content accordingly. Furthermore, the integration of virtual reality (VR) and augmented reality (AR) into classrooms can transform traditional learning environments, making education more engaging and accessible.

4.2.2. SDG Target 4.2: Early Childhood Education

The foundation of lifelong learning begins in the early years. Smart communities emphasize the importance of early childhood education and care, utilizing digital tools to enhance learning environments and support educators [50]. Platforms that offer interactive and developmentally appropriate content are becoming more prevalent, providing children with a strong start in their educational journey. Additionally, these communities often facilitate partnerships between educational institutions and parents through apps and online platforms, enhancing the continuity of learning and care at home.

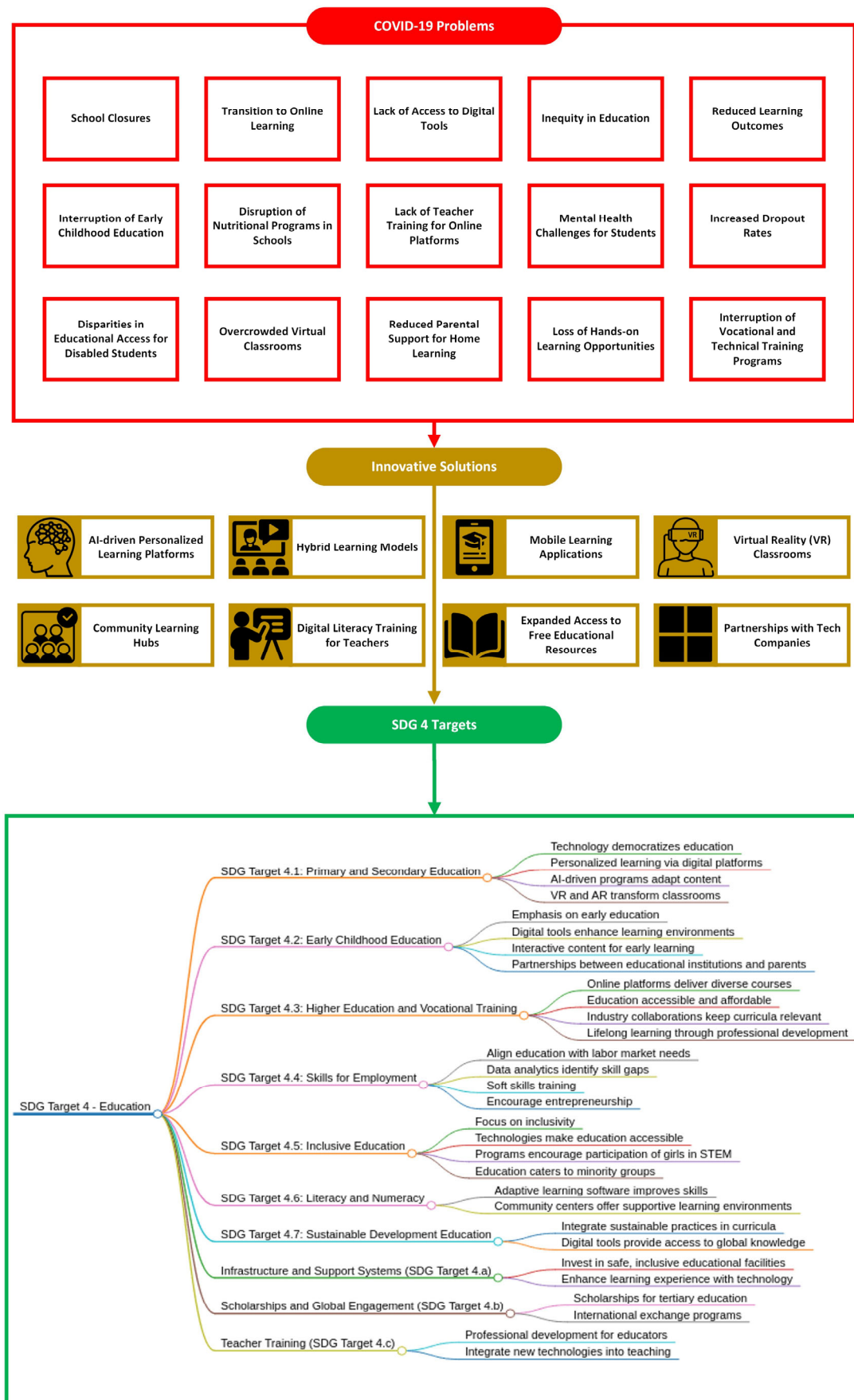


Figure 4. Innovative solutions aligned with SDG 4 targets.

4.2.3. SDG Target 4.3: Higher Education and Vocational Training

In terms of higher education and vocational training, smart communities are pioneering the use of online learning platforms that can deliver a wide array of courses ranging from technical skills to university-level programs [51]. These platforms make education more accessible and affordable, removing geographical and financial barriers to learning. Collaborations with industries ensure that the curricula remain relevant to evolving job markets, thus enhancing the employability of graduates. Moreover, lifelong learning is promoted through continuous professional development offerings that are tailored to meet the needs of the community's workforce.

4.2.4. SDG Target 4.4: Skills for Employment

Smart communities are particularly adept at aligning educational outcomes with labor market needs [52]. Through data analytics, they can identify skill gaps in the local economy and tailor educational programs to address these needs. Training in soft skills, such as problem-solving and communication, is integrated into technical and vocational education to prepare students for a dynamic work environment. Furthermore, entrepreneurship is fostered through educational programs that encourage innovation and support the establishment of start-ups.

4.2.5. SDG Target 4.5: Inclusive Education

One of the most significant contributions of smart communities to educational management is their focus on inclusivity [53]. Technologies such as speech-to-text converters, screen readers, and customized learning modules ensure that education is accessible to all, including those with disabilities. Smart communities also strive to eliminate gender disparities in education by offering targeted programs that encourage the participation of girls and women in STEM fields. Additionally, educational initiatives are designed to be culturally sensitive, catering to the needs of indigenous populations and other minority groups.

4.2.6. SDG Target 4.6: Literacy and Numeracy

The commitment to ensuring that all community members achieve literacy and numeracy is bolstered by smart technologies [54]. Adaptive learning software helps identify areas where individuals struggle and provides customized support to improve their skills. Community centers equipped with digital learning tools offer spaces where adults can learn in a supportive environment. These initiatives are crucial for empowering citizens with the skills needed to navigate their personal and professional lives effectively.

4.2.7. SDG Target 4.7: Sustainable Development Education

Education for sustainable development is a core component of curricula in smart communities. Schools and higher education institutions integrate courses that teach students about sustainable practices, civil rights, and global citizenship [55]. These programs are supported by digital tools that provide students with access to a global repository of knowledge and collaborative projects that span across borders.

4.2.8. Infrastructure and Support Systems (SDG Target 4.a)

Smart communities invest in creating educational facilities that are safe, inclusive, and equipped with the latest technology. This includes the development of physical and digital infrastructures that enhance the learning experience and ensure that educational facilities are resilient to both physical and cyber threats [55].

4.2.9. Scholarships and Global Engagement (SDG Target 4.b)

To support higher education, smart communities often establish scholarship programs that enable students from low-income families to pursue tertiary education. These scholarships are complemented by international exchange programs that enrich the educational experience and foster global understanding.

4.2.10. Teacher Training (SDG Target 4.c)

Recognizing the central role of educators, smart communities focus on professional development programs that equip teachers with the skills necessary to integrate new technologies into their teaching practices. This not only improves the quality of education but also ensures that it remains relevant in an ever-changing world [56].

Open innovation by institutional investors and higher education systems can enhance SDG 4 (Quality Education) [57]. The findings interpreted from [57] suggest that collaborative investments and the sharing of resources lead to more innovative and inclusive educational frameworks. However, the conceptual review might benefit from empirical data to substantiate the proposed benefits of open innovation strategies. It overlooks potential challenges such as intellectual property issues and unequal resource access. Addressing these limitations and providing practical examples of successful implementations would strengthen the argument and offer a more straightforward pathway for integrating open innovation into achieving transformative educational outcomes.

The pattern of association among the indicators of SDG 4 was presented and critically examined by [58], who employed a genetic algorithm to identify patterns of association among SDG 4 (Quality Education). Their innovative approach highlights how interconnected and dependent various educational metrics are on each other. The study notably finds that improvements in one indicator can positively influence others, suggesting a synergistic effect within educational systems. However, the reliance on a genetic algorithm, while novel, may introduce complexity in interpreting the results, as these algorithms can sometimes generate solutions that are not intuitively obvious. Additionally, while the methodology is robust in finding patterns, it might overlook contextual factors such as socio-economic conditions or cultural variations that affect educational outcomes. Addressing these factors and considering external influences could provide a more comprehensive understanding of the dynamics between different educational indicators and enhance the practical application of these findings in policy-making and academic planning.

Ref. [59] critically analyzes the relationship between smart cities and SDG 4, focusing on how smart city initiatives can enhance achieving these goals. The authors of [59] argue that integrating intelligent technologies and data-driven approaches within urban planning can significantly contribute to sustainable development across multiple SDGs, including SDG 4 (Quality Education). Their critical examination of smart cities posits that when strategically deployed, technology can improve access to educational resources, personalize learning, and bridge educational gaps in urban environments. However, few areas in [59] could include more empirical evidence supporting these theoretical linkages, which is somewhat limited, suggesting more case studies and real-world data are needed to validate the proposed models and ensure their adaptability and effectiveness in diverse urban settings.

The role of educators is imperative to address when analyzing the trends of SDG 4 in education. In this context, Ref. [60] discusses the evolving roles of teachers in the context of Development Goal 4 (SDG 4), which aims for inclusive and equitable quality education. Their study [60] emphasizes that in the SDG 4 era, teachers are not just facilitators of knowledge but also crucial actors in promoting sustainable development. Ref. [60] argues that teachers must integrate sustainability concepts into their curricula and practice transformative teaching strategies that encourage critical thinking and problem-solving among students.

Teacher training programs must adapt and provide educators with the skills to meet these new challenges and opportunities for global collaboration [60]. Their research [60] ultimately calls for a redefinition of teaching roles to better align with the holistic goals of SDG 4, fostering a generation that is not only well-educated but also deeply aware of and engaged with sustainability issues.

To further understand the educators' need for SDG around the globe, a review carried out by [61,62] analyzes the challenges and opportunities within South Africa's and Botswana's teacher education sector concerning SDG 4, which targets quality education for

all. The findings from [61] outline significant limitations in the current system, including resource disparities, teacher preparedness, and curriculum relevance, which hinder the achievement of SDG 4. Despite these challenges, the authors identify potential improvements through enhanced teacher training programs, better educational policy integration, and increased investment in educational infrastructure. They advocate for a more robust and inclusive approach to teacher education that could drive progress towards equitable and quality education in South Africa.

Other examples presented by [63] focus on enhancing the quality of higher education in ASEAN by improving teacher preparedness through sustained quality assurance measures. It underscores the critical role of teachers in achieving SDG 4 by advocating for robust professional development and continuous learning to meet international standards. This relationship is portrayed as essential for fostering an educational environment that is inclusive, equitable, and capable of providing quality lifelong learning opportunities across the ASEAN region.

Furthermore, an examination of state-owned ICT enterprise's role in facilitating access to education in the Indonesia–Timor Leste border area is proposed by [64], emphasizing their potential to support the realization of the right to education and SDG 4. Ref. [64] highlights how technological interventions can bridge educational gaps in remote and underserved regions by providing digital learning resources and connectivity. A more detailed analysis of the implementation challenges, such as infrastructure limitations, maintenance of technology, and training for both teachers and students in using digital tools, could be further investigated [64]. Furthermore, a deeper exploration of the socio-economic impacts of these initiatives on the local communities would strengthen the paper, ensuring a holistic view of how state-owned ICT enterprises can sustainably contribute to educational advancement in border areas.

Not far away from educators' needs, teaching pedagogy and the influence of SDG 4 in teaching style have been a subject of debate in many studies. The critique in [65] identifies the current approaches to measuring the effectiveness of teachers and pedagogy within the framework of Sustainable Development Goal 4 (SDG 4), emphasizing the need for more refined metrics. As argued in [65], the existing metrics overly simplify the complex role of teachers, reducing them to mere elements of 'supply' in the educational system. The approach in [65] proposes developing more comprehensive evaluation methods that recognize the multifaceted contributions of teachers to academic quality and outcomes. By advocating for a deeper understanding and assessment of pedagogical practices, the chapter calls for a shift towards metrics that genuinely reflect the critical role of educators in achieving quality education for all [65].

Still in pedagogy, Ref. [66] explore the innovative use of Foldscopes—low-cost, paper microscopes—in STEM education as a case study for advancing Sustainable Development Goal 4 (SDG 4) in India. However, the workshops conducted by [66] lack a critical examination of long-term educational outcomes and scalability issues, such as teacher training and curriculum integration, which are essential for this innovative approach's broader implementation and sustainability in diverse educational settings.

The link between a global pandemic such as COVID-19, and educational instruments to advance SDG 4 is further investigated. Ref. [67] discuss the profound impact of the COVID-19 pandemic on the educational landscape, prompting a reevaluation of future learning methodologies. They argue that the crisis has accelerated the adoption of digital learning tools and reshaped educational priorities and approaches. The authors emphasize the need for an educational transformation incorporating more flexible, inclusive, and technology-driven methods to better prepare for future disruptions. It is important to address digital divides and ensure equitable access to technology to support all learners effectively and guide the development of resilient educational systems that can adapt to changing global conditions [67].

4.3. SDG 9 (Industry, Innovation, and Infrastructure)—Industry 5.0 in Smart Cities and Communities

The integration of a human-centric approach within Industry 5.0 represents more than a technological advancement; it is a strategic necessity for societal and environmental progress, closely aligning with Sustainable Development Goal (SDG) 9, which focuses on building resilient infrastructure, promoting inclusive industrialization, and fostering innovation [5,68,69]. As shown in Figure 4, Industry 5.0, evolving from Industry 4.0, shifts from a purely technology-focused outlook to one that emphasizes human collaboration, placing human needs and skills at the center of the manufacturing process.

Figure 5 provides a visual summary of the evolution of industrial development from Industry 1.0 to Industry 5.0. Starting with Industry 1.0, it highlights the use of steam engines and mechanization which revolutionized manufacturing during the Industrial Revolution. Moving to Industry 2.0, the focus shifts to assembly lines and mass production techniques that were introduced in the early 20th century [70]. Industry 3.0 is characterized by the integration of automation, IT systems, and electronics into manufacturing, significantly enhancing production efficiency and capabilities [70–72]. Industry 4.0, often referred to as the fourth industrial revolution, incorporates cyber-physical systems, cloud computing, and the Internet of Things (IoT), which facilitate highly automated and interconnected industrial practices [71]. Finally, Industry 5.0 is depicted as focusing on human-robot collaboration and mass customization, emphasizing the return of human touch to industrial processes, blending technological advancements with personalized and flexible production approaches to better meet modern consumer demands and improve workplace ergonomics [73].

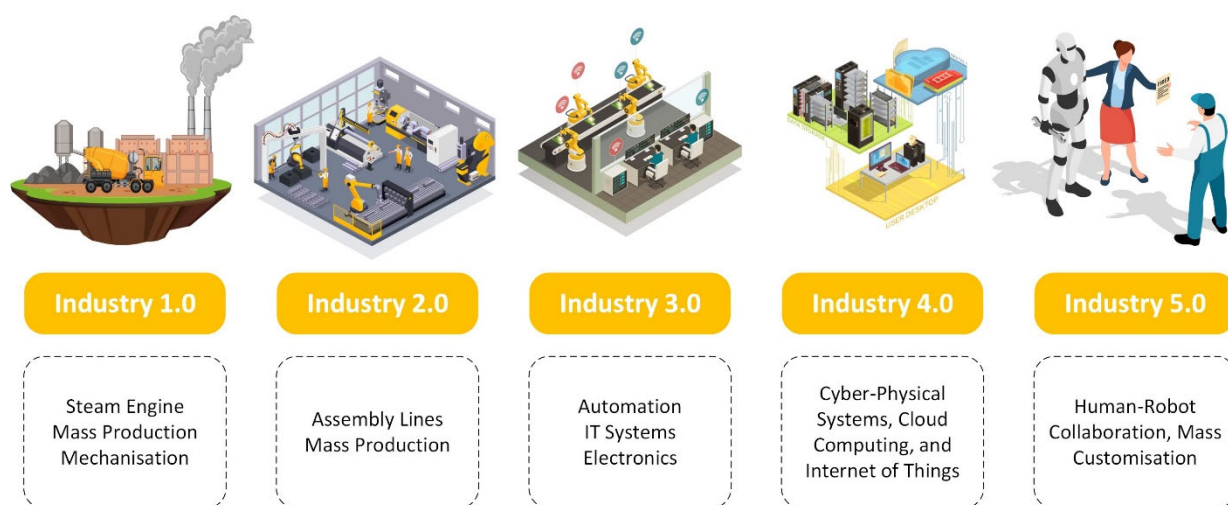


Figure 5. Evolution of industrial revolutions from Industry 1.0 to Industry 5.0.

While many studies highlight the role of advanced technologies in modernizing industries, there is insufficient focus on the holistic integration of Industry 5.0 and Society 5.0 to drive innovation and infrastructure development. The literature lacks comprehensive frameworks that address how AI, IoT, and blockchain can be utilized to create resilient infrastructure, foster industrial innovation, and support sustainable industrial practices. Our research addresses these gaps by presenting a coordinated approach to leverage these technologies, contributing to the achievement of SDG 9.

Transitioning to Industry 5.0, the focus shifts towards integrating human intelligence with advanced robotics and AI, promoting personalization in manufacturing [71,74,75]. This era enhances automation by incorporating human skills to achieve more effective human-machine interaction [71,76]. It leverages data not only for efficiency but also to enhance worker safety and enable real-time production customization. Industry 5.0 elevates customization to mass personalization, offering greater flexibility to meet specific customer demands [77]. The objective is to empower the workforce by augmenting human

capabilities with AI and robotics, thus enhancing both productivity and job satisfaction. The ultimate reward of Industry 5.0 is the seamless integration of automation and human creativity, leading to the creation of innovative products and fostering a happier and more engaged workforce [76].

Figure 6 offers a comparative visual analysis between Industry 4.0 and Industry 5.0, highlighting the shift from a technology-driven approach to a more human-centric model in manufacturing. In Industry 4.0, the emphasis is on cyber-physical systems, IoT (Internet of Things), and cloud computing, enabling high automation in smart factories where machines operate independently of human intervention [78,79]. This era uses big data and analytics to boost efficiency and predictive maintenance. Although it allows for mass customization, it generally maintains a standardized production approach and focuses on reducing human labor in repetitive tasks, thus potentially decreasing workforce size [80]. The primary benefit of Industry 4.0 is a significant boost in efficiency and productivity, which reduces production costs and improves supply chain management.

This approach enhances human efficiency and productivity by employing advanced technologies to reintegrate human workers into the core of production activities. For example, Collaborative Robots (Cobots) in industry 5.0 take on repetitive and hazardous tasks, freeing human workers for creative and strategic roles [81]. This symbiotic relationship between humans and machines not only optimizes workflow but also allows for customization, ensuring that products meet societal needs and preferences. Notable implementations include 'intelligent factories' by automotive giants like Audi and Volkswagen, which prioritize enhanced human-robot interactions to boost production flexibility [82].

Moreover, integrating industry 5.0 technologies with skilled professionals stimulates production optimization and innovation, addressing efficiency and bridging the gap between production and consumption. This synergy enables a faster response to customer needs, aligning with SDG 9's goal to enhance industrial innovation and infrastructure [83].

However, this shift presents challenges, including the need for robust training programs to ensure that workers can effectively collaborate with advanced, intelligent technologies. These educational programs must not only impart technical skills but also address the ethical implications and societal impacts of technological advancements. Additionally, the transition to industry 5.0 requires substantial investment, not only in technology but also in training initiatives that are human-centric [84].

As industry 5.0 technologies continue to evolve, addressing these challenges is crucial for fostering a resilient, inclusive, and sustainable industrial base. This alignment of industry 5.0 with SDG 9 has the potential to significantly contribute to global development, emphasizing the importance of integrating technological innovation with a strong focus on human needs and capabilities.

The rise of Industry 5.0 heralds a new era in sustainable industrial practices, prioritizing resource efficiency and enhanced human-machine collaboration [84–86]. This paradigm shift advocates for environmentally conscious design in products and processes, power conservation, and waste reduction. Industry 5.0 represents a departure from the purely technology-centric focus of Industry 4.0, moving towards a sustainable production model that features reduced energy consumption, heightened resource efficiency, and minimized waste production.

Central to Industry 5.0 is the innovative interaction between humans and machines, supported by Business Model Innovation (BMI) that aligns with sustainability goals [87]. This includes adopting lean production techniques to minimize resource wastage and overproduction. Industry 5.0 also aims to bolster economic sustainability by promoting localized manufacturing which aligns production closer to local needs and reduces the negative impacts associated with global supply chains.



Figure 6. Industry 4.0 vs. Industry 5.0.

The broader impact of Industry 5.0 on industrial environments calls for a comprehensive policy framework [86–88]. Essential elements of this framework include ethical standards for new technology use, stringent data governance, industry standardization, educational and workforce initiatives to match Industry 5.0 skills requirements, R&D incentives, robust cybersecurity measures, policies that foster an innovation-conducive environment, consumer protection standards, and sustainability practices that encourage minimal waste and efficient resource management [89].

To enhance sustainability, Industry 5.0 leverages advanced technologies like Artificial Intelligence (AI) to optimize resource use. The integration of intelligent, interconnected machines and Machine Learning (ML) enables precise real-time production forecasting, allowing industries to adjust operations dynamically, thus preventing losses and boosting efficiency. An example of this in action is BMW's iFACTORY, which commits to sustainable production through the use of eco-friendly materials, renewable energy, and extensive recycling practices [90].

However, transitioning to sustainable practices within Industry 5.0 presents challenges, such as significant initial costs that can burden smaller enterprises and the lack of global standards for sustainable practices. These factors are crucial for ensuring broad and uniform adoption across industries and geographical regions [91].

The balance between economic growth and sustainability is critical, necessitating a thorough cost-benefit analysis to integrate sustainable practices effectively within the industrial sector [92]. This is especially pertinent given the uncertainties of high energy costs driven by geopolitical tensions. For example, recent spikes in global coal consumption and the dependency on critical raw materials from geopolitically sensitive regions highlight the complex challenges facing sustainable industrial development.

The resilient infrastructure, sustainable industrialization, and innovation have been critically assessed in [93,94]. Ref. [93] provide a narrative review on the role of biomaterials in supporting SDG 9, which focuses on resilient infrastructure, sustainable industrialization, and innovation. The role of bio-based building materials in sustainable development, emphasizing environmental benefits and resource efficiency [94]. Their work highlights the integration of these materials in construction to meet SDG goals, particularly in reducing carbon footprints and enhancing building sustainability. In contrast, Ref. [93] discusses a broader spectrum of biomaterial applications across various industries, linking their use to SDG 9 by emphasizing innovation and sustainable industrial practices. While both Refs. [93,94] highlight the importance of biomaterials in achieving sustainability, Ref. [94] provide a more targeted analysis of construction, whereas Ref. [41] offer a wider review across industrial applications.

The interplay between emerging technologies and Sustainable Development Goal 9 (SDG 9) was the primary investigation of [88] that focused on promoting industry, innovation, and infrastructure. The findings emphasize how AI, blockchain, and IoT can drive industrial innovation and build resilient infrastructure. The study highlights the transformative potential of these technologies in optimizing manufacturing processes, enhancing supply chain transparency, and improving infrastructure management through data-driven insights.

On the other hand, the analysis in [95] might benefit from addressing the challenges related to technology adoption, such as high initial costs, the need for skilled personnel, and the digital divide that could hinder equitable access to these benefits. Additionally, the environmental impact of scaling up technological solutions remains a concern that could contradict the sustainability aspect of SDG 9. A more balanced critique of these issues would enhance the relevance of the findings, ensuring they comprehensively address both the opportunities and constraints within the context of sustainable industrial and infrastructural development.

Patterns of emerging technologies to drive sustainability across various sectors are proposed by [96]. They delve into how innovations such as artificial intelligence, blockchain, and advanced materials can fundamentally reshape industries like energy, waste management, and agriculture to be more sustainable. The authors [96] emphasize that these technologies can help reduce environmental footprints, enhance resource efficiency, and create more resilient systems. They advocate for robust policy frameworks and interdisciplinary collaboration to ensure these technologies are deployed effectively and ethically, addressing potential risks associated with rapid technological change. The book serves as a comprehensive guide to understanding the intersection of technology and sustainability.

The synergistic interconnections between Sustainable Development Goal 9 (industry, innovation, and infrastructure) and other SDGs emphasize their mutual reinforcement. They are examined by [97] using a preliminary exploratory approach, employing a conceptual analysis to map and understand the interlinkages between SDG 9. Their preliminary findings highlight the synergistic potential of SDG 9 to advance broader sustainability aims, demonstrating how industrial innovation can catalyze improvements in education, health, and environmental sustainability.

While Ref. [97] provides valuable insights into the interdependencies among the SDGs, it lacks depth in addressing the potential trade-offs or negative impacts that industrial expansion could have on environmental and social systems. For instance, increased industrial activity can lead to environmental degradation or exacerbate inequalities if not managed properly. The exploration would benefit from a more nuanced discussion of these challenges and the strategies needed to mitigate them. Incorporating case studies or empirical data could strengthen their arguments and provide a more comprehensive understanding of the practical implications of enhancing SDG 9 in conjunction with other goals.

SDG 9 could bring immense opportunities to small and medium organizations (SMEs) in many industries. The study conducted by [98] explores the implementation of SDG 9 within the small-scale mining industry, focusing on community capacity-building for sustainable resource governance. The authors detail how enhancing local capabilities in governance and technology can lead to improved sustainability practices in mining. They emphasize the critical role of local community engagement and education in driving industry innovation and infrastructure improvements. Their approach aims to empower communities, reduce environmental impacts, and create more sustainable mining operations. However, the study in [98] could further elaborate on specific strategies and technologies to demonstrate practical applications of these concepts in the field.

This exploration into Industry 5.0 and its alignment with SDG 9 provides a nuanced understanding of the interplay between advanced industrial technologies and Sustainable Development Goals, illustrating the complex journey towards integrating sustainable practices in the global industrial landscape.

4.4. SDG 11 (*Sustainable Cities and Communities*)—*World We Want*

Sustainable Development Goal 11 (SDG 11) aims to make cities and human settlements inclusive, safe, resilient, and sustainable [99]. This goal is a crucial component of the broader United Nations Agenda for Sustainable Development, which envisions a world where urban environments support the health, well-being, and prosperity of all their inhabitants. As urban populations continue to grow at an unprecedented rate, the challenges of urbanization become more pronounced, making SDG 11 not just beneficial but essential for the future of human societies [99,100].

The rapid expansion of cities around the globe presents significant challenges in terms of sustainability, resilience, and inclusivity [101]. Urban areas are often the epicenters of economic growth and innovation but also face problems such as congestion, lack of affordable housing, environmental degradation, and social inequality. Effective urban planning and management are therefore crucial to address these challenges, ensuring that cities do not just grow but grow in a way that benefits all residents [101,102].

One of the key aspects of SDG 11 is promoting inclusivity in urban development [103]. This means ensuring that all residents, regardless of their economic status, have access to essential services such as safe and affordable housing, transportation, and public spaces. Inclusivity also involves enhancing participation in urban planning and decision-making processes, allowing residents from diverse backgrounds, including marginalized communities, to have a voice in how their cities are shaped.

Inclusive cities are not only fairer but also stronger, as they harness the full potential of their populations. For instance, providing access to adequate housing and transportation can significantly enhance the economic productivity of lower-income residents by reducing commute times and increasing access to job opportunities.

Resilience in urban planning refers to the ability of cities to withstand and recover from adverse events, including natural disasters, economic shocks, and the impacts of climate change. Building resilient infrastructures—such as flood defenses, earthquake-resistant buildings, and robust public health systems—is essential to minimize the impact of such events [104].

Smart city technologies play a crucial role in enhancing urban resilience. For example, IoT sensors can monitor structural health in buildings and bridges to detect and address potential failures early. Similarly, advanced data analytics can help predict traffic flows and optimize emergency responses during disasters [68].

Figure 7 illustrates the integration of various technological sectors with the United Nations Sustainable Development Goals (SDGs) to promote the concept of Society 5.0. Society 5.0 is envisioned as a human-centered society that balances economic advancement with the resolution of social problems by incorporating the integration of physical space and cyberspace. Figure 6 captures the essence of technological diversity and its potential to drive societal progress, particularly through the lens of Society 5.0. It underscores the role of technology in not just advancing economic objectives, but in addressing broader societal challenges, aiming to create a sustainable, inclusive, and resilient future for all.



Figure 7. Society 5.0 model for Sustainable Development Goals.

Sustainable urban development also involves preserving cultural heritage and fostering a sense of community [105]. Cultural heritage sites are not only tourist attractions but also serve as symbols of a city's history and identity. Preserving these sites amidst urban development is a challenge that requires innovative solutions, which can include integrating modern infrastructure with traditional designs or using technology to digitally preserve historical artifacts [105,106].

Environmental sustainability is another critical aspect of SDG 11 [107,108]. Cities consume a significant portion of the world's natural resources and are responsible for a large share of greenhouse gas emissions. Thus, sustainable management of these resources is imperative. This includes promoting renewable energy sources, enhancing energy efficiency in buildings and transportation systems, and managing waste more effectively [108].

Green spaces such as parks and riverbanks also play a vital role in urban sustainability [109]. They not only provide recreation and relaxation areas but also help regulate air quality and climate, mitigate flood risks, and enhance urban biodiversity.

One of the pioneer examples of emerging technologies in SDG 11 that foster smart communities is the harness of IoT because this example provides rich context [110]. The authors explore the use of Internet of Things (IoT) technology in smart cities and villages, highlighting similarities and differences in application and discussing prospects. They argue that IoT enables efficient resource management, enhanced service delivery, and improved quality of life through real-time data collection and analysis. The study provides a comprehensive look at how IoT facilitates urban and rural connectivity, supporting a range of functions from city traffic management to precision agriculture in villages.

Critically, while Ref. [110] underscores the transformative potential of IoT, significant challenges such as cybersecurity risks, privacy concerns, and the technological infrastructure required to support such widespread IoT deployment also need to be addressed. Moreover, the digital divide between urban and rural areas could exacerbate inequalities if not managed carefully. A deeper analysis of these issues would provide a more balanced view of IoT's role in advancing sustainable development in diverse environments.

Other research scrutinized by [111] aims to build sustainable cities and communities, focusing on how emerging technologies can drive these objectives. The text highlights innovative solutions like smart grids and IoT for enhancing urban efficiency and sustainability. The critique of the chapter is that while it successfully outlines the potential of technology to advance SDG 11, it lacks a critical discussion on the challenges of technology deployment, such as privacy concerns, funding, and infrastructure gaps. Furthermore, the discussion could benefit from more concrete examples and a deeper exploration of socio-economic impacts on diverse urban populations, to fully grasp the practical implications of these technologies.

The evident relationship between SDG 11, and the New Urban Agenda is analyzed in [103], detailing how these global frameworks guide local sustainability efforts. They emphasize the importance of integrating these goals into local policies to address urban challenges effectively. The critique, however, is that while the paper robustly outlines the theoretical alignments between global frameworks and local actions, it lacks detailed case studies or empirical evidence to show practical implementation and the outcomes of such integrations. More real-world applications and assessments would provide a stronger, evidence-based argument for the frameworks' effectiveness.

Different machine learning approaches were studied by [112], which investigated the use of artificial neural networks (ANNs) in smart cities with an emphasis on achieving Sustainable Development Goal 11 (SDG 11), which aims to make cities inclusive, safe, resilient, and sustainable. Their findings highlight the potential of ANNs to enhance various aspects of urban management, such as traffic control, public safety, and infrastructure monitoring, contributing to safer communities.

However, Ref. [112] could benefit from more critically examining the limitations and ethical concerns associated with deploying ANNs, such as data privacy, surveillance issues, and the potential for biased algorithms that could lead to unequal urban development.

Additionally, the implementation challenges in different urban contexts, particularly in under-resourced cities or areas with limited technical expertise, are not thoroughly addressed. Exploring these dimensions would provide a more holistic view of the practicality and implications of applying ANNs in real-world intelligent city initiatives.

Achieving the objectives of SDG 11 requires active participation from all segments of society, including local communities, private sector, and various levels of government [113]. Smart governance models that utilize digital tools to engage citizens can help gather insights and feedback on urban projects, ensuring that they meet the actual needs of residents.

Public-private partnerships are often essential in financing and implementing large-scale urban infrastructure projects. However, these partnerships need to be managed carefully to ensure that the benefits are distributed equitably and that projects do not exacerbate existing social inequalities.

Research on smart cities often emphasizes individual technological advancements without addressing the combined impact of Industry 5.0 and Society 5.0 on urban sustainability. There is a notable gap in studies exploring how integrated technologies can enhance urban planning, improve resource management, and promote inclusive and sustainable urbanization. This study fills this gap by providing a detailed analysis of how disruptive technologies can be employed to develop sustainable cities and communities, aligning with the objectives of SDG 11.

5. Smart Communities and Smart Apps within SDGs

Smart communities utilize a range of technologies, including the Internet of Things (IoT), artificial intelligence (AI), and big data analytics, to optimize resource use and improve the quality of life. These technologies enable real-time management of city services such as transportation, energy, waste management, and water resources. For example, smart grids can enhance energy efficiency (SDG 7: Affordable and Clean Energy) by dynamically balancing supply and demand, reducing emissions and lowering costs [114]. Similarly, smart waste management systems contribute to SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production) by increasing recycling rates and optimizing waste collection routes, reducing the overall environmental footprint of urban areas.

Smart apps are the user interfaces of these technologies, providing citizens with access to services and information that improve their daily lives. These apps can facilitate everything from public transit and parking solutions to public safety and health services. They not only enhance convenience and efficiency but also promote inclusivity by ensuring that these benefits reach a broad spectrum of the population, including marginalized and vulnerable groups. This directly supports SDG 10 (Reduced Inequalities).

The following sub-section discusses the intersection between the different technologies and smart applications and their role in smart communities including challenges and future prospects.

5.1. Blockchain Integration with SDG 3 (Good Health and Well-Being)

The integration of blockchain technology in healthcare ecosystems contributes significantly to the enhancement of data integrity, security, and accessibility. Blockchain provides a decentralized ledger that records all transactions across a network of computers. This makes it nearly impossible to alter any piece of information without the consensus of all participants. In a healthcare context, this means medical records are securely stored and maintained, preventing unauthorized access and ensuring patient privacy.

Furthermore, blockchain facilitates a unified patient data management system where records are instantly accessible to authorized healthcare providers, regardless of their location. This interoperability addresses one of the major challenges in current healthcare systems—data silos that hinder efficient patient care and medical research. By streamlining access to medical data, blockchain-based systems can lead to more accurate diagnoses,

timely treatments, and personalized healthcare plans, thus directly contributing to SDG 3 (Good Health and Well-Being).

In Figure 8, the diagram illustrates a blockchain-based data management system designed to enhance the integrity and accessibility of clinical data across various stakeholders, including hospitals, governments, research institutes, and factories. This system centers around a smart contract, which automatically enforces agreements between data owners and data users without the need for an intermediary.

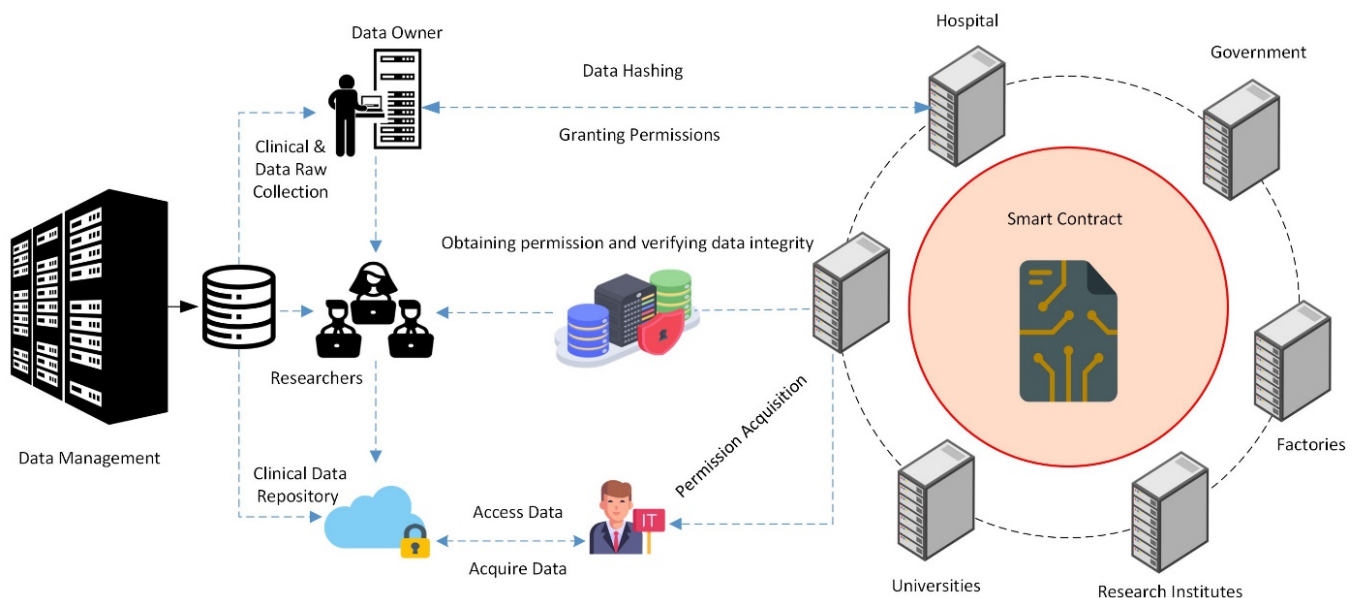


Figure 8. Blockchain-based healthcare ecosystem.

The process begins with the data owner, who collects clinical and raw data, storing it securely in a data repository. This data is then hashed, ensuring its integrity and privacy. Researchers and other authorized entities can request access to this data through smart contracts, which verify permissions and maintain a log of all access, ensuring compliance and transparency. Once permission is granted, data can be accessed and used for various purposes such as medical research and healthcare improvements.

This approach not only secures data but also streamlines the process of data sharing and utilization, making it highly efficient for environments that demand high levels of data integrity and quick access to information. This kind of system could significantly enhance the capabilities of healthcare facilities, including those that might need to securely manage large volumes of sensitive data, possibly improving the overall healthcare delivery in your community.

5.1.1. Promoting Inclusivity and Reducing Inequalities

One of the transformative impacts of blockchain in smart healthcare ecosystems is its potential to democratize health data and ensure equitable access to healthcare services. Blockchain-based platforms can empower patients by giving them control over their own medical data, enabling them to share it securely with any provider worldwide. This not only enhances the patient's autonomy but also facilitates medical tourism and global health initiatives.

Additionally, blockchain can help reduce healthcare disparities seen in underprivileged communities and developing countries. By eliminating intermediaries and reducing administrative costs, blockchain-based solutions can make healthcare services more affordable and accessible, aligning with SDG 10 (Reduced Inequalities).

5.1.2. Smart Apps: The Interface for Blockchain Healthcare Solutions

Smart apps are crucial interfaces that enable the practical application of blockchain technology in healthcare. These apps can provide patients with secure access to their medical records, real-time health monitoring, and direct communication channels with healthcare providers. Smart apps can also utilize AI algorithms to provide personalized health recommendations based on blockchain-stored medical data, enhancing patient engagement and preventive care strategies.

Moreover, smart healthcare apps can integrate with other smart city infrastructures, such as emergency services and public health notifications, thereby creating a cohesive ecosystem that supports proactive health management and rapid response to health crises. This integration is vital for achieving SDG 11 (Sustainable Cities and Communities) by fostering an environment where advanced technologies and data-driven strategies enhance public health and safety.

5.1.3. Achieving SDGs through Partnerships

The full potential of a blockchain-based healthcare ecosystem can only be realized through robust partnerships among governments, technology providers, healthcare institutions, and communities. Collaborative efforts are necessary to develop standards and regulations that ensure technology interoperability, privacy, and ethical use of medical data. Partnerships are also crucial for fostering innovation and scaling successful models across different regions and demographics, directly supporting SDG 17 (Partnerships for the Goals).

5.1.4. Challenges and Future Prospects

Despite its potential, the implementation of blockchain technology in healthcare faces several challenges, including technological complexity, regulatory uncertainty, and the need for significant initial investment. Overcoming these barriers requires continuous innovation, community engagement, and supportive policies that encourage the adoption of smart healthcare solutions.

Looking forward, the expansion of blockchain-based healthcare ecosystems in smart communities represents a promising pathway towards achieving the SDGs. As technology evolves and more stakeholders recognize the benefits of blockchain technology, it is likely to become a cornerstone of sustainable, inclusive, and efficient healthcare systems worldwide.

5.2. Immersive Learning Experiences (ILX) Integration with SDG 4 (Quality Education)

Immersive learning experiences (ILX), which leverage advanced technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR), are transforming educational landscapes by providing more engaging, interactive, and effective learning environments. Integrating ILX with Sustainable Development Goal 4 (Quality Education) aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

ILX tools allow learners to explore complex concepts in a hands-on, visually stimulating manner. For example, VR can transport students to historical sites or simulate scientific experiments, offering experiences that are otherwise inaccessible in traditional classrooms. This not only enhances understanding and retention but also democratizes access to high-quality education resources, especially for students in remote or underserved areas.

By fostering a more engaging learning environment, ILX helps reduce disparities in educational access and outcomes, contributing significantly to the achievement of SDG 4. This approach ensures that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity.

In Figure 9, the proposed conceptual framework for the integration of Industry 5.0 in higher education is displayed. This framework is divided into four key stages: input, process, output, and outcome.

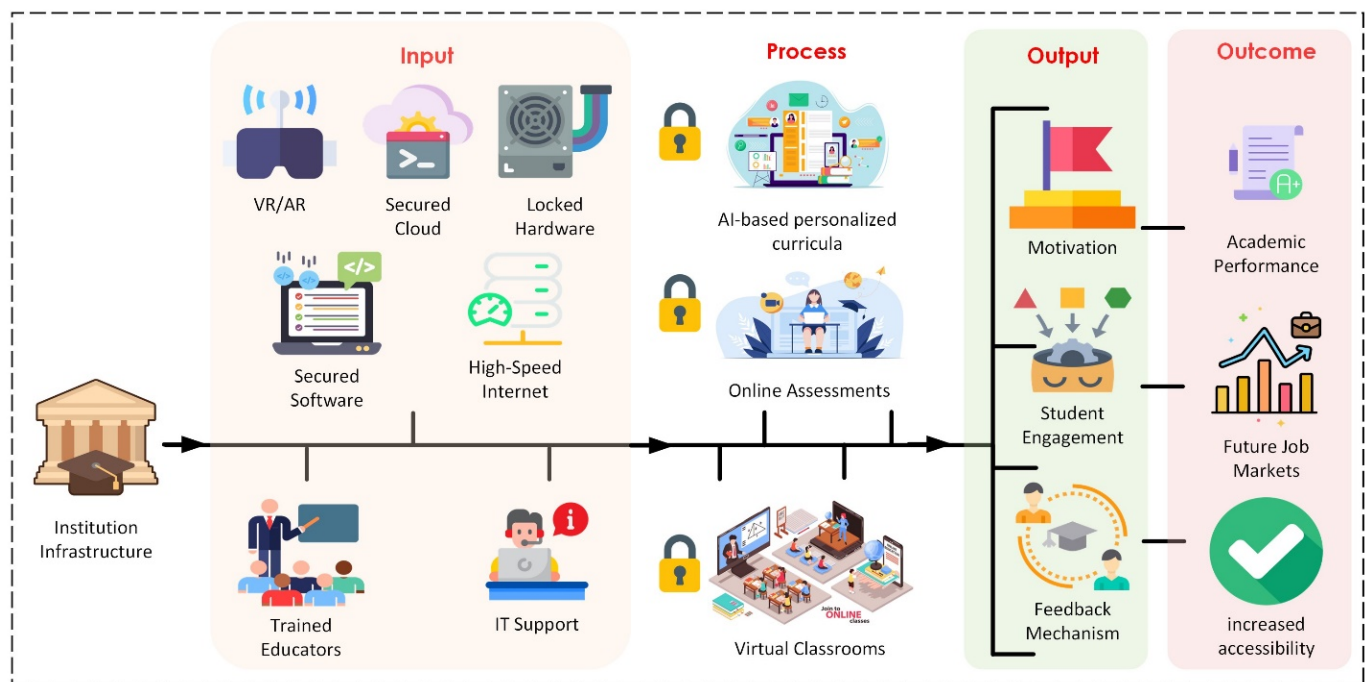


Figure 9. Conceptual framework of Industry 5.0 integration in education.

- **Input:** The first stage identifies the necessary components required for implementing Industry 5.0 technologies in higher education. These include the actual Industry 5.0 technologies such as artificial intelligence (AI), machine learning, augmented reality (AR), and virtual reality (VR). Additionally, human capital is critical, which includes educators who are trained in using these technologies, IT support staff to maintain the technical infrastructure, etc. Infrastructural requirements encompass all the physical and digital necessities, including hardware, software, and high-speed internet connectivity.
- **Process:** This stage reflects how the inputs are transformed within the educational setting. It includes development and implementation of AI-based personalized curricula, establishment of AR-/VR-enabled virtual classrooms, and the application of machine learning algorithms for assessing students' performance and progress.
- **Output:** This is the immediate result of the implementation processes. The outputs include adaptive learning experiences customized to individual students' needs, enhanced levels of student engagement and interaction, improved and timely assessment and feedback mechanisms, and creation of a more collaborative and inclusive learning environment.
- **Outcome:** This final stage represents the long-term impacts and benefits resulting from the integration of Industry 5.0 technologies. These include improved academic performance due to personalized learning, increased accessibility of higher education resources for students regardless of their geographical location or socio-economic status and preparing students for the future job market by equipping them with the skills and experience to work with advanced technologies.

Arrows are used to demonstrate the flow from one stage to the next, indicating that each stage builds upon the previous. This progression illustrates how the strategic integration of resources (input), coupled with an effective execution (process), leads to immediate benefits (output) and, over the long term, results in significant positive impacts (outcome) on students and the overall higher education landscape.

The mind map in Figure 10 shows the impact of Industry 5.0 on education and how Industry 5.0 can contribute to the development of creative environments that encourage both students and teachers to create knowledge.

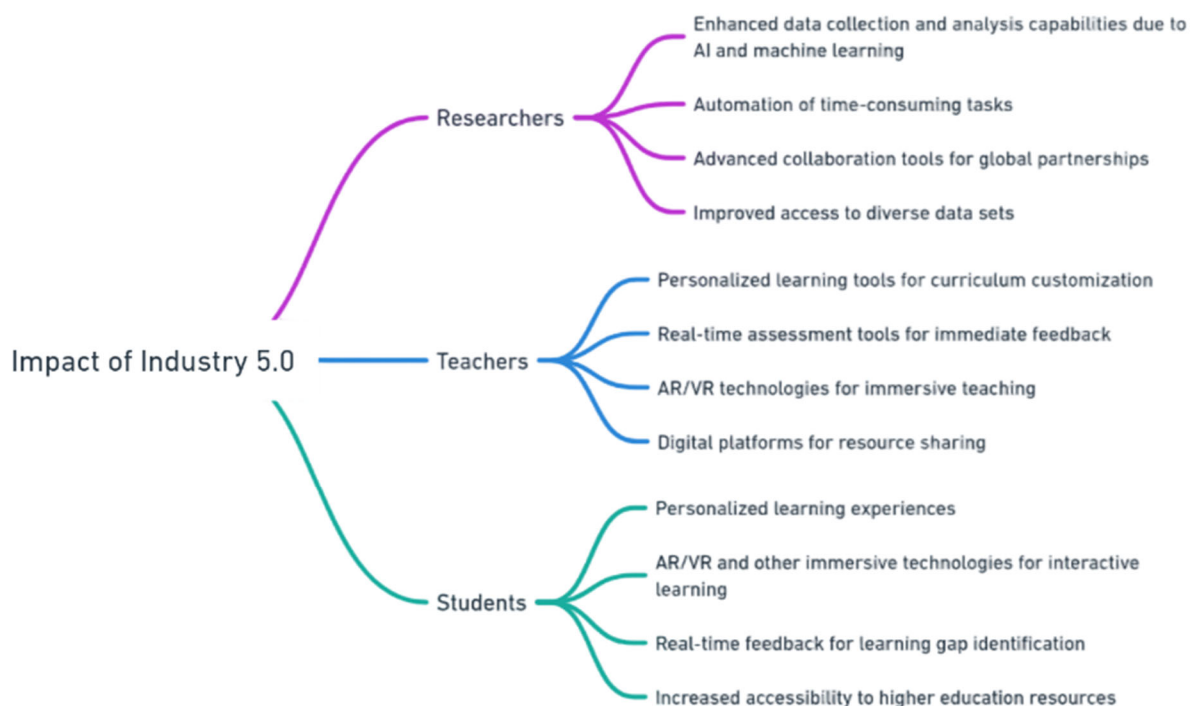


Figure 10. Impact of Industry 5.0 in education.

Implementation and Validation: Immersive Learning Experience (ILX)

Immersive learning experience (ILX) represents a groundbreaking shift in education, utilizing advanced technologies such as virtual reality (VR), augmented reality (AR), and mixed reality (MR) to create highly interactive and engaging learning environments. ILX goes beyond traditional learning methods by enabling students to explore, interact with, and become part of the subject matter. This innovative approach supports experiential learning, where students gain knowledge and skills through firsthand experiences within an artificial, yet highly realistic, environment. Whether it's a student virtually exploring ancient ruins for a history class, or a medical student performing a complex surgical procedure in a safe, simulated setting, ILX enhances understanding, retention, and application of knowledge. By creating a sense of presence and involvement, ILX not only enriches the learning process but also makes it more enjoyable and memorable for students.

The proposed conceptual framework, designed to integrate Industry 5.0 into higher education, has undergone a practical test of its efficiency and effectiveness. As part of this validation process, a specialized game was developed and launched for master's students in the cybersecurity class. The game, informed by the principles of immersive learning experience (ILX), was strategically designed to support and enhance the students' learning journey. It leverages advanced technologies inherent in Industry 5.0, creating an interactive, engaging, and realistic learning environment where theoretical concepts are transformed into practical, hands-on experiences.

5.3. Smart Manufacturing Integration with SDG 9 (Industry)

Smart manufacturing in industry 5.0 integrates human creativity with advanced technologies to promote sustainable and human-centric industrial production. This approach aligns directly with Sustainable Development Goal 9 (Industry, Innovation, and Infrastructure), emphasizing sustainable industrialization that is inclusive and beneficial for all.

Industry 5.0 prioritizes the collaboration between humans and machines, leveraging the strengths of each to enhance innovation, flexibility, and decision-making. For example, collaborative robots (cobots) are used alongside human workers to perform complex tasks, enhancing productivity while ensuring workplace safety and ergonomics. This human-machine interaction enhances quality and efficiency in production, reflecting a significant advancement in manufacturing technologies.

Furthermore, Industry 5.0 focuses on customizing production to meet specific consumer demands while minimizing waste, which supports SDG 9's targets on making industries sustainable and efficient. The use of smart sensors and IoT in manufacturing processes also aids in optimizing energy usage and reducing emissions, contributing to environmental sustainability and resource efficiency.

Siemens' digital factory in Amberg, Germany, stands as a quintessential example of smart manufacturing, utilizing autonomous systems that communicate and coordinate with each other to enhance production efficiency and flexibility. This factory embodies the principles of Industry 4.0 by integrating advanced digital technologies that optimize resource use and minimize waste. These technologies contribute to sustainable industrialization by improving operational efficiencies and reducing the environmental impact of manufacturing processes.

5.3.1. Integration of Process Simulate Applications

The integration of Tecnomatix Process Simulate applications into a setting like Siemens' digital factory could further enhance these capabilities. Process Simulate offers a suite of dedicated tools designed to streamline modeling and simulation tasks, providing additional value to manufacturing processes. These tools described as follows:

5.3.2. Assembler

The Assembler tool could optimize the assembly of complex electronic components by determining the most efficient sequence for assembly and disassembly. This would minimize time and reduce potential collisions, leveraging dynamic creation and simulation capabilities to enhance throughput and accuracy.

5.3.3. Robotics

The Robotics application within Process Simulate could be pivotal for the automation of the factory. It allows for virtual development, simulation, and commissioning of robotic systems. Applying this tool, Siemens could plan collision-free robotic paths, optimize robot placement, and synchronize multi-robot operations, thereby increasing the overall efficiency and reducing energy consumption in automated tasks.

5.3.4. OLP—Offline Programming

OLP allows for the programming and optimization of robotic processes in a dynamic 3D environment without halting production. Siemens could utilize this tool to enhance its robotic systems by refining robot-specific programming, improving motion paths, and optimizing cycle times without disrupting existing operations.

5.3.5. VC Lite—Virtual Commissioning

Virtual commissioning is crucial for ensuring that the integration of new systems into the production line is seamless. Using VC Lite, Siemens could simulate and analyze the installation and commissioning of new manufacturing zones or cells before actual physical implementation, minimizing risks and downtime.

5.3.6. Continuous Manufacturing

For continuous manufacturing processes such as welding, sealing, or painting, Process Simulate tools could be used to develop and optimize robotic paths. This could help

Siemens in improving the placement of robots, optimizing their reach and efficiency, and ensuring quality control in continuous manufacturing lines.

5.3.7. Human

Integrating human considerations into the manufacturing process, Process Simulate Human can help Siemens design workstations that optimize human–robot interactions. This tool can assess ergonomics and safety, ensuring that operations meet industry standards and contribute to a productive work environment.

5.3.8. VR Analyze—Virtual Reality

Finally, VR Analyze can bring a virtual reality component into the process review and troubleshooting phases. Siemens could use this tool to immerse engineers and operators in the manufacturing environment, allowing them to conduct detailed analyses and collaborative reviews in a virtual space, enhancing both design and operational processes.

5.4. Smart Communities and Smart Apps within SDG 11

Sustainable development goal 11 (SDG 11) focuses on making cities inclusive, safe, resilient, and sustainable. The conceptual taxi service system in Figure 11 provides a valuable example of integrating technology to enhance urban transportation systems. This system contributes to reducing urban congestion and emissions through efficient route optimization and potentially incorporates eco-friendly vehicle technologies, aligning with the goal of minimizing urban environmental impacts. Figure 11 illustrates a modern taxi service infrastructure. Number 1 represents the “Call Taxi” feature, enabling customers to request a ride. Number 2 represents the taxi service operator, managing dispatch and logistics. Number 3 is the data center, handling vast amounts of operational and customer data. Number 4 signifies the call center, providing customer support and service. Number 5 depicts customer ratings, crucial for driver feedback and service improvement. The integrated payment system ensures secure and efficient transactions. Additionally, the integration with public transportation could improve accessibility, providing essential last-mile connectivity and promoting inclusive mobility. The central data center highlights the use of big data in managing and optimizing urban transport, which can support more informed urban planning and resource management. Automated features within the system can reduce operational costs, enhancing economic efficiency, while real-time tracking and user feedback mechanisms improve safety and customer satisfaction. Overall, this innovative taxi service model embodies the principles of SDG 11 by fostering a more sustainable, efficient, and user-friendly urban transportation environment.

Smart communities utilize a network of interconnected devices and systems to collect, analyze, and act upon data in real time. Key functionalities include:

1. **Resource Management:** Smart apps facilitate efficient resource management by monitoring and optimizing the use of water, energy, and waste. For example, smart grids can adjust energy distribution based on demand, while smart water management systems can detect leaks and monitor consumption patterns.
2. **Mobility and Transportation:** Intelligent transportation systems (ITS) are integral to smart communities. These systems use data from traffic sensors, GPS, and IoT devices to manage traffic flow, reduce congestion, and promote the use of public transport. Apps can provide real-time updates on traffic conditions, public transportation schedules, and optimal travel routes.
3. **Public Safety:** Smart communities enhance public safety through surveillance systems, emergency response coordination, and crime prediction models. Apps can alert residents to emergencies, provide access to emergency services, and even enable community policing initiatives.
4. **Healthcare:** Telemedicine and remote health monitoring apps allow residents to access healthcare services from their homes, reducing the burden on healthcare facilities and improving accessibility, especially for the elderly and disabled.

5. **Citizen Engagement:** Smart apps promote civic engagement by providing platforms for residents to participate in local governance, report issues, and receive updates on community developments. These platforms encourage transparency and foster a sense of community ownership.

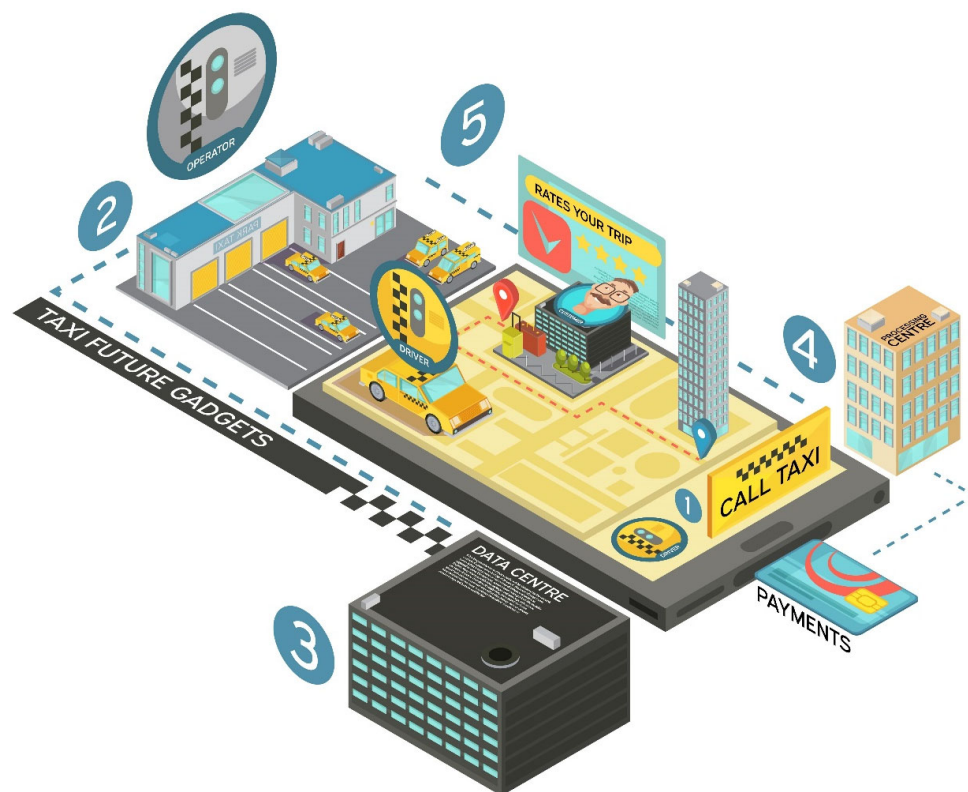


Figure 11. Taxi app in Society 5.0 for Sustainable Development Goals.

The layout of smart communities is designed to maximize the efficiency and effectiveness of smart apps. Key aspects include:

1. **Centralized Data Hubs:** At the core of a smart community is a centralized data hub that aggregates data from various sources. This hub facilitates data sharing and analysis, enabling informed decision-making and coordinated responses.
2. **Zoned Infrastructure:** Smart communities are often divided into zones based on functionality, such as residential, commercial, and industrial areas. Each zone is equipped with tailored smart solutions to address specific needs, such as smart lighting in residential areas and smart logistics in industrial zones.
3. **Integrated Network Systems:** The physical infrastructure of smart communities includes an extensive network of sensors, IoT devices, and communication networks. This integration ensures seamless data flow and connectivity, essential for the real-time functionality of smart apps.
4. **Green Spaces and Sustainable Design:** Smart communities emphasize the inclusion of green spaces and sustainable urban design. This not only improves the quality of life but also supports environmental sustainability by integrating nature into urban settings.

While the goals of SDG 11 are clear, the path to achieving them is fraught with challenges. These include political, financial, and technical barriers. Moreover, the global nature of urbanization requires coordinated efforts across borders, as cities often face similar problems and can benefit from sharing solutions. The future of sustainable urban development will likely see increased reliance on new technologies, such as AI and blockchain, to manage urban systems more efficiently and transparently. However, technology should be viewed as a tool to enhance human-centered urban design, not a panacea.

6. Proposed Framework: Discussion and Analysis

Existing studies often focus on either Industry 5.0 or Society 5.0 in isolation, with limited emphasis on their integration for achieving SDGs. Furthermore, while the application of disruptive technologies is widely discussed, there is a lack of focused research on their direct impact on specific SDGs, particularly SDGs 3, 4, 9, and 11. Our research fills these gaps by proposing a coordinated framework that integrates these technologies into smart cities, providing detailed insights and practical guidance for stakeholders.

The integrative technology for sustainable development (ITSD) framework aims to align advanced technological innovations with the Sustainable Development Goals (SDGs). To ensure that our framework is grounded in a robust theoretical foundation, we incorporate insights from various schools of thought regarding well-being and the role of technology. These include Austrian economics, new institutional approaches, new Keynesians, post-Keynesians, and socialist perspectives [115,116]. This comprehensive theoretical underpinning provides a balanced view and contextualizes our propositions within broader economic and social theories.

6.1. Austrian Economics and New Institutional Approaches

Austrian economics (AE) and new institutional approaches (NIA) offer valuable perspectives on the benefits of technological innovation and market-driven solutions. These schools of thought emphasize the role of entrepreneurship, market processes, and the spontaneous order resulting from decentralized decision-making. AE, for instance, highlights how technological improvements can lead to better utilization of resources and labor, ultimately enhancing productivity and economic growth. The NIA perspective further supports the idea that institutions and regulatory frameworks can facilitate technological adoption by reducing transaction costs and fostering innovation.

6.2. New Keynesian and Post-Keynesian Perspectives

New Keynesian and post-Keynesian perspectives focus on the role of government intervention in addressing potential market failures that can arise from unregulated technological adoption. These schools advocate for co-active central planning and public policies to ensure the equitable distribution of technological benefits, address externalities, and mitigate risks such as technological unemployment. They underscore the need for robust public infrastructure and social safety nets to support the transition towards a more automated and digital economy.

6.3. Socialist Approaches

Socialist perspectives emphasize collective ownership and the role of the state in managing technological advancements to promote social equity and public welfare. This approach advocates for the democratization of technology and highlights ethical considerations in AI and digital innovations. Policies that prioritize human well-being over mere economic growth are central to this viewpoint, ensuring that technological progress benefits all members of society.

6.4. Bridging the Gaps

The ITSD framework integrates these diverse theoretical perspectives to provide a holistic approach to achieving SDG 11 (Sustainable Cities and Communities). This involves recognizing the strengths and limitations of both market-driven and government-led strategies. Our framework advocates for a balanced approach where technological innovations are harnessed through market mechanisms, while ensuring adequate regulatory oversight and public investment to address social and ethical concerns.

6.5. Methodological Approach

Our methodological approach includes a systematic literature review, comparative analysis, and case studies to test the hypotheses and achieve the research goals. This involves the following:

- Conducting a thorough review of the existing literature on smart cities, Industry 5.0 technologies, and sustainable development.
- Analyzing case studies to provide empirical evidence of the ITSD framework's impact on achieving SDG 11.
- Using qualitative and quantitative methods to evaluate the effectiveness of different technological solutions and policy interventions.

The “Integrative Technology for Sustainable Development” (ITSD) framework in Figure 12 represents a comprehensive approach designed to leverage advanced technology to support and enhance the United Nations Sustainable Development Goals (SDGs). The ITSD framework addresses the intersection of technology, society, and sustainability, focusing on creating systems that not only meet the current technological advancements but are also aligned with global efforts to improve environmental, social, and economic conditions.

6.6. Framework Overview

The ITSD framework is structured around three core components: technological integration, human-centric design, and sustainability focus. It encapsulates various facets of advanced technologies such as IoT platforms, smart health, assistive robotics, distributed cloud systems, blockchain technology, and adaptive systems intelligence. These technologies are mapped across different SDGs to show how each can contribute to specific goals, ranging from poverty alleviation and zero hunger to climate action and life below water.

6.7. Technological Integration

This component emphasizes the integration of diverse technologies to solve complex global challenges. For example, IoT platforms can enhance resource management in smart cities, contributing to SDG 11 (Sustainable Cities and Communities), while blockchain technology can improve transparency in supply chains, supporting SDG 12 (Responsible Consumption and Production). By integrating these technologies, the ITSD framework ensures a robust, reliable infrastructure that is adaptable to both current and future needs.

6.8. Human-Centric Design

Human-centric design is central to the ITSD framework, ensuring that technological advancements are accessible and beneficial to all segments of society, thus addressing SDG 10 (Reduced Inequalities). This includes developing assistive robots to aid the elderly or disabled (SDG 3: Good Health and Well-Being) and designing educational technologies that adapt to the needs of diverse learning populations (SDG 4: Quality Education).

6.9. Sustainability Focus

The sustainability focus ensures that all technological integrations consider environmental impacts, aligning with SDGs such as Climate Action (SDG 13) and Life Below Water (SDG 14). This involves promoting technologies that enhance energy efficiency (SDG 7: Affordable and Clean Energy) and developing systems that manage natural resources more effectively, such as smart agriculture technologies that reduce water usage (SDG 6: Clean Water and Sanitation).



Figure 12. (ITSD) Proposed framework.

6.10. Implementation Strategies

1. **Multi-Stakeholder Partnerships:** Implementation of the ITSD framework requires collaboration among governments, industry, academia, and civil society. These partnerships facilitate resource sharing, innovation, and policy-making that are essential for the widespread adoption of sustainable technologies.
2. **Policy Integration and Incentivization:** Effective policy frameworks and incentives are necessary to encourage the adoption of sustainable technologies. This includes subsidies for clean energy technologies, regulations that promote data privacy and security, and standards that ensure technologies are both sustainable and inclusive.
3. **Education and Capacity Building:** Developing human capital is critical to the successful implementation of the ITSD framework. Educational programs and training workshops can equip individuals with the skills needed to operate and innovate within technologically advanced and sustainable systems.
4. **Continuous Monitoring and Feedback:** To ensure the ITSD framework remains relevant and effective, continuous monitoring and evaluation are required. This involves collecting data on the impact of technological implementations and making iterative improvements based on feedback from stakeholders and technological advancements.

A SWOT analysis of the proposed framework to achieve SDGs with Industry 5.0 technologies as the foundation is shown in Tables 3 and 4.

Table 3. Strengths and weaknesses.

Strengths	Weaknesses
Technological Integration: Utilizes a comprehensive array of technologies such as IoT, AI, blockchain, ensuring versatile and robust solutions across various sectors. Human-Centric Design: Emphasizes user accessibility and usability, ensuring benefits across all societal segments and promoting inclusivity. Sustainability Focus: Aligns with environmental sustainability goals to promote resource conservation and waste reduction. Adaptability and Scalability: Flexible design allows for adjustments and scaling to meet evolving demands and technologies. Enhanced Efficiency: Improves operational efficiencies, reducing costs and enhancing outcomes.	Complexity and Integration Challenges: The integration of diverse technologies can lead to significant coordination challenges and complexities. High Initial Costs: Significant upfront investments are required for technology and infrastructure development. Dependency on Technology: Over-reliance on technology could introduce vulnerabilities, especially in cybersecurity. Skill Gaps: Necessitates a workforce skilled in new technologies, which might be lacking in regions with educational disparities. Regulatory and Policy Barriers: Diverse regulations may hinder technology deployment, affecting consistency and effectiveness.

Table 4. Opportunities and Threats.

Opportunities	Threats
Global Push for Sustainability: Increased focus on sustainability globally supports the adoption of sustainable frameworks like ITSD. Partnerships and Funding: Potential for collaborations with governments, NGOs, and the private sector, providing support and financial backing. Technological Advancements: Ongoing innovations enhance the framework’s capabilities and adaptability. Educational Expansion: A global emphasis on education can mitigate skill shortages, aligning well with the framework’s needs. Market Demand: Rising demand from consumers and businesses for sustainable practices drives adoption of frameworks like ITSD.	Technological Disruption: Rapid changes in technology can quickly make current solutions obsolete. Economic Instability: Economic downturns can reduce investments in new technologies and sustainability efforts. Political Factors: Shifts in political climates can influence the level of support for sustainable initiatives. Cybersecurity Risks: Increased cyber threats could jeopardize the integrity of integrated systems. Resistance to Change: Cultural and organizational inertia may slow down the adoption of new technologies and processes.

The examination of the “Integrative Technology for Sustainable Development” (ITSD) framework highlights a significant stride towards harmonizing technological innovation with the Sustainable Development Goals (SDGs) through Industry 5.0. This paper has explored various aspects of disruptive technologies, their integration into smart cities and communities, and the potential enhancements in human-centric approaches facilitated by these advancements.

6.11. Synergistic Integration of Technologies and SDGs

The ITSD framework embodies a holistic integration of cutting-edge technologies such as AI, IoT, blockchain, and big data analytics with the core objectives of the SDGs. This synergy is crucial in creating resilient infrastructures, promoting inclusive industrialization, and fostering innovation (SDG 9). Moreover, the application of these technologies in smart cities enhances sustainability (SDG 11), ensures good health and well-being through improved healthcare systems (SDG 3), and enriches education (SDG 4). The framework’s strength lies in its comprehensive approach, which not only addresses individual SDG targets but also ensures that the technological solutions are sustainable, inclusive, and equitable.

6.12. Human-Centric Design: A Paradigm Shift

A key takeaway from the ITSD framework is the pivotal shift towards human-centric design. This approach ensures that technological advancements are not just high-performing but are also accessible, enhancing user experience and inclusivity. The emphasis on human-centric design within Industry 5.0 fosters a collaborative environment where technology complements human skills, enhancing creativity and innovation. This is particularly evident in sectors like manufacturing and healthcare, where cobots and smart health systems respectively are being designed to augment human capabilities, thereby improving safety, efficiency, and job satisfaction.

6.13. Challenges and Resilience

Despite the promising prospects of integrating Industry 5.0 technologies within the ITSD framework, several challenges persist. The complexity of technology integration is a significant barrier, often requiring a coordinated effort across multiple domains and sectors. High initial costs associated with deploying advanced technologies such as AI, IoT, and robotics can be prohibitive, particularly for developing regions and smaller enterprises. Additionally, there is a pressing need for substantial upskilling and reskilling of the workforce to effectively operate and manage these technologies. This requirement can strain existing educational and training infrastructures, necessitating innovative approaches to lifelong learning and vocational training.

Moreover, cybersecurity risks are a critical concern. As the integration of interconnected systems grows, so does the vulnerability to cyber-attacks. Ensuring robust cybersecurity measures is imperative to protect sensitive data and maintain the integrity of technological systems. Ethical concerns regarding data privacy and AI decision-making also need to be addressed to build public trust and ensure the responsible use of technology. The potential for biased algorithms, the misuse of personal data, and the transparency of AI decision-making processes are all issues that require careful consideration and regulation.

However, the framework’s adaptability provides a pathway to overcome these challenges. Continuous monitoring and feedback mechanisms are essential to identify and address issues promptly. Iterative improvement of technologies, based on real-time data and stakeholder feedback, ensures that the framework evolves in alignment with both technological advancements and societal needs. This dynamic approach allows for adjustments and enhancements that can mitigate the identified challenges over time.

Fostering strong partnerships among governments, industry, academia, and civil society is crucial to overcoming implementation hurdles. Governments can provide regulatory support and funding, industry can drive innovation and investment, academia can contribute research and educational resources, and civil society can ensure that technological

advancements align with public interests and ethical standards. Collaborative efforts can lead to the development of standardized protocols, shared resources, and joint initiatives that enhance the resilience and scalability of the ITSD framework.

By addressing these challenges through a resilient and adaptable approach, the integration of Industry 5.0 technologies within the ITSD framework can significantly contribute to achieving the Sustainable Development Goals. Building a robust, inclusive, and ethical technological ecosystem will not only advance economic and industrial growth but also ensure that these advancements benefit society as a whole.

7. Conclusions and Future Prospects

As we reflect on the expansive journey traversed in this paper, the “Integrative Technology for Sustainable Development” (ITSD) framework emerges as a beacon for the amalgamation of cutting-edge technology with the United Nations’ Sustainable Development Goals (SDGs). This paper has meticulously laid out how various Industry 5.0 technologies—ranging from IoT and blockchain to smart health and robotics—can pivotally enhance SDG achievements, underscored by their deployments in smart cities and communities to foster an inclusive, sustainable future.

The ITSD framework’s robust structure, integrating technological advancements, human-centric design, and a strong sustainability focus, provides a resilient foundation for tackling contemporary global challenges. It offers a versatile approach that not only addresses the direct needs of today’s technological landscape but also anticipates future demands and shifts in societal needs. The convergence of these technologies within the ITSD framework not only aims to optimize resource management and efficiency but also seeks to enhance quality of life and promote equitable access to technological benefits.

7.1. Pros and Cons of the ITSD Framework

Pros: The ITSD framework offers several advantages and some challenges. Pros: The ITSD framework provides a comprehensive integration of various Industry 5.0 technologies, such as AI, IoT, robotics, and blockchain, with sustainability principles. This holistic approach enhances the efficiency and effectiveness of achieving the Sustainable Development Goals (SDGs). The framework is scalable and flexible, adaptable to different regional and cultural contexts, allowing for customization based on specific local needs. This adaptability makes it applicable to a wide range of urban and rural settings. By leveraging advanced technologies, the ITSD framework aims to improve public services such as healthcare, education, and transportation, thereby enhancing the quality of life for residents in smart communities. Additionally, the focus on sustainable practices ensures that technological advancements contribute to environmental conservation and the efficient use of resources, aligning with SDG 11 (Sustainable Cities and Communities).

Cons: Implementing the ITSD framework requires significant initial investment in infrastructure and technology, which can be a barrier, particularly for developing regions with limited financial resources. The integration of multiple advanced technologies can be complex and may require substantial technical expertise and coordination among various stakeholders. As with any technology-driven initiative, there are inherent risks related to data privacy and cybersecurity. Ensuring robust security measures is crucial to protect sensitive information and maintain public trust. Furthermore, the deployment of AI and other advanced technologies raises ethical concerns, particularly concerning data privacy, decision-making transparency, and potential biases in algorithmic processes.

7.2. Future Prospects

Looking ahead, the ITSD framework is poised for evolutionary growth as it adapts to the dynamic tech-scape and the ever-changing global environment. The continuous integration of emerging technologies, such as artificial intelligence, next-generation IoT devices, and quantum computing, holds promise for even more profound impacts on Sustainable Development Goals. Future research should focus on refining these technologies to

enhance their scalability and effectiveness across different regions and cultures. Moreover, interdisciplinary collaborations will be essential to foster innovative solutions and leverage diverse expertise.

7.3. Educational Initiatives and Policy Development

Educational programs and policy initiatives will play a critical role in the widespread adoption and success of the ITSD framework. Tailored educational curricula need to be developed to prepare the next generation of engineers, designers, and policymakers to think critically about how technology intersects with sustainability. Additionally, policies that foster a conducive environment for sustainable technological innovations will be essential to encourage investment and support from both public and private sectors. Policies should also address issues of digital equity, ensuring that technological advancements do not exacerbate existing inequalities but rather contribute to bridging the digital divide.

7.4. Monitoring, Evaluation, and Iterative Improvement

To ensure the ITSD framework remains relevant and effective, ongoing monitoring and evaluation are crucial. This will involve not just assessing the impact of technological implementations but also staying ahead of technological obsolescence by continuously integrating advancements into the framework. Iterative improvements based on real-world data and feedback will enhance the framework's robustness and responsiveness to global sustainability needs. Establishing comprehensive metrics and evaluation frameworks will help in tracking progress and identifying areas for improvement.

7.5. Building Resilience and Fostering Partnerships

The challenges of technology adoption, such as high initial costs and the complexity of integrating diverse systems, call for innovative solutions in policymaking, education, and capacity building. By fostering strong partnerships among governments, industry, academia, and civil society, the ITSD framework can navigate these challenges effectively. Collaborative efforts will lead to the development of standardized protocols, shared resources, and joint initiatives that enhance the resilience and scalability of the framework.

7.6. Conclusions

In conclusion, the ITSD framework represents a forward-thinking approach to harmonizing technological innovation with sustainable development. It emphasizes the importance of adaptability, continuous learning, and strong partnerships in overcoming the inherent challenges of integrating advanced technologies. As we look to the future, it is imperative that we continue to foster the synergies between technology and sustainability, ensuring that the advancements we embrace today do not just solve the problems of the present but pave the way for a more resilient, inclusive, and sustainable tomorrow. The ITSD framework stands as a testament to the potential of human ingenuity and collaboration in achieving a sustainable future.

Author Contributions: Conceptualization, A.A. and N.H.A.; methodology, A.A.; software, A.A.; validation, A.A., N.H.A.; formal analysis, A.A.; investigation, A.A.; resources, N.H.A.; data curation, A.A.; writing—original draft preparation, A.A.; writing—review and editing, N.H.A.; visualization, A.A.; supervision, A.A.; project administration, A.A.; funding acquisition, N.H.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

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