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KEY ENABLING TECHNOLOGIES FOR SOCIETY 5.0

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Abstract:
Society 5.0 represents a human-centered paradigm that integrates cyberspace and physical space to address complex societal challenges through advanced digital technologies, with the aim of improving the quality of life. This paper explores the role of key enabling technologies, including Artificial Intelligence (AI), Internet of Things (IoT), Big Data, Cloud Computing, Edge Computing, 5G/6G and wireless communication technologies, Robotics, and Cyber-Physical Systems (CPS), in enabling the transition toward Society 5.0.
The paper examines how these technologies contribute to key Society 5.0 domains, including smart cities, healthcare, industry, education, sustainability, and quality of life. In addition to technological opportunities, the paper addresses critical challenges related to data privacy, digital ownership, cybersecurity, ethical implications of AI, and digital inequality.
A conceptual framework is proposed to map enabling technologies to major Society 5.0 domains, highlighting their interdependencies and combined impact on human-centric and sustainable development. The findings suggest that the successful realization of Society 5.0 requires not only technological advancement but also interdisciplinary integration, governance frameworks, and a strong human-centric focus..

Keywords: *Artificial Intelligence (AI), Internet of Things (IoT), Edge Computing, Society 5.0*

Introduction

Society 5.0, which as a concept was originally introduced in Japan, represents a new phase in societal evolution that builds upon previous industrial paradigms with a focus on a human-centered and technology-integrated approach [1, 2]. Unlike earlier concepts such as Industry 4.0, Society 5.0 emphasises the seamless integration of cyberspace and physical space to address complex social and economic challenges.

Recent rapid advances in digital technologies have created new opportunities to transform traditional systems into intelligent, interconnected, integrated, and adaptive environments [3]. Key enabling technologies have their roles in different aspects of Society 5.0. Technologies such as Artificial Intelligence, Internet of Things, and Big

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Data play a crucial role in enabling data-driven decision-making and automation [4]. In addition, advancements in Cloud Computing and Edge Computing have significantly improved the scalability, responsiveness, and efficiency of digital infrastructures [5]. Emerging communication technologies such as 5G and 6G networks further enable real-time connectivity and support the development of highly distributed systems [6]. Furthermore, Cyber-Physical Systems and Robotics facilitate the interaction between digital intelligence and the physical world, enabling automation and smart services [7].

The convergence of these technologies forms the foundation for innovative applications in domains such as smart cities [8], healthcare [9], and sustainable industry [10]. However, the adoption of these technologies also raises important challenges related to privacy, security, ethical considerations, and digital inequality [11, 12].

In this context, this paper aims to analyze the role of key enabling technologies in the development of Society 5.0 and to propose a conceptual framework for understanding their impact on its core principles. Unlike many existing review papers that discuss individual technologies separately, this paper proposes an integrated conceptual framework that systematically maps enabling technologies to major Society 5.0 application domains and analyzes the role of contemporary wireless communication technologies within this ecosystem.

1. Key Enabling Technologies of Society 5.0

Key enabling technologies represent the technological foundation of Society 5.0, enabling the integration of data, intelligence, and physical systems into a unified ecosystem [13]. The following key enabling technologies were identified:

- Artificial Intelligence (AI) plays a central role by enabling data analysis, pattern recognition, and decision-making processes that support intelligent and autonomous systems [14, 15].
- Internet of Things (IoT) provides the infrastructure for collecting real-time data from physical environments through interconnected sensors and devices [16].

- Big Data technologies enable the storage, processing, and analysis of large volumes of structured and unstructured data, forming the basis for data-driven insights [13, 17].
- Cloud Computing offers scalable and flexible computing resources, allowing efficient data storage and centralized processing across distributed systems [17, 18].
- Edge Computing extends cloud capabilities by processing data closer to the source, reducing latency and enabling real-time decision-making [19].
- Advanced communication technologies such as 5G and 6G networks provide high-speed, low-latency connectivity, which is essential for supporting massive IoT deployments and real-time services [20, 21].
- Cyber-Physical Systems (CPS) integrate computational elements with physical processes, enabling monitoring and control of real-world systems through digital technologies [22, 23, 24].
- Robotics contributes to automation by performing physical tasks with high precision and efficiency, particularly in industrial, healthcare, and service environments [23, 25].

In addition, Digital Twin technology represents an advanced integrative concept that creates virtual replicas of physical systems for simulation, monitoring, and optimization [26, 27].

The convergence and interaction of these technologies create synergistic effects that enable complex, adaptive, and intelligent systems characteristic of Society 5.0. Therefore, understanding both the individual roles and the interdependencies of these technologies is essential for analyzing their overall impact on the development of Society 5.0.

2. Society 5.0 Core Domains Identification

Emerging technologies in Society/Industry 5.0, such as AI, IoT, robotics, blockchain, cloud/5G, etc., are consistently framed as tools to transform specific domains rather than technology for its own sake. The reviewed literature consistently identifies industry, smart cities, education, sustainability, quality of life, and healthcare as central application areas.

Society 5.0 is characterized by several core principles, including human-centricity, sustainability, intelligent infrastructure, and data-driven decision-making. Mapping enabling technologies to these principles provides a structured approach for understanding how technological advancements contribute to societal transformation.

In the following text, the six core domains of Society 5.0, identified within this research, are briefly described.

2.1. Industry

Industry 5.0 provides the industrial and technological foundation for the broader Society 5.0 vision, transforming industry with human–machine collaboration, robotics, AI, and linking directly to SDG 9 (Industry, Innovation and Infrastructure) and green, resilient production.

Manufacturing and broader industrial systems are key arenas where robotics, IoT and AI are deployed for sustainable, human-centric innovation [28], while Robotics and Cyber-Physical Systems enable automation and intelligent manufacturing processes. In addition, Artificial Intelligence and Big Data support predictive maintenance and production optimization. Edge Computing ensures real-time control and decision-making in industrial environments.

2.2. Smart Cities

Smart cities are repeatedly named as flagship Society 5.0 applications, integrating IoT, 5G, edge/cloud, CPS, AI, and open data to improve infrastructure, resource management, resilience, and citizen services. Frameworks explicitly couple Industry 5.0 + Society 5.0 to smart cities as the locus for SDG 11 (Sustainable Cities and Communities) [29].

Internet of Things and 5G/6G networks enable real-time data collection and communication, forming the backbone of smart urban infrastructure. Artificial Intelligence and Big Data support intelligent traffic management, energy optimization, and predictive urban planning, while Edge Computing enhances responsiveness in time-sensitive applications such as autonomous transportation and public safety systems.

2.3. Education

SDG 4 (Quality Education) is a central domain for the application of emerging technologies, with AI-enabled personalized education and

competencies required for Society 5.0 highlighted as central to the new society. Higher education sustainability and education as an engine of Society 5.0 are named themes in Industry 5.0 for sustainability reviews [18, 30].

To support this, Artificial Intelligence offers personalized learning experiences and adaptive educational systems, and Cloud Computing supports scalable access to digital learning platforms and resources. Finally, the Internet of Things can enhance smart classrooms and interactive learning environments.

2.4. Sustainability

Big Data and Artificial Intelligence enable resource optimization, energy efficiency, and environmental monitoring. Internet of Things supports real-time tracking of environmental parameters such as air quality, water usage, and energy consumption. Cyber-Physical Systems integrate physical infrastructure with digital control systems to improve sustainability in energy and industrial processes. All these capabilities highlight the importance of emerging technologies for Society 5.0.

2.5. Quality of Life

The integration of all enabling technologies contributes to improved quality of life through better services, increased accessibility, and enhanced user experience. Artificial Intelligence and Internet of Things enable personalized and context-aware services tailored to individual needs. Advanced connectivity and automation technologies reduce human workload while improving safety, comfort, and overall well-being. Multiple works explicitly state improving QoL as a main objective of integrated AI/IoT/blockchain cloud platforms and disruptive technologies.

The uses of the emerging technology may appear as a double-edged sword. So, the challenges of using the new technologies will be discussed at the end of the paper.

2.6. Healthcare

Finally, Healthcare is repeatedly treated as a key application sector for AI, IoT, robotics, telemedicine and personalized medicine, and it is tied to SDG 3 (Good Health and Well-Being). Artificial Intelligence enables

personalized medicine, diagnostics, and decision support systems that improve healthcare outcomes. Internet of Things supports remote patient monitoring and telemedicine through connected medical devices. Cloud Computing and Big Data facilitate large-scale medical data storage and analysis for research and public health management.

3. Framework: Enabling Technologies on Society 5.0 Domains

The mapping of key enabling technologies to the six different domains of Society 5.0 is presented in Fig. 1.

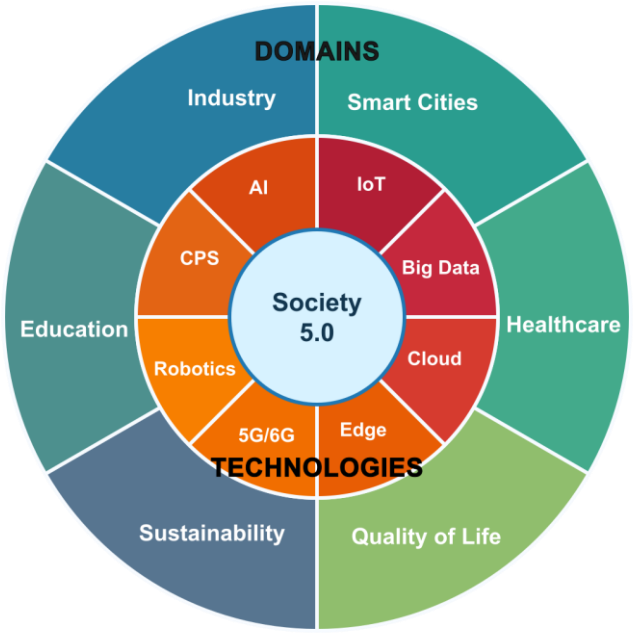


Figure 1. *Mapping Enabling Technologies on Society 5.0 Domains*

The more detailed impact of key technologies on each of the six Society 5.0 domains is given in Table 1. The mapping presented in Table 1 was developed through qualitative synthesis of the reviewed literature. Each technology was categorized according to the frequency and significance of its reported contribution within the analyzed publications rather than by quantitative scoring.

Table 1: *The detailed review of the technology's significance to the Society 5.0 domains*

Domain	*AI*	*IoT*	*Big Data*	*Cloud*	*Edge*	*CPS*	*Digital Twins*	*Robotics*	*Connectivity*
Industry	Strongest	Medium	Medium	Weakest	Weakest	Medium	Medium	Weakest	Weakest
Smart Cities	Strongest	Strongest	Strongest	Medium	Medium	Medium	Medium	Weakest	Weakest
Education	Strongest	Medium	Medium	Medium	Weakest	Weakest	Weakest	Weakest	Weakest
Healthcare	Strongest	Strongest	Strongest	Weakest	Weakest	Medium	Medium	Non-present	Weakest
Sustainability	Medium	Strongest	Medium	Medium	Strongest	Strongest	Weakest	Weakest	Weakest
Quality of Life	Strongest	Strongest	Non-present	Medium	Medium	Weakest	Weakest	Weakest	Strongest

Legend:
Strongest = Strongest Impact
Medium = Medium Impact
Weakest = Weakest Impact
Non-present = Not Mentioned

The mapping reveals that Artificial Intelligence (AI) has the highest overall impact, being identified as the strongest technology in five out of six application domains (Industry, Smart Cities, Education, Healthcare, and Quality of Life) and having a medium impact only in Sustainability. This gives the justification that AI should be considered the primary enabling technology across most sectors.

The Internet of Things (IoT) also demonstrates a significant influence, showing the strongest impact in Smart Cities, Healthcare, Sustainability, and Quality of Life, while maintaining a medium impact in Industry and Education. Its importance reflects the growing need for interconnected devices and real-time data acquisition. All these findings place the IoT in the second place on the list of most influential technologies, based on the number of domains where each technology was rated Strongest.

Big Data exhibits a mixed level of importance. It has the strongest impact in Smart Cities and Healthcare, a medium impact in Industry, Education, and Sustainability, and is not explicitly identified as a key technology for Quality of Life applications. This leads to the conclusion that data-driven decision-making is particularly critical in domains characterized by large-scale information processing, and makes Big Data the third most important technology.

Cyber-Physical Systems (CPS) play a prominent role in Sustainability, where they have the strongest impact, while their contribution is moderate in Industry, Smart Cities, and Healthcare, and relatively limited in Education and Quality of Life.

Edge Computing has variable levels of importance. It is considered strongest only in Sustainability, medium in Smart Cities and Quality of Life, and weakest in Industry, Education, and Healthcare, thus giving the conclusion that distributed processing is especially valuable in applications requiring low latency and localized decision-making. The Cloud computing has a similar, but slightly lower importance, with no strongest, but with more medium impacts compared to edge computing.

Connectivity technologies exhibit a diverse impact profile. They are identified as having the strongest impact on Quality of Life, while being of the weakest importance in all other domains, thus making the crucial role of communication infrastructure in enabling citizen-centric and quality-of-life applications.

Digital Twins are generally regarded as technologies with medium or weakest impacts. They have medium importance in Industry, Smart Cities, and Healthcare, while remaining supportive technologies in the other domains.

Finally, Robotics is predominantly classified as having the weakest impact across the analyzed domains, except Healthcare, making robotics currently considered a specialized technology rather than a universally applicable one.

Overall, the analysis indicates that AI and IoT are the dominant cross-domain technologies, whereas Cloud Computing, Digital Twins, Robotics, and Connectivity primarily provide supporting capabilities whose importance depends on the specific application domain. Big Data, Edge Computing, and Cyber-Physical Systems occupy an intermediate position, with their significance varying according to domain-specific requirements.

4. Connectivity technologies impact on Society 5.0

Considering the rapid growth of wireless communication technologies, especially in recent decades, the next phase of research is focused on identifying the impact of the most popular wireless technologies on

Society 5.0 domains. The most popular long-, middle-, and short-range technologies are considered in this research, and their impact is presented in Table 2. The impact levels shown in Table 2 represent qualitative assessments derived from the surveyed literature and should not be interpreted as quantitative performance metrics.

Table 2: *Relative impact (Low/Medium/High) based on use cases in the papers*

Tech / Domain	*Industry*	*Smart Cities*	*Education*	*Healthcare*	*Sustainability*	*Quality of Life*
LoRa / LoRaWAN [38, 39, 40, 41, 42]	Medium	High	Low–Med	Medium	High	Medium
NB-IoT / LTE-M [38, 40, 41, 43, 44, 45]	Medium	High	Low–Med	Medium	High	Medium
Wi-Fi [40, 42, 43, 47]	High	Medium–High	High	Medium	Medium	High
Zigbee / 802.15.4 [42, 43]	Medium	Medium	Low–Med	Medium	Medium	Medium
Bluetooth / BLE [47]	Medium	Low–Med	Medium	Medium–High	Low–Med	Medium
5G [38, 47, 48, 49, 50, 51, 52]	High	High	Medium–High	High	High	High
6G [38, 47, 53]	Very High	Very High	High	Very High	Very High	Very High

Legend:
Very High = Transformational impact across the domain
High = Strong positive impact
Medium = Moderate impact / supportive role
Low–Medium = Limited or emerging impact
Very Low = Minimal impact at present
Not Applicable / Not Mentioned = No significant impact or not specified

The comparative analysis indicated that 6G and its vision are consistently identified as the most transformative communication technology, achieving a Very High impact across all application domains. Although still conceptual, it is expected to provide the communication foundation for future intelligent, highly connected cyber-physical ecosystems.

Similarly, 5G demonstrates a High impact in Industry, Smart Cities, Healthcare, Sustainability, and Quality of Life, while serving a Medium role in Education, thus reflecting its capability to support ultra-reliable

low-latency communications, massive IoT deployments, and high-bandwidth services required by next-generation digital applications.

LoRa/LoRaWAN and NB-IoT/LTE-M exhibit similar impact profiles. Both technologies achieve a High impact in Smart Cities and Sustainability, where long-range, low-power connectivity is essential for large-scale sensor deployments. Their influence is Low–Medium in Industry, Healthcare, and Quality of Life, while remaining Very Low in Education, where such communication requirements are less prominent.

Wi-Fi technologies, including Wi-Fi 6, Wi-Fi 6E, and Wi-Fi HaLow, provide a High impact in Industry, Education, and Quality of Life, and a Medium impact in Smart Cities. Their contribution to Healthcare and Sustainability is more limited, reflecting their role as local-area networking technologies rather than wide-area communication infrastructures.

Zigbee (IEEE 802.15.4) primarily serves as a specialized short-range communication technology. Its impact is generally Low–Medium across most domains and Very Low in Education. The relevance of this technology is thus focused to specific IoT and sensor network applications.

Bluetooth Low Energy (BLE) has a similarly specialized role. It reaches a Medium impact only in Healthcare, where wearable devices and personal health monitoring systems are increasingly important. In other domains, its contribution ranges from Low–Medium to Very Low, setting its suitability for short-range, low-power communication.

In total, the analysis shows that 6G and 5G constitute the core communication technologies for future digital ecosystems, while Wi-Fi remains the dominant local networking solution. LoRaWAN and NB-IoT are particularly important for large-scale IoT deployments in Smart Cities and Sustainability, whereas Zigbee and Bluetooth LE primarily support specialized, short-range IoT applications.

5. Challenges in society 5.0

The rapid adoption of digital technologies in Society 5.0 introduces significant concerns regarding data privacy and the protection of personal information. The extensive use of Big Data and interconnected systems increases the risk of unauthorized data access and misuse.

Digital ownership becomes a critical issue, raising questions about who controls, manages, and benefits from data generated by individuals and systems.

The expansion of Internet of Things and Cyber-Physical Systems introduces new vulnerabilities, making cybersecurity a key challenge in protecting critical infrastructures.

The growing reliance on Artificial Intelligence raises ethical concerns related to transparency, bias, accountability, and decision-making autonomy. Ensuring fairness and avoiding algorithmic discrimination is essential for maintaining trust in AI-driven systems. Digital inequality remains a major challenge, as unequal access to technologies may widen the gap between different social groups and regions.

Bridging the digital divide is crucial to ensure inclusiveness and equal participation in Society 5.0. Addressing these challenges requires not only technological solutions but also regulatory frameworks, ethical guidelines, and interdisciplinary collaboration.

Across domains like industry, smart cities, education, healthcare, sustainability, and quality of life in Society 5.0, several recurring, unresolved challenges appear around privacy, ownership, security, ethics, and inequality. The key challenges are shown in Table 3.

Table 3: *Overview of critical challenges for Society 5.0*

Topic	*Example Critical Challenges*
Data Privacy & Ownership [54, 55, 56]	Ambiguous rights; Consent; Purpose limitation; Secondary use of data
Cybersecurity [54, 57, 58]	DDoS attacks; Data breaches; DTN/IoT exploitation; Weak security standards
Governance & Law [54, 59, 60]	Global data flows; Regulatory lag; Enforcement gaps
Inequality & Digital Divide [56, 59, 60]	Unequal access; Data colonialism; Exclusion through AI and Big Data

The rapid adoption of data-driven and connected technologies introduces several critical challenges that must be addressed to ensure secure, ethical, and sustainable digital transformation.

Data Privacy and Ownership remains one of the most significant concerns. The increasing collection and exchange of personal and

organizational data raise issues related to ambiguous ownership rights, informed user consent, purpose limitation, and the secondary use of collected data beyond its original intent. These challenges require transparent governance frameworks and privacy-preserving data management practices.

Cybersecurity represents another major challenge as digital infrastructures become increasingly interconnected. Organizations must address threats such as distributed denial-of-service (DDoS) attacks, large-scale data breaches, vulnerabilities in IoT and Delay-Tolerant Network (DTN) environments, and inconsistent security standards. Strengthening cybersecurity requires both technological solutions and coordinated security policies.

Governance and Legal Frameworks continue to lag behind technological innovation. The globalization of digital services complicates cross-border data governance, while rapidly evolving technologies often outpace existing regulations. Regulatory gaps and limited enforcement mechanisms create uncertainty for governments, businesses, and citizens, highlighting the need for adaptive legal and policy frameworks.

Inequality and the Digital Divide remain persistent barriers to inclusive digital transformation. Unequal access to digital infrastructure and services limits participation in the digital economy, while concerns regarding data colonialism and algorithmic exclusion through AI and Big Data may reinforce existing social and economic inequalities. Addressing these issues requires investments in digital inclusion, equitable access, and responsible AI governance.

Overall, these challenges demonstrate that technological advancement alone is insufficient to achieve sustainable digital transformation. Long-term success depends on balancing innovation with privacy protection, cybersecurity, effective governance, regulatory adaptation, and social inclusion. Addressing these issues requires close collaboration among governments, industry, academia, and civil society to develop trustworthy, resilient, and human-centered digital ecosystems.

Conclusion

Society 5.0 represents a fundamental shift from technology-driven digitalization toward a human-centered model in which advanced digital technologies serve societal needs rather than technological progress itself. This paper has reviewed the principal enabling technologies supporting this transformation and analyzed their contribution across six major Society 5.0 domains, namely industry, smart cities, education, sustainability, healthcare, and quality of life. The analysis demonstrates that Artificial Intelligence and the Internet of Things constitute the central technological pillars of Society 5.0, while complementary technologies including Big Data, Cloud and Edge Computing, Cyber-Physical Systems, Digital Twins, Robotics, and next-generation communication networks collectively create an integrated digital ecosystem capable of supporting intelligent and sustainable services.

A key contribution of this paper is the proposed conceptual framework that systematically maps enabling technologies to Society 5.0 application domains and highlights their interdependencies. Rather than considering individual technologies independently, the framework emphasizes that the successful realization of Society 5.0 depends on the coordinated integration of multiple technologies operating within a common human-centric ecosystem. Furthermore, the comparative analysis of contemporary wireless communication technologies demonstrates that different communication paradigms address different societal requirements, with 5G and future 6G networks providing the foundation for highly connected intelligent environments, while technologies such as LoRaWAN, NB-IoT, Wi-Fi, Zigbee, and Bluetooth Low Energy continue to play important complementary roles depending on application-specific requirements.

Despite the significant opportunities offered by these technologies, the transition toward Society 5.0 cannot rely solely on technological innovation. Challenges related to cybersecurity, privacy protection, digital ownership, ethical Artificial Intelligence, governance, regulatory harmonization, and digital inclusion remain equally important for ensuring trustworthy and sustainable digital transformation. Addressing these issues requires close interdisciplinary collaboration among researchers, industry, governments, and society to establish transparent governance models and responsible technology deployment.

Future research should focus on validating the proposed conceptual framework through quantitative methodologies, bibliometric analyses, and expert evaluation, as well as extending the framework to emerging technologies such as generative Artificial Intelligence, federated learning, quantum computing, semantic communication, and future 6G intelligent network architectures. Such efforts would contribute to a more comprehensive understanding of how enabling technologies can collectively support resilient, sustainable, and human-centered digital societies.

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