Industrial Revolution and Innovation Evolution: Analyzing the Past to Envision the Future

Bilal Azfal, Xiaoni Li,
Ana Beatriz Hernández-Lara

Abstract

This chapter explores the concept of Innovation 5.0, examining its consequences and implementations within the context of Industry 5.0. We focus on four key perspectives: technology integration, societal well-being, organizational adaptability, and sustainability. Through a combined literature review and content analysis, we provide an overview of past industrial revolutions and the subsequent evolution of innovation paradigms. This analysis culminates in the emergence of Innovation 5.0, characterized by a shift towards an innovation process that prioritizes human well-being, sustainability, and resilience. The chapter contextualizes Innovation 5.0 through the sextuple helix model. This model expands upon the conventional triple helix model by integrating civil society, environment, and media and ICT, fostering a comprehensive approach to addressing contemporary challenges. This framework emphasizes a human-centric perspective focusing on sustainability and adaptability, and encourages collaboration among multiple sectors within the context of Industry 5.0.

Keywords: Industrial Revolution; Innovation Evolution; Industry 5.0; Innovation 5.0; Sextuple Helix Model.

1. Introduction

The relentless advancement of the fourth industrial revolution (Industry 4.0), driven by digital transformation has profoundly reshaped industries worldwide. Digital transformation refers to the integration of digital technologies into all aspects of an organization, fundamentally altering how businesses operate, deliver value, and interact with stakeholders (Vial, 2019). It encompasses not only technological adoption but also cultural, organizational, and societal shifts, enabling data-driven decision-making, enhanced customer experiences, and agile business models (Hess et al., 2016). As the advent of the fifth industrial revolution (Industry 5.0) looms ahead, we anticipate the emergence of even more substantial transformations on a global scale, bringing both exciting opportunities and significant challenges.

Nevertheless, this process is not taking place in a vacuum, unprecedented global challenges, such as the extensive ramifications of the COVID-19 pandemic, which accelerated digital transformation initiatives across sectors, and the ongoing conflict in Ukraine, have brought

about an unparalleled degree of uncertainty and intricacy within the global economic landscape. Consequently, organizations are obligated to embrace Industry 5.0 and reassess their existing operational and strategic frameworks, leveraging digital transformation to adeptly navigate these emerging realities effectively. This requires addressing not only technological advancements but also broader societal, ethical, and environmental challenges. While Industry 5.0 promises greater human-centricity and sustainability, it also raises critical questions about its feasibility and risks of unintended consequences, particularly when navigating geopolitical instability and systemic inequality.

In this dynamic context, characterized by the rapid adoption and integration of digital technologies and their transformative impact on innovation methodologies, ensuring organizational sustainability has become paramount. To effectively navigate these challenges, it is imperative for organizations to strategically align their innovation initiatives rooted in digital transformation with a forward-thinking, but holistic approach that balances innovation with societal well-being and long-term resilience. The alignment mentioned allows organizations to effectively address the swiftly changing global context (Cui et al., 2015), where it is of utmost importance to attain sustainability, resilience, and human centrism (Ivanov, 2023). Organizations must embrace a proactive mindset and utilize innovation, amplified by digital transformation, as a catalyst for facilitating beneficial transformations.

Recognizing the limitations of existing innovation models in addressing these complexities, the advent of Industry 5.0 has underscored the need for a fresh perspective on innovation, appropriately labeled as Innovation 5.0. This paradigm emphasizes resilience, sustainability, and human-centered progress (Afzal et al., 2024), extending beyond the efficiency-focused goals of Industry 4.0's digital transformation. However, critical questions remain regarding its implication and implementation. Further research is needed to explore the concept of Innovation 5.0 and its practical implications (Daniel et al., 2020), particularly changes to business model innovation, business processes, organizational culture, harmonizing technological advancements, societal welfare, and organizational longevity (Srisathan et al., 2022).

This chapter seeks to contribute to this dialogue by offering a conceptual framework for Innovation 5.0 that emphasizes human-centric sustainability, adaptability, and resilience. To achieve this, the chapter critically examines the evolution of industrial revolutions—from Industry 1.0 to Industry 5.0—and their associated innovation paradigms, highlighting the role of digital transformation as both an enabler and disruptor. It contextualizes *Innovation 5.0* within the sextuple helix model, integrating civil society, the environment, and media and

information communication technologies including the use of artificial intelligence alongside traditional innovation drivers. This expanded framework reflects the need for inclusive, interdisciplinary approaches to innovation that addresses contemporary challenges holistically and equitably. By doing so, the chapter provides a balanced perspective on how *Innovation 5.0* can support organizations in navigating the complexities of Industry 5.0 while avoiding the drawbacks of technology-driven approach while harnessing the strategic potential of digital transformation.

Background: The progression of industrial revolutions and innovation evolution

1.1.Industrial revolutions

The term "industrial revolution" refers to a historical period of rapid industrialization and technological advancement. The late 18th and mid-19th centuries saw significant industrialization and technical growth, which led to the creation of this term. This first industrial revolution shifted production and distribution from human labor to machine-based manufacturing and entailed large socio-economic developments, including city expansion, wage labor, and new transportation (Crafts, 2019). Industry 1.0 refers to the earliest stage of industrial growth. During this first industrial revolution, water and steam power, and the development of the steam engine and power loom, mechanized and transformed manufacturing and transportation, creating textile mills, iron foundries, and other businesses (Crafts, 2019). The second industrial revolution, also known as Industry 2.0, occurred in the late 19th and early 20th centuries. It was characterized by the advent of new technologies such as electricity, the rise of mass production, and the development of the assembly lines, which transformed the nature of manufacturing and led to significant improvements in productivity and economic growth (Hobsbawm, 1996; Landes, 1969; Rifkin, 2011). The third industrial revolution, also known as Industry 3.0, began in the mid-20th century and was marked by the emergence of computers, automation, and digital technologies (Schwab, 2016). The fourth industrial revolution, also known as Industry 4.0, refers to the current stage of industrial development marked by the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and robotics (Jafari et al., 2022).

Industry 4.0's influence extends to other related neologisms with Extension 4.0 (Reischauer, 2018). This trend reflects a shift in cognitive patterns, where innovation strategies and processes now encompass a broader spectrum of participants and drivers, signifying a more comprehensive and inclusive approach to innovation (Straßburger & Strassburger, 2019).

On the progression track of industrial revolution, the fifth industrial revolution, or Industry 5.0, is emerging as a prospective evolution beyond Industry 4.0, which proposes a transformative approach to manufacturing by integrating human skills and creativity into the production process (Adel, 2022; Jafari et al., 2022; Pizoń & Gola, 2023; Zizic et al., 2022). In addition to that, Industry 5.0 aims to stress a human-centric approach, sustainability, resilience, and collaboration, emphasizing minimal environmental impact, enhanced adaptability, and societal well-being (Ivanov, 2023). The main challenges and significant voids that still entail its concept are related to its aim of leveraging Industry 4.0 advanced technologies with human skills, such as creativity and problem-solving, to deliver high-quality customized products, which makes Industry 5.0 unique from its predecessor. The transition from Industry 4.0 to Industry 5.0 involves the inclusion of ethical, social, and environmental considerations to achieve sustainable and responsible manufacturing (Jafari et al., 2022), as well as the shift from mass production to customized production, where the focus is on customer-centric production rather than cost optimization (Adel, 2022; Alves et al., 2023; Jafari et al., 2022; Maddikunta et al., 2022).

1.2.Innovation evolution

Innovation has evolved extensively over time, shaped by shifts in economic, technological, and societal landscapes. Early theories, such as Schumpeter's innovation theory (Schumpeter, 1934), emphasized the disruptive role of entrepreneurship and technological change. Subsequent perspectives, including process and product innovation (Utterback & Abernathy, 1975), the product life cycle, and the knowledge base of innovation (Lundvall, 1992), highlighted the dynamic and multifaceted nature of innovation. These frameworks underscore that innovation is not a linear phenomenon but one shaped by complex interactions among various actors and contexts.

More recently, helix models of innovation, particularly the triple helix model and its subsequent extensions, have been employed to explore the interplay between academia, industry, government, and other societal actors in fostering innovation. These models, especially relevant for understanding Innovation 3.0 and beyond, provide a foundation for examining how innovation ecosystems evolve to address emerging challenges. However, critiques of such models suggest the need for a more inclusive approach that integrates societal, environmental, and ethical dimensions, paving the way for discussions around Innovation 5.0 (Carayannis & Rakhmatullin, 2014; Leydesdorff, 2000).

a) Innovation 1.0

Rooted in the first industrial revolution, Innovation 1.0 emphasized internal R&D and secrecy to safeguard intellectual property. This model, characterized by incremental improvements, dominated a period when industry operated in isolation from external collaboration (Herzog & Leker, 2010). Innovation 1.0 or closed innovation was prominent during the first industrial revolution, refers to an inward-focused approach to research and development, where companies relied solely on internal resources to generate and commercialize ideas, products, and technologies to ensure strict control over innovation processes and to protect intellectual property (Hafkesbrink & Schroll, 2011).

b) Innovation 2.0

Introduced by Henry Chesbrough (2003), open innovation or Innovation 2.0 reflected the post-World War II era's demand for collaboration and knowledge sharing across organizations. Firms recognized the value of integrating external knowledge to complement internal resources, signaling a shift from insular approaches to cooperative innovation ecosystems (Chesbrough & Vanhaverbeke, 2011). Open innovation arose in response to the growing complexity of technologies and markets, highlighting the need for openness in innovation processes. This paradigm shift, driven by external knowledge and collaborative strategies, marked a departure from traditional, insular innovation approaches and paved the way for later models like Innovation 3.0 (Chesbrough, 2003; Mutlu, 2013). While Innovation 2.0 fosters external partnerships to augment internal capabilities, it lacks a clearly defined framework for identifying and organizing the social units involved, making it less structured than subsequent models.

c) Innovation 3.0

Innovation 3.0, which is also known as embedded innovation, builds on both closed and open innovation ideas to make a more complete, integrated, and long-lasting notion of innovation (Horstmeier & Reichwald, 2006). It tries to overcome the limitations of outmoded closed innovation models, which rely only on internal R&D and may not be able to keep up with innovation through access to external expertise and resources, and of conventional open innovation models, which rely on external innovation sources but may have problems combining external knowledge with internal resources while preserving intellectual property (Chesbrough, 2003; Hafkesbrink & Schroll, 2011). Combining the benefits of open and closed innovation, firms can use internal and external expertise and resources while controlling intellectual property and managing risks.

Innovation 3.0 is more structured regarding identifying key social units involved in the innovation process, encompassing the utilization of the triple helix model of innovation that explicitly defines some of these key societal units, which aim to foster collaboration (Leydesdorff, 2000). The model encompasses academia, governments, and industries as the main institutions accountable for innovation, with a strong emphasis on promoting responsible and transformative innovation through collaborative and cooperative endeavors among these entities. On this basis, embedded innovation practices demand consumers' participation, long-term links between value-creating agents, and the vital development of complementarities, which plant the sustainable economies of the future (Costa & Matias, 2020). Moreover, Innovation 3.0 incorporates the dimensions of corporate social responsibility and sustainability, acknowledging the significance of ethical and environmentally conscious behaviors.

Embedded innovation allows companies to establish and manage their own innovation ecosystems within the larger external innovation ecosystem, paving the way for the emergence of the innovation ecosystem concept, which entails a dynamic network of organizations, institutions, and individuals that collectively contribute to innovation activities and benefit from them, reflecting the increasing recognition of collaborative relationships and interactions between diverse innovation stakeholders.

(Rifkin, 2011)

d) Innovation 4.0

Innovation 4.0 supplements previously established innovation paradigms, being considered not a substitute but rather a complement to the previous models (Costa & Matias, 2020). Innovation 4.0 places greater emphasis on the establishment of innovation ecosystems and the cultivation of more varied collaborative relationships with external stakeholders. It encompasses a more comprehensive and interconnected approach, involving not only academia, industry, and government as main stakeholders in innovation processes. This integration of multiple actors and considerations results in a more holistic approach to innovation.

There is not a single established helix model that directly corresponds to Innovation 4.0. Instead, it is characterized by the strategic and technological integration of diverse actors, often encompassing a broader perspective that acknowledges the complexity of modern innovation ecosystems, and provoking the rise of more evolved and extended helix models. The strategic and technological integration of all these actors is the main theme of Innovation 4.0 (Sikhwal & Childs, 2018), including natural and social-ecological environments, which imply a broader consideration of sustainability issues within innovation processes, and also encouraging

investments in corporate training and education, which give employees the skills and knowledge they need to succeed in this new era of innovation (Costa & Matias, 2020).

The key components of Innovation 4.0 encompass innovation ecosystems, collaborative relationships among a varied spectrum of stakeholders that entail co-creation and knowledge exchange, a focus on continuous learning, corporate social responsibility, and the utilization of advanced technologies for smart production.

2. Helix models of innovation and innovation evolution

As we move forward from the initial discussion of the helix model and its connection to innovation ecosystems and the evolution of innovation, this chapter now dives deeper into the specificities and evolution of helix models. These models provide a structured method for depicting the primary entities within the innovation ecosystem and comprehending their influence and role on innovation in a given context, symbolizing each "helix" as a different actor (Streitz et al., 2022). Given the relevance of these models to understand innovation evolution, the bases of the main helix models are described in this section.

a) Triple helix model

The triple helix model, which integrates academia, industry, and government, (Etzkowitz & Leydesdorff, 1995) has been instrumental in conceptualizing innovation ecosystems and fostering collaborations. However, the existing top-down triple helix model of innovation systems has faced critiques for assuming linear and harmonious collaboration, overlooking regional disparities, the complex interplay of societal and environmental factors, and the vital role of entrepreneurs (Brannback et al., 2008; Cai & Etzkowitz, 2020). As innovation ecosystems evolve to address increasingly interconnected challenges, more evolved frameworks have sought to build on this foundation by incorporating additional actors and dimensions.

In the triple helix model, the first helix, academia, symbolizes the presence and significance of universities and research institutions in the innovation process. The academic sphere plays a crucial role in the generation of novel knowledge through the undertaking of research and development endeavors. Academic institutions facilitate an environment conducive to innovation through the implementation of scientific inquiries, cultivation of creative thinking, and the education and training of future innovators (Etzkowitz & Leydesdorff, 2000; Leydesdorff, 2000).

The second helix corresponds to the presence of various industries and commercial enterprises. Companies stimulate innovation by effectively transforming academic research into tangible

applications and commercially viable products or services. Organizations allocate resources towards research and development endeavors, embrace novel technologies, and facilitate economic expansion by means of commercialization (Etzkowitz & Leydesdorff, 2000; Leydesdorff, 2000).

The third helix symbolizes government agencies and policymakers. Governments facilitate the development of an enabling ecosystem for innovation by implementing policies, regulations, and funding programs. The public regulations provide backing for research and development initiatives and foster partnerships between academic institutions and industries to tackle societal issues by means of innovative approaches (Etzkowitz & Leydesdorff, 2000; Leydesdorff, 2000).

The triple helix model shows how important it is for the three helices to work together and share their knowledge in order to get good results. This can lead to fostering innovation, promoting economic growth, and advancing societal advancement. The basis for the concept of Innovation 3.0 was the combination of closed innovation, open innovation, and the triple helix model. This approach was also enriched by the integration of corporate social responsibility (CSR) and some sustainability dimensions, which emphasize that organizations should incorporate social and environmental issues into their innovation processes (Porter & Kramer, 2007; Schaltegger & Wagner, 2011), as well as the focus on user-driven innovation and the role of lead users to identify new market opportunities and drive innovation (von Hippel, 2005).

Hafkesbrink and Schroll (2011) went a step further and explained Innovation 3.0 by linking enterprises with community knowledge to learn together, stressing organization-community information sharing, cooperation, and co-creation. Their study proposed a conceptual framework for a better understanding of Innovation 3.0 and the presentation of Web 4.0 ("symbiotic web") as a mechanism for enabling it. Web 4.0 is a transformative phase of the World Wide Web that seamlessly integrates advanced technologies and the internet, enabling users unprecedented control over data sharing and access, ultimately enhancing their capabilities, facilitating decision-making, and contributing to overall well-being (Panwar et al., 2022). These advances announced the evolution towards a new innovation approach, although they overlook data integration, interoperability, and collaborative platforms, which are relevant traits missing for a concrete definition of the next step in innovation evolution.

b) Quadruple helix model

The quadruple helix model introduced civil society as the fourth helix, signifying its pivotal role in facilitating innovation. Civil society refers to non-governmental organizations, community groups, citizens, and cultural and societal stakeholders who actively participate in shaping innovation. This innovative framework underscores the essential integration of civil society to foster and propel development across varied societal dimensions (Carayannis & Campbell, 2009; Sikhwal & Childs, 2018). The significant role of civil society resides in their location at the heart of innovation developments, as far as users or citizens own and drive the innovation process for their involvement as lead users, co-developers, and co-creators (Carayannis & Rakhmatullin, 2014).

c) Quintuple helix model

The quintuple model adds another helix that concentrates on the environment in which society operates, thus incorporating the ecological dimension into the innovation paradigm. The incorporation of the environmental dimensions shows their importance as drivers of knowledge production and innovation (Carayannis et al., 2012; Liyanage & Netswera, 2022), providing information on the barriers and triggers of the natural environment and the natural resources of the region for innovation (Carayannis & Rakhmatullin, 2014), and giving relevance to the notions of social ecology, society-nature interaction, and socio-ecological transition.

d) Sextuple helix model

The sextuple helix model lacks substantial empirical research and a universally accepted sixth helix within the framework of multi-helix models. Therefore, there is still some debate on the most prominent new actors in current innovation ecosystems. Various perspectives have been put forth regarding the sixth helix. One viewpoint suggests that it could be centered around entrepreneurship, emphasizing the role of entrepreneurial endeavors in driving innovation (López-Rubio et al., 2021, 2022), although entrepreneurs could be considered a societal actor and part of the industry unit. Another, more widely accepted view identifies media and information and communication technology (ICT), including artificial intelligence (AI), as key elements of the sixth helix. This perspective highlights how advancements in media, ICT, and AI are reshaping innovation dynamics by enabling better data integration, enhancing collaboration, and streamlining decision-making processes (Dwi Wahana et al., 2022; Fikri et al., 2023).

Furthermore, the effective use of AI depends on the synergy between artificial and human intelligence. For instance, crafting well-designed prompts to guide AI systems demonstrates

the essential role of human ingenuity in maximizing AI's potential. This integration underscores the need for ongoing development in both technological capabilities and human expertise to fully leverage AI in fostering innovation. This ICT and AI based approach seems to concentrate more consensus given its more holistic and general scope. Figure 1 displays the sextuple helix model, showing the inner knowledge economy core, composed of the three traditional units, and the outer contextual actors of new innovation ecosystems.

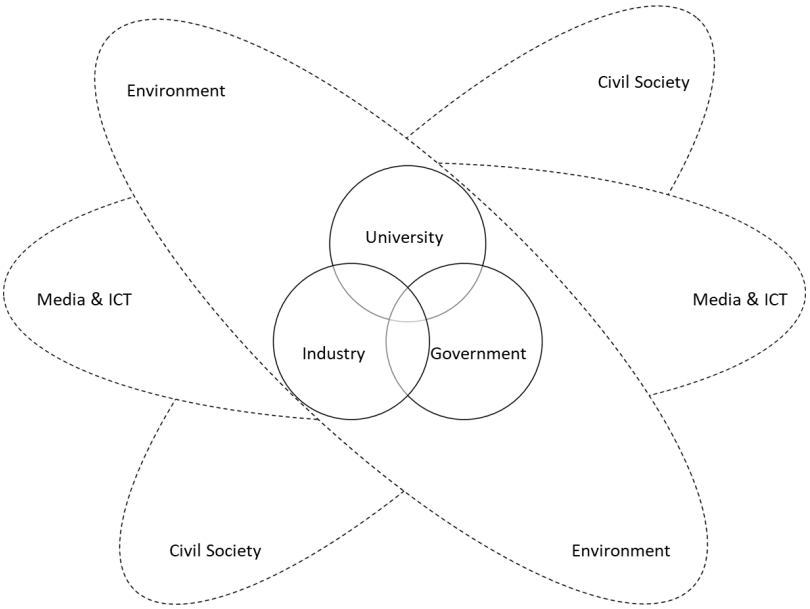

Figure 1. Sextuple Helix Model

Source: Self-created using Smart Draw, derived from foundational concepts of Carayannis et al., (2012)

The wider spectrum of actors incorporated by the sextuple helix model can provide a systemic approach to address multiple challenges, such as:

- Increased collaboration: The addition of the sixth helix, media and ICT, allows us to harness the power of communication in promoting collaboration among diverse stakeholders, leading to more effective knowledge exchange and shared decision-making (Godoe, 2014).
- Regional innovation ecosystem: The model strengthens the focus on regional innovation ecosystems by acknowledging the pivotal role of media. This recognition allows for a more integrated approach to economic development and social progress, as media plays a vital role in disseminating knowledge, fostering collaboration, and promoting innovation within regional contexts (Heitor & Horta, 2015).
- Social innovation ecosystems: The involvement of media and communication channels in the sextuple helix model strengthens the foundation for solving social problems, allowing innovations to reach more people, and providing a clearer social nature to

innovation. This integration of media and communication not only acknowledges their role in the model but also highlights their interdependence with different social systems, shaping ecosystems of social innovation (Agostinho et al., 2019; Carvalho et al., 2019).

- Innovation in higher education: The model recognizes the impact of media and culture/environment on higher education and emphasizes the need for a creative and adaptable educational environment to provide training and education that support future innovations (Almeida et al., 2020).
- Development of the knowledge-based society: The comprehensive perspective of the sextuple helix model enables a deeper understanding of the interplay between academia and media platforms and communication channels in the formation of a knowledge-based society (Kebir et al., 2018).
- Triple Bottom Line: The sextuple helix model places significant emphasis on the "Triple Bottom Line", which encompasses the holistic consideration of sustainability within the social, economic, and environmental dimensions (Leal Filho et al., 2020).

While this approach aligns with Industry 5.0's emphasis on human-centric and sustainable innovation, it faces significant challenges. Critics of expanded helix models highlight potential overlaps between helices, leading to ambiguity and theoretical dilution. Practical implementation is also questioned, with concerns about how diverse actors and goals can be effectively harmonized. Moreover, disparities in access to ICT resources and risks of exacerbating inequality further complicate integration. The balance between inclusivity and functionality is vital to ensuring that technology empowers rather than marginalizes underrepresented groups (Rosenlund et al., 2016; Taratori et al., 2021).

3. Fifth industrial revolution and Innovation 5.0

According to Intra and Paxton (2020), the emerging concept of Industry 5.0 involves the reconciliation of a focus on digital transformation as well as human centrism, introducing the utilization of cutting-edge technologies like quantum computing, nanotechnology, biotechnology, machine learning, deep learning, neural networks, and large natural language models to solve human and social needs like the promotion of social inclusivity and sustainability. This statement reflects the fundamental principles behind Industry 5.0, which prioritize a human-centric perspective in the development and implementation of cyber-physical cognitive systems. These systems refer to a group of cutting-edge technologies that combine cyber, physical, and cognitive components, representing a new generation of intelligent and adaptive systems that harness the power of digital connectivity, physical

equipment, and sophisticated cognitive capacities, including artificial intelligence (AI). In addition to human centricity, Industry 5.0 focuses on resilience, sustainability, and environmental, social, and economic implications (Ivanov, 2023).

The development of Industry 5.0 brings a new era of innovation, also known as Innovation 5.0, that aims to balance technological advancements with human values, ethics, and sustainability. The focus is on creating innovative solutions that not only improve the efficiency and productivity of businesses but also have a positive impact on society and the environment (Nahavandi, 2019). The successful realization of innovation necessitates the effective application and utilization of knowledge within and between organizations, fostering an environment that is conducive to both, innovation, and entrepreneurship (Isenberg, 2010; Osterwalder & Pigneur, 2010). Our conceptualization draws upon insights from open innovation theory, which emphasizes the strategic disclosure of technological information as a key mechanism for attracting and engaging diverse actors in the innovation ecosystem, thereby accelerating the pace of innovation evolution (Gao et al., 2020; Gupta et al., 2017; Zhang & Ming, 2023). The concept of Innovation 5.0 highlights the importance of knowledge sharing through media and ICT within and among organizations, as it is the fundamental foundation for promoting adaptable and sustainable innovation (Aslam et al., 2020; Nonaka & Takeuchi, 1995).

Innovation 5.0 takes part in wider movement that includes the “5.0” extension into varied notions, like mobility, health, work, education, democracy, operator, society, government, industry, leadership, energy, retail, or manufacturing, just to cite some of them, and which are mostly oriented towards the integration of advanced technologies to obtain more sustainable, equitable, and participatory societies. However, this ambitious vision raises important questions on potential challenges, including the risks of technological overreach, ethical considerations, and the need for inclusive frameworks to ensure that the benefits of these innovations are equitably distributed.

Thus, most 5.0 concepts, whether developed or in the conceptualization stage, involve the following dimensions:

- Human-centric: The “5.0” extension emphasizes the importance of putting human needs, well-being, and experiences at the center of development. Digital transformation can support this by leveraging technologies such as AI, IoT, and big data to create personalized experiences, enhance collaboration, and foster creativity (Nahavandi, 2019).

- Sustainable: Sustainability is a key aspect of the "5.0" extension, focusing on addressing environmental challenges and promoting the responsible use of resources. Digital transformation can contribute to sustainability through advanced technologies, such as renewable energy systems, smart grids, and circular economy models, which help optimize resource consumption and reduce waste (Xu et al., 2021).
- Inclusive: The "5.0" extension highlights the need to ensure that all members of society can benefit from and participate in development. Digital transformation can support this by promoting digital literacy, increasing access to education, healthcare, and employment opportunities, and fostering social inclusion through digital platforms and services (Carayannis & Rakhmatullin, 2014).
- Holistic approach: The "5.0" extension calls for a more integrated and holistic approach to development, in which various sectors and stakeholders collaborate to address complex challenges. Digital transformation can facilitate this by enabling data-driven decision-making, fostering cross-sector collaboration, and connecting stakeholders through digital platforms (Aslam et al., 2020).
- Resilience: This refers to highlighting the urgent need to strengthen the flexibility of industrial output to a greater extent, fortifying it against possible interruptions, and guaranteeing steadfast support for vital infrastructure during crises such as the COVID-19 outbreak or the Ukraine war (Xu et al., 2021).

In short, the "5.0" extension can be associated with the concept of digital transformation, highlighting the significance of digital technologies in fostering societies that prioritize human well-being, sustainability, and inclusivity. This approach promotes the utilization of sophisticated technologies to tackle societal challenges and enhance the well-being of individuals and communities. The inclusion of these elements in the "5.0" extension signifies a paradigm shift that transcends mere technological progress, encompassing a more comprehensive evaluation of the societal implications of digital transformation.

Drawing upon previous research on the evolution of innovation from Innovation 1.0 to Innovation 4.0, and taking into account the significant previous academic contributions in relation to the advancement of next-generation innovation (Carayannis & Campbell, 2021; Carayannis & Rakhmatullin, 2014; Chesbrough, 2003; Dodgson et al., 2014; Hafkesbrink & Schroll, 2011; Streitz et al., 2022), it can be concluded that the concept of Innovation 5.0 represents a paradigm shift towards fostering innovations characterized by adaptability, resilience, and the capacity to flourish in the face of disruptions, uncertainties, and changing

conditions, while emphasizing the broader incorporation of social units. Due to the profound influence of media and ICT in modern innovation landscapes and considering their relevance in an era where technologies play an unprecedented role in shaping various aspects of society, including economic, cultural, and social dimensions (Dwi Wahana et al., 2022; Fikri et al., 2023), media and ICT emerge as a dynamic force driving innovation, and we endorse its inclusion as another actor in the multi-helix models (Dwi Wahana et al., 2022; Fikri et al., 2023). By incorporating media and ICT as a distinct helix, the model recognizes its status as an integral and indispensable component, alongside academia, industry, government, civil society, and the environment, in shaping the innovation ecosystem. This recognition highlights the necessity to understand, integrate, and collaborate with media and ICT as a key player, reflecting the model's responsiveness to contemporary shifts in innovation dynamics. This addition broadens the scope of social unit participation and contributes to the cultivation of resilient innovation.

Table 1 elucidates the evolution of Innovation 5.0 in relation to its preceding generations of innovation, considering the fundamental principles of the different innovation systems established by various researchers.

Table 1. *Features of innovation systems: From Innovation 1.*0 to Innovation 5.0

Innovation Level	Industrial Epoch	Focus	Relevant Helix Model	Primary Objective	Social Inclusion
Innovation 1.0	First Industrial Revolution	Inward and Linear	None	Efficiency	Information Dissemination
Innovation 2.0	Second Industrial Revolution	Outward and Collaborative	None	Engagement	Consultative Approach
Innovation 3.0	Third Industrial Revolution	Outward and Integrated	Triple Helix	Synergy	Co-Design Endeavors
Innovation 4.0	Fourth Industrial Revolution	Outward and Semi-Holistic	Quadruple and Quintuple Helix	Sustainability	Co-Creative Endeavors
Innovation 5.0	Fifth Industrial Revolution	Outward and Societal-Centric	Sextuple Helix	Adaptability	Co-Resilience Strategies

Source: Self-elaborated using foundational concepts of Hafkesbrink and Schroll (2011) and Streitz (2022)

The first iteration of innovation, referred to as Innovation 1.0, is characterized by an internal and sequential approach that places significant emphasis on optimizing efficiency and facilitating the spread of information. During the second industrial revolution, Innovation 2.0

emerged as a more outward and collaborative approach, emphasizing engagement and a consultative methodology. As society progresses towards Innovation 3.0 within the context of the third industrial revolution, the prevailing approach shifts towards an outward and integrated perspective. This approach is distinguished by the pursuit of synergy and collaborative design efforts, as facilitated by the triple helix model. The fourth industrial revolution, corresponding to Innovation 4.0, places emphasis on external factors and takes a partially holistic approach. Sustainability is a central aspect, and collaborative efforts are facilitated by the quadruple and quintuple helix models. In the context of the fifth industrial revolution, Innovation 5.0 adopts a societal-centric approach that emphasizes the use of cutting-edge technologies for enhancing adaptability and co-resilience strategies. This approach is aligned with the sextuple helix model.

4. Conclusion

This chapter embarked on a journey through the evolution of innovation paradigms, navigating the landscape of past industrial revolutions and their corresponding innovation models. This analysis illuminated the emergence of Innovation 5.0, a paradigm intrinsically linked to Industry 5.0, and characterized by its focus on adaptability, resilience, and human-centric sustainability. These core principles equip organizations with the necessary tools to navigate the complexities and uncertainties of Industry 5.0, fostering long-term success. To comprehensively analyze Innovation 5.0, we utilized the sextuple helix model, a novel framework that expands upon the traditional triple helix model by incorporating civil society, the environment, and media and ICT. This inclusive approach underscores the importance of collaboration between diverse stakeholders, fostering a dynamic and interconnected ecosystem for innovation.

In light of the intricate relationship between Industry 5.0 and Innovation 5.0, a clear message emerges: organizations must embrace a human-centric approach to innovation, prioritizing sustainability, adaptability, and societal well-being, leveraging media and ICT. By adopting the principles of Innovation 5.0 and fostering collaboration within the framework of the sextuple helix model, organizations can position themselves at the forefront of innovation and contribute to building a sustainable and inclusive future.

This chapter offers a conceptual approach for a better understanding of the notion of Innovation 5.0, but it is not exempt of limitations. Firstly, it is important to recognize that our analysis operates primarily within the framework of open innovation theory. As such, it provides a representative narrative focused on this lens, which inherently excludes other historical or

alternative perspectives on innovation. Secondly, assessing Innovation 5.0's effectiveness in different organizational contexts, it may be difficult to isolate its impact from other organizational changes or biases in measuring "resilience" or "human-centricity". Thirdly, Innovation 5.0 frameworks may struggle to balance generality and industry-specificity. Lastly, Innovation 5.0 implementation may face resistance to change, resource constraints, or technical issues. Failure to capture sector dynamics or comparable data may also hinder implementation analysis across industries. Innovation 5.0 ethics must address data privacy, regulatory changes, and environmental impacts.

Future research should address several key areas to overcome these limitations. First, future studies could broaden the scope of analysis by exploring how different innovation paradigms, beyond open innovation theory, have evolved historically and intersected with societal, technological, and economic changes. Second, measuring Innovation 5.0's impact on adaptability, resilience, sustainability, and human-centricity across organizational contexts. Third, creating frameworks for Innovation 5.0 and Industry 5.0's unique needs and complexities. Lastly, exploring ways organizations can integrate Innovation 5.0 principles of human-centricity, sustainability, and resilience.

References

Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. In *Journal of Cloud Computing* (Vol. 11, Issue 1). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1186/s13677-022-00314-5

Afzal, B., Li, X., & Hernández-Lara, A. B. (2024). The innovation journey and crossroads of sustainability, resilience and human-centeredness: a systematic literature review. *Transforming Government: People, Process and Policy*, *18*(3), 368–383. https://doi.org/10.1108/TG-10-2023-0151

Agostinho, S., Ferreira, J. J., & Carayannis, E. (2019). The sextuple helix and corporate social responsibility: A new paradigm for social innovation and sustainable tourism. *Journal of Destination Marketing & Management*, *11*, 64–69.

Almeida, M., Fernandes, A., & Fernandes, C. (2020). The sextuple helix model of innovation and higher education institutions: A systematic literature review. *Technology in Society*, *63*, 101400.

Alves, J., Lima, T. M., & Gaspar, P. D. (2023). Is Industry 5.0 a Human-Centred Approach? A Systematic Review. *Processes*, *11*(1), 193. https://doi.org/10.3390/pr11010193

Aslam, F., Aimin, W., Li, M., & Rehman, K. U. (2020). Innovation in the era of IoT and industry 5.0: Absolute innovation management (AIM) framework. *Information (Switzerland)*, *11*(2). https://doi.org/10.3390/info11020124

Brannback, M., Carsrud, A., Jr., N. K., & Elfving, J. (2008). Challenging the triple helix model of regional innovation systems: A venture-centric model. *International Journal of Technoentrepreneurship*, *1*(3), 257. https://doi.org/10.1504/IJTE.2008.020539

Cai, Y., & Etzkowitz, H. (2020). Theorizing the Triple Helix model: Past, present, and future. *Triple Helix*, *6*, 1–38. https://doi.org/10.1163/21971927-bja10003

Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The Quintuple Helix innovation model: global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, *1*(1), 2. https://doi.org/10.1186/2192-5372-1-2

Carayannis, E. G., & Campbell, D. F. J. (2009). "Mode 3" and "Quadruple Helix": Toward a 21st century fractal innovation ecosystem. In *International Journal of Technology Management* (Vol. 46, Issues 3–4, pp. 201–234). Inderscience Publishers.

Carayannis, E. G., & Campbell, D. F. J. (2021). Democracy of Climate and Climate for Democracy: the Evolution of Quadruple and Quintuple Helix Innovation Systems. *Journal of the Knowledge Economy*, *12*(4), 2050–2082. https://doi.org/10.1007/s13132-021-00778-x

Carayannis, E. G., & Rakhmatullin, R. (2014). The quadruple/quintuple innovation helixes and smart specialisation strategies for sustainable and inclusive growth in Europe and beyond. *Journal of the Knowledge Economy*, *5*(2), 212–239.

Carvalho, L., Ferreira, J. J., & Carayannis, E. (2019). Using the Sextuple Helix model of innovation ecosystems to analyze the dynamics of social innovation ecosystems in Portugal. *Journal of Open Innovation: Technology, Market, and Complexity*, *5*(3), 62.

Chesbrough. (2003). *Open Innovation The New Imperative for Creating and Profiting from Technology* (Vol. 658).

Chesbrough, & Vanhaverbeke. (2011). A new paradigm for understanding industrial innovation. *Innovation in the Public Sector*, *18*, 1–17.

Costa, J., & Matias, J. C. O. (2020). Open innovation 4.0 as an enhancer of sustainable innovation ecosystems. *Sustainability (Switzerland)*, *12*(19). https://doi.org/10.3390/su12198112

Crafts, N. (2019). Forging ahead, falling behind and catching up: A new perspective on Britain's economic growth from the industrial revolution to the present day. *The Economic History Review*, *72*(1), 1–27.

Cui, T., Ye, H. (Jonathan), Teo, H. H., & Li, J. (2015). Information technology and open innovation: A strategic alignment perspective. *Information & Management*, *52*(3), 348–358. https://doi.org/https://doi.org/10.1016/j.im.2014.12.005

Daniel C, Bindu Swetha Pasuluri, D.S. Vijayan, V.J.K Kishor Sonti, & V. Lakshmi Prasanna. (2020). Innovative Teaching and Learning Process during COVID 19. In *Innovative Teaching and Learning Process during COVID 19*. IOR PRESS. https://doi.org/10.34256/iorip2025

Dodgson, M., Gann, D. M., & Phillips, N. (2014). *The Oxford Handbook of Innovation Management*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199694945.001.0001

Dwi Wahana, H., Ilham, M., & Maryani, D. (2022). *The Effect of Quintuple Helix in Increasing Creativity and Innovation to Competitive Advantage the Creative Village in Bandung Municipality West Jawa Province*. https://doi.org/10.33258/birci.v5i1.3961

Etzkowitz, H., & Leydesdorff, L. (1995). The Triple Helix -- University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development. *EASST Review*, *14*(1), 14–19.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "'Mode 2'" to a Triple Helix of university-industry-government relations. In *Research Policy* (Vol. 29). www.elsevier.nlrlocatereconbase

Fikri, E., Firmansyah, Y. W., Ramadhansyah, M. F., Widyantoro, W., Lewinsca, M. Y., Berlian, A. I., Fuadi, M. F., Diyana, S., Solehuddin, M., Triguswinri, K., & others. (2023). Sextuple helix model for recovery COVID-19 in Indonesia: A scoping review. *AIP Conference Proceedings*, *2722*(1).

Gao, H., Ding, X. H., & Wu, S. (2020). Exploring the domain of open innovation: Bibliometric and content analyses. In *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2020.122580

Gupta, Dey, & Singh. (2017). Connecting corporations and communities: Towards a theory of social inclusive open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, *3*(3). https://doi.org/10.1186/s40852-017-0062-3

Hafkesbrink, J., & Schroll, M. (2011). Innovation 3.0: embedding into community knowledge - collaborative organizational learning beyond open innovation. *Journal of Innovation Economics & Management*, *n°7*(1), 55–92. https://doi.org/10.3917/jie.007.0055

Heitor, M., & Horta, H. (2015). The Sextuple Helix Approach to Regional Innovation Ecosystems: An exploratory study of four European cities. *European Planning Studies*, *23*(7), 1316–1336.

Herzog, P., & Leker, J. (2010). Open and closed innovation - Different innovation cultures for different strategies. *International Journal of Technology Management*, *52*(3–4), 322–343. https://doi.org/10.1504/IJTM.2010.035979

Hess, T., Matt, C., Benlian, A., & Wiesböck, F. (2016). Options for Formulating a Digital Transformation Strategy. *MIS Quarterly Executive*, *15*, 123–139.

Hobsbawm, E. J. (1996). *The Age of Capital: 1848-1875*. Vintage.

Horstmeier, N. A., & Reichwald, R. (2006). Embedded innovation: A new innovation paradigm. *International Journal of Technology Management*, *34*(3–4), 262–280.

Isenberg, D. (2010). How to start an entrepreneurial revolution. *Harvard Business Review*, *88*(6), 40–50.

Ivanov, D. (2023). The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. *International Journal of Production Research*, *61*(5), 1683–1695. https://doi.org/10.1080/00207543.2022.2118892

Jafari, N., Azarian, M., & Yu, H. (2022). Moving from Industry 4.0 to Industry 5.0: What Are the Implications for Smart Logistics? *Logistics*, *6*(2), 26. https://doi.org/10.3390/logistics6020026

Kebir, L., Carayannis, E. G., & Mezouaghi, M. (2018). The sextuple helix model in the knowledge-based society: A Tunisian case study of higher education policy for economic development. *Journal of the Knowledge Economy*, *9*(4), 1199–1219.

Landes, D. S. (1969). *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*. Cambridge University Press.

Leal Filho, W., Azeiteiro, U. M., Alves, F., & Pace, P. (2020). The role of the sextuple helix approach in shaping the environmental and sustainability discourse: A systematic literature review. *Journal of Cleaner Production*, *267*, 122134.

Leydesdorff, L. (2000). The triple helix: An evolutionary model of innovations. *Research Policy*, *29*(2), 243–255. https://doi.org/10.1016/S0048-7333(99)00063-3

Liyanage, S. I. H., & Netswera, F. G. (2022). Greening Universities with Mode 3 and Quintuple Helix Model of Innovation–Production of Knowledge and Innovation in Knowledge-Based Economy, Botswana. *Journal of the Knowledge Economy*, *13*(2), 1126–1156. https://doi.org/10.1007/s13132-021-00769-y

López-Rubio, P., Roig-Tierno, N., & Mas-Tur, A. (2021). A Research Journey from National Systems of Innovation to National Systems of Entrepreneurship: Introducing the Sextuple Helix. *International Journal of Innovation and Technology Management*, *18*(8). https://doi.org/10.1142/S0219877021300081

López-Rubio, P., Roig-Tierno, N., & Mas-Tur, A. (2022). Which regions produce the most innovation policy research? *Policy Studies*, *43*(5), 1112–1134. https://doi.org/10.1080/01442872.2021.1937595

Lundvall, B.-Å. (1992). *National systems of innovation: Towards a theory of innovation and interactive learning*. Pinter.

Maddikunta, P. K. R., Pham, Q. V., B, P., Deepa, N., Dev, K., Gadekallu, T. R., Ruby, R., & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. In *Journal of Industrial Information Integration* (Vol. 26). Elsevier B.V. https://doi.org/10.1016/j.jii.2021.100257

Mutlu, H. (2013). *Open Innovation. Geschäftsmodelle, Prozesse, Chancen und Risiken: Anhand des Ansatzes nach Henry Chesbrough*. GRIN Verlag. https://books.google.es/books?id=6iB6ngEACAAJ

Nahavandi, S. (2019). Industry 5.0-a human-centric solution. *Sustainability (Switzerland)*, *11*(16). https://doi.org/10.3390/su11164371

Nonaka, I., & Takeuchi, H. (1995). *The Knowledge-creating Company: How the Japanese Companies Create the Dynamics of Innovation*. Oxford University Press. https://books.google.es/books?id=N76hzQEACAAJ

Osterwalder, A., & Pigneur, Y. (2010). *Business model generation: a handbook for visionaries, game changers, and challengers*. John Wiley & Sons.

Panwar, A., Shyla, & Bhatnagar, V. (2022). Blockchain-based web 4.0: Decentralized web for decentralized cloud computing. In *Cloud IoT: Concepts, Paradigms, and Applications*. https://doi.org/10.1201/9781003155577-19

Pizoń, J., & Gola, A. (2023). Human–Machine Relationship—Perspective and Future Roadmap for Industry 5.0 Solutions. In *Machines* (Vol. 11, Issue 2). MDPI. https://doi.org/10.3390/machines11020203

Porter, M. E., & Kramer, M. R. (2007). *Strategy & Society The Link Between Competitive Advantage and Corporate Social Responsibility*. www.hbrreprints.org

Reischauer, G. (2018). Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing. *Technological Forecasting and Social Change*, *132*, 26–33. https://doi.org/10.1016/j.techfore.2018.02.012

Rifkin, J. (2011). *The Third Industrial Revolution: How Lateral Power is Transforming Energy, the Economy, and the World*. Palgrave Macmillan.

Rosenlund, J., Rosell, E., & Hogland, W. (2016). Overcoming the triple helix boundaries in an environmental research collaboration. *Science and Public Policy*, scw045. https://doi.org/10.1093/scipol/scw045

Schaltegger, S., & Wagner, M. (2011). Sustainable entrepreneurship and sustainability innovation: Categories and interactions. *Business Strategy and the Environment*, *20*(4), 222–237. https://doi.org/10.1002/bse.682

Schumpeter, J. A. (1934). *The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle*. Transaction Publishers.

Schwab, K. (2016). *The Fourth Industrial Revolution*. World Economic Forum.

Sikhwal, R. K., & Childs, P. R. N. (2018). *Design for Mass Individualisation: Introducing Networked Innovation Approach*.

Srisathan, W. A., Ketkaew, C., Jitjak, W., Ngiwphrom, S., & Naruetharadhol, P. (2022). Open innovation as a strategy for collaboration-based business model innovation: The moderating effect among multigenerational entrepreneurs. *PLoS ONE*, *17*(6 June). https://doi.org/10.1371/journal.pone.0265025

Straßburger, S., & Strassburger, S. (2019). *On the Role of Simulation and Simulation Standards in Industry 4.0*. https://doi.org/10.22032/dbt.38300

Streitz, N. A., Riedmann-Streitz, C., & Quintal, L. (2022). From 'Smart-only' Island Towards Lighthouse of Research and Innovation. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *13325 LNCS*, 105–126. https://doi.org/10.1007/978-3-031-05463-1_8

Taratori, R., Rodriguez-Fiscal, P., Pacho, M. A., Koutra, S., Pareja-Eastaway, M., & Thomas, D. (2021). Unveiling the Evolution of Innovation Ecosystems: An Analysis of Triple, Quadruple, and Quintuple Helix Model Innovation Systems in European Case Studies. *Sustainability*, *13*(14), 7582. https://doi.org/10.3390/su13147582

Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *Omega*, *3*(6), 639–656.

Vial, G. (2019). Understanding digital transformation: A review and a research agenda. The Journal of Strategic Information Systems, 28(2), 118–144. https://doi.org/10.1016/j.jsis.2019.01.003

von Hippel, E. (2005). Democratizing innovation: The evolving phenomenon of user innovation. *Journal Fur Betriebswirtschaft*, *55*(1), 63–78. https://doi.org/10.1007/s11301-004-0002-8

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception and perception. *Journal of Manufacturing Systems*, *61*, 530–535. https://doi.org/10.1016/j.jmsy.2021.10.006

Zhang, B., & Ming, C. (2023). A patent portfolio value analysis based on intuitionistic fuzzy sets: An empirical analysis of artificial intelligence for healthcare. *Journal of Open Innovation: Technology, Market, and Complexity*, *9*(3). https://doi.org/10.1016/j.joitmc.2023.100124

Zizic, M. C., Mladineo, M., Gjeldum, N., & Celent, L. (2022). From Industry 4.0 towards Industry 5.0: A Review and Analysis of Paradigm Shift for the People, Organization and Technology. In *Energies* (Vol. 15, Issue 14). MDPI. https://doi.org/10.3390/en15145221