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Industry 4.0 and Industry 5.0—Inception, conception and perception

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ABSTRACT

Industry 4.0, an initiative from Germany, has become a globally adopted term in the past decade. Many countries have introduced similar strategic initiatives, and a considerable research effort has been spent on developing and implementing some of the Industry 4.0 technologies. At the ten-year mark of the introduction of Industry 4.0, the European Commission announced Industry 5.0. Industry 4.0 is considered to be technology-driven, whereas Industry 5.0 is value-driven. The co-existence of two Industrial Revolutions invites questions and hence demands discussions and clarifications. We have elected to use five of these questions to structure our arguments and tried to be unbiased for the selection of the sources of information and for the discussions around the key issues. It is our intention that this article will spark and encourage continued debate and discussion around these topics.

1. Introduction

The Fourth Industrial Revolution (a.k.a. Industry 4.0, translated from Industrie 4.0 as in German) originated in 2011 from a project in the high-tech strategy of the German government. It advanced the concept of Cyber Physical Systems (CPS) [1,2] into Cyber Physical Production Systems (CPPS) [3]. SmartFactory is one of the key associated initiatives of Industry 4.0 [4]. The term Industry 4.0 was publicly introduced in 2011 at the Hannover Fair [1,2], and it is on the back of the following definitions of the first three Industrial Revolutions. The First Industrial Revolution was marked by a transition from manual production methods to machines powered by steam or water. Thanks to electricity, the Second Industrial Revolution transformed factories into modern production lines resulting in high productivity and significant economic growth. The Third Industrial Revolution saw field-level computers like Programmable Logic Controller (PLC) and communication technologies in the production process, leading to automated production. In the Industry 4.0 era, production systems, in the form of CPPS, can make intelligent decisions through real-time communication and cooperation between "manufacturing things[1] " [5], enabling flexible production of high-quality personalized products at mass efficiency [6,7]. To progress the initiative and ensure a coordinated, cross-sectoral approach, the professional associations BITKOM, VDMA and ZVEI have established the joint Industrie 4.0 Platform [8]. Globally, many countries have introduced similar strategic initiatives, for example, Industrial Internet Consortium (USA), Industria 4.0 (Italy), Produktion 2030 (Sweden), Made in China 2025, and Society 5.0 (Japan), to name a few.

As businesses started to embrace Industry 4.0, along came the Fifth Industrial Revolution (Industry 5.0). Industry 5.0 is understood to recognize the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity, by making production respect the boundaries of our planet and placing the well-being of the industry worker at the center of the production process [9,10]. The introduction of Industry 5.0 is based on the observation or assumption that Industry 4.0 focuses less on the original principles of social fairness and sustainability but more on digitalization and AI-driven technologies for increasing the efficiency and flexibility of production. The concept of Industry 5.0, therefore, provides a different focus and point of view and highlights the importance of research and innovation to support the industry in its long-term service to humanity within planetary boundaries [9]. Indeed, leading up to this formal introduction of Industry 5.0, there have been some discussions about "Age of Augmentation" where the human and machine reconcile and work in symbiosis [11]. Similarly, Bednar and Welch [12] described

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[1] Though manufacturing and production are sometimes used interchangeably, we make the following differentiations. Manufacturing is the process in which raw material is converted into the tangible products, whereas production creates utility made for the purpose of the consumption. Therefore, production is a broader term involving, for example, manufacturing, logistics and finance.

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"Smart Working" practices.

It is fair to say that co-existence of the two Industrial Revolutions has promoted a few questions. The questions are rooted in the scientific community as well as the industry. With no attempt to be exhaustive, some of these questions are:

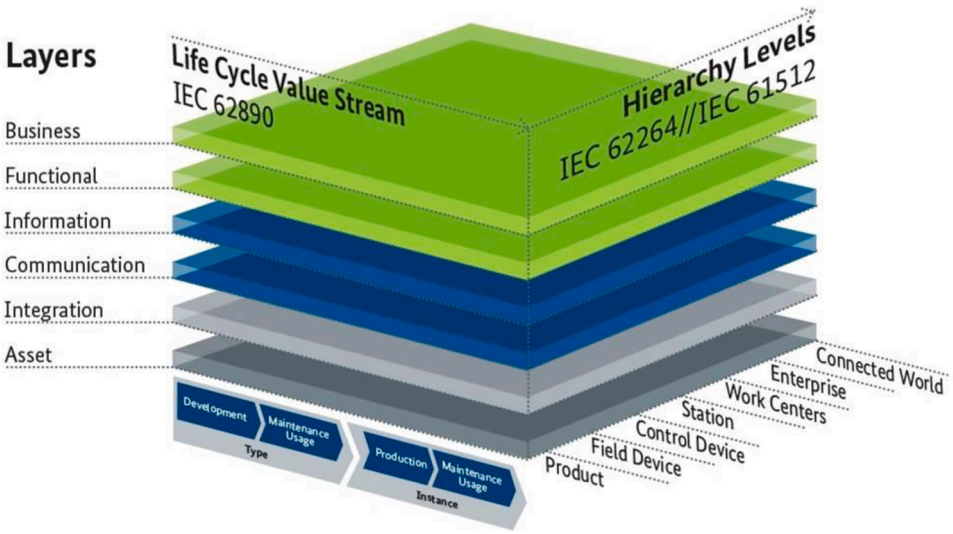
- To what extent is Industry 4.0 technology-centric and oblivious of human-centricity, sustainability and resilience?
- Can Industry 4.0 enabling technologies also help realize the goals of Industry 5.0, or do we need to develop new Industry 5.0 technologies?
- Is Industry 5.0 a chronological continuation of Industry 4.0, similar to their predecessors (i.e., Industry 1.0 through to Industry 4.0)?
- Are we living amongst two Industrial Revolutions, or effectively one – techno-social revolution?
- What would industry's journeys of Industry 4.0 and Industry 5.0 look like?

This article intends to stand on an unbiased ground to ascertain the landscape co-occupied by both Industry 4.0 and Industry 5.0, and to shed some light on possible ways of responding to these questions and possibly more. If the above questions echo some of your bafflements, it is the authors' hope that you will be in a better position to respond to some of the questions after reading this article. It is also the authors' intention to spark and encourage further discussions about these topics. The following two sections intend to provide an accurate but succinct account of Industry 4.0 and Industry 5.0 more at their intersections than otherwise. We finish off with discussions around the imposed questions and set a stage for continued debates.

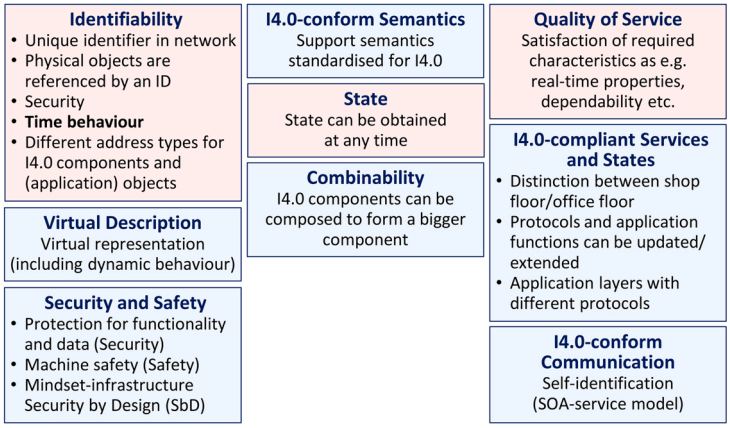
In order to remain focused, this article makes no attempt to define and discuss what an "Industrial Revolution", or Industry 4.0 and Industry 5.0 are. The main associated concepts are considered well understood, with the only exception of Industry 5.0, a more nascent term. The debate over Revolution vs Evolution is still ongoing but also falls outside the scope of this article.

2. Understanding Industry 4.0

Industry 4.0 refers to the intelligent networking of machines and processes for the industry based on CPS – a technology that achieves intelligent control using embedded networked systems [8,13]. There are different understandings of Industry 4.0, albeit all agree upon the Reference Architecture Model Industrie 4.0 (RAMI4.0). RAMI4.0 was developed by the German Electrical and Electronic Manufacturers'



(a) RAMI4.0 architecture model



(b) selected characteristics of RAMI4.0

Fig. 1. Reference Architecture Model Industrie 4.0 (RAMI4.0) [16].

Association (ZVEI) to support Industry 4.0 initiatives [14]. RAMI 4.0 model consists of a three-dimensional coordinate system (Fig. 1(a)) that depicts the architecture of Industry 4.0 systems. The "Hierarchy Levels" axis is derived from the information model of automation [15] and represents the different functionalities within factories or facilities; the "Layers" axis describes the decomposition of a machine into its properties and the "Life Cycle Value Stream" axis represents the life cycle of facilities and products. The latter includes business models and the benefit of using Industry 4.0 as well. Fig. 1(b) summarizes some of the characteristics of Industry 4.0 components based on RAMI4.0.

Vogel-Heuser and Hess [1] discussed the main design principles of Industry 4.0, which are summarized as the following:

- Service-oriented reference architecture.
- Intelligent, self-organizing CPPS.
- Interoperability between CPPS and humans.
- Adaptability and flexibility to changing requirements.
- Optimization for Overall Equipment Effectiveness.
- Data integration across disciplines and entire life cycle.
- Reliable and secured communications between businesses.
- Data security.

2.1. Technology, flexibility and productivity-focused

Industry 4.0 is considered a technology-driven revolution to achieve higher efficiency and productivity and, as a high-tech strategy of the government, to enhance Germany's competitiveness in a global market. This may be further reinforced by the three dimensions of RAMI4.0 (Fig. 1(a)), i.e., Product Life Cycle, Business Layers and Factory Hierarchy. Boston Consulting Group identified nine key enabling technologies of Industry 4.0 [17], i.e., Big data and analytics, Autonomous robots, Simulation, Horizontal and vertical system integration, Industrial Internet of Things, Cybersecurity, Cloud, Additive Manufacturing, and Augmented Reality. These technologies underpin the five Industry 4.0 central research themes [18]:

- Horizontal integration through value networks
- End-to-end engineering across the entire value chain
- Vertical integration and networked manufacturing systems
- Cyber-Physical Systems technology
- New social infrastructures in the workplace

2.2. Sustainability, resilience and human-centric

Industry 4.0 may have been considered as a technology-driven transformation. Some considerations and projected impacts from societal needs, such as sustainability, human-centricity and resilience, are also visible.

2.2.1. Resource-efficient, sustainable and resilient industries

Industry 4.0 intends to address challenges such as resource and energy efficiency, urban production, societal needs, and demographic change [18]. In order to reduce the consumption of energy and resources, changes in manufacturing processes and the design of machinery and plant are required.

The Green Production Index is suggested as one of the main decision-supporting KPIs, together with the basic data required to make transparent, resource-oriented investment decisions [18]. Though Industry 4.0 is pre-Covid, an Example Application was discussed, i.e., "Sudden change of supplier during production due to a crisis beyond the manufacturer's control" [18]. Industry 4.0 makes the necessary changes smoother by running simulations of the affected downstream services, thus allowing different suppliers to be evaluated and the best alternative to be selected.

2.2.2. Human-centric approach

Industry 4.0 may not be considered a human-centric initiative. That's as may be, the like of human-machine cooperation or operator assistant technologies, socio-technical approach, and work-life balance is not to be ignored.

2.2.2.1. Technologies. Industry 4.0 promotes new socio-technical infrastructures by transforming different aspects of a workplace such as health management and work organization, lifelong learning and career path models, team structures and knowledge management. This is described as a socio-technical approach of the Industry 4.0 initiative leading to a paradigm shift in human-technology and human-environment interactions [18]. It is anticipated that a worker's role is set to change significantly due to the increased use of technologies that are more open, virtual and extensive [18]. This is reflected by some of the design principles of Industry 4.0 [1]. Reflective of the second and third design principles (i.e., Information transparency and Technical assistance) is the increased use of the technologies such as robot-assisted systems and augmented reality (AR) to provide workers with real-time information in order to improve decision-making and work procedures [19–21].

2.2.2.2. Worker up-skilling and re-skilling, and workers' wellbeing. Smart assistance systems release workers from routine tasks so that they can focus on more creative and value-added activities. Flexible work organization is promoted to enable all workers to continue professional development more effectively and have a better work-life balance. The relevant technologies will also allow older workers to extend their working lives and remain productive longer [18]. It has been recognized that in a smart factory, the role of employees will change significantly. Implementation of a socio-technical approach to work organization will offer workers the opportunity to enjoy greater responsibility and enhance their personal development [18,22].

Industry 4.0's socio-technical approach strives for the so-called motto, "better, not cheaper". It argues that adopting an extreme version of the Taylorist approach to work organization based on frequent repetition of highly standardized and monotonous tasks is hardly the most promising way to implement Industry 4.0. The fact that smart factories will be configured as highly complex, dynamic and flexible systems means they will need empowered employees to act as decision-makers and controllers [18].

2.3. Demonstrations and use cases

The past decade has seen a large number of demonstrations, testbeds and use cases for Industry 4.0 implementations, most of which are in the form of smart factories or elements of smart factories. Some of the examples include SmartFactory^{KL}, a network of industry and research organizations [6,23], the French initiative Industrie du future [24], and the Japanese Robot Revolution and Industrial IoT Initiative [25].

3. Understanding Industry 5.0

Since 2017, scattered academic efforts have been pushing the introduction of the Fifth Industrial Revolution [26–29]. In 2021, the European Commission formally called for the Fifth Industrial Revolution (Industry 5.0), after discussions amongst participants from research and technology organizations as well as funding agencies across Europe in two virtual workshops organized by Directorate "Prosperity" of Directorate-General for Research and Innovation, on 2 and 9 July 2020, by the formal release of the document titled "Industry 5.0: Towards a Sustainable, Human-centric, and Resilient European Industry" on 4 January 2021 [9]. This is similar to Industry 4.0 in 2011 by the German government, devising a top-down initiative in response to the changing societal and geopolitical landscape. Our analysis on Industry 5.0 in this

article is principally based on the sentiment from European Commission.

3.1. Concept

Industry 5.0 recognizes the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the center of the production process. Industry 5.0 complements the existing Industry 4.0 paradigm by having research and innovation drive the transition to a sustainable, human-centric and resilient European industry [9]. It is apparent that Industry 5.0 results from the European Commission's consensus on the need better to integrate social and environmental European priorities into technological innovation and shift the focus from individual technologies to a *systematic approach*.

With the acknowledgment that technology advances transform the way value is created, exchanged and distributed, there is a pressing need for these technologies to be designed towards supporting future societal values. The advent of these changes and questions closely linked to technological innovation requires the industry to re-think its position and role in society [7]. In addition, the political priorities in Europe have significantly shaped their thinking. The Green Deal will require a transition to a more circular economy and increased reliance on sustainable resources, including energy. The Covid-19 crisis has highlighted the need to re-think existing working methods and approaches, including the vulnerability of global supply chains, with an aim to make their industries more future-proof, resilient, sustainable and human-centric.

3.2. Core values

Industry 5.0 centers around three interconnected core values: human-centricity, sustainability and resilience (Fig. 2).

The human-centric approach puts core human needs and interests at the heart of the production process, shifting from technology-driven progress to a thoroughly human-centric and society-centric approach. As a result, industry workers will develop new roles as a shift of value from considering workers as "cost" to "investment". Technology is to serve people and societies, meaning that technology used in manufacturing is adaptive to the needs and diversity of industry workers [30]. A safe and inclusive work environment is to be created to prioritize physical health, mental health and wellbeing, and ultimately safeguard worker's fundamental rights, i.e., autonomy, human dignity and privacy. Industrial workers need to keep upskilling and re-skilling themselves for better career opportunities and work-life balance [9].

For the industry to respect planetary boundaries, it needs to be **sustainable**. It needs to develop circular processes that re-use, re-purpose and recycle natural resources, reduce waste and environmental impact, and ultimately lead to a circular economy with better resource efficiency and effectiveness [9].

Fig. 2. Core values of Industry 5.0 [9].

Resilience refers to the need to develop a higher degree of robustness in industrial production, arming it better against disruptions and ensuring it can provide and support critical infrastructure in times of crisis. The future industry needs to be resilient enough to swiftly navigate the (geo-)political shifts and natural emergencies [9].

3.3. Enabling technologies

Industry 5.0 identified the following six enabling technologies [31].

1 Individualized human-machine interaction technologies that interconnect and combine the strengths of humans and machines.
2 Bio-inspired technologies and smart materials that allow materials with embedded sensors and enhanced features while being recyclable.
3 Digital Twins and simulation to model entire systems.
4 Data transmission, storage, and analysis technologies that are able to handle data and system interoperability.
5 Artificial Intelligence to detect, for example, causalities in complex, dynamic systems, leading to actionable intelligence.
6 Technologies for energy efficiency, renewables, storage and autonomy

As seen above, Industry 5.0 is not a technology-driven revolution but a value-driven initiative that drives technological transformation with a particular purpose (Fig. 3).

3.4. Challenges and responses

Industry 5.0 present some unique challenges that are not seen in the past [9], such as

- Social heterogeneity in terms of values and acceptance
- Measurement of environmental and social value generation
- Integration from customers across entire value chains to SMEs
- Interdisciplinarity of research disciplines and system complexity
- Ecosystem-oriented innovation policy with agile, outcome-orientation
- Productivity is required, while large investments are needed

As a new initiative, the European Commission also outlined a series of implementation strategies from investment, marketing, and governance dimensions to promote Industry 5.0 [9]. Response from other governments and industries is still limited for the time being. Academia though has quickly embraced the discussions on Industry 5.0, as Journal of Manufacturing Systems, International Journal of Production Research and IEEE Transactions on Industrial Informatics all established relevant Special Issues to encourage the research on Industry 5.0 in 2021. IEEE Robotics and Automation Society (RAS) Technical Committee (TC) on Digital Manufacturing and Human-centered Automation has also highlighted its relevance to Industry 5.0 [32].

Similar to Industry 4.0, Industry 5.0, aiming for success, will need substantial investment from government agencies. Regardless of the future of Industry 5.0, its core values – human-centricity, sustainability and resilience, have become major driving forces for societal progress instead of as a by-product of GDP-driven prosperity development. This is evident from recent government progress towards embedding them in national policies, such as Paris Agreement [33], Sustainable Development Goals (SDGs) [34] from the United Nations, Well-being of Future Generations Act [35], Genuine Progress Indicator 2.0 [36], The Economy of Well-being [37], National Performance Framework [38], and OECD Better Life Index [39].

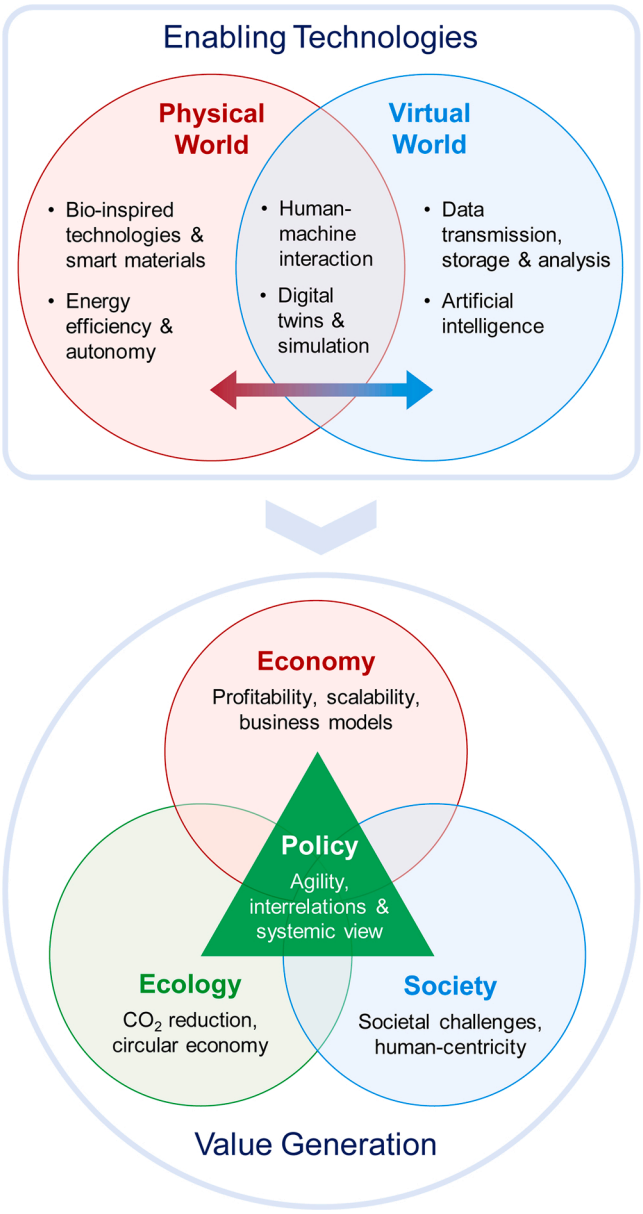


Fig. 3. Industry 5.0 goals and the technological enablers (reproduced based on [21]).

4. Discussions and final remarks

It has been the authors' intention to stand on neutral ground to provide the account for both Industry 4.0 and Industry 5.0 through Sections 1–3. This section may include some opinionated comments from the authors, but otherwise, the intention to remain impartial is still upheld. The remaining section is structured by following the five questions imposed at the beginning of this article. One should, however, not expect the provision of definitive answers to each of the questions. Instead, the questions are utilized for pertinent discussions to provide an answer or a partial answer as it may be to the question.

4.1. Questions and discussions

- To what extent is Industry 4.0 technology-centric and oblivious of human-centricity, sustainability and resilience?

The perception by many has been that Industry 4.0 has a strong focus on technologies or technological solutions. Such a focus is evident from some of the early policy and government manifestos. Research publications in the early years tend to be technology-focused, too. Whitepapers and business reports published by some top consulting firms, e.g., McKinsey and Boston Consulting Group, also have a clear technology slant. Industry 4.0, however, may not be considered oblivious of human-centricity, sustainability and resilience. Resource efficiency and societal needs are found in some of the key publications [18]. The Factory2Fit project, for example, aims at empowering and engaging workers in a more connected industrial environment. The workers are given more influence and hence greater responsibility in shaping the production process through virtual means.

However, Industry 4.0 addresses the issues of human-centricity, sustainability and resilience from a consequential perspective and with a clear technological approach. Unlike Industry 4.0, Industry 5.0 makes a bold focus shift from individual technologies to a systematic approach. This approach empowers the industry to achieve societal goals beyond jobs and growth and places the wellbeing of the industry worker at the center of the production process. This may help explain why Industry 5.0 is considered a different type of Industrial Revolution from the other Industrial Revolutions.

- Can Industry 4.0 enabling technologies also help realize the goals of Industry 5.0, or do we need to develop new Industry 5.0 technologies?

Boston Consulting Group identified nine key enabling technologies of Industry 4.0, whereas the EU identified six enabling technologies of Industry 5.0. The terminologies used for these technologies may differ, but there is a clear cross-over. It is believed that many enabling technologies of Industry 4.0 can help, and will undoubtedly be used to, achieve the societal goals of Industry 5.0. There are, however, some more targeted technologies of Industry 5.0 that require attention, such as bio-inspired technologies and technologies for energy efficiency, storage, and renewable energy.

- Is Industry 5.0 a chronological continuation of Industry 4.0, similar to their predecessors (i.e., Industry 1.0 through to Industry 4.0)?

Industry 5.0 is not a chronological continuation of, or an alternative to, the existing Industry 4.0 paradigm. Industry 5.0 is the result of a forward-looking exercise, a way of framing how industry and emerging societal trends and needs will co-exist. As such, Industry 5.0 *complements* and *extends* the hallmark features of Industry 4.0 [9]. This may help set aside Industry 5.0 as a different type of Industrial Revolution from the others, acknowledging the other Industrial Revolutions are the chronological continuation of their predecessors.

It needs to be pointed out that some of the latest Industry 4.0 research has already extended the original thinking and intention of Industry 4.0. This is particularly evident in Germany, where fresh initiatives on resource efficiency, energy footprint and Arbeit 4.0 (Labour or Work 4.0) [40,41] have been pushed out in recent years.

- Are we living amongst two Industrial Revolutions, or effectively one – Techno-Social Revolution?

The notion of Industry 5.0 complementing and extending the hallmark features of Industry 4.0 suggests that they are to be considered side-by-side, i.e., the co-existence of technology-driven Industry 4.0 and value-driven Industry 5.0. In the interest of simplifying the terminology but running the risk of further introducing new terms, we may be led to believe that we are witnessing a Techno-Social Revolution (or perhaps Social-Techno Revolution), with technology as the enabling tools and societal needs as the ultimate goal, acknowledging that the term Techno-Social System has existed for some time.

- What would industry's journeys of Industry 4.0 and Industry 5.0 look like?

Many companies are on their journey of Industry 4.0, and this journey is not to be derailed. This said, it may need to be re-purposed and/or adjusted with a more prominent consideration of some of the core values of Industry 5.0, i.e., sustainability, human-centricity and resilience. Therefore, there is, and should be, just one journey for a business.

4.2. Final words

Typically, an Industry Revolution is driven by transformative technological advances, which has led to fundamental changes in how the industry functions. These changes have economic and societal consequences. Some are intended and desirable; others unintended and undesirable. Like other predecessors, Industry 4.0 is technology-driven. Industry 5.0 is, however, value-driven. The former needs the latter to remind the essential societal needs, value and responsibility as ultimate goals; the latter requires the former for the technological pushes and solutions.

However, a word of caution is that a proliferation of buzz words, such as Industry 4.0+, Industry 4.5 and even Industry 6.0 and Industry 7.0 in a not-too-distant future, may dawn upon us. These buzz words may be inviting for paper-writing or grant applications; they are not conducive to making any business decision and facing technological challenges. To this end, cool heads and wise minds are required. It is our intention that this article will spark and encourage further, extensive and in-depth discussion around these topics as we owe the industry a clear vision into the future.

Declaration of Competing Interest

The authors report no declarations of interest.

References

[1] Vogel-Heuser B, Hess D. Guest editorial: Industry 4.0–prerequisites and visions. IEEE Trans Autom Sci Eng 2016;13(April 2).
[2] Bauernhans T, Vogel-Heuser B, ten Hompel M. In: Allgemeine Grundlagen, editor. Handbuch Industrie 4.0 Bd.4. Springer; 2017. ISBN: 978-3-662-53254-53256.
[3] Vogel-Heuser B, Bayrak G, Frank U. Forschungsfragen in "Produktionsautomatisierung der Zukunft". Diskussionspapier für die acatech Projektgruppe "ProCPS – Production CPS". acatech Materialien. 2012.
[4] Zuehlke D. SmartFactory—towards a factory-of-things. Annu Rev Control 2010;34 (April 1):129–38. https://doi.org/10.1016/j.arcontrol.2010.02.008.
[5] Lu Y, Xu X, Wang L. Smart manufacturing process and system automation – a critical review of the standards and envisioned scenarios. J Manuf Syst 2020;56: 312–25. https://doi.org/10.1016/j.jmsy.2020.06.010.
[6] Wang S, Wan J, Zhang D, Li D, Zhang C. Towards smart factory for Industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. Comput Netw 2016;101:158–68.
[7] Zhong RY, Xu X, Klotz E, Newman ST. Intelligent manufacturing in the context of Industry 4.0: a review. Engineering 2017;3(5):616–30.
[8] Plattform Industrie 4.0. https://www.plattform-i40.de. (Accessed 28 September 2021).
[9] Breque M, De Nul L, Petridis A. Industry 5.0: towards a sustainable, human-centric and resilient European industry. Luxembourg, LU: European Commission, Directorate-General for Research and Innovation; 2021.
[10] European Economic and Social Committee. Industry 5.0. 2021. Available online: https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en (Accessed 28 September 2021).
[11] Longo F, Padovano A, Umbrello S. Value-oriented and ethical technology engineering in Industry 5.0: a human-centric perspective for the design of the factory of the future. Appl Sci 2020;10:4182. https://doi.org/10.3390/app10124182.
[12] Bednar PM, Welch C. Socio-technical perspectives on smart working: creating meaningful and sustainable systems. Inf Syst Front 2020;22:281–98. https://doi.org/10.1007/s10796-019-09921-1.
[13] Fay A, Gehlhoff F, Seitz M, Vogel-Heuser B. Agents for the realisation of Industrie 4.0 - VDI Status Report. August. 2019. https://doi.org/10.13140/RG.2.2.23998.84805.
[14] DIN SPEC 91345:2016-04 - Referenzarchitekturmodell Industrie 4.0 (RAMI4.0). Veröffentlichung 20.04.2016.
[15] Process Automation Device Information Model (PA-DIM). OPC Foundation. 2021. https://opcfoundation.org/markets-collaboration/pa-dim/.
[16] VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik: Statusbericht; Industrie 4.0; Wertschöpfungsketten. Düsseldorf: VDI e.V.. 2014. April.
[17] Rüßmann M, Lorenz M, Gerbert P, Waldner M, Engel P, Harnisch M, et al. Industry 4.0: the future of productivity and growth in manufacturing industries. 09 April. Boston Consulting Group; 2015.
[18] Forschungsunion acatech. Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group. 8 April. 2013.
[19] Liu C, Cao S, Tse W, Xu X. Augmented reality-assisted intelligent window for cyber-physical machine tools. J Manuf Syst 2017;44:280–6.
[20] Zhu Z, Liu C, Xu X. Visualisation of the digital twin data in manufacturing by using augmented reality. Procedia CIRP 2019;81:898–903.
[21] Villani V, Sabattini L, Barańska P, Callegati E, Czerniak JN, Debbache A, et al. The INCLUSIVE system: a general framework for adaptive industrial automation. IEEE Trans Autom Sci Eng 2020. https://doi.org/10.1109/TASE.2020.3027876.
[22] Flores E, Xu X, Lu Y. Human Capital 4.0: a workforce competence typology for Industry 4.0. J Manuf Technol Manag 2020;31(4):687–703. https://doi.org/10.1108/JMTM-08-2019-0309.
[23] SmartFactoryKL, https://smartfactory.de/en/ (Accessed 28 September 2021).
[24] https://www.lafrenchfab.fr/2021/05/12/industrie-du-futur-gouvernement-accelere/. (Accessed 28 September 2021).
[25] Robot Revolution and Industrial IoT Initiative. https://www.jmfrri.gr.jp/english/. (Accessed 28 September 2021).
[26] Demir KA, Döven G, Sezen B. Industry 5.0 and human-robot co-working. Procedia Comput Sci 2019;158:688–95. https://doi.org/10.1016/J.PROCS.2019.09.104.
[27] Longo F, Padovano A, Umbrello S. Value-oriented and ethical technology engineering in Industry 5.0: a human-centric perspective for the design of the factory of the future. Appl Sci 2020;10:4182. https://doi.org/10.3390/APP10124182.
[28] Nahavandi S. Industry 5.0—a human-centric solution. Sustainability 2019;11: 4371. https://doi.org/10.3390/SU11164371.
[29] Paschek D, Mocan A, Draghici A. Industry 5.0-the expected impact of next industrial revolution. Thriving on future education, industry, business, and society. In: Proceedings of the MakeLearn and TIIM International Conference; 2019. p. 15–7.
[30] Lu Y, Adrados JS, Chand SS, Wang L. Humans are not machines—anthropocentric human–machine symbiosis for ultra-flexible smart manufacturing. Engineering 2021;7:734–7. https://doi.org/10.1016/J.ENG.2020.09.018.
[31] European Commission. Directorate General for Research and Innovation. Enabling Technologies for Industry 5.0 Results of a workshop with Europe's technology leaders. 2020.
[32] Huang GQ, Vogel-Heuser B, Zhou M, Dario P. Digital technologies and automation: the human and eco-centered foundations for the factory of the future [TC Spotlight]. IEEE Robot Autom Mag 2021;28:174–9. https://doi.org/10.1109/MRA.2021.3095732.
[33] Agreement P. Paris agreement. Report of the Conference of the parties to the United Nations framework convention on climate change (21st session, 2015: Paris), vol. 4. HeinOnline; 2015. Retrieved December, p. 2017.
[34] Assembly G. Sustainable development goals. SDGs transform our world. 2015. p. 2030.
[35] Government Wales. Well-being of future generations (Wales) act 2015. 2015.
[36] Talberth J, Weisdorf M. Genuine progress indicator 2.0: pilot accounts for the US, Maryland, and City of Baltimore 2012–2014. Ecol Econ 2017;142:1–11.
[37] Llena-Nozal A, Martin N, Murtin F. The economy of well-being: creating opportunities for people's well-being and economic growth. OECD; 2019.
[38] National Performance Framework | National Performance Framework, n.d., https://nationalperformance.gov.scot/ (Accessed 28 September 2021).
[39] OECD Better Life Index, n.d., https://www.oecdbetterlifeindex.org/ (Accessed 28 September 2021).
[40] German's Platform for Artificial Intelligence. https://www.plattform-lernende-systeme.de/home-en.html. (Accessed 28 September 2021).
[41] Salimi M. Work 4.0: an enormous potential for economic growth in Germany. ADAPT bulletin. 2015. 16 December 2015 (Accessed 28 September 2021, http://www.adaptinternational.it.