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SURVEY AND STATE OF THE ART

Industry 4.0, a revolution that requires technology and national strategies

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Abstract

Since 2011, when the concepts of Industry 4.0 were first announced, this industrial revolution has grown and expanded from some theoretical concepts to real-world applications. Its practicalities can be found in many fields and affect nearly all of us in so many ways. While we are adapting to new changes, adjustments are starting to reveal on national and international levels. It is becoming clear that it is not just new innovations at play, technical advancements, governmental policies and markets have never been so intertwined. Here, we generally describe the concepts of Industry 4.0, explain some new terminologies and challenges for clarity and completeness. The key of this paper is that we summarise over 14 countries' up-to-date national strategies and plans for Industry 4.0. Some of them are bottom-up, such as Portugal, some top-down, such as Italy, a few like the United States had already been moving in this direction long before 2011. We see governments are tailoring their efforts accordingly, and industries are adapting as well as driving those changes.

Keyword Industry 4.0

Introduction

Looking back to the previous industrial revolutions: the first started at the end of the eighteenth century with the increasing use of steam and water power and resulted in a transition from hand production methods to machines (i.e. mechanisation); the second began in the late nineteenth century, utilised on electrical energy and enabled mass production (i.e. intensive use of electrical power); the third made use of electronics and internet technology from the 1970s and automated productions (i.e. digitalisation) [1–9]. We may see from previous industrial revolutions that technological advances met broader industrial demands amongst their trigger conditions.

Right now, we are on the brink of a new industrial revolution, namely the Fourth Industrial Resolution or Industry 4.0 [1–3,5,10–20]. Why now? A convincing reason pointed out by many, such as Lasi et al. [1], is that we have reached a point that there exists a clear application-pull (industrial demands) and technology-push (technological advances), acting together as a driving force for this new revolution.

On the one hand, amongst general social, economic and political fields, there is a remarkable need for change and Lasi et al. [1] listed five particular points.

- Shortening the development period with the use of highly innovative means.
- Using ultra-customisation to end the traditional "one for all" and to promote uniqueness or is sometimes called "batch size one" in manufacturing.
- Productions are integrated with higher flexibility.
- Enabling faster decision-making procedures by decentralisation as opposed to lengthy organisational hierarchy.
- Promoting sustainability and resource efficiency in the context of the ecological aspect.

On the other hand, the recent decade saw numerous technologies booming from novel research and development of all sides. To name a few: radio frequency identification [21], various wireless network protocols [2,22,23], enterprise resource planning [3,24–27], knowledge management [28–32], Internet of Things [6,33], cloud-based computation [17,34,35] and manufacturing [2,7,36–40]. Typically, we summarise this technology-push as the following [1],

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- more extensive use of mechanisation and automation;
- digitalisation and networks linking all components within the industry;
- revolutionary miniaturisation which has made a significant impact on electronics, transportation and logistics.

The idea of Industry 4.0 arose from the Hannover Fair in 2011, and the German government officially announced it in 2013 as a German strategic initiative, to play a pioneering role in its manufacturing sector [4–8,41–60]. As Zhong et al. [7] have summarised, in the context of Industry 4.0, intelligent manufacturing systems feed on advanced information from every corner of the relevant fields, so that they become flexible, smart and customisable to address a dynamically ever-changing global market. The key is to have all information flow through the whole holistic manufacturing supply chain and all relevant industries. Some argue this concept had already been raised, as early as 1988 by Rostow [2,61].

According to [62,63], the goals of Industry 4.0 are to provide IT-enabled mass customisation of manufactured products; to make automatic and flexible adaptation of the production chain; to track parts and products; to facilitate communication among parts, products, and machines; to apply human–machine interaction (HMI) paradigms; to achieve IoT-enabled production optimization in smart factories; and to provide new types of services and business models of interaction in the value chain. [8] concludes "the principles of Industry 4.0 are interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity". Similarly, [5,20] point out, the five major features of Industry 4.0 are digitization, optimization, and customisation of production; automation and adaptation; human–machine interaction (HMI); value-added services and businesses, and automatic data exchange and communication. [62,63] discuss flexibility, reduce lead times, customize with small batch sizes, and reduce costs. [41,64] expand the talk points to include cloud/intranet, data integration, flexible adaptation, intelligent, self-organizing, interoperability, manufacturing process, optimization, secure communication, and service orientation. [1,5,65–67] believe that the key point through various connections (e.g. cyber-physical systems, the Internet of Things and the Internet of services) is the communication of information, thus to do with knowledge management. Communication from various perspectives is discussed in [68–72].

Industry 4.0 is still in its infancy. It is in a conceptual state which intends to integrate very large number of dynamic technological concepts. In this review paper, we aim to explain these concepts of Industry 4.0 and their implications. More importantly, how it has evolved and concerning the large number of new jargon that have developed since 2011, we would like to provide a jargon buster to our reader. In the next section, we summarise several fundamental concepts of Industry 4.0. Due to the fact that there is no single-clear standard for Industry 4.0, each country is implementing its own version of it. Differences in their approaches are typically caused by each market and industry specialisation. This will eventually change the outcomes of Industry 4.0 as what we have predicted now. In Germany, there is a focus on trying to develop fully automated, Internet-based "smart" factories. [73] mentioned an early-stage example that is called the Amberg plant, where most units in this 100,000-plus square-foot factory can fetch and assemble components without further human input. The European Union encourage research into the field of smart technologies as a whole. Its research program "Horizon 2020" offers funding for research and development projects such as smart cities and communities' information, strategic roles of smart cities for tackling energy and mobility challenges, analysing the potential for wide-scale rollout of integrated smart cities and communities' solutions, and so on [5,74]. Other countries are targeting their advantages with different policies. In the following section, we list several countries which have recently announced their particular Industry 4.0 plans and explore the different implications at levels of politics and policy-making. A conclusion with possible topics of future discussions is presented in the final section.

Industry 4.0 concepts

There were nine pillars of Industry 4.0 when it was first announced: cyber-physical systems, Internet of Things, Big data, 3D printing, robotics, simulation, augmented reality, cloud computing and cyber security. As the world keeps exploring the concepts of Industry 4.0 and their practicalities, we see from many literature, [4–8,41,75] to name a few, that some of the concepts have been shifted around. Whether it is a better-fitting name or some further clarifications, we see an increasing individualization in our understanding of the Industry 4.0 itself. In Table 1, we would like to provide a jargon buster and further in this section, we summarise these concepts of Industry 4.0 and provide some easy descriptions to the reader. Technical details may be found from the references.

Cyber-physical systems

Cyber-physical systems are the core of Industry 4.0 [34,53, 76–78]. On a simple term, it could just mean linking a typical equipment to a computer, such as a valve to a electrical switch, but the full picture is far beyond hardware adjustments. When to switch the valve and what the effect it would have towards the whole operation are just some straightforward questions. Furthermore, what is behind the decision of this switch, how confident this decision is made, how good

Table 1 A jargon buster for a number of Industry 4.0-related terminologies

Applications	Explanations
Advanced manufacturing, smart factory, smart manufacturing, intelligent factory, factory of the future	This is the foundation of Industry 4.0 and a board category of manufacturing concepts. They are often based on artificial intelligence platforms and combine with other advanced techniques such as automatic decision making using data analysis or automatic production via various robotics. The aim is to make manufacturing as efficient and reliable as possible
Self-organisation	This is a process to decentralise the distribution of all components in manufacturing, this allows a large degree of freedom to supply chain and logistics and improve efficiency as a result. In robotics and artificial intelligence, it often means "learn how to learn"
Smart product	This is an Internet-of-Things-related term, the product can connect and communicate to the network to maximise performance
Smart city	This is an ideal goal for Industry 4.0, nearly all functions within a city are optimised and automatically adjusted if required, the allocation of resource is distrusted according to dynamic needs, community and infrastructure are interacting and cooperating to provide the best quality life to its citizens
Artificial intelligence	A machine that can think and operate as a human being, often it has a collective of knowledge so is capable to outperform individuals
Blockchain	This is a decentralised system that optimises the entire supply chain by utilising collaborative efforts to improve commercial transactions and the global market
Circular economy	This is a regenerative approach that allows businesses, society and the environment to co-exist and eliminating waste and the use of non-renewable resources
Connected enterprise	This concept illustrates a vision that all companies as well as associated entities share all information so the process is optimised end-to-end
Data literacy	The ability to read, understand, communicate and innovate data as information. A goal for all post-Industry 4.0 employees
Digital literacy	The ability to search, evaluate, create digital information. A goal for all post-Industry 4.0 employees
Lean manufacturing	A methodology in manufacturing that is minimising waste and maximising productivity
Machine learning	This can be seen as a part of artificial intelligence, that teaches a machine to understand by automatically improve itself through experience
Operational technology	A system detects or initiates changes through automatic monitoring and control to ensure the quality and safety of an operation
Platform economy	This is a vision where economy and society are facilitated by platforms which optimally matchmake the provider with the user
Pull economy	An economy where the consumers have the initiative and the suppliers aim to meet their demand
Shared economy	An economy where the suppliers push the demand onto the consumers

is our prediction of what is going to happen afterwards, and finally what is the error margin in all of these are the mission-critical issues that we must understand.

From 2011, when the idea of Industry 4.0 was announced, to the present, the concept of cyber-physical systems has been subdivided via various perspectives, and interpreted with many new names. When [75] talks about "learning" and "making high-level cognitive decisions", it is mainly on the algorithmic level, which is often handled by the software. This is artificial intelligence. Allowing machines to solve problems by self-expanding its own behaviours is driving us towards the world of autonomous, self-regulating systems. The direct benefits of applying appropriate artificial intelligence could mean less downtime in smart factories, optimised production, better energy management. Outside of production, it could mean seamless information flow in logistics, where suppliers, self-organised work orders and schedules and better order fulfilment. According to [75], the current range of artificial intelligence is low. The figures range from 4% for small firms with less than 10 employees, to 9% for firms with between 10 and 250 employees, but this could change very quickly and significantly.

An another view of cyber-physical systems, such as [7,79,80], describes it as a mechanism of which physical objects and software are closely intertwined, allowing components to communicate in a myriad of ways. Sometimes this view is termed as "horizontal and vertical integration". [4,37] state there are three essential integrations in the paradigm of Industry 4.0: (a) horizontal integration across the entire value creation network, (b) vertical integration and networked manufacturing systems (c) end-to-end engineering across the entire product life cycle. A fully digitalised and integrated process in the horizontal and vertical dimension would yield an automation of manufacturing process [81]. An example is the so-called embedded system. By closely linking the physical devices to their computational elements, it can enable highly coordinated functions [82]. The latest development employs interactive connections to form a large network. Typically, a large number of devices are involved. Many are sensors such as touch screens, light sensing and force sensing devices.

To sum up, traditional cyber-physical systems have been used in a large range of industries, such as manufacturing, aerospace, automotive, chemical, energy, healthcare and transportation [83–85]. From 2006, the National Science Foundation of the United States and other United States agencies have sponsored research projects on cyber-physical systems [6]. Since the launch of the concept of Industry 4.0, many countries and industries have started investing and developing in the cyber-physical domains. Despite differences in definitions of those cyber-physical systems, cyber (software) and physical (hardware) are increasingly interconnected [86]. A higher level of integration of coordination between all components is on the horizon. The current developing trends aim to achieve reliable, secure and certifiable system and control methodologies [87]. It is widely shared that integrating systems and subsystems from different hierarchies is time-consuming and costly, sometime the whole system has to be kept operational and yields further complications [6,7]. Multidisciplinary collaboration is believed to be the key [7]. A large number of interdisciplinary methodologies have been used to develop these systems, such as cybernetics theory, mechanical engineering and mechatronics, design and process science, manufacturing systems, and computer science.

Internet of Things

In simple terms, the Internet of Things consists of physical devices that are embedded with electronic sensors, actuators, and digital devices with specific software enabling communications [7,75]. All of them are connected to an internetworking world, typically through the Internet [7]. Typical example of these devices may include almost all suitable home appliance such as kettles and light switches, as well as industrial machines like pumps and motors. Some literature refers to the industrial section as Industrial Internet of Things [4,6,7,75]. Additionally, it is also known as Internet of Everything which consists of Internet of Service, Internet of Manufacturing Services, Internet of People, an embedded system and Integration of Information and Communication technology [4,88]. Although the connectivity is not unique to the Industry 4.0 revolution, the integration via Internet of Things allows data to be collected and exchanged on a unprecedented scale. According to the research firm Gartner, there were more than eleven billion connected things estimated worldwide in 2018 [75]. This number becomes nearly 20.8 billion by 2020 [89]. Industry Internet plays a big part of this industrial revolution [90,91].

On a detailed perspective, to handle a gigantic number of devices and dynamically manage these connections, there are innovative key techniques required. In fact, when the Internet of Things first emerged, it was referred to uniquely identifiable interoperable connected objects using radio-frequency identification technology [6,92,93]. One may trace back to 1982, when researchers connected a modified Coke Machine to the Internet at Carnegie Mellon University [7,94]. This identification technique servers as a tag that is uniquely identified and allows tracking in real-time. Later on, this technique is expanded to cooperating via wireless network, Bluetooth, cellular networks or near field communication [6]. van Kranenburg [95] defines the Internet of Things as "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network."

A large number of Internet of Things application have already been applied, for example, monitoring in fields of industries, environments, transportation, and healthcare [96–100]. However, we note that to connect billions of devices, some standard protocols must be followed by all players in the new ear of Industry 4.0. This can cause new issues such as privacy, security as well as proprietary ownership. Thus, innovative interdisciplinary research is ever paramount to address news problems from new solutions.

Big data and data analytics

Imaging the amount of information we have created from the dawn of civilisation to 2003, we now create as much every 2 days, this is according to a former executive chairman of Google Eric Schmidt [75]. That is approximately five exabytes a day (around 5 million TBs). Initially, storage and handling of the data were at the centre of research and development. Then we worried about the quality of the data. Now it is clear that data has become a commodity [7,75].

In general, Industry 4.0 generates data from a large various channels, such as sensor readings, log files, video/audio, network traffics, transactions, social media feeds [4]. Industries such as big technology companies have already tasted success at analysing big data and mining valuable information from it [75]. Those information could give companies insights into the business market and get ahead of its competition. For example, with shop-floor data from all across a large region, advanced algorithm can find patterns and correlations identify future market trends and customer preferences. According to [101], research has shown an increase of 15–20% in return on investment by introducing big data analysis. Big data visualisation is another research trend to tackle the difficulties of making senses from a gigantic dataset [102].

Cloud and information technology

Industry 4.0 is based upon the changes from advanced information technologies and cloud has become a major part of the this paradigm. It is clear cloud has become a mainstream in communication and hub of information exchange [75]. Cloud, or cloud computing, is a general term referring to computational services that offers scalable resources for various activities over the Internet [103,104]. Some literature such as [7,105] considers it as “the fifth utility”, alongside with electricity, gas, water and telephone. Cloud serves as remote servers that is generally available around the clock [6]. Its high-performance and low-cost feature suits perfectly for information storage, and over the recent years, rapid resource sharing, dynamic allocation, flexible extension have expanded its influence to our day to day life. [75] reports from a survey that 88% of companies participated stated cloud yields positive outcomes, and often allows access to new markets and new customers. According to a chief officer of Facebook, Sheryl Sandberg, more than 50 million business using Facebook Pages to communicate with customers [75]. One third of customers now have an expectation to receive an response from a business within half an hour and over 40% expect within an hour.

With the increasing use of cloud, the idea of cloud manufacturing has emerged that allows modularization and service-orientation [6]. For example, design from cloud manufacturing enables a large number of participants from all stages of the production process. Therefore, customer suggestions and engineer concerns can all be included into the design phase, largely reduce its turnaround time. Apart from the design, there are aspects of cloud manufacturing such as software as a service, customer relationship management, platforms for data analytics, collaboration and business planning [75].

Robots and automated machinery

Robots play an important role in Industry 4.0. Depending on different requirements, it can be robotics arms, a whole assembly line, vehicle-type rover, android or legged patrol robots. Many can already be seen in the fields of chemical processing, pharmaceutical manufacturing, food and beverage productions [75]. Here are some examples. KUKA iiwa is a lightweight robot for sensitive industrial tasks, developed by KUKA Robotics. Baxter from Rethink Robotics is an interactive production robot for packaging purpose. BioRob Arm can be used in close proximity with humans. Automated machinery is aimed to perform repeated actions with high speed and precision as well as be able to work where human workers are restricted [4,106]. [107] illustrates an interface that controls industrial robots with augmented reality.

3D printing

3D printing, officially known as additive manufacturing in the Industry 4.0 terminology, enables construction of various complex geometries of structures using metal or plastic. In the recent years, it has attracted increasing investment. By 2023, the 3D printing market is estimated to be worth $32.78 billion [75]. The growth is believed in customised products and 3D printing is the ideal way of reducing overall manufacturing costs, flexible and extremely fast at producing small quantity. It also helps to reduce component weight and minimise waste, thus is of particular benefit to the automotive and aerospace industries [75]. In other cases, 3D printing allows flexible production locations, reduced transportation and stock on hand [4].

3D printing shows the way forwards as decentralised manufacturing as it makes production faster and cheaper. With increasing digitisation and the demand to decrease product life cycles, more areas find its benefits. Associated technologies have also been focused, such as fused deposition method, selective laser melting and selective laser sintering [4]. As product individualization becomes the trends, we are expecting to see ever more customised 3D printing services in the coming years.

Simulation

Simulation is the combination of isolation and recreation. It first identifies variables within a situation and makes hypothesises, then comparing the simulation results to observation. After repeated testing, when the results are satisfactory, we can then make predictions with a given set of variables and conditions.

Simulation requires extensive work and is very important in areas like plant operations. For example, while monitoring real-time data, any oscillations or intended changes can be put into a well-studied simulation to predicted the real-world outcomes. Simulation can be used to ensure the quality of the product, as well as minimising costs from market price changes [4]. When errors occur, simulations can be used to shorten the down times. If possible outcomes can be predicted, it can also help decision-making [108].

Portable devices

There is no denial on the rise of popularity in portable devices such as smart phones, laptops and other wearable electronic products in recent years. The change of software development to adapting relatively smaller screen size of a phone has led to a big app market and two massive players (i.e. Google Play Store and Apple Store) dominating the scene. Portable devices also promote remote working, bring-your-own-device schemes and a various series of cross-platform compatibilities [75]. There are typically more than one connection methods on large portion of the portable devices, such as wireless and cellular networks. This offers manufacturers as well as developers a large degree of freedom in terms of the practical goals they would like to achieve.

Apart from day-to-day mobile app usage nearly becomes a necessity, augmented reality systems have also been developed and made practical in many fields. Augmented reality is a way of communicating via immersing the real-world surroundings and other real-time information. A typical example would be augmented reality headset or goggles that would be able to highlight and graphically demonstrate a series of repair instructions while the user is looking at the actual system [4].

Issues and challenges in Industry 4.0

There are two facts about Industry 4.0 that we can say with a degree of certainty. A new around of digital revolution is inevitable and this revolution is still in progress [4]. While we enjoy a wealth of benefits from those new technologies, issues and challenges will arise.

In the short term, first, a lack of autonomy in many current systems will limit industries moving towards smart manufacturing [109]. Second, a lack of bandwidth in majority of the current network protocols could become the bottleneck that requires decades to improve [109]. Third, many industries are yet to ensure the quality and integrity of their data recorded. There is a lack of standard approach for the annotations of data entities [110]. Fourth, modelling and analysis on complex systems are yet to be satisfactory for practical purposes [109]. Fifth, there are many difficulties to adjust the current production routes to adapt a large dynamical reconfiguration for individualized and customised products [4]. Finally, it is still unclear how best different sectors (e.g. small- and medium-sized enterprises vs Fortune 500) would invest and what are the optimal support from the governments of each country [5].

In the long term, one critical issue is cyber security. We have seen cyber-attacks such as WannaCry, Petya and NotPetya in the last 5 years [75]. A chocolate manufacturer in Australia was hacked in June 2017, leaving their system data locked and demanding a crypto-currency payment as ransom [75]. Although there are standard methods to increase cyber security, such as end-to-end encryptions, intrusion detection and prevention systems and virtual private networks, the increasing digitalisation still have vulnerabilities [5]. There have been a large amount of research on improving cyber security, one of them is termed “Blockchain” technique [111]. Fernandez-Carames and Fraga-Lamas described this concept in [111] and provided a detailed guide how Blockchain is applied into different Industry 4.0 applications. [112] illustrates a middleware approach of the Blockchain technique to enable more secured smart manufacturing application. [113] summarised existing Blockchain techniques within Internet of Things and discussed industry-specific challenges.

Data privacy is another critical issue. Different from being attached, data privacy highlights the possibility that our data may be misused, or the intention of usage was not disclosed initially. There is an increasing debate on social media about who owns the data and what they are allowed to do with it. An issue would need international collaboration on regulation and law making. Further or new education on people is yet another challenge [5]. With expanding digitalisation, people would have to develop “digital thinking” despite their educational background [114]. Some worry Industry 4.0 would eventually lead to redundancy in human labour force [115]. It is yet unclear what adaptation measures would be required to avoid this technological unemployment [116,117].

International efforts

The continuous development and practical applications of Industry 4.0 rely on government policies and supports. At the same time, it is to the governments’ benefits for materialising the outcomes of various Industry 4.0 practices. What has become clear is that many governments quickly followed suit after Germany and announced their versions of Industry 4.0 [2]. We see a united response from relevant governments across the globe acknowledging Industry 4.0 and in many cases, a competition to achieving this goal. On an international stage, we see for example “the Digital Economy and Society Index” (https://ec.europa.eu/digital-single-market/en/desi) of EU Member States to track the evolution and summarises a number of indicators every year on each country’s performance. There are five categories: Connectivity, Human Capital, Use of Internet, Integration of Digital Technology and Digital Public Services. These indices are having a profound influence to motivate each country to develop and practice the latest technologies. As individual countries, we see a so-called “Trilateral Cooperation” between Italy, France and Germany for Industry 4.0. Led by a “steering committee”, the involved countries are to bring together the implementing bodies of national strategies, promote the

Table 2 .

Countries (alph.)	Iconic industrial plan	References
Australia	Industry 4.0 Testlabs	[118]
Belgium	Made Different	[119]
Denmark	Manufacturing Academy of Denmark (MADE)	[120]
France	Industrie du Futur	[121]
Germany	Germany: Industrie 4.0	[122]
Italy	Impresa 4.0	[123]
Japan	Society 5.0	[124]
The Netherlands	Smart Industry	[125]
People's Republic of China	Made in China 2025	[126]
Portugal	Indústria 4.0	[127]
Singapore	Research, Innovation and Enterprise 2020 Plan	[128]
South Korea	Manufacturing Industry Innovation 3.0	[129]
Spain	Industria Conectada 4.0	[130]
The United Kingdom	The Future of Manufacturing	[131]
The United States of America	Advanced Manufacturing Partnership	[132]

digitisation of the manufacturing section and provide wider support in this area.

We introduce some of major countries and their Industry 4.0 strategies in Table 2, and illustrate in this section of their purposes.

Australia

Australia has officially announced its Industry 4.0 intention in August 2017 [118]. Namely, the Testlabs are a strategic initiative from its Prime Minister's Industry 4.0 Taskforce. The aim is to improve the competitiveness of its manufacturing industries and start a transformation amongst its workforce. It also seeks research organisations and encourages them to be in partnership with its industry. The key actions from this Testlabs initiative are, first, to develop a network involving Australian universities and companies (particularly those small- and medium-sized enterprises), allowing them access to relevant governmental information and regulations; second, to build infrastructures for Industry 4.0 related technologies, for example, computational power, connectivity and energy. The pilot program of this initiative has been established at five Australian universities and awarded businesses $5 million to transition to the smart factories of the future. In 2018, a further $2.4 billion has been invested in growing Australian research, science and technology capabilities. Apart from funding, policies such as tax incentive, kick-start programmes to Australian space industry and job opportunity expansion have also been planned.

Alongside the Testlabs initiative, there is a special collaboration with Germany. The main aims are to expand Testlabs strategies to German companies and universities. promoting collaborations between the two countries.

Belgium

Belgium has been one of the high-performing countries, its federal system is highly decentralised in policymaking, and this allows it to avoid hierarchy. In Belgium, small- and medium-sized enterprises account for 98% of all manufacturing companies. Thus, decentralisation is ideal for integrating Industry 4.0 concepts, tailored to individual advantages [75]. From a period of 2014–2019, regional governments of Belgium have made and implemented different policies regarding their digital transformation. At the federal level, "Digital Belgium" is an initiative that was launched in April 2015, supported by many CEO-s from digital companies, entrepreneurs, investors and academics. Its outlined a five-pillar action plan, digitalising economy, infrastructure, skills and jobs, trust and digital security, and government [119]. At the regional level, the Flemish government further developed transformation policies with sustainability as a leading principle and knowledge development as a driving force. In Wallonia, the smart specialisation strategy becomes the guiding policy framework.

The most eye-catching initiative of Belgium is the so-called "Made Different", launched in 2012. It is organised by the Belgian federation of the technology industry, Agoria, and Belgian Collective Research Centre, Sirris. They have over 1800 and 2500 member companies, respectively. "Made Different" is an industry-led, bottom-up programme to provide manufacturing companies with advisory services, from many dedicated experts. This customisation service takes into account of each company's practical situations and advises according to several transformation perspectives: world-class manufacturing technologies; end-to-end engineering; digital factory; human-centred production; production network; eco-production; and smart production system [119]. Over 300 companies have already completed or in the process of one or more these transformations by the end of 2017.

Denmark

Denmark ranked 1st out of the 28 EU member states in 2017 and 4th in the latest overall results in the Digital Economy and Society Index. With the broadest 4G converge in Europe and fast connections, Denmark ranked 1st on Connectivity and Use of Internet Services. The iconic "MADE", stands for Manufacturing Academy of Denmark, started in 2013 is a bottom-up initiative, collaborated between Danish manufacturing companies, five universities, three research and technology organisations. It is similar to Belgium's initiative but is partly funded by the government as well as the private sector, with the budget totalling around €50 million from 2014 to 2019. The Danish government allows "MADE" to flourish without much state intervention. Such a risky approach paid off: 15 companies participating in various projects reported revenue increases of €135,000 and collective savings of around €5.5 million by the end of 2019 [75]. In December 2016, "MADE Digital" was launched with a further €26 million governmental funding to strengthen Danish manufacturing and expand participating members.

Denmark has maintained a consistent long-term national policy at delivering online public services and the "Digital Strategy 2016–2024" is amongst latest governmental plans, presented in May 2016 [120]. It is to enhance close public sector collaboration and deliver efficient, coherent services to the public and businesses. Three general objectives have been listed [120]:

- all citizens have a share in the benefits of digitisation;
- business unlock the growth and small- and medium-sized enterprises need at digital upgrade;
- good digital framework conditions.

France

As early as in 2012, there were warnings that the French industry was suffering from significant under-investment in digitisation. To maintain long-term competitiveness, the French government has launched many initiatives and programmes. For example, in September 2013, the "La Nouvelle France Industrielle" (New Industrial France) and the strategic programme "Investissements d'Avenir" (Invest for the Future) with €47 billion was set up to support innovative projects on fundamental research, innovation, technology transfer and maturation [121]. Subsequently, there have been many industrial plans, but individual programmes were challenging to draw board collaborations. As a consequence, the French government selected 34 industrial plans and the cross-cutting "Industrie du Futur" (Industry of the Future) was launched in April 2015. It aims to support French companies to deploy digital technologies, transform business models and modernise production practices. In detail, this France initiative comprises five pillars,

- cutting-edge technologies: to support companies with research funding, subsidies and loans;
- business transformation: over 550 experts to help over 2000 small- and medium-sized enterprises identify transformation projects by 2016;
- training: to upskill the workforce, create future-joint visions with unions and develop training programmes and curricula;
- international cooperation: to establish alliances such as a bilateral approach with Germany on standardisation.
- self-promotion: to boost French interest at the European level and its "Creative France Industry" brand.

It gained popularity and quickly found supports from the government, industry, technology and research stakeholders as well as trade unions. Approximately €10 billion has been made available from public sources, €550 million on calls for projects, €250 million for this initiative programme, €100 million for staff training, €4.2 billion for small- and medium-sized enterprises in the form of loans and €5 billion through tax aid for investments for the 2014–2020 period [121]. To encourage private investments, parts of the funding requires the private sector to invest in the same amount as the government. Through the tax-aid route, every €100 million spent in public fund induces €500 million from private financing.

Germany

As the birthplace of Industry 4.0, Germany has made its brand and fortified it with its strong industrial sectors. The first use of the term "Industrie 4.0" can be traced back to 2006 when the German government launched the "High-Tech 2020 Strategy". In April 2011, three engineers held a press conference at Hannover Fair: Dr Henning Kagermann of the National Academy of Science and Engineering; Dr Wolfgang Wahlster of the German Research Centre for Artificial Intelligence; and Dr Wolf-Dieter Lukas from the Federal Ministry of Research and Education [75]. The world quickly embraces this technological revolution.

This German initiative has become a global platform, serves as a central point of contact for policy-makers. Approximately 15 million jobs in Germany are either directly or indirectly linked to the new digital evolution. The Boston Consulting Group predicts €90–150 billion worth of benefits over the next decade [122].

In April 2013, the “Plattform Industrie 4.0” was created by three private associations: the Federal Association for Information Technology, Telecommunications and New Media; the German Association; and the Electrical and Electronic Manufacturers’ Association [75]. It expanded in 2015 by including companies, associations, trade unions, science and politics nationwide. Today, it has over 300 active players from 159 organisations. It is also cooperating with the “Industrial Internet Consortium” with the USA, the “Alliance Industrie du Futur” with France, the “Robot Revolution Initiative” with Japan and a memorandum of understanding with China [133].

The German success demonstrates the powerful impact on a global scale from a fledgeling industrial movement. The combination of national-level-policy support and cross-industry technological innovation presents a model worth copying.

Italy

In comparison, the “Impresa 4.0”, Italian Industry 4.0 national plan is relatively recent. It was first presented in late September 2016 in Milan and officially launched in February 2017 by the government. This is a top-down approach initiated by the Italian government, with academia, business associations and trade unions actively involved in the Steering Committee [134]. This national plan has two main focus areas. First, it supports the use of innovative technologies, digital transformation, and in turn, boosts Italian competitiveness. Second, it aims to develop skills through digital innovation hubs, competence centres, education programmes, vocational training and industrial PhDs.

The Italian Ministry of Economic Development details the following measures as its governmental top-down approach [123].

- “Hyper- and super-depreciation”: offering incentives to companies that invest in digital and technological transformation with new capital goods and assets.
- “Nuova Sabatini”: offering bank loans to support digital technologies (both hardware and software) in production.
- “Tax credit for research and development”: encouraging private investment to ensure and improve the competitiveness.
- “Patent box”: attracting investors with a special rate of taxation on intellectual property rights; bringing back aboard assets and keeping domestic assets relocating; favouring research investments.
- “Innovative startups and small- and medium-sized enterprises”: supporting and sustaining Italian startup ecosystem.
- “Guarantee fund for small- and medium-sized enterprises”: granting sufficient guarantees for businesses and professionals to access bank loans.
- “Development contracts”: reducing minimum investment threshold in specific sectors.
- “Innovation agreements”: providing financial supports to “Horizon 2020”-related projects.
- “Tax credit for Training 4.0”: offering expenditures in relevant training and filling the skill gap.
- “Fund for intangible capital, competitiveness and productivity”: funding in strategic areas for both public and private entities globally in line with the national plan.

Japan

Thirty Japanese companies, including Mitsubishi Electric, Fujitsu, Nissan Motor and Panasonic commenced an Industrial Value Chain Initiative in 2015. This initiative following the German Industry 4.0 plan, combines manufacturing and information technologies to promote industrial collaboration [135]. However, this did not satisfy the Japanese ambition. Thinking outside of the box, all previous industrial revolutions, by implementing the most advanced technologies at the time, eventually were to improve the wider society and individual’s wellbeing. Therefore, in 2019, the concept of “Society 5.0” was launched by the Japanese [124], following what can be called the hunting society (Society 1.0), agricultural society (Society 2.0), industrial society (Society 3.0) and information society (Society 4.0).

“Society 5.0” outlined a basic plan for a future that is benefited by the full implementation of Industry 4.0. The Japanese Cabinet Office defines it as “a human-centred society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space” [124]. Within our current information society, humans may actively seek relevant information about their needs. This can be seen as a limitation and a burden to individuals. The fundamental concept of “Society 5.0” is by integrating people, things and systems in cyberspace, so that information will be analysed and pushed to individually tailored to each specific needs. This can lead an active and enjoyable life.

The implementation of “Society 5.0” will involve large information collection via various physical space terminals, such as sensors, user inputs to the electronics, big data is then analysed with each individual’s parameters, and results are fed back in different forms. This concept uses the industrial revolution to balance economic advancement and personalised needs and eventually provide an optimal solution to the social problems that we are currently facing. In [124], many examples in different fields are discussed, including mobility, healthcare and care-giving, manufacturing, agriculture, food, disaster prevention and energy.

The Netherlands

The Netherlands launched its Smart Industry initiative in November 2014. It seeks to utilised existing knowledge and accelerates Information and Communication Technology (ICT) in industry. The Netherlands has a robust ICT infrastructure and a tradition of collaboration in clusters and networks. In comparison, the Smart Industry is on a relatively low budget and limited resources. Thus, with a well-built network-centric production, a boost in the Dutch digital transformation is achievable.

The Smart Industry is a bottom-up approach. It is based on public funding from the government (€25 million for 3 years) and European regional funds (€10 million) [125]. However, financial contributions from industry and private sectors are expected to cover over 50% of the costs. The Dutch also introduced the concept of "Triple Helix" alludes, which focusses on collaboration between universities, industry and government.

The Dutch government outlined a three-line action plan for rolling out its Industry 4.0 [125]. First, it provides companies with technological and market understanding, up-to-date best practices from existing knowledge. Second, it aims to build national and regional ecosystems and interrelated networks of industries, hence accelerate innovative and technological practices. The third action is a long-term vision to improve knowledge, skills and ICT conditions.

People's Republic of China

For the past 4 decades, a concerted effort has been made and China has become an industrial leader. China became the largest exporter in 2010, the largest trading nation in 2013 and the largest economy in 2016, according to the World Factbook [75]. Its industries around material processing, such as iron, steel, aluminium, coal, and textiles, food, cement, automobile, trains, ships and electronics are amongst the highest gross outputs in the whole world. However, the majority of the Chinese industries are regarded as relatively low skilled, heavily manual-labour-dependent and obvious gaps of innovations in its industrial chain. The Chinese ambition, namely "Made in China 2025" set out in 2015, and was preciously to change its landscape [126]. Its aim was to upgrade and accelerate technological development, re-structure its manufacturing strategies to adapt competitions from other low-labour-cost countries, and promote Chinese brands. One additional point is that process industries play a major role in the making of this strategy. It is a big component in the Chinese economic and manufacturing. Its advancements will contribute to automation, computer and communication and data science, which are all fundamental challenges to achieve Industry 4.0 [136].

The underlying philosophy of "Made in China 2025" is to establish its independence from resources, research and technologies of other countries. The principles extends to innovation, high-quality manufacturing, green development, structure optimisation and training its workforce [75]. There are four stages of this plan. First, by 2020, it is to increase industrialisation, digitalisation, develop core technologies in key areas, strengthen competitiveness and reduce industry pollution. The second stage is set for 2025, focusing on improving quality in all aspects, increasing information technology at an advanced level, and achieving a reduction to pollution to global standards. Third, by 2035, Chinese manufacturing would reach the median level amongst global leaders, improve upon innovation capability and make breakthroughs in major areas. Finally, when it comes to 2049, Chinese industries should be a leading force on the global stage and holding a significant competitive advantage in major manufacturing areas.

Portugal

"Indústria 4.0", the Portuguese strategy for Industry 4.0 was launched in January 2017. The Portuguese vision is oriented around three axes: digitalisation, innovation and training. In comparison, the noticeable differences are that it mainly targets small- and medium-sized enterprises and has a strong focus on upskilling the workforce. Over 200 Portuguese companies (120 of which were small- and medium-sized enterprises) participated in the design of the strategy. It aims to have an impact on over 50,000 companies and train over 20,000 workers in Information and Communications Technology skills [127].

It is a bottom-up approach, initiated by the Ministry of Economy but is managed by COTEC, a private company. €4.5 billion has been made available through Portugal 2020 ERDF funds, and the private sector is expected to invest another half of the measures. €7,500 per each application has been distributed in vouchers to support small- and medium-sized enterprises' digital transformation. Universities such as Minho and Aveiro have also been participating in the development of digitalisation [127].

Singapore

Technology and innovation have been one of Singapore's traditional cornerstones. Singapore's universities, such as the National University of Singapore and the Nanyang Technological University, provide world-leading research and development. Together with global collaborations with universities in Asia, Australia, the United States, etc., Singapore benefits from world-renowned research outputs.

Singapore has been focusing to develop a knowledge-based innovation-driven economy and society for over

30 years. Funding from the government to promote innovation and science has been steadily increasing. Every 5 years, Singapore provides a national strategic plan. It started in the “National Technology Plan 1995” with $2 billion. The latest is the “Research, Innovation and Enterprise 2020 Plan” and provides $19 billion from the public investment [128]. The targeted domains and programmes are separated into seven categories: advanced manufacturing and engineering, health and biomedical sciences, urban solutions and sustainability, services and digital economy, academic research, manpower, and innovation and enterprise.

South Korea

In 2014, South Korean launched its “Manufacturing Industry Innovation 3.0” strategy. A total of $376 million was invested in developing smart manufacturing technologies. There were four categories: smart manufacturing proliferation, creative economy, smart innovation and business re-organisation [129].

Spain

The Spanish strategy, “Industria Conectada 4.0”, was announced in 2014, aimed at digitising and enhancing the competitiveness of Spanish industrial sector [130]. There have been many resources allocated, such as €97.5 million in loans for innovation and €68 million for Information and Communication Technology companies. The main objectives are threefold [130]:

- improve industrialisation and employment in the relevant sectors;
- encourage the development of a Spanish industrial model;
- enhance the local supply of digital solutions and boost Spanish industries.

At the initial stage of policymaking, one of the issues was on how to motivate the Spanish industry to participate. To address this, the Spanish government established a strategic group: the Santander bank to provide digital financing knowledge; Telefonica to provide telecommunications; Indra to become the technological consultancy [130]. Its focus is on Spanish small- and medium-sized enterprises and micro-enterprises. Micro-enterprises are those typically employ fewer than ten people and less than €2 million in turnover.

The United Kingdom

The United Kingdom (the UK) has been traditionally recognised for its strong research and innovation. It is ranked the second for the “Inward Foreign Direct Investment” in 2017 by the United Nations Conference on Trade and Development. The urge for modern innovative technological development can be traced back before the German Industry 4.0 concept [131]. In 2004, the Department of Trade and Industry established the Technology Strategy Board. It became an independent advisory body, namely Innovate UK, in 2007. In 2017, the Higher Education and Research Act 2017 was passed into law by the House of Parliament. The following year, seven research councils, Innovate UK and parts of the Higher Education Funding Council for England merged with the UK Research and Innovation organisation that directs research funding [137], all of which share a common purpose, that is, to help develop innovative technologies.

The UK’s industrial strategy is built on nearly 2000 formal responses from all types of organisations in the wide society. It lists five foundations [138]: ideas, people infrastructure, business environment and places. We summarise each of them here. First, the aim is to develop the world’s most innovative economy, by raising investment equivalent to 2.4% of GDB by 2027, increasing tax credit to 12%, and investing £725 million to the funding programme. Second, the UK is to provide good jobs and greater earning for the public, by establishing technical education systems, investing £406 million to relevant educational departments, and £64 million for re-training people in latest technical fields. Third, £31 billion is to be invested in general infrastructure, £400 million in hardware related to electric vehicles, and over £1 billion digital infrastructure such as 5G and full-fibre networks. Fourth, the UK is set to increase its productivity with £20 billion in high potential businesses. Finally, £1.7 billion is to be invested for intra-city transport and £42 million to pilot a Teacher Development Premium.

On top of this industrial strategy, the UK has set out four Grand Challenges: artificial intelligence and data revolution, clean growth, future of mobility, and ageing society. It promotes interdisciplinary research and development from industry, universities and the government.

The United States of America

In 2011, the USA launched the Advanced Manufacturing Partnership, which aims to bring together industry, academics and the federal government [132]. This scheme focusses on emerging technologies to create high-quality manufacturing and boost its global competitiveness. $500 million is to be invested as the initial step, and the plan includes four main steps: building domestic manufacturing capabilities in critical industries; reducing the time to develop and deploy advanced materials; next-generation robotics; and developing innovative energy-efficient manufacturing techniques. The following year, General Electric introduced the concept of the Industrial Internet of Things, emphasises on the integration of artificial intelligence, analytics and connected people [7]. In 2014, with the support of many industries such as General Electric, Intel, IBM, etc., the Industrial Internet Consortium was setup. The main principle of the Industrial Internet is centred around three components: intelligent equipment, intelligent systems and intelligent decision-making.

Soon after, almost all Industrial 4.0 topics have been introduced within the USA. In 2016, the name "Manufacturing USA" was adopted by the National Institute of Standards and Technology. In February 2020, this institute described a strategy to expand the Manufacturing USA network [139]. Multiple pathways were introduced to included innovation and manufacturing centres which are not receiving federal sponsorship.

Conclusion

From the launch of Industry 4.0 in 2011 to the current day, its influence has been felt across almost all sectors. Many governments have started their tailored policies to support this technological revolution. However, we are still in the beginning of its transition. In this paper, we have looked at the concepts of Industry 4.0. Although we summarise them with its 9-pillar scheme that was initially described, many descriptions have further shifted, highlighting an individualization paradigm. In "Industry 4.0 concepts", we went through cyber-physical systems, Internet of Things, big data and data analytics, cloud and information technology, robots and automated machinery, 3D printing, simulation, portable devices and Industry 4.0 challenges. From the existing literature, it is clear and have been repeatedly highlighted that within the industries, an interdisciplinary approach is essential to the Industry 4.0 development. In Addition, it is widely accepted that an international coordination and governmental support are necessary. For the first time in this paper, we summarise a range of governmental industrial plans and policies, including Belgium, Denmark, France, Germany, Italy, Japan, the Netherlands, China, Portugal, Singapore, South Korea, Spain, the UK and the US. We can see in many countries, the idea of an industrial revolution has long been on the horizon before 2011. Countries are tailoring their plans in accordance with their strength. We also see international efforts such as the "Trilateral Cooperation". Through this paper, we would like to communicate to the reader, wherever you are and whatever sector you work in, embrace the positives this revolution is to offer and be ready to change.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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