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A sequential roadmap to Industry 6.0: Exploring future manufacturing trends

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Abstract

It has been speculated that by the year 2050, technology will have progressed to the point of complete autonomy. This paper scrolls through patent pathways and intellectual developments throughout the industrial revolutions listing significant products and services that landmarked each revolution up to Industry 4.0. The patent trails and the recent IPR inputs are expected to assist readers in fast-tracking up to speed on the bleeding edge of the current research pools while having an eagle's eye perspective on the previous developments so far. The research pools of Industry 4.0 are classified and explored. A lack of Human-machine workforce synergy in Industry 4.0 and the nascent "customized manufacturing" concept is addressed in subsequent sections. The paper classifies two expected phases of Industry 5.0, highlighting the subdomains touted to be its focal areas. Lastly, Industry 5.0's niche research areas are checked and a suitable pathway to achieve the goals set for the sixth revolution is proposed.

1 | INTRODUCTION

The current decade is experiencing a phase of a gradual merger of artificial and human intelligence. The onset of Industry 4.0 has completely altered the workforce skill sets required at almost all hierarchical levels. This, in turn, laid the foundation for an "Industry 5.0" wherein robotic assistance and human workforce work together in seamless synergy with the human component focussed upon as the "Centre of the universe" [1]. While the concept of Industry 5.0 deals with personalization and synergy between human and machine labour, The era of Industry 6.0 will be one of renewable energy, total machine independence, interplanetary resource gathering and manufacturing, Aerial manufacturing platforms, anatomical enhancements, quantum control. Industry 4.0 introduced the usage of smart and connected technologies to reduce the production manufacturing time, Satellite traffic will become a trend and orbital traffic could become a trend with more firms attempting to push out their own modules into space with the objective of establishing their own networking beacons to assist seamless communication with their production pods. With the gradual transition of agenda from philanthropic task automation which led to the realization of job-consuming AI models in numerous domains to the agenda of realistic adaptation of smart technologies in a more accommodating fashion with adaptive and viable business models revolving around the use of said technologies while creating evolved employment opportunities [2].

The current technological developments must go hand in hand with the administrative sector in order to establish regulated, controlled functionality within the bounds of legality. As a skeletal framework of sorts, enterprise architecture must be designed to ensure that the human input component is never alienated from an entirely automated process chain. Inclusivity of organic cogs in a purely artificial environment ensures that the end product never loses touch with the demand of users from natural reality, satisfying two major factors of Industry 5.0; synergy and personalized manufacturing. The new framework might allow for a flexible work schedule which, as lucrative as it sounds to the workforce, might end up as a boon with two banes. A flexible schedule is bound to have a negative impact on the average income of the workers. Secondly, the income might not be a continuous stream, causing un-forecasted kinks along the way which in turn might disrupt modern society financially [3].

The ideological concept of Industry 6.0 encompasses adjustments and advancements in virtually all domains. To perform an intensive categorical analysis, the advancements have been classified into 4 major sectors; robotic automation, society and policies, and lastly, intelligent manufacturing. Section 3.1 discusses in length the current policies and societal changes leading on to the path of Industry 6.0, followed by medical and bionic enhancements in Section 3.2, robotic automation in Section 3.3, and finally, neo-critical manufacturing trends in Section 3.4. In the section dealing with society and policies, the impact of personalized manufacturing and adaptive physical task automation over the demographic in terms of economic development, the evolution of the employment system is discussed. Section 4 identifies the fields with scope for study. Sections 5 and 6 talk about Industrial Revolution 6.0 speculation and how to anticipate it.

2 | INDUSTRIAL REVOLUTIONS

Throughout history, there have been gradual upgrades in the pursuit of qualitative and faster production. Amid the consistent progression in the growth curve, there were a couple of kinks wherein the upgradations caused critical boosts in production aspects and their impact on the overall quality of life. The entire social framework was thereafter threaded around a handful of major inventions and failure to adapt to the new technologies in due time brought about severe economic repercussions to enterprises. The same major developments also had lots of related/non-related inventions during the same time frame as themselves, and collectively the time durations in context to these inventions began to be referred to as industrial revolutions.

2.1 | Industrial revolutions leading up to 3.0

The main reason that led to the first industrial revolution being termed a revolution was that it was a culmination of technological developments in virtually all domains within a short time period leading to a complete paradigm shift in the lifestyle of mankind during those times [Figure 1].

The first industrial revolution (1760–1850) was of an intrinsically mechanical theme, revolving around the usage of coal and forging of mechanical tools made from iron for agriculture, textile looms, jennies, and steam-powered locomotives for transportation [4]. The second revolution spanned over (1880–1973) and oversaw the upgradations of raw materials from iron to steel, and energy sources from coal to refined crude oil. Electrification of towns and cities became a norm. Steam engines were replaced by internal combustion engines. Bigger firms started taking form. The Toyota Production System was introduced to establish seamless mass production of consumer articles and goods using partial cross-training of the workforce for adjustable job switching to compensate for gaps. Cell manufacturing for modular part-wise manufacturing and job shop for separate mechanical operations were also prominent production architectures during the second revolution, extended by SERUS which were introduced a decade into the third revolution. The SERUS design featured partially cross-trained workers linearly performing various operations sequentially to finish a product instead of static designed assembly lines while the FMS design featured automated programmable CNC/operation lines. It was a period of motorization of industries [5, 6]. Meanwhile, following the invention of the dual-sided through-hole PCB design in 1947 [7], in 1948, the BJT was invented and integrated electronics would gradually creep in to pave the way for yet another industrial revolution. The third industrial revolution was more about making every analogue process digital, enabling it to be performed by machinery with mechanical precision. The integration of multiple assembly bay sections reduced production times by a huge margin. The form factor of otherwise gigantic circuits was reduced. Computerized assembly terminals were introduced. Operating systems made an entry into the product market and led to a whole new software development product segment. The following years witnessed the birth of a new product segment that generated a demand that had never existed in the first place. The software revolution brought about a demand for user data in an attempt at providing a personalized experience. The inflow of the user-data generated a potential for usage

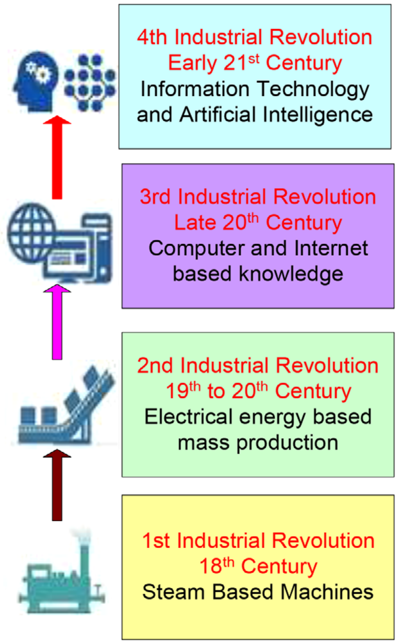

FIGURE 1 Industrial Revolution 4.0

into the production scheme. A six-stage virtual factory projection system was discussed for setting up smart industries and another method was suggested for the transformation of industrial workflow to adopt digitalized designs with smart and interconnected flow lines [8]. The mid-latter part of the third industrial revolution oversaw the commercialization of networking with the emergence of ISPs from 1989 onwards [9]. The spread of free information from the 'WWW' altered market demands by huge margins. Soon after, the internet featured online shopping among other facilities, generating the need for robust logistics. Most pre-existing logistics firms took to delivering to the demands and evolved into more sophisticated online services, using the vast cyberspace as an open billboard area. Advertising firms capitalized on this trend, and new jobs were generated for web development and online advertising. While Pizza hut was the first to jump in on the WWW online shop's bandwagon, Intershop AG, a German commerce company in 1995 became the first-ever online retail goods shopping platform, quickly followed by Amazon and eBay in the same year. The era of internet-based services had just started. The internet would further be employed for other services which would require users to remember URLs. In 1998, Google was created as the first-ever website indexing service. Other hardware applications were yet to be appended as per consumer requirements. In 1999, Further explorations into the utility of the internet brought the world to one of the key forces of the fourth industrial revolution; the internet to control hardware. This concept was termed IOT (Internet of Things) by Kevin Ashton, executive director of auto-ID centre [10].

The IoT trend involved technology from several domains to merge and create novel manufacturing sequences. Its primary aim was to enable reception of sensor data of the production floor from anywhere around the world and issue remote directives accordingly, but with users getting more and more informed, the technology made it into the market as an e-service for channelling user data securely and quickly to control power outlets and subsequently, appliances of smart homes. Moreover, the automotive industry had been embedding sensor data modules of their own to provide advanced features in cars. With an increased user base came more sensor data, to the point that it became so voluminous that conventional programming languages took more processing resources to respond to every data query. This, in turn, generated the demand for a system that could process queries across huge databases. The issue was solved by the programming language 'R', (1997), with its initial building blocks borrowed from the S language, it would soon contribute to the second key force of the 4^{th} revolution; Big Data [11]. Meanwhile, the work on automating certain tasks had been in progress in the academic sector with numerous papers across multiple domains utilizing machine learning algorithms to solve specific problems. The concept which had started out way back in 1950–1960 had finally started gaining traction. Digitalization of mechanical production processes which had been a pillar of the third industrial revolution underwent a major overhaul. The digitalized manufacturing processes now had the potential of being conditionally scheduled via software. The control systems of PLCs had been in the picture since the mid-

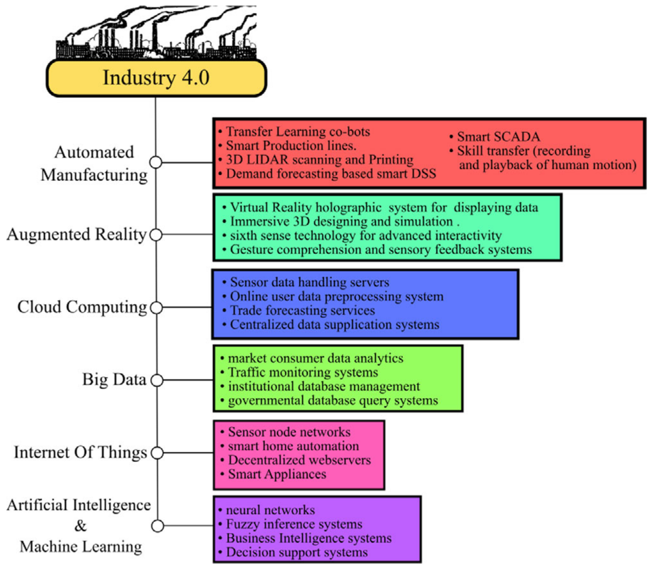

FIGURE 2 Components of Industry 4.0

third revolution following their invention in 1968. The PLC systems too underwent digitalization and the development of SCADA came to be the resultant technological advancement at the beginning of the third revolution. By the end of it, the SCADA was developed to the extent that entire distributed chains of industrial manufacturing units could be controlled from anywhere around the globe with internet access. Manufacturing tasks could not only be automated but also set to be triggered by statistically analysed online data.

2.2 | Industrial Revolution 4.0

While the third industrial revolution is not believed to have completely ended yet, its major landmarks have been successfully been achieved, resulting in most of its research hotspots being benched. It is a classic case of research preceding commercial implementation by decades. The fourth industrial revolution was first introduced by the German government in 2011 while attempting to promote computerization in manufacturing as a revolutionary trend [12]. This trend had already been developed way back in the 1980s but had not set off globally yet. The axioms for the fundamental trends in the fourth revolution were laid out in 2014 [13]. Since then, PLCs have gotten patched with modular systems which can run ML algorithms over statistical data to approximate the market demand. All that is required for this to be a viable system is accurate data; the current revolution's spine. The current fourth revolution has a converse flow compared to the third, with computers requiring data from humans to make their machine learning algorithms more organic and accurate. As the fourth revolution is currently in its nascent implementation stage, there are certain design concepts that yet exist merely on paper or as lab prototypes awaiting their upscaling. The key concepts of Industry 4.0 [Figure 2] are divided into the following six major research pools, apart from the miscellaneous research:

- Augmented reality(AR)
- Automated manufacturing
- IoT
- Cloud computing
- Artificial intelligence and machine learning(AI-ML)
- Big Data

The Tech trends of IoT, Automated Manufacturing, and Big Data were appended and carried forward from the aftermath of the previous revolution while the trend of cloud, AR, and AI-ML are comparatively newer. The key idea is to merge cyber and physical dimensions together in a way that the production sector eliminates human dependence entirely. This can be achieved by creating mould-able neural algorithms which can auto-adapt to changes and "learn" from errors.

Automated manufacturing in the commercial sector has had the 'skill transfer' trend worked upon extensively wherein the movements of a person are recorded and then replicated using a 6 DoF robot. It has potential in manufacturing artisanal products for which either the automation is not feasible, or manually writing G-code and M-code and designing a 3D model for it would be too complex. Augmented Reality attempts to achieve higher levels of integration of cyber-physical visual enhancement systems which are capable of providing information to users non-invasively in a way that they can interact with their environment in a smarter, more informed way. This technology enables users to append to visual reality through HUD enhancements and optical accessories, helping them in simulation, design, navigation, and other spatial information-backed tasks. Cloud computing is a concept that was generated as a result of an exploration into potential enterprise opportunities the internet services could generate. Business models centred around the provision of high computing resources to consumers who could not afford them but required them for a short time on lease for faster complex data computation. The business models evolved into data tunnelling channels, online network storage, IoT device data redirectors, and sensor data-based prediction/forecasting servers.

Industry 4.0 has a set of goals that might be too far-fetched to implement in a singular fell swoop. The fundamental ideology powering the fourth industrial revolution is the concept of computer-based automation which currently has a plethora of external variables that require addressing and stabilization. The rapid adoption of AI and ML to solve menial tasks has brought about more reliance upon computer terminals which are nowadays replacing manual labour in many aspects. While this increases the accuracy, precision, and production speed, it also brings about another problem set that requires dealing with. To address that problem set, the term Industry 5.0 had been introduced as a research keyword.

The key aim of Industry 5.0 is to establish an industrial system wherein the co-bots and human labour can co-exist in synergy and that manufacturing is made to be highly personalized for the consumers with every module having maxed out customizability. For fulfilling those specific axioms, the most likely research domains to be explored have to be picked in a way that they cover both hardware and software advancements in the technical domain as well as the non-technical consequential changes in society while assuming that the fourth revolution has successfully been implemented universally. The prominent research pools that strike all the criteria are then sub-categorized into further research pathways.

The trending research in Industry 5.0 [Figure 3] has been broadly classified into four major pools:

- Society 5.0 and Modern policies
  - human machine synergy—the workforce must be balanced, with humans involved for personalized production.
  - Economic reforms—workforce wages would change as the collective focus shifts to a different skill set. Lesser manual work and increased design complexity would affect the economy.
  - Legal reforms—more tasks being taken over by AI would result in oblique scenarios requiring suitable legislature to deal with them.
- Intelligent manufacturing
  - Analytic automation—with BI gradually being integrated into AI-enabled manufacturing, the industrial units would soon be able to pre-order input resources, keep inventory, manage the demand and supply cycle all based on cloud-stored big-data
  - Fiscal evolution—upon the entry of fully automated manufacturing units into the scene, a fiscal evolution could ensue. The manufacturing units would be deemed as open civil services and be run as enterprises employing maintenance personnel only.
  - Demand triggered production—the automated manufacturing units, in an attempt to reduce overproduction, would limit the import of resources and generate a product only if the pre-stipulated inventory is short.
- Advanced robotics
  - monolith bots—would have all sensors and actuators and processing power in-house.
  - Modular bots—would have the ability to interface multiple standardized components based on the requirements
  - Compound bots—these would have unique structural differences based on use cases. They would be the most common ones to interface with physical elements.
- Medical healthcare and bionic technologies
  - Sensory add-ons—with AR-VR growing more advanced, it can be expected that humans would experience the world with artificially enhanced sensory modules capable of much more than natural sensations
  - Surgical automation—while it is already being attempted, it is stipulated that automated surgeries would gain much more precision and popularity as research ventures upon bio-enhancement gaining more acceptance.
  - Unified diagnostics AI—upon having machine learning and AI models taking over almost every disease-specific medical diagnosis, a unified diagnostics cloud-data-based service AI could virtually be the next trendy research path.

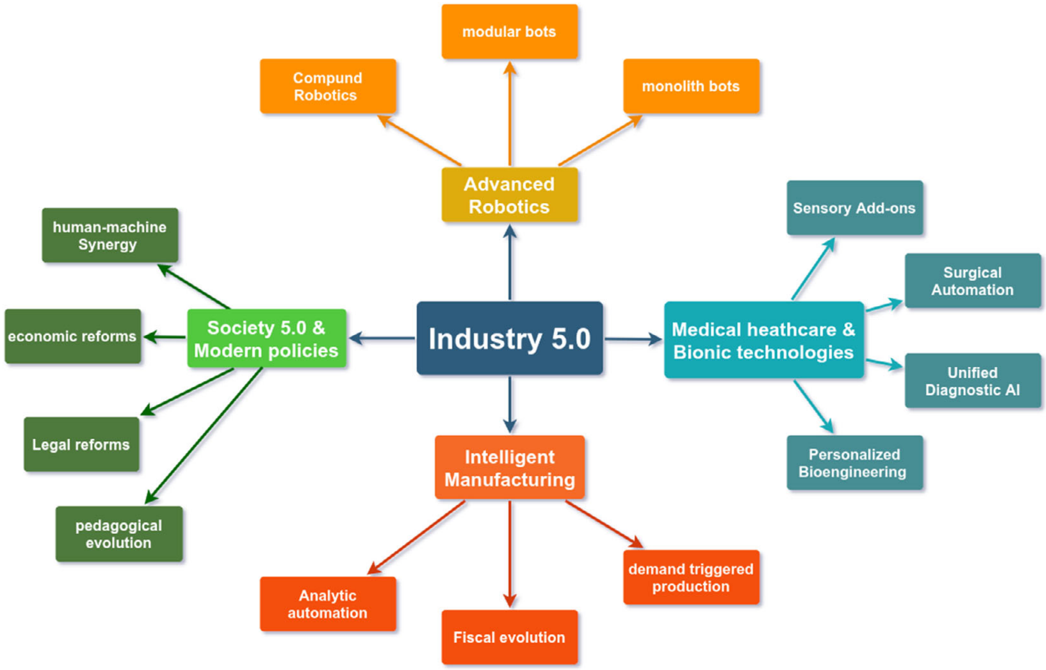

FIGURE 3 A generic block diagram for Industry 5.0

- Personalized bioengineering—once 3D printing has developed sufficiently, the likely next step in a medical perspective would be to store data pertaining to individual anatomical dimensions for worst case scenarios wherein an exact ergonomic prosthetic could be replicated.

2.3 | Society 5.0 and modern policies

This paper suggests Industry 5.0 which will democratise the co-production of Big Data information based on the modern symmetrical innovation concept. Industry 5.0 uses IoT. However, the 3D symmetry of the innovative architecture framework varies from predecessor automation systems: In order to render the Industry 5.0 revolution of synergic co-production, by using IoT orthogonal exit methodology, a 3D technique was proposed. In case of disconnections without permanently affecting the automation network equivalent technological means to control the rate of innovation in case things go south and the model incurs diminishing returns; and lastly, (3) modernized social sciences and humanities research on the topic of emerging technologies [14].

The next Industry 5.0 will feature an elevated level of collaboration among humans and robots, exclusively in the manufacturing sector. Under this strategy, machines will take over the monotonous industrial tasks while the creative tasks are undertaken by the human workforce, along with the responsibility to oversee the automation bots for maintenance and quality assurance. From the studies conducted previously, the advancement is closely adapted by the telecommunications and transportation sector. Next in the stack is the Technology industry followed by the manufacturing sector which stands toe to toe with the commerce sector in terms of adaptation. The slowest adaptation can be witnessed in the construction, chemical, and the energy sector [15].

The upcoming age is one of Innovation and requires a framework to handle new constructs using IoT and other technologies. An Absolute Innovation Framework is presented to take personalization and synergetic labour into account, such that novel thoughts can instantly be converted into prototype designs implementing cutting-edge techniques with minimal effort [16]. The idea of interfacing between industry and society in the upcoming revolution has been presented in an analogy of a control system using technologies such as IoT, Big Data, and AI. The dependant variables include human mobility, living, and working. A feedback loop has been inserted in order to design a fully functional stable control system including multitasking interactions [17].

Another study displays a completely different perspective and philosophy for the upcoming Industry 5.0, deeming it to be the age of augmentation with symbiotic assistive technology, in a way that the machines do not take over the jobs completely, but rather perform the monotonous tasks, leaving the workforce to perform creative and supervisory roles. In spite of the backlash citing that the term 'Industry' is being used too loosely, the concept of socially sustainable automation is an entirely new school of thought. Terms like 'human-centric factory', and 'Operator 4.0' may hit close to home but are inherently different in their core philosophy from Industry 4.0 which is mainly focused on technological advancement. This sub-study deals specifically with the ethical issues generated with modern technologies currently in use by workers, and how their advancement might lead to mass unemployment in factories that adopt the future-safe model. In the same fashion, it was agreed upon that the issues arising from the aforementioned tech can be resolved if and only if the technological advancements are designed around the idea of them being human-centric. According to the general opinion around these topics, tools are required to translate socio-cultural norms into design rules. A new framework of guidance measures had been proposed to aid in the fabrication of technologies such that the tech is centred around human values, known as the Value Sensitive Design (VSD) approach towards systemic robustness [18]. The trend of plugging in the fourth revolution as a keyword for branding all modern research has become the current norm of this age of digitalization. Sans a select few, most research follows through with the concept of automation without paying attention to the human-centric aspects. The aftereffects of this gradual surge are beginning to reflect on society, upgrading it to a more modernized, synergic Society 5.0. The need of the current age is the introduction of cohesive technology that utilizes artificial intelligence, Big Data, robotics, automation, machine learning, and the Internet of Things [19]. Modern promising technologies which are absolutely necessary for the optimum functioning and organization of digital enterprises have been analysed. A bunch of technological upgrades which would gradually assist the industrial transition from 4.0 to 5.0 was explored. The outcome depicts a sturdy core of Industry 4.0 and a skeletal structure present underneath the incremental indulgence in subsequent Industry 5.0. To develop the neotechnical framework of Industry 5.0, an enterprise architecture is proposed [20]. The content overview is indirectly deciphered from an initially developed framework. Earlier works on content characteristics deal with the core systems in environmental, social, and economic perspectives. Earlier works are coupled with various inversions of CSR in the modern society pertaining to luxury services, Innovative sustainable practices, and bioadvancements. Logistics and inventorial services addressing end user's requirements modularly while solving social issues, keeping economic upgradation in sync, the overall aim is to enable integration of all technological subsystems into one collective monolithic omega industry [21].

In another study, two different phases of policies are presented. The first phase includes the redevelopment of workforce skillset from scratch and future-proofing the labour. The resultant might affect the aged workforce which might be unable to adapt and hence, have to be let off. Finding new workers to perform the updated tasks will raise issues unaccounted for, making it advisable to redeploy the pre-existent labour post-training. Subsequently, introducing a fresh pedagogy and an education policy in synchronization with employment policies is in order, failing to update which, unemployment on a large scale might ensue. Since the tasks demanding higher mechanical strength and lower creative skills are bound to be assigned to co-bots, the upcoming generations [3]. The next revolution will feature another upgrade in the education front. Teaching is expected to be taken over by soft robots establishing an 'Education 5.0' using the internet to provide quality information from carefully filtered data in the classrooms. The teaching bots will be thoroughly trained to be human-interactive, designed to be child-proofed, and easy to interface with [22].

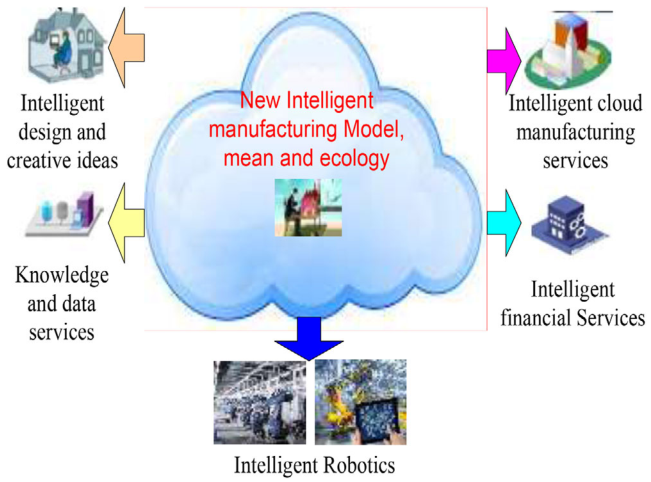

FIGURE 4 New smart production models, means and forms [23]

2.4 | Intelligent manufacturing

The new models are an autonomous manufacturing structure built on the internet, which is service-oriented, collaborative, adaptable, agile, and socialized. New means stand for integrated, human-machine, digitalization, Internet of Things, virtualization, services, teamwork, adaptation, versatility and intelligence, and smart Production Processes. New form means intelligent production ecology with all-embracing connectivity features, data-driven, cross-border convergence, self-service intelligence, and mass creativity. The combination of these models, resources, and types with the application will eventually shape an ecosystem [23] [Figure 4].

In relation to the future of energy demand and sources, a detailed exploratory analysis providing a view into how the usage of nuclear fusion energy being employed late into the fifth and in the early onset of the sixth industrial revolution has been estimated. Theoretical work on the world's biggest nuclear fusion facility 'ITER' has been ongoing and shall officially proceed into the DEMO power stage of planning under the support of several countries aiming to be ahead of the curve in terms of becoming independent from fossil fuel imports. With multiple nations expending major shares of their investments in alternate energy sources, it is expected that the "burning plasma" fusion reaction will soon exist in equivalent status as the trinity test, as an independent self-sufficient closed feedback event in its entirety. The whole process of experimentation could be sped up with the declaration of this pursuit as a global priority [24].

The constantly reducing fossil fuel reserves in the current age are pushing forth research on alternative fuels and energy sources. Bio-fuel from algae processing is one of the frontline contenders. In light of these facts, an in-depth exploration of the cultivation and generation of bioenergy by identifying and tweaking various environmental and economic factors in algae growth has been performed in alignment with the sustainable development goals. In further pursuit of higher efficiency and fuel output, genetic engineering was also explored as an approach that would expectedly be followed in the fifth industrial phase [25].

It is estimated that future manufacturing units, in the pursuit of higher orders of creative design and consumer-personalized ergonomics, will opt for an automated configuration at every nodal level with collaborative bots mimicking artisanal moves precisely [26]. Another study drew parallels between each past industrial revolution and the organic manual means with which the functions they replaced were performed previously. In that analogy, the first revolution could be equated to the basic fundamental cellular level, the second revolution to the power source, the third to the motor limbs, the fourth to the nervous system, and congruently, the fifth revolution could be analogous to an intelligent organism with its constituents working in perfect synergy. Drawing that analogy, work was done on building a distributed system working for a central unifying goal; a swarm robotic system [27]. Since the introduction of advanced organic elements in production is one of the distinguishing factors of the fifth revolution, the technical back ends involving motor units and control systems require a higher order of accuracy and precision to replicate the fluidity of organic effects artificially. This outcome is brought forth by implementing critical thinking skills [28].

accelerating precision agriculture, automating menial tasks like plant classification, weed identification and removal using dedicated mechanisms using A* and RRT (Rapid exploring Random Forest Technique) for path programming [30].

An *endoscopy* involves inserting into the body a small camera in a long wire through a 'natural opening' to seek injury, foreign objects, or traces of illness. This technique is painful to perform over sensitive tissue, and could be a thing of the past. The slim, flexible robots that can also be operated as RC cars manouvered to the precise location the physician wants are used by companies like Medineering to develop the treatment further. Modern *disinfecting robots* autonomously travel to the patient's unloaded rooms and then blast the empty space for several minutes with powerful UV rays until no microorganism has been left alive. For up to five years and longer, proof of concept pharmacy (pharmabotics) was successfully used for hospital use at the University of California, San Francisco. *Anti-bacterial nanotubes* are small devices composed of golden nanoblinges, which are covered with red blood cells and tracts so that the bacterial infections can actually be removed from the blood of a patient (Figure 5) (https://interestingengineering.com/15-medical-robots-that-are-changing-the-world). In another development, a 3D-vision based offline path programming system using spatial data

S. No.	Rubrics	Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0	Industry 5.0Phase-I	Industry 5.0 Phase-II
1.	Philosophy	Replacing manual labour	Upgradation of resources	Inter-connecting the world	Computerized automation	Synergetic co-production	Bio-upgradation
2.	Technology	Steam engines	IC engines, trivial automation devices	Computers, Internet, SCADA, PLCs, HMIs	Artificial intelligence, machine learning	Co-bots, Skill transfer systems	Bionic enhancements, personalized bioengineering
3.	Energy source	Coal, steam	Fossil fuels	Hybrid fuels (renewable, fossil, nuclear)	Renewable Electricity	Renewable Electricity	Renewable Electricity
4.	Key research	Mechanical design, material science	Semiconductor technology, computer networks	Industrial Automation, AI-ML	Human -machine Synergy	Space resources, Bio-integration	Advanced Agriculture, Waste reduction

Bringing the industry closer to the layman consumer, the co-bot structure will witness an overall revamp in a way that they will become capable of human-like motor functions like manipulator motion based on environmental stimuli, pre-set programs, and circumventive explicit real-time commands. In spite of programming having reached depth-wise into far-fetched milestones, breadthwise, it still hides some esoteric underdeveloped hardware-specific potential. It is believed that the upcoming revolution will patch all such untapped resources [29].

2.5 | Advanced robotics

Recent developments in robotic structure and algorithms have accommodated AI-assisted computer vision and portable robotic systems in the domain of agriculture with the aim of

from CAD models has been proposed and developed. It is the culmination of features from OLP platforms and a simplistic 3D vector space depicting IDE [31]. In another work, a sequential guidance platform for the design and programming of generic robots tasked with handling items and structures is proposed. The code it outputs is made in a way that it runs on every platform. The target user base consists of domain-specific experts with no prior experience in making robotic automation machinery aiming to automate some tasks [32].

2.6 | Medical healthcare and bio-engineering technologies

According to the alternative vision of Industry 5.0, bioengineering upgrades will undergo elevated structural personalization to

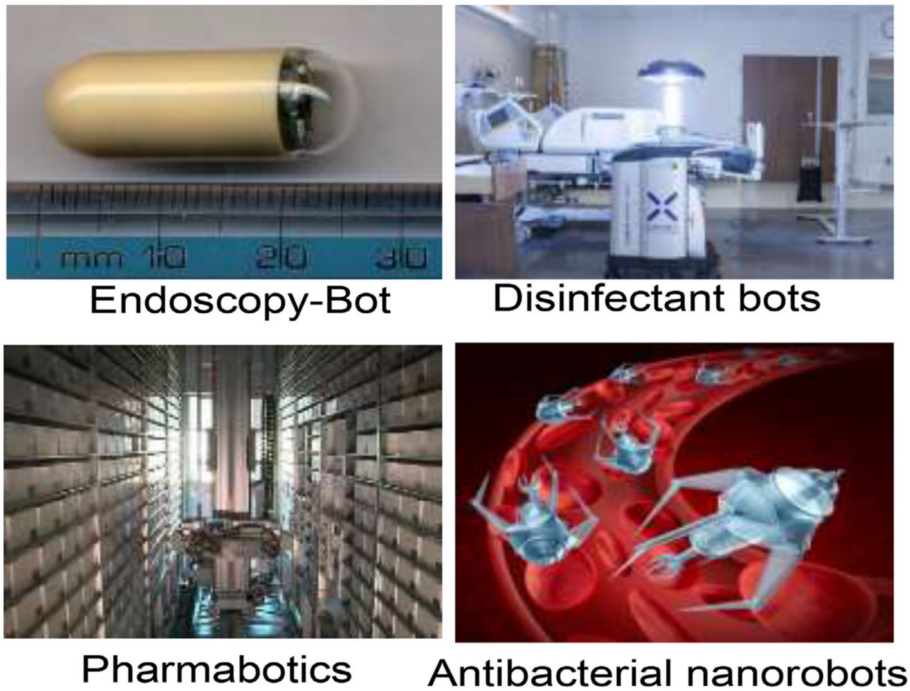

FIGURE 5 Various robots

fit the user's physical and medical profile accurately, minimizing usage discomfort and complexity. Even though the technology works, currently, the customizable systems are limited to a small production magnitude. Going ahead, the domain of medical science is expected to slowly adopt AI to perform patient data-driven diagnostics and other critical tasks requiring absolute precision. An initial instance of such practices could be an automatic regulated insulin administration device based on sensing sugar levels in the bloodstream. The entire event might gradually be made into a continuous background process. Industrial robots in the 5.0 times will assist humanity by boosting bio-support via personal tools and devices, tremendously easing the load on orthopaedics. Manufacturing techniques will evolve to account for the profile of individual users [32]. The use of advanced technologies has accelerated upon the sudden and extended event of the COVID-19 pandemic during which the medics had to employ non-contact means of monitoring, diagnosis, and treatment in every way possible way to control the spread [33]. The most valuable of techniques include online virtual OPDs for reducing patient traffic in clinics. The assistive AI projected to be featured in Industry 5.0 would extract medically relevant data from the patient, analyse it, develop a complete health profile, and suggest the most suitable medicine and dosage as trained prior by expert doctors and historical data of similar cases. Moreover, high-risk cases could be detected and dealt with in a rapid response wherein the AI could alert the local medics to practice triple caution and quarantine the patient subjected to the virus [34]. In another perspective, the ethical and medical implications of advanced bioengineering practices leading up to bionic anatomy are explored. Technical advancements ranging from bio-electronics to xenobiology are classified and their recent prospects of fusion, discussed. A requirement of open dialogue over the subject of consequences of these progressions is raised [35].

3 | AREAS WITH RESEARCH POTENTIAL

There are certain niche domain-specific research topics lying right on the pathway towards the next industrial revolutions. There are multiple lanes branching out into patent footprints, assembly-line modifications, even experimental studies. Some modern product markets include drone delivery, portable medical DDx kits, bionic organs, co-morbidity cures, quantum computing, commercialized computing, auto-driving AI, EEG deep dive technology. Although the research on drones might be an old subject, coupling the drones with other devices to implement a viable novel service/ product could open up new avenues previously unexplored. Drones can be employed in industrial logistics to reach places where the conventional methods cannot be reached due to uncontrolled external factors like temperature, electrical hazards, chemical hazards etc.

Portable medical diagnostics is another nifty research area holding tremendous immense way into the sixth revolution. As an extended goal, the user's medical profile could be plugged into smart kitchens and healthcare systems smart gyms, enabling even more personalized healthcare solutions.

In the field of printing, 5D printing has already taken form wherein the die platform has twin degrees of freedom while the nozzle has 3. The technology can be extended further to incorporate 3D free-form circuits with conductive filaments [36]. There's scope for organic biodegradable filament possessing high structural integrity while also being ductile under certain temperatures.

4 | SPECULATIONS ABOUT INDUSTRIAL REVOLUTION 6.0

The regressive pathway leading to the next industrial revolution indicates that co-existent robots will be the industrial norm by its end. The likely outcome from the previous revolutions focussed on technical automation and personalized manufacturing would be monolithic production houses in the sense that the machines are plugged into multiple task-specific AI algorithms running in conjunction to produce on a consumer requirement basis. The sixth revolution will be one that uses the following technologies for the purpose of advancement in various aspects of production and the overall quality of life:

- multidimensional printing
- robo-medics
- assistive home-robotics
- cumulative-alternative energy
- deep dive EEG

The upcoming 3D printer technology will be updated adding more degrees of freedom to the already pre-existent Penta-dimensional printing systems, adding the feature of printing using a wider array of chemicals and materials in additive manufacturing while also utilizing the technology for printing other materials such as controlled release medicine [36]. In addition to printing custom medicine designed to dissolve at certain target areas of the digestive tract, the domain of robotics is inclined towards the practice of general medicine in combination with statistical data, AI, ML, and mechatronic systems to minimize human contact in an OPD scenario. This ensures that a potential spread of germs is reduced, if not entirely negated [37]. Taking into perspective the current events of the Covid-19 bi-phase pandemic, a robotic medical system could ensure that contact procedures that require expert anatomical handling can be performed without involving any risk of viral spread to the human practitioner [38].

The domain of robotics has had been envisioning the integration of robots in the home front ever since the launch of wakamaru by Mitsubishi in 2005. it is speculated that the home assistant robotic system will finally be a focal area in the sixth revolution with more structurally varied application-specific inversions made available for aiding the elderly [39]. As an instance, recently, an extended wireless sensor cluster cum online dashboard-assisted article fetching motor system was proposed [38]. Such systems can also be controlled using wearable sensors which could take in data from the wearable device and transmit it to the home assistant within a small localized range [40].

Focusing on alternative energy sources, the current trend is moving more towards centralization of energy provision with the hyped-up introduction of EVs in the global market. With solar plants working their way into the back end, the onus of installing panels and batteries in individual homes is shifted to the corporations supplying energy to clients. The corporations can then implement multiple non-conventional methodologies coupled together to boost output. The alternative energy sources industrially used are natural gas, biomass and waste, nuclear energy, wind, and solar energy respectively based on decreasing order of percentage of usage [41]

For the matter of deep-dive EEG, the current technology allows for limited control of prosthetic limbs as of yet [42]. The EEG controlled prosthetic technology displays huge prospects moving forward, with future advancements potentially including artificial pain receptors which would allow for realistic skin grafting using synthetic materials.

5 | PROPOSED PATHWAYS: STEP ZERO

For each individual key in the sixth industrial revolution, there would be a target-specific ideal step zero. For the aspect of the integration of multidimensional printing into other domains of medicine, the chemical composition of the printing ink has to be made to be non-toxic, edible, ductile, and must conform to the temperature ranges that a 3D printer is capable of. This work seems to be an optimal research area for scholars pursuing food technology.

Taking robotic medics into perspective, a good starting point would be to collect data pertaining to the health stats of a local geographic region, complete with the doctor's observations and resultant remedy and consult. For most issues, a general consult would work flawlessly unless it is a critical complication, in which case, a robotic manipulator consisting of a precision robotic arm mounted on a heavy motor platform controlled by fully controlled thermistors triggered by the edge node device relaying a tele-calling data stream along with motor instructions from a cloud node would be ideal.

The aim is to manage production resources, enhance business and safety and minimize waste—on the floor as well as in processes at the back office, whilst fulfilling customers' supply and quality requirements. Manufacturers are successful in this with the new MES, smart devices, machine-to-machine connectivity, and data processing for their production lines and facilities. In the case of extending the fifth revolution's smart manufacturing, AI can be trained to construct the most efficient designs based on the constraints mentioned by users. By extension, Another AI can be trained to establish structural constraints based on the user's physical profile for the empirical purposes mentioned by the user. This could lead up to a higher order of smart manufacturing wherein the user does not even have to enter the product specifications in order to get an output.

6 | CONCLUSION AND FUTURE SCOPE

According to the future trends, the prime focus of the sixth industrial revolution would be on medical technology with multi-dimensional printed controlled release medicine, automated medical diagnostics entirely, removing any extra burden from practitioners, leaving them to focus on critical cases. Another key would be automated capital generation via robotic manufacturing, a practice that has had been envisioned in the fourth revolution, but could not be implemented on a mass scale due to it not being feasible for a mass-production scale. Domestic robotics would likely be next with cleaning and other task-specific robots integrated into our daily lifestyle. Alternative energy sources will play a major role, gradually replacing fossil fuels until the major time-consuming resources run on renewable energy sources. The fusion of ideas provides the most fundamental growth catalyst for companies and will redefine the market borders by changing the emphasis on digital business values from one commodity to another. Convergence is also a danger, though, because other firms may consume the main business of the enterprise in order to achieve their own goals of convergence. A comprehensive environment approach, a choice of appropriate partners, and the implementation of an industrial growth strategy focus on the success of the cross-industry value experiences.

DATA AVAILABILITY STATEMENT

Data openly available in a public repository that issues datasets with DOIs

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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