Blockchain Technologies

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Blockchain Technology for Industry 4.0

Secure, Decentralized, Distributed and Trusted Industry Environment

Springer

Blockchain Technologies

Series Editors

This book series aims to provide details of blockchain implementation in technology and interdisciplinary fields such as Medical Science, Applied Mathematics, Environmental Science, Business Management, and Computer Science. It covers an in-depth knowledge of blockchain technology for advance and emerging future technologies. It focuses on the Magnitude: scope, scale & frequency, Risk: security, reliability trust, and accuracy, Time: latency & timelines, utilization and implementation details of blockchain technologies. While Bitcoin and cryptocurrency might have been the first widely known uses of blockchain technology, but today, it has far many applications. In fact, blockchain is revolutionizing almost every industry. Blockchain has emerged as a disruptive technology, which has not only laid the foundation for all crypto-currencies, but also provides beneficial solutions in other fields of technologies. The features of blockchain technology include decentralized and distributed secure ledgers, recording transactions across a peer-to-peer network, creating the potential to remove unintended errors by providing transparency as well as accountability. This could affect not only the finance technology (crypto-currencies) sector, but also other fields such as:

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Blockchain Business Models
Blockchain Consensus
Bitcoin and Crypto currencies, and related fields

The initiatives in which the technology is used to distribute and trace the communication start point, provide and manage privacy, and create trustworthy environment, are just a few examples of the utility of blockchain technology, which also highlight the risks, such as privacy protection. Opinion on the utility of blockchain technology has a mixed conception. Some are enthusiastic; others believe that it is merely hyped. Blockchain has also entered the sphere of humanitarian and development aids e.g. supply chain management, digital identity, smart contracts and many more. This book series provides clear concepts and applications of Blockchain technology and invites experts from research centers, academia, industry and government to contribute to it.

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Contents

History of Industrial Revolutions: From Homo Sapiens Hunters to Bitcoin Hunters

Hasan Tinmaz

Abstract Homo sapiens have become the leading force of the earth by their ability of transformations. Initial hunter-gatherers transformed to agriculture-oriented small groups which finally led to early of civilizations. Civilizations produced more complex social human lives in the forms of cities and states. In distinct geographical areas, humans discovered new tools and methods to make their lives better. In that search for "effectiveness", humans tended to spend less (force, money or time) but achieve more. At the end of thousand years of this tendency, 18th century became the witness of early industrial revolution efforts. It was defined as a revolution due to its game-breaker or disruptive nature. Besides, it was associated with the term industry, since the source of power shifted from humans to different tools or machines. From that time to the current date, many scholars divide that timeline into four time-zones by considering the most disruptive technology of the time. In that manner, the first industrial revolution has linked to steam engines (using the power of water). The second revolution has associated to the electricity for assembly lines and mass production. The third revolution has been connected to computer technologies forming automation and lastly the fourth industrial revolution has been named with its capacity for cyber-physical system development with the application of advanced technologies. In those four revolutions, we can realize two essential points; the latter revolution has been stemming from the advancements in former revolution and the total time of revolution has becoming shorter. Therefore, it is clear that the effects of Industry 4.0 revolution will be widespread in public very soon. Among all the other high level technologies, blockchain technology which could be perceived as one of the most complicated and ultimate level of Industry 4.0 implementations could be listed as the last but not the least historical advancements for human beings.

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1 Introduction

Human history has been written in many different ways; civilizations' history, religions' history, finance history and so forth. While writing about these histories, they have been either finalized or kept stable for a long time. On the other hand, writing about technology related histories is very challenging, since the technology changes more rapidly than our expectations. Moreover, the technology history of humans has not been experienced the same way in different parts of the planet. As some countries are working on spaceships projects, some other countries are dealing with better waterline or electricity projects.

In order to understand that digitally divided situation, the author believes that we need to visit the early history of human-beings. Although different sources point out different timelines for the first homo-sapiens on earth, recent discoveries by famous archeologists Peter Benedict and Halet Çambel in 1963 unfolded a new Neolithic period settlement in modern day of Turkey; 'Gobekli Tepe' which is dated back between 12000 and 10000 BC (Fig. 1a). As a center of human gathering, Gobekli Tepe has changed the history of human civilizations (Fig. 1b) [4].

Initial homo-sapiens were having survival challenges such as finding food, shelter or protection. By developing their first social and communication skills, homo-sapiens were altered from individuals than to groups. These new groups of homo-sapiens were hunter-gatherers. Initial success of group dynamics guided these hunter-gatherers was followed by the development of agricultural centers (they were neither villages nor cities in modern terms). The more they experienced agriculture, the more they learned about development of new tools for each step of farming. In that sense, these tools could be named as the very first technological advancements in human history. By having more food and safety, humans initiated their first civilizations around bigger groups [14].

Fig. 1 **a** Gobekli Tepe complex, **b** one pillar in Gobekli Tepe

The ability of feeding more people and providing more food triggered an increase in the capacity of labor force. That working groups constructed bigger living centers where we can call cities in today's terms [34]. These cities were not only bigger in population, but also bigger in the opportunities/services provided. For example, first schooling started in cities or a wealthier job opportunity in the state or city administration was appeared in that cities. As a result, more people moved from rural areas to urban areas.

That shift toward urban areas has still been continuing for centuries and unfolding several overt or covert outcomes for humans. First of all, the increase in labor force for cities has been pushing people to kick off first industrial attempts. It may not be very plausible to call these attempts as factories, but there at least exists of group of people producing similar materials or tools. Besides, the cities have been demanding more food to offer these new labor forces. Totally, an increase in capital formation and exchange has been formed around cities. That financial capital has finally turned out to be investments in different industries.

As a result, humanity met with industrial revolutions starting from mid 18th century. Industrial revolutions primarily altered muscle based production to mechanical power which was followed by augmented cognitive power in production [34].

Last but not least, we can conclude that without finalization of agricultural revolution settlement, it would be highly challenging to fully achieve industrial revolutions. That could be seen how certain countries have been experiencing different timelines on industrial revolutions.

2 Industrial Revolutions at Glance

Understanding industrial revolution cannot be separated from centralization of the technology as a concept. Hence, industrial revolution can also be defined as industrial utilization of different technologies. The industrial revolutions have shaped the way we live today. 'Industrial Revolution' as a concept could be defined in various different ways. According Britannica Encyclopedia [5], the term "Industrial Revolution" was named by Arnold Toynbee (1852–1883) referring to the economical progress in Britain from 1760 to 1840. According to Tomory [42], industrial revolution as a concept indicates economical changes in England as a result of technological innovation from 1760 to 1830. Essentially, it characterizes an enormous change in how humans perform their manufacturing, business or any other industrial actions. In another way of depiction, industrial revolution could be perceived as a significant shift in producing things manually to factory situated serial production.

Understanding industrial revolutions requires another clarification on 'evolution' versus 'revolution' terms. Evolution also refers to change, yet it happens gradually as a process. Hence, when an analog dial-up phone changes to a digital digital-up phone, it is an evolutionary change from one phase to another phase. On the other hand, when these phones change mobile/smart phones, the change is radical and affects the fundamentals of phone technologies. In that sense, mobile phone technology could be labeled as a revolution. Hence, a revolution represents an "…abrupt and radical change" [34]. In 2019, Samsung authorities are demonstrating new foldable phones which could be marked as evolutionary approach to phone technologies. Last but not least, it is clear that revolutions are followed by several additional evolutions.

From the social part of human history, industrial revolutions have altered innate traditional and hierarchical social structure of nations. Although there is no consensus about the underlying reasons of these changes, it is clear that people started to question their social roles and positions as they were becoming financially more independent. French Revolution of 1789, which was also listed as one of the triggers toward industrial revolution, remarked as another contributor to that change as well [13]. Possible overt outcomes of these changes could be listed as; the shift from lower income class to middle income class level for more people, the increase in the average life span (which was even lowered to 38 in British cities), the educational endeavors overcoming the new jobs' required skills and abilities and democratization (including labor unions and employee rights agreements).

By considering the industrial changes from past to the present, it is possible to delineate industry revolutions in four phases;

- Industry 1.0 as the initial attempts toward mechanization supported by the steam engines of water power,
- Industry 2.0 as the period of electricity guided, assembly line supported mass production,
- Industry 3.0 as the stage of computer technologies leading effective automated systems,
- and lastly, Industry 4.0 as current phase of industrial revolutions which is associated to cyber physical systems.

From steam engines to advanced digital productions, these industrial revolutions have disseminated drastic changes in different processes and procedures of manufacturing systems [7].

Before we move forward to scrutinize each industrial revolution separately, it is important to remind that there is no sharp cutting edge between those industrial revolutions. Therefore other than thinking a linear developmental phases of these industrial revolutions, it is better to perceive them in a spiral or curve-linear time-line (similar approach to Harari [14] explaining the history of humankind) (Fig. 2). Besides, not all the countries or all the world citizens are experiencing the effects of industrial revolutions together. While some countries give the impression of Industry 2.0 endeavors, some other countries discuss about advanced stages of Industry 4.0 infusion to different sectors.

3 Industry 1.0—the Mechanical Period

As a consensus, first industrial revolution has been believed to start in England and disseminated to Europe continent and then the rest of the world. After Britain,

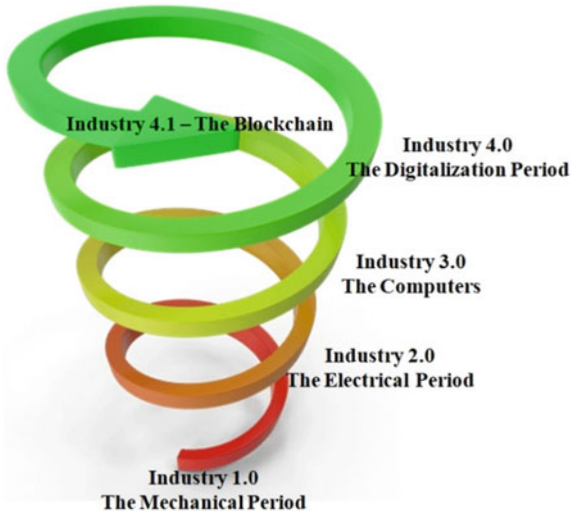

Fig. 2 The spiral history of industrial revolutions

industrial revolution developments jumped to mainland Europe, especially Belgium and France. Germany and the rest of the European countries were not fast followers of these advancements. Many scholars agree that first industrial revolution began in England which unfolded a radical change from an agricultural society to industrial society [7].

Two main changes of Industry 1.0 revolution were dominance of machine based production over manual productions and dominance of factory massive production over small scale workshop manufacturing. As a result, Industry 1.0 enabled the growth for economies which changed the dynamics of previous economical relationships. Factory is a term commonly used for contemporary big buildings surrounded by tall towers/chimneys, comprising an immense number of people working, encircled by many transportation devices like trucks, producing mass amount of everything. On the other hand, factories of 18th or 19th centuries were small shops where a small group of people, who were trained for specific manufacturing processes, was manually producing only certain things [38].

Since new cities demand more raw materials for production, railroad construction became a priority for transportation. In parallel to evolving from agricultural period to industrialized period, it was obvious to find alternative transportation methods (especially against animal power provided logistics). Therefore, an innovative method of steam engines was utilized on these railroads [34]. Steam engines mechanism fundamentally works by coal fire stimulating water vaporization leading to pumping of cylinders and pistons integrated in the locomotives. As a note, steam engine triggered transportation yielded an obvious dependence on coal mines and coal production as well.

The coal for the steam engines was initially transported by animal-dominant power, such as horse wagons. On the other hand, that was very expensive and the amount of coal was very limited in comparison to the overall demand. After using coal based steam engines for transportation, that situation changed deeply that more coal moved easily to far distances with lower costs, which reflected on decreasing general trade costs and effect of first industrial revolution disseminated to other countries and continents [37].

Although stem engines were not forgotten by their contribution to railroad transportation, steam engines were actually serving a wide range of other industries as well (Fig. 3). Thus, steam engines could be perceived as a key power for Industry 1.0 but addressing the needs of other industries as an all-purpose technology. Since steam engines were changing heat energy to mechanical energy, all industries requiring mechanical energy were in need to utilize steam engines. For instance, ship industry was radically altered by the shift from sailing to steam empowered energy. While travelling/logistics to longer distances became possible and shorter in time, workers of that ship industry were learning new skills and becoming more engineer-wise workers than regular sailors [8].

Another field of production which was affected innately from Industry 1.0 changes in England was the cotton/textile industry. Two fundamental processes of cotton based productions; spinning and weaving, were shifted from home-based manual tasks to machine guided industries. Moreover, new steam engine based iron machines were yielding mass production of textile manufacturing [43].

Fig. 3 Steam locomotive [24]

4 Industry 2.0—the Electrical Period

While first industrial revolution was leading the formation of an industry culture paying attention to quality, competence and amounts, second industrial revolution culture was focusing on new and advanced production management methods for the progress of quality and products [16]. Industry 2.0 is associated by two concepts; advancements in electricity as a new source of energy and mass-production via assembly lines as an implementation of electricity to production [34].

As an innovative effect of first industrial revolution's transportation opportunities (such as steamboats), the second industrial revolution witnessed an important shift from the dominance of regional agricultural communities to geographically accessible, industry oriented, skill based, connected communities [11]. Therefore, it was easy to transfer labor force (immigrants) and industrial developments from Europe to the United States. In that sense, second industrial revolution is associated with the United States whereas the first industrial revolution is labeled with the UK dominantly.

The generally accepted start for the second industrial revolution is the mass production age in the USA. As a result of enhanced transportation network with steam engines and USA's new prosperous natural resources from new regions, transportation of any type of raw materials, products and workers became very straightforward. Moreover, according to the Library of Congress sources, fourteen million people immigrated to this new country from 1860 to 1900. Hence, relatively in short time, USA possessed an immense number of human resources whom can work in a wide range of industries in all over the country [40].

Henry Ford's automobile factory was first implemented that mass-production approach which was later widely adopted during post-World War II period. In this period, the influences of Keynesian spending policies were dominant. High uses of assembly lines created new economical issues around mass production and mass consumption dilemma (Fig. 4). The characteristic feature of this period was the presence of the sliding assembly line systems which were allowing massive production of a single outcome in a short period of time. Due to this one-type production feature, in the following years, factories failed to address the diversity in local/global competitions and diversification in consumer preferences. Hence, this system collapsed in mid 70s [1].

During Industry 2.0 period, many American inventors contributed to existing technologies guiding many other personal and professional changes in transportation, communication and manufacturing. For example, Alexander Graham Bell invented a machine which can transfer human voice for distances, which we call it as telephone today. Furthermore, Thomas Edison was becoming the father of electricity and newly developed other technologies (such as the light bulb or electric dynamo), while contributing the existing technologies at hand, such as telegraph, as well [40].

The second industrial revolution observed several technological innovations which were mutually affecting each other in development. In 1870s, the telephone, electrical lighting and typewriters were invented. In 1880s, first elevators and steel

Fig. 4 The assembly lines of the Bell Aircraft Corporation in 1944 (the United States Library of Congress's Prints and Photographs division)

structures for the buildings were at the stage and making the construction of skyscrapers possible. Afterwards, in the form of fundamental filming industry, the phonograph and motion pictures were developed. Steam powered engines were starting to be replaced by the electric generators where fridges and washing machines were supported with that new engines. Another engine related change in 1890s was the internal combustion engines which contributed to the later invention of first automobiles and airplanes [11].

Another important change in this period was about replacements in workers' skills and abilities. After the infusion of electricity into different industries, the ways of performing job tasks also altered dramatically. In that case, workers had to learn new skills either to keep their existing job (although the job and related tasks were not the same as before) or to find jobs in newly shaped industries [8]. Many people started working around assembly lines in big companies where each individual was functioning like a robot for continuously repetitive one small task of production. In most cases, workers, who were dominantly men, were working in very unhygienic and hazardous conditions. Hence, after a certain time, men were supported by women labor force. Regrettably, child labor was also becoming common issue for the society.

Although mass production and all other developments were bringing several advantages for the countries, the governments were not generous enough to compensate the hard work of the employees. For instance, some US companies were making their employees to work up to sixteen hours for seven days in a week or shifts were so tight that employees could not get rest in between. Moreover, working conditions were not safe, hygienic or human-friendly. Due to lack of labor unions in many cases and lack of health insurances, the employee rights were not either not protected or maintained.

5 Industry 3.0—the Computers

The failure in one type production on assembly lines triggered more programmable machines so that the existing production systems could address customers' diversified needs. These programmable machines were changed their names to computers or robots and the period of Industry 3.0 began [1]. Industry 3.0 witnessed a series of technological developments in a relatively short time starting from improvements in semiconductors and leading mainframe computers in mid 60s, personal computers in mid 70s (Fig. 5) and finally the Internet in 90s [34].

The third industrial revolution has resulted in the development of automated machines in subsequent to the invention of transistors and integrated circuits. In that period, Programmable Logic Controller (PLC) was the trigger of this automation progress from 1960s [16]. The more different electronic devices (also called as hardware) adjusted to manufacturing processes and systems, the more programs

Fig. 5 Early version of IBM PC (Model 5150)

(also known as software later on) needed to enable these devices. Thus, the innovations in the electronic devices have created the software market with all its derivates for different industries, such as ERP (enterprise resource planning), SCMS (supply chain management systems), TPS (transaction processing systems) or IMS (inventory management systems).

The drastic changes in hardware and enduring demand from different industries for automation have stimulated different software products for manufacturing. The demand toward these innovative manufacturing software and hardware systems have decreased their prices and promoted a wider range of utilization not only in developed countries but also in developing states as well.

Generally, the third industrial revolution has been advanced by USA founded information and communication technologies companies focusing on the Internet and mobile technologies more than ever before. In addition to that hardware issues, the developers have been addressing the social dimension of computing as well. With the advancements of social media, advance technologies have been infused into daily human lives. Especially mobile technologies (Fig. 6) and related fields such as artificial intelligence, smart audio and visual designs and gaming fields have gained a special importance. Hence, it has been comprehensible that the third industrial revolution has the potential to influence all other industries ultimately.

The industry culture in the third revolution has been specified on better accuracy, augmented pace and decreased effort [16]. In parallel to technological advancements, general public have started to question mass production techniques and looking for more customized and user-friendly products. The customization efforts have had an effect on many industries such as construction, architecture, health, fashion and education. For instance; one of the most important dimensions of Industry 3.0 has been observed in biotechnology field where scientists have started the discovery of human genome (all the genes a human has) system mysteries with big data analytics

Fig. 6 Nokia 9110 and 9000

working on supercomputers and advanced software such as Hadoop. Genome studies have started around 1990s and the full sequence of genome was accomplished in 2003, April where $2.7 billion spent during the entire project. Eventually, Human Genome Project has discovered that we have 20,500 genes in our body [23].

The third industrial revolution has experienced many innovations, evolutions and changes. Table 1 shows a summary of major events or developments within the history of Industry 3.0 [6, 22, 36, 39].

On the other hand, industrial revolutions have altered human history in way that people have realized that they could utilize, manipulate and change the environmental elements. Unfortunately, until the mid 20th century, people did not realize how much they have been damaging the nature as they experience industrial revolutions. Therefore, starting from Industry 3.0 and expanding to Industry 4.0 actions, people have initiated new consensus toward green technologies, nature-friendly devices and less carbon dioxide emission factories.

Third industrial revolution has been experiencing new type of energy; nuclear energy. Human beings were witnessed the power of nuclear energy in two atomic bombs to Hiroshima and Nagasaki. Then Chernobyl nuclear reactor accident (1986) showed how much it could damage the nature, humans and animals. Recently after the big earthquake in Japan, Fukushima nuclear reactor (2011) could not struggle with tsunami effects. In spite of these adverse events, nuclear energy is still perceived as an effective energy source within the fourth industrial revolution context. Additionally, solar energy has become an essential source starting from Germany and China. Besides, wind turbulences have been widespread in countries where air conditions yield strong winds, such as the Netherlands or Jeju Island in South Korea.

6 Industry 4.0—the Digitalization Period

The term 'Industry 4.0' was firstly unfolded at the Hannover Fair (Germany) in 2011 referring to how advancements in technologies would deeply change "… the organization of global value chains" [34]. Even though Industry 4.0 (as a term from Germany) is commonly welcomed by stakeholders, similar concepts have also been derived to refer digitalization of production in this era [32] (Fig. 7).

One of these terms is 'Industrial Internet' which was coined by General Electric (GE) Company in late 2012. Originally, GE has been aiming to bring digitalization to their core operations through their new software business and the Internet of Things approach [17]. Furthermore, GE believes that Industrial Internet has applications in different industries such as mining, manufacturing, healthcare, smart energy systems, public service sector and transportation/logistics. To serve that global economy contributing purpose, GE has become a leading company to establish "Industrial Internet Consortium" where a special architecture has been published to promote the effective utilization of interconnected machines and devices to advanced analytics with people at work [18].

Table 1 The technological turning points in millennial Industry 3.0

Year	The turning point of the year
1958	• 'Integrated Circuit' (also known as microprocessor or the chip) was invented—which provided better and affordable computing power
1968	• First database management system serving commercial purposes was released by IBM
1969	• The establishment of many Internet protocols by the US Advanced Research Projects Agency Network (ARPANET)
1973	• Ethernet was invented by Bob Metcalfe—the technology allowing data exchange among computers
1983	• Domain naming system (DNS) was established to offer URL extensions for labeling websites, such as .com, .org, .edu
1986	• Personal computers were managed to be linked to programmable logic controllers (PLCs)
1990	• As a result of PLC connection, first Internet of Things device was programmed to prepare breads in a toaster controlled via the Internet
1991	• Tim Berners-Lee created first web page ever
1995	• The Internet was shifting toward being a profitable endeavor where Amazon, Craigslist and eBay became online on the year
1998	• Ethernet has become indispensable for many industries to function • Google search engine was released
1999	• The 'Internet of Things' was named by Kevin Ashton
2000	• The Sims game was released—a social game with customizable characters supported by artificial intelligence and advanced graphics which was bloomed the gaming industry • The introduction of Honda's 'Advanced Step in Innovative Mobility' (ASIMO) humanoid robot—a unique attempt toward the implementation of artificial intelligence and robotics fields • The initiation of USB /flash drives—a simple way of data storage and transfer
2001	• Dot Com changed the game—a phenomenon where different industries realized the fact that the Web would alter the underlying dynamics for many businesses where people started applying new business models for their future • Apple Store openings—a new retailing approach to technology shopping where customers can find Apple products, related programs and different accessories, and can ask the support of specialists called 'the Genius Bar' • Apple iTunes was released—a game changer for music industry where the users could record songs from CDs in order to listen or mix them which contributed to formation and understanding of 'online services' as a concept
2002	• 'Earth Simulator' was announced as the world fastest supercomputer (kept the title until 2004)—a joint project of government of Japan (aerospace, energy, and marine bodies) for global climate modeling based on massively parallel and vector-based systems • Centibots project from DARPA was initiated—another important project from American Defense Advanced Research Projects Agency (DARPA) on no-human-supervised (fully autonomous), aiming the group success (when one robot fails, the other robot takes its tasks), designed to serve on dangerous lands to create a real-time mapping while searching for the targeted objects

(continued)

Table 1 (continued)

Year	The turning point of the year
2003	• CSAIL (The Computer Science and Artificial Intelligence Laboratory) at MIT was established—as a merge of Laboratory for Computer Science (originally founded in 1963) and the Artificial Intelligence Laboratory (opened in 1959) serving for many innovative academic and industrial projects • MySpace was founded—an earlier version of today's social networking websites which was also offering online games and data storage features, was offering web presence for many musicians or entertainment industry stakeholders
2004	• Gaming industry met with online game; 'World of Warcraft'—a Massive Multiplayer Online Role Playing Game (MMORPG) which still keeps its leadership in the market • 'Anonymous' hacktivist group was formed—a group of hackers wearing Guy Fawkes masks for recognition targeting different organizations' web servers, such as governmental agencies or Church of Scientology • 'Web 2.0' concept was revealed—an innovative approach named by Tim O'Reilly to depict content sharing and development abilities on previously static Web systems where the users have also become content editors for blogs, wikis, social networking websites and so forth • Facebook has become online for all
2005	• 'Arduino' board was released for regular users—a small size card entrenched a low-priced microcontroller and signal connectors using Java integrated development environment allowing to control different electronic devices. Arduino has triggered 'Maker' movement where people from different ages could enjoy programming together to control different devices—also assisted the dissemination of 'Internet of Things' developments • 'Hadoop' was introduced to data stakeholders—an open source software to mine outcomes from large unstructured data set (Big Data focused) which has been utilized by many companies like Twitter, Google, IBM or Yahoo due to its cost effectiveness, error tolerance and scalability for large networks
2006	• 'The Cloud' has become popular—an important movement for computing and networking where both regular end-users or big companies can store their data on cloud utility and even run different programs for saving storage and cost • 'Cloud-Based Services' has been launched by Amazon Web Services—a new service for users allowing them to rent time on cloud to make their servers work efficiently by preventing users from complicated networking and computing procedures
2007	• 'Dropbox' company was established—another important cloud-based service for effectively storing, ubiquitously accessing and functionally sharing files where standard users could use the system for free with certain limitations • The first 1 terabyte (TB) hard disk was released by Hitachi—a tremendous improvement for information technology where 1.44 MB floppy disks was released by IBM in 1986 • 'Scratch' as a free programming language was launched for standard users—an instructional setting with full of applications for different age groups to learn programming basics • 'iPhone' was released by Apple—another game changer disruptive technology allowing its users to download different applications (aka 'apps') from Apple store online and giving users an unforgettable experience of many utilities, audio-visual elements, Internet access and many other features including high-resolution camera and touch screening

(continued)

Table 1 (continued)

Year	The turning point of the year
2008	• 'MacBook Air' was released to Apple Stores—an ultra thin notebook with its high capacity battery
2009	• 'BitCoin' system was launched—a crypto-currency system where users could use bitcoins like real money to spend. The term of 'Bitcoin' was initially specified in the manuscript named 'Bitcoin: A Peer-to-Peer Electronic Cash System' by 'Satoshi Nakamoto' as a pen name in 2008. The paper was talking about how the users could utilize peer-to-peer networks to create their 'crypto-currency'. 2009 is the year where Satoshi Nakamoto mined the first bitcoins. Afterwards, in 2010, 10,000 bitcoins were used to buy two pizzas which actually cost around $25 at that time. At the second of 2013, Bitcoin has become more popular not only for regular users but also illegal groups where the governments have created new laws, regulations and systems to control Bitcoin flows in their states • 'Cloud Based Online Backup' systems were released—a solution to backup related problems where servers could automatically be backed up their data to other remote servers in the form of clouds, which offered data protection and recovery alternatives • 'Mobile Internet' has altered the world—the advancements in high speed mobile data transfer (such as effective 3G networks), the dissemination of mobile devices (such as iPhone and Android), the augmented speed of mobile application developments and the increased cost-effectiveness of mobile data and devices have influenced the underlying dynamics of mass-market
2010	• 'Stuxnet' virus was the major issue of security—a virus used to attack Iran's nuclear reactors demonstrated the delicateness of networked infrastructures • 'iPad' was released by Apple—a similar technology to smart iPhones where the screen is wider and phone feature is absent
2011	• 'Siri' was announced by Apple—a smart voice recognition and activation technology with the feature of understanding daily human language to respond people's questions • BYOD (Bring Your Own Device) has become a new approach for organizations

Fig. 7 Industry 4.0 offers many opportunities for nations

Another Industry 4.0 synonym has been named in France; 'Industrie du Futur (IdF)'—'Industry of the Future' in April 2015. The major destination of IdF is digital transformation of companies and their business models which assist the modernization of manufacturing processes and procedures [12]. The plan has been addressing nine fields as the solutions to current social and economical problems in France; "*data economy; smart objects; digital trust; smart food production; new resources; sustainable cities; eco-mobility; medicine of the future; transport of tomorrow*" [20]. IdF has focused on five pillars for these industrial solutions; (i) cutting edge technologies (such as 3D printing, Internet of Things and virtual/augmented reality), (ii) assisting French companies for their digital transformations, (iii) offering trainings for overcoming the problems in the requirement of new job related knowledge and skills, (iv) strengthening international collaboration among other European Union member/non-member states, and (v) encouragement of IdF [12, 20].

We also see additional Industry 4.0 strategy plans in Asia which were released by South Korea (2014) and China (2015). South Korean 'Innovation in Manufacturing 3.0' strategy aims to augment general productivity with the developments of business actions starting from the lower layers of Korean economy. To serve that ultimate purpose, the chief reform areas are described as (i) the dissemination of smart manufacturing in the forms of smart factories (and necessary adaptations and improvements to serve core technologies in these smart factories, including the development of necessary software and sensors), (ii) the representation of new industry (including the R&Ds toward intelligent materials), (iii) strengthening the regional level smart manufacturing actions with a specific focus on startups and (iv) the restructuring the existing business processes and procedures for the adaptation of smart factory business models. The strategic plan also reveals the concept of smart factory as a reference toward the interconnected usage of data exchanges, automation and improved manufacturing technologies [19, 35].

In 2015, China announced a ten-year action plan '[21]' toward taking its place in the fourth industrial revolution era. The major objective of this plan is to support innovation-driven transformation in Chinese manufacturing which will diminish the dependence on technology imports from other countries. China has been protecting its competitiveness among other high-tech nations such as Germany and the US. The plan has been focusing on the transformation of ten strategic sectors to smart manufacturing systems; *new information technology, numerical control tools, aerospace equipment, high-tech ships, railway equipment, energy saving, new materials, medical devices, agricultural machinery and power equipment*. The key performance indicators of improvements in these sectors are defined as innovation capability, quality & value, IT & Industry integration and green industry. The strategic plan defines long term objectives as a reformation in Chinese manufacturing industries, shifting from low-cost product to high-quality product level (not only as an artifact quality but also the perception in public), becoming a leader in front of Germany and Japan until 2035 and ultimately top world power until 2049 [9, 21] (Fig. 8).

As one of the famous authors for industrial revolution related books, Rifkin [31] summarizes the underlying forces bringing another industrial revolution, Industry 4.0 or its synonyms, for the current era as declining pace of global economies, decreasing

Fig. 8 'Made In China [21]' is an action plan toward Industry 4.0 in China

productivity rate, unstoppable state of unemployment, the big gap between the rich and the poor in societies, the density of industry-leaded global warming and climate change problems and world's disrupted water cycle. Hence, it is easy to understand why the different strategic plans have been paying specific attention to innovation, employment, manufacturing and nature-friendly solutions as described earlier. More innovative and proactive technological actions have been taking toward solving these problems within Industry 4.0 framework. Industry 4.0 has been expected to bring a new breath to stationary economic situation or recessions happening for the last decade.

In 2018, the World Economic Forum published "The Readiness for the Future of Production Report [30]" report and listed 25 countries from all over the world which have been well adapted to Industry 4.0 from the points of structure of production (horizontal axis) and drivers of production (vertical axis). These countries in alphabetical order are; "*Austria, Belgium, Canada, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Ireland, Israel, Italy, Japan, Republic of Korea, Malaysia, Netherlands, Poland, Singapore, Slovenia, Spain, Sweden, Switzerland, United Kingdom and United States*". These countries could be exemplary for the rest of the states for now. The report highlights two significant issues; the on-going challenge for the digital transformation of manufacturing systems and the polarization in the speed of digital transformation in manufacturing systems all around the world [30]. As noted earlier, industrial revolutions are not happening in the same way of speed for different nations. This report also noted that the gap between the industrialized and industrializing nations has been widening.

Companies have become more conscious about Industry 4.0's possible game-changer role offering innovative business models around new products and services. For example, Festo Didactic, world-wide technical training solutions company, designates the differences between Industry 3.0 and Industry 4.0 from the roles changed in manufacturing as a shift from serving roles of automated manufacturing (in Industry 3.0) to driving role of data-based manufacturing (in Industry 4.0). While Industry 3.0 has been focusing on repetitive or easy tasks for standardization, Industry 4.0 has been considering data-based decision making and error detection while monitoring decentralized tools serving for preventive maintenance [2] (Fig. 9).

It is fundamental to comprehend what Industry 4.0 brings to current decade. Carvalho, Chaim, Cazarini and Gerolamo [7] have listed the main principles of Industry 4.0 as

- *Interoperability*; could be defined as a fundamental feature of effective functionalization for machines and tools from different manufacturers working together. Interoperability requires networks of trusted bodies which make blockchain more important for current and prospective operations.
- *Decentralization*; allows localization of manufacturing processes in their original spots by dedicating a control mechanism over the system. Decentralized networks are one of the major components of blockchain technologies.
- *Virtualization*; focuses on creating a virtual twin of the physical world of objects via abstraction of real objects through constant monitoring and sensor based machine

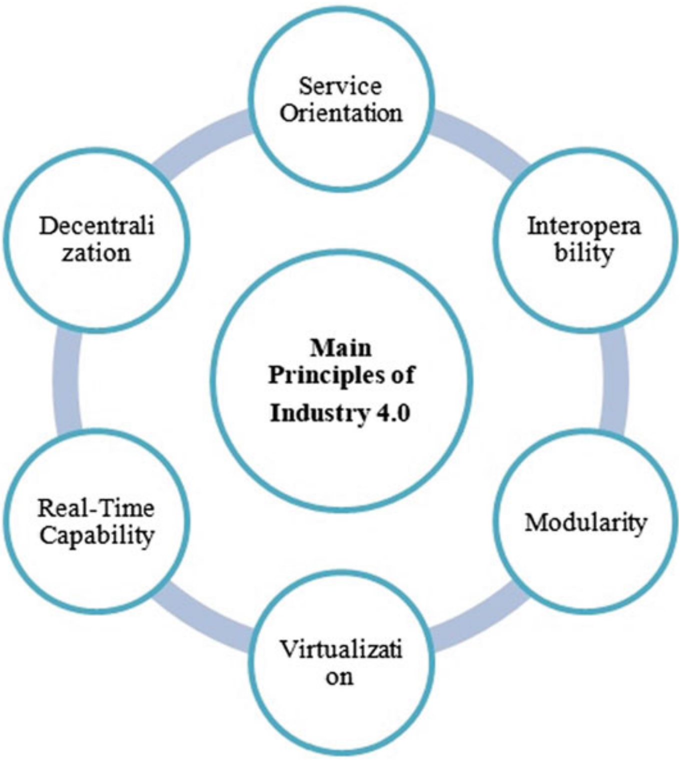

Fig. 9 Main principles of Industry 4.0

to machine interaction. Virtualization actually provides one of essential component of Industry 4.0 in cyber physical systems.

- *Real-Time Capability*; initially focuses on real time data collection and their analysis and extends to the point of taking immediate actions toward identified problems or communication demands. Smart grid systems are good examples of real-time capabilities for the energy maintenance of any system.
- *Modularity*; brings an immense advantage to entire production life-cycle where any module of production could be replaced by another one due to its flexible structure addressing need changes of production.
- *Service Orientation*; makes the production processes more agile as a response toward supply demands. Different stakeholders of the production could facilitate that agility by providing their data to the system.

Industry 4.0 has also been identified as the effective connection of online (virtual) and offline (real) lives leading to cyber physical manufacturing systems for different industries. Therefore, many traditional manufacturing organizations are experiencing massive changes in their processes and procedures. That is why those changes are gathered around the revolution umbrella. Cyber physical systems are essential for the virtualization of industries revealing their remotely monitoring and management capabilities for manufacturing. That new forms of manufacturing have created Internet of Things (IoT) where people, smart devices, processes and all other infrastructure elements have been linked to each other on a network for more effective management and sustainability of the entire production cycle (Fig. 10).

Fig. 10 Internet of Things (IoT) will bring many opportunities due to its unlimited connection capabilities

Industry 4.0 revolution is highly linked to digital products and services. Schwab [34] designates Industry 4.0 as omnipresent mobile internet technologies, sensors which are smaller in size, cheaper in price but more powerful in capacity, and artificial intelligence supported by machine and deep learning algorithms. Besides, the fourth industrial revolution is strongly connected to smart machines which increase industries' preparedness level while decreasing delays for them. The superiority of these smart machines stems from their abilities to unremitting monitoring of systems, detection/prediction of system errors and suggestion not only precautionary measures but also solutions to existing problems [16]. For example; in biotechnology field, Industry 4.0 has brought many advantages by the utilization of increased computing capabilities which are more sensitive toward measurement errors. While scientists were spending 13 years and $2.7 billion for unfolding a genome, new technologies have decreased that to couple of hours with a cost one thousand dollar at the end of 2015 [23].

Earlier industrial revolutions have been addressing mass production to fulfill huge demand of publics. On the other hand, Industry 4.0 experiences have been offering not only more efficient mass production opportunities but also flexible mass customization features. Hence, the customers are not only getting what they want, but also able to choose among the best-fitting alternatives. Until the end of 2040, it is expected that three billion more people will be the members of middle economical class. These financial advancements will make the people want more of everything, such as more vehicles, more technological devices, better health and career opportunities.

As an example of customization, well-known shoe company Nike has initiated a new approach called NikeID [25] where the customers visit the webpage for customize their shoes as they wish. This new business to customer (B2C) channel not only positively affected Nike's sales but also contributed its customer proximity. Another example comes from famous car production company; Nissan. Nissan customers have been able to choose model of their engines, color of their vehicles and other accessories to personalize their vehicles. Nissan is aiming to increase their after-sales revenue by twenty-five percent at the end of 2022 as a result of their customization opportunities [26]. Last example of successful customization story is from Nutella where its customers are able to put their names on the jar. This sweet customization marketing strategy has become viral on social media where Nutella customers have been sharing their jars on different platforms [28].

Industry 4.0 also brings many alterations to modern day companies (also known as smart factories). While traditional manufacturing processes are highly firm and manual, smart factories focus on responsive and automated business processes. Therefore, the outcomes of smart manufacturing processes (aka products) are customized and personalized to bring more direct and closer customer proximity whereas traditionally manufactured products are more standardized. Additionally, the supply chain of these smart manufacturing is more analytical based on dynamic data based decision-making. Yet, traditional supply chain approaches dominantly address stock based planning processes (Fig. 11).

On the other hand, studies also point out that our planet cannot fulfill that immense demand for such a long time [44]. In that sense, sustainability of the existing sources

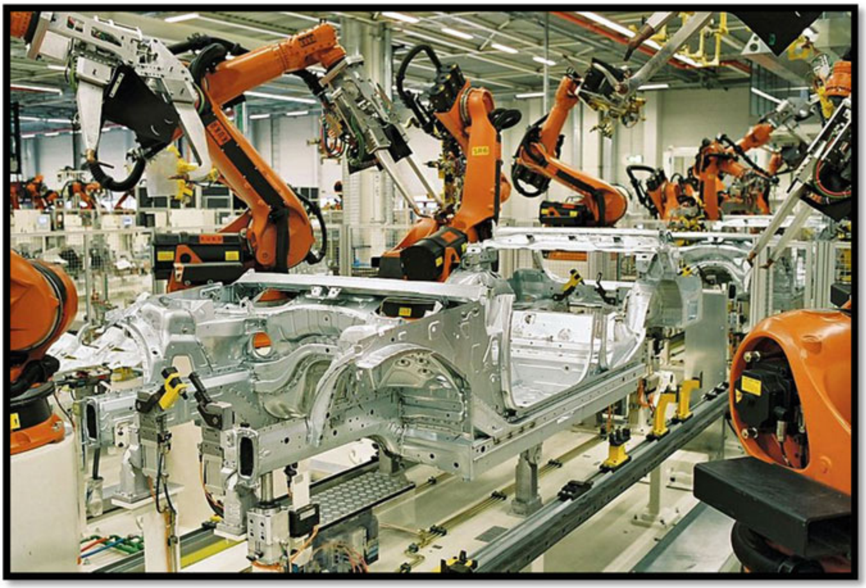

Fig. 11 Smart factory of BMW production

(energy, forest, water and so forth) has been becoming a vital issue of this decade. That is where Industry 4.0 technologies come to the stage to play a significant role for the future of the planet. Carvalho, Chaim, Cazarini and Gerolamo [7] remarked that Industry 4.0 is a new model of industrialization which aims precautions toward environmental pollutions stemming from previous industrial revolutions, and yields more feasible and sustainable solutions for today's manufacturing systems.

While the workplaces are becoming more automated and observing rapid digitization in production, it is very clear that employees' personal and professional lives will never be the same again. In one dimension, current occupations are expected to reshape their existing processes and procedures with the harmony of changes. In another dimension, some jobs are believed to be vanished as a result of high automation and digitization. Although there is no clear guess about to what extent employees will their jobs, it is obvious that industries will not be functioning like a decade ago. Despite of the dark scenarios, new industries and related jobs have already been emerging which will require new workforce demand [15].

Most of the countries have already recognized the challenges of their Industry 4.0 transformations (Fig. 12). One of the most major concerns is the employment related issues. Due to several technological developments (such as automation, digitalization and robotics), people discuss whether or not they will keep their jobs or positions in their professions. The answer is two-folded; if today's labor forces do not update their existing knowledge, skills and abilities in parallel to recent advancements or new job requirements, obviously they will not keep their positions or jobs. Therefore, with a great emphasis on European Union policies, many countries have been triggering

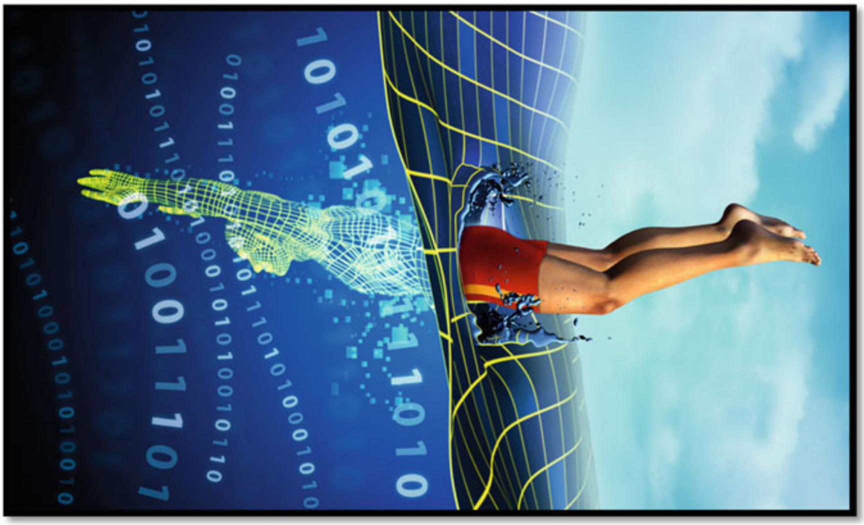

Fig. 12 Digital transformation is indispensable

'life-long learner' phenomena for the sustainability of industries for the next decades. Additionally, it becomes more unconcealed that prospective jobs will require more cognitive and systems oriented skills than previously demanded physical abilities.

As an example to changing required skills and abilities, Aulbur and Bigghe [3] have been offering a list of significant skills and abilities for the employees of Industry 4.0. The list has been divided into two major branches: more focus (knowledge about ICT and ability to work with data) versus less focus (technical know-how and personal skills) in Industry 4.0. 'Knowledge about ICT' covers knowing the fundamentals of information and communication technologies, utilization of computers, robots, tablets and similar smart devices, being acquainted with the basics of machine to machine communication and being aware of cyber security and data confidentiality issues. Second more focus issue about 'ability to work data' which shows the unique emphasis on the significance of data-driven decision making. That group includes the fundamentals of statistical knowledge, the ability to gather data from different smart machines and to process and analyze that data set, an understanding of visual data output and lastly using the previous steps to make an efficient decision on the issue.

Beyond that specific and dominant focuses, Aulbur and Bigghe [3] continue their list with secondary focuses. 'Technical know-how' addresses general technological knowledge with an interdisciplinary approach, focused knowledge on job related production processes and technical know-how for smart machines' maintenance. Last item of the list focuses the social dimension of humans; 'personal skills' wrapping written and oral communication skills, ability to work in teams, shifting toward being a lifelong learner, creative decision making and personal adaptability capacity toward changes in workplace.

7 Industry 4.1—the Blockchain

While IoT has been offering distributed, autonomous and interconnected communication and cooperation in Industry 4.0 framework, it also brings several challenges of security resulting from its innate connected structure. That super connected world has often described as the Achilles Heel of the Industry 4.0 which brings many cyber security issues and concerns to the smart manufacturing. That is where Blockchain technology helps the existing IoT and all other Industry 4.0 processes and procedures by providing a distributed ledger technology for their security in transactions and interactions. In that case, Blockchain could be perceived as an evolution in Industry 4.0 making a change enough to be called as Industry 4.1 (Fig. 13).

Blockchain could contribute to all different manufacturing processes, procedures or projects when there are different stakeholders interacting on a networked business model. These contributions could be depicted as the assistance in supply chain automation and integration, the tracking and tracing the life cycle of products, and the security of IoT intelligence within the system [29]. As industrial revolutions have been influencing the dynamics of supply chains, it is expected that Industry 4.0 will alter many things for supply chain management and sustainability issues. Blockchain technology has become one of the central issues for the prospective supply chains where the procedures will be more secure with its fraud detection and prevention features in which each manufacturer will be able to follow the flow of supply chains [6].

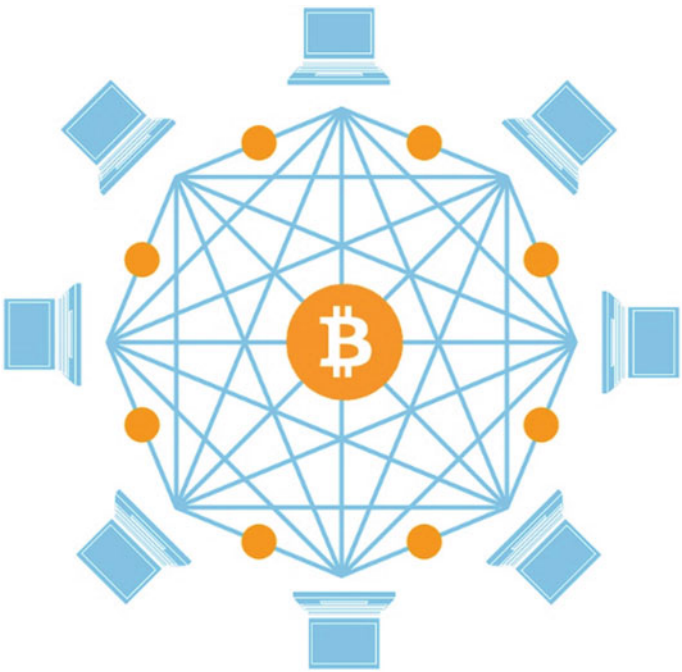

Fig. 13 Blockchain evolution plays an important role in Industry 4.0 revolution

Big data has also a strong relationship with Blockchain technologies since large datasets are travelling through different network paths. For instance; Encryption algorithms will provide more freedom to people to focus more on their business processes and customers. Same encryption will decrease the tension for cloud based solutions where the storage and transfer of personal or financial data are labeled as not-secure-enough. Moreover Blockchain technologies also offer real-time decision making opportunities for augmented reality integrated systems, especially for mobile gaming industry. Last but not least, crypto-currencies are another hot topic for not only personal level but also state level discussions [33]. Starting with the mining/hunting bitcoins, Blockchain has suddenly become a dinner table or party topic. Although many other advanced technologies have emerged within Industry 4.0 framework, none of them has become that famous as Blockchain, or Industry 4.1.

8 Conclusion

Humanity has spent thousands of years to witness life-changing world-wide revolutions after the Homo Sapiens' imperative agricultural revolution. As the world population has grown exponentially, the demands have also amplified. Therefore, people have changed their production processes and procedures to overcome those immense demands. At the end of the 18th century, humanity faced with the first industrial revolution yielding toward mass production (the mechanical period). After initial attempts toward providing demands, that time humans asked for customization which triggered the second industrial revolution and its electricity based devices, such as assembly lines (the electrical period).

Having the power of electricity, people have produced more devices with huge capabilities, such as computers, robots and the Internet. In that Industry 3.0 period (also called as the computers' period), many information and communication technologies have been designed, produced, implemented and integrated not only into the different industries but also into the daily lives of many people. Previously unimaginable things have become the realities of the humans. People have possessed the computers and several other mobile devices in along with the super communication power of the Internet.

In the last stage of industrial revolutions, people have been introduced to cyber-physical systems which have brought smartness to existing technologies. For example, factories which were initially developed to address mass production demands have become smart factories where many processes and procedures have altered to automatic actions controlled by computers. Recently, people have been witnessing to smart homes, smart phones, smart transportation or any other smart cyber-physical systems.

Among all these highly-connected lives, people have developed security and trust related issues. Hence, Industry 4.0 revolution has evolved with a new technology named Blockchain. Blockchain (as I call 'Industry 4.1' evolution) technologies have been providing trust-establishment and confirmation to all stakeholders connected through different technologies in different networks.

9 Summary

In the thousand years of human history on this planet, we have seen many revolutionary acts changing the human lives from deep inside. The industrial revolutions have an exceptional standpoint among all other revolutions due their complex nature of affecting economies, technologies and social lives. Although writing absolute time of changes has been difficult, the industrial revolutions were divided into four period of time starting from the late 18th century up to today.

The first industrial revolution was triggered by the uses of alternative energy sources (especially steam power) and leaded the advancements in transportation, logistics and cotton/textile industries. Starting in England, the effects of first industrial revolution jumped to mainland Europe and then the USA. The second industrial revolution was happening in the USA as a result of high immigration rates changing the demographics of the country and the usage of new energy source; the electricity. The assembly lines which were working by the electricity resulted in mass production approach where the high demand from public was satisfied by big factories.

In a relatively short period of time, the third industrial revolution has begun where the mass production and electricity contributed to the development of integrated circuits, programmable logic controllers, the Internet/Web and computer technologies addressing hardware/software developments (from the end of the second world war to the millennium). The focus of manufacturing has also shifted from mass production to mass customization.

In 2011, the fourth industrial revolution has been labeled in Germany and defined by cyber physical systems serving to digitalization of industries. Applications of advanced technologies (artificial intelligence, virtual/augmented reality, robotics/drones, cloud/parallel/quantum computing, big data, Internet of Things, 3D printing and many others) into different industries and their manufacturing services and processes have altered the dynamics of everything. Many other countries such as France, the US, South Korea and China have been released their strategic plan toward the digitalization of their manufacturing processes.

As a final evolutionary technology; Blockchain offers several opportunities and contributions to existing Industry 4.0 framework and any related manufacturing processes and procedures. Therefore, the future of industrial revolutions will be witnessing more blockchain integrated solutions.

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Blockchain and Industry 4.0: Overview, Convergence, and Analysis

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Abstract As a consequence of the upcoming fourth Industrial Revolution, also known as Industry 4.0 (Industry 4.0), new disruptive technologies are being considered to be incorporated in the factory environment. One of these solutions are the Blockchain, which aims to integrate heterogeneous systems, manage commercial transactions and foster the assets' traceability. Thus, this technology contributes to create a whole optimized supply chain that can impact in the global market. This chapter exposes the convergence of Blockchain and Industry 4.0. In this way, academical, commercial, and governmental initiatives are explored to present examples of what is currently being proposed, fostered and developed. In addition, a critical analysis covers the aspects of how these technologies can be synergically and efficiently integrated in a future society and industrial environment.

Keywords Blockchain · Industry 4.0 · Another keyword

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1 Introduction

As a consequence of the upcoming fourth Industrial Revolution, also known as Industry 4.0, new disruptive technologies are being considered to be incorporated in the factory environment. Since this approach encompasses the complete industrial cycle, from the raw material extraction to the final good disposal, Blockchain technology poses as an exceptional candidate to be integrated in the industrial plants, given its key features such as immutability, traceability and reliability of information.

Considering the convergence of Blockchain on Industry 4.0, the Blockchain technology might increase the own Industry 4.0 efficiency, security and provenance concerning the related data of goods, assets, and operations. Moreover, Blockchain also aims to integrate heterogeneous systems, manage commercial transactions, and foster the own assets' traceability. In another way, Blockchain empowers resources as provenance records, quality control, and transactions with virtual smart contracts that involve autonomous agents. Furthermore, it can be combined to the smart Enterprise Resource Planning (ERP) technology to make the inventory management, the production scheduling, and products purchasing and selling processes in an autonomous fashion. Additionally, the Blockchain can validate whether a given enterprise is complying with the proper regulations, for instance concerning the hazardous materials disposal. Thus, this intertwining is vital to create a whole optimized Supply Chain that can impact in the global market.

This chapter surveys Blockchain application in Industry 4.0, exploring its usage in the extent of Machine-to-Machine interactions, Cyber-Physical Systems, and Smart Contracts. Whenever it is possible, academical, commercial, and governmental initiatives are explored to present examples of what is currently being proposed, fostered and developed. In addition, a critical analysis covers how these technologies can be synergically and efficiently integrated in a future society and industrial environment. Moreover, it is shown how the Blockchain technology can enable upcoming trends such as Smart Contracts and Economy of Things, uplifting the Industry 4.0 impact and also enduring the autonomous systems' resiliency, scalability and safety.

In order to achieve these aims, it is presented a background in the Sect. 2, which includes a broad explanation of Blockchain and its development, the previous three Industrial Revolutions and the upcoming Industry 4.0, separately. Moreover, the Sect. 3 focuses on the convergence of both Blockchain and Industry 4.0, providing some background on their synergy and challenges that one might face during their integration, always grasping on the possible impacts that might be seen in the whole society and how these trends can interact to optimize the current industrial related processes. Further, the Sect. 4 briefs this chapter in a comprehensive manner, consisting in an overview of what has been discussed in the previous sections. Finally, Sect. 5 concludes the chapter.

2 Background

This Section contextualizes the Blockchains' technology and the industrial evolution through the Industrial Revolutions, acting as a background to the reader. The goal is to provide a comprehensive overview of the basics of each trend solely, which is truly important to achieve a better understanding of what is going to be discussed further. Thus, it covers what is this current "hot topic" called Blockchain, discussing its technology, how it differs from the cryptocurrency, which is a common assumption that they are the same thing, and its evolution. After this, it is offered a brief review on the Industrial Revolutions, encompassing a vision of how the world was before the very first until the third one. Finally, this Section is concluded with the Sect. 2.6 focused on the Industry 4.0 solely, offering a view of what is this thematic alone, which technologies are being analyzed as enablers of this concept and how this may change the overall society.

It was chosen this approach in this section to provide a far-reaching vision of each trend alone, without considering their convergence. This topic relates to what is discussed in the Sect. 3.

2.1 Blockchain

In the context of Industry 4.0, one of the technologies described as an enabler for this revolution is the Blockchain. It has provoked a lot of excitement and enthusiasm in several segments, but we cannot talk about Blockchain without mentioning Bitcoin, the origin of everything. In the late 2008, an article called "Bitcoin: A Peer-to-Peer Electronic Cash System" [33] was published by the author under the pseudonym of Satoshi Nakamoto, a mysterious figure who is not yet known. In this document, he proposed a decentralized digital currency without intermediaries and owner, which would not require trust between the parties, a true revolution. Many consider Bitcoin as the web of money.

In the development of his work, Satoshi Nakamoto proposed a solution to the double-spending problem, since digital currency is actually a set of binary information stored in a device, it could be easily created, copied, and reused indefinitely. Another key point was the development of a consensus protocol called Proof-of-Work (PoW) to support a decentralized and distributed network with partners, in which trust and intermediates are not required. In short, his proposal was composed of:

1. Digitally signed cryptographic currency transactions recorded in an accounting book (in Bitcoin's terminology, one block). Each block also has its own unique signature, called a hash, which is stored in the block behind it, forming a chain of signatures (Blockchain). The signatures of the blocks are used to verify the integrity of the block and consequently of all the blocks before it.

2. A server with timestamp to digitally sign the date and time of each block, serving as proof of its existence on the network.
3. The Proof-of-Work protocol, which determines how each transaction should be processed, validated and registered. In addition, it also delineates how the network will behave in case of adulteration and divergence in the records. In other words, since each participant has a copy of the data, they may have every incentive to tamper with it, while presenting themselves as true and fool the network.
4. The network structure and policy definitions governing the entire arrangement.
5. Financial incentive for participants who are engaged in processing transactions.
6. Digital ballast and traceability of all currencies in the network, to prevent someone from creating money out of nothing.
7. Privacy through the employment of public keys that identify participants anonymously, even though the registration of transactions is a public information.

Based on these guidelines, Bitcoin is born, a cryptocurrency enabled through the first generation of the Blockchain technology. This electronic cash is a totally decentralized and distributed system, without intermediaries and totally safe. Figure 1 illustrates a simple overview of the Bitcoin network and its main elements.

After the vertiginous growth of the Bitcoin, other Cryptocurrencies has been appearing exponentially. Currently, there are more than 1,000 different Cryptocurrencies, with an initial market value of at least US$400,000 for the less valuable coin. In March 2019, the cryptocurrency market is estimated at US$ 177.70 Billion, in Fig. 2 we can see the participation of the main cryptocurrencies and their share in the market.

Although Blockchain was developed as part of the enabling solutions for the operation of the Bitcoin network, it has propagated independently, existing out of applications with cryptocurrency. The operation of Blockchain is quite simple. Technically, we can classify it as a shared database, formed by hash strings. Figure 3 gives a closer look at how the Blockchain operates.

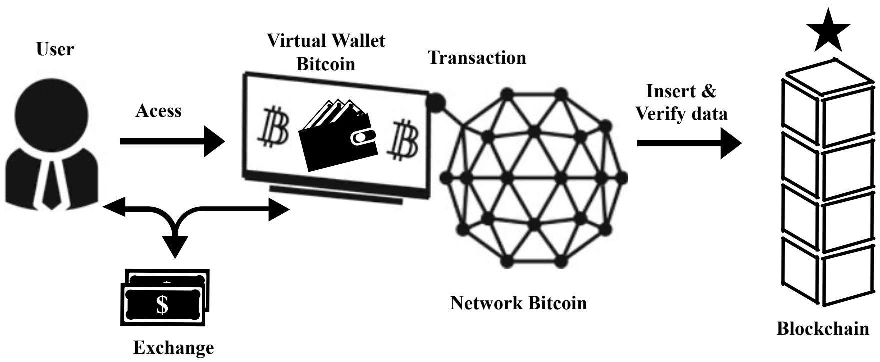

Fig. 1 A simple bitcoin network

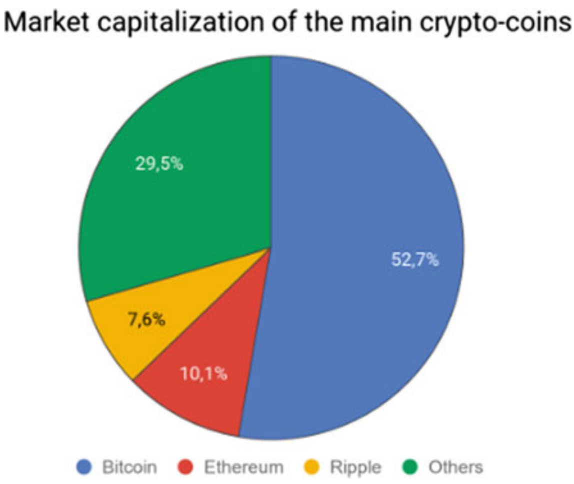

Fig. 2 Market capitalization of the main crypto-coins. *Source* https://coincodex.com/

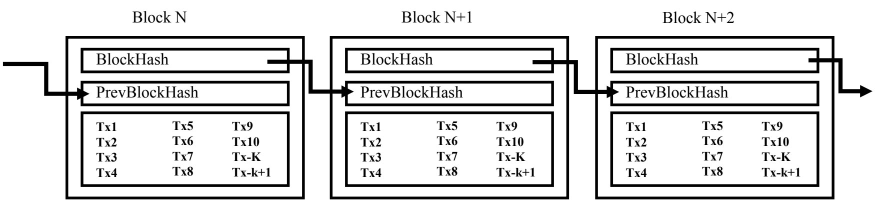

Fig. 3 Blockchain design

The boldness of the Blockchain system lies in implementing a shared database that everyone has access to their information [47]. This implies that it could compromise the security and privacy of the information stored within its database, yet Blockchain technology remains completely secure to the point where people trust their money to Blockchain (lots of money). Nevertheless, this fact is only possible thanks to the use of encryption and the consensus protocol, which in Bitcoin's implementation is called Proof-of-Work.

Conceptually, Proof-of-Work is one of the possible solutions to the problem of the Byzantine fault, which models situations that a decision must be taken from several sources of information, even considering that they may be contradictory. In Proof-of-Work designed Blockchains, it is necessary that 51% of the nodes in the network are honest to guarantee a reliable system. In spite of being effective, this type of protocol requires an enormous demand of electrical energy by the validating nodes (in the Bitcoin network they are called miners), which have the function of validating the information of a block. Due to this electrical consumption, China is currently considering to restrict or ban this mining activity in its country because of the number of miners and the impact in electricity generation.

Table 1 Consensus protocol comparison

Protocol	Description	Performance
Proof-of-Work	The validators in Bitcoin's protocol use their computational power to work on a mathematical problem that is difficult to solve, but easy to verify the solution. The one who resolves first wins a prize and his block is published as true. To subvert the network, the attacker must have computational power greater than 51% of the entire network	10 transactions/min in Bitcoin
Proof-of-Stake	The validators in Ethereum's protocol participate through their economic power. In an alternate way, the validators propose and vote in the next block, the weight of which depends on the amount deposited in custody. Bad behavior is penalized by the loss of investment	12 transactions/min in Ethereum
Consensus	The validators in Ripple's protocol have a certain level of trust. Participants choose a set of validators, and they must not be compatible with each other. At each stage the validators add or remove transactions to their proposal until they reach consensus	1000 transactions/min in Ripple

However, any node could publish information in Blockchain as if it were true, creating chaos if the Proof-of-Work did not exist in its layout. In order to give another examples of this protocol, we can cite the Proof-of-Stake [34] used in the Ethereum (ethereum.org) and Consensus [49] platform in Ripple (ripple.com). Table 1 provides a comparison between such consensus protocols.

2.2 *Blockchain 1.0*

Since the launch of Bitcoin, Blockchain has undergone a process of maturation and evolution, as well as consensus protocols. In its first release, Blockchain 1.0 was just a shared ledger that recorded transactions, with a full focus on money [35]. The process of validating a transfer is done through the traceability of the origin of the money that such user claims to possess and the digital signature of the fund that proves its belonging, since all money circulating in the network is produced by itself in a totally virtual process. In other words, there is no external monetary data entry in Blockchain 1.0. This feature is essential to guarantee security and reliable traceability of money, since it has a bearing on the origin of the currency that is formed in a block by the mining process and not on an external information that may be untrue or a fictitious creation and unbridled. We can draw a parallel with the real money banknotes, which can be generated in an infinite way and are under the centralized control of the government. Another example is gold, which is a finite resource, with its value fixed in an interaction between supply and demand markets (so it is not centralized) and can not be artificially created.

During the construction of Bitcoin, its core was defined in a very solid way to be able to support any type of transaction imaginable [36]. However, the diversification of transaction types would require support codes and specific data fields that would need to be introduced in Blockchain for each special case, even if they were not used by all, thus generating an infinite demand for special cases. The generalization of this problem has the concept in which the parties involved can describe their conditions in the form of scripts for certain transactions to occur. Therefore, the network only has the function of evaluating if the conditions are being fulfilled. This concept was developed and implemented by Satoshi Nakamoto, who foresaw that these applications would be explored in the future, but they should be designed in the beginning.

In a 2010 statement, Nakamoto stated that "The design supports a tremendous variety of possible transaction types that I designed years ago. Escrow transactions, bonded contracts, third party arbitration, multi-party signature, etc." [36] As a consequence, this is the starting point to the so-called second-generation Blockchain.

If Blockchain 1.0 is considered to be the decentralization of money and payment, Blockchain 2.0 has come to bring the decentralization of the markets, enabling an environment with smart contracts, tokens, decentralized application (DApps), decentralized autonomous organizations (DAOs), crowdfunding, mutual funds, transfer of properties, records, securities, loans, intellectual property, among others. The main point in this evolution points to the diversification of applications using Blockchain in addition to cryptocurrency.

2.3 Blockchain 2.0

The Blockchain 2.0 is being referenced with the milestone in the application of smart contracts, which became popular through the Ethereum Blockchain platform. Although the term "smart contract" has attracted much attention recently, it has been known since 1997, introduced by computer scientist Nick Szabo. With security intent in mind, Nick Szabo argued that "the formalizations of our relationships, especially contracts, provide the ideal security model" [37]. Therefore, through the incorporation of contractual clauses in hardware and software, one could achieve the breaking of ambiguity caused by different interpretations in a contract, once that programs in a computer act deterministically. Based on this concept, it would also be possible to offer resources such as guarantees, binding, property rights and other relationships that would act automatically (without the need for an intermediary to validate/guarantee both parties) and also avoids the unilateral breach of the contract. An example to demonstrate the aforementioned statements can be observed in the possibility of correlating the vending machines to a conceptual test of smart contracts. Through the mechanism of receiving notes, coins and cards, the vending machines carry out the sale of a specific product, upon receipt of the pre-agreed amount. Thus, establishing a buying and selling relationship without intermediaries. Confidence in this contract lies in the correct functioning of the machine and the security against fraud and intrusion so that implementation becomes viable. This relationship also exists in smarts contracts that resides in Blockchains 2.0, but at a more sophisticated and also dangerous level. Therefore, smarts contracts in a Blockchain allow the development of business logic in the form of a program, triggering events of this logic through messages, digital signature as a foothold in security identification and lastly immutability. A famous and catastrophic example that an error in the implementation of a smart contract can cause is the case of Genesis DAO, or "The DAO" [38] in the platform Ethereum, a DAO is a decentralized autonomous organization.

The DAO was an entity that operated on the Ethereum platform through smart contracts. This was created in 2016 with the intention of operating as a venture capital fund, but without a central authority, depending on the operation of a Blockchain. Shortly after its implementation, it became a major success, becoming the largest crowdfund with an estimated value of US$ 250 million. The goal was to fund promising projects and ideas, by which any user who invested in the fund received DAO tokens as a return. The tokens received were used to vote for a given project, receiving rewards if it generated profit. However, exploiting a flaw in the coding of the DAO smart contract, a hacker was able to unduly withdraw US$ 70 million from the fund. In response, the Ethereum developers proposed a hard-fork, creating a second timeline on the network, starting from the block before the hacker attack, to restore The DAO's funds. This action was accepted by almost 90% of the users of the network, yet those who did not accept continued to mining in the main branch, causing the appearance of Ethereum Classic. As of this episode, the Blockchain Ethereum continued existing, being considered the official asset, but suffering from great loss of credibility and market value for hurting the principles of immutability and impartiality, since the hacker did not hurt the clauses of the pre-established contract even being unethical.

In principle, smarts contracts in a Blockchain are mere permanent and irreversible codes, and are subject to the same flaws and bugs as any other software. As each person before signing contract needs to be aware of the terms in an agreement, the code in a smart contract is transparent and available for anyone to read it. This feature of smarts contracts in a Blockchain ensures that everyone is aware of the clauses before adhering to it, but it also enables malicious agents to exploit flaws more easily, since the codes are completely accessible. Such vulnerability was not related to Blockchain itself, but to the application developed on it. By design, smart contracts in a Blockchain are immutable. Therefore, even presenting unexpected behavior, they can not be rescinded or updated, which is a fundamental point in the development of software to reach maturity [39]. Even a clause permitting this type of action would be another point of vulnerability because it could allow the unilateral breach of the contract for unfair reasons. Thus, exploited bugs in a smart contracts that have direct control over the assets managed by them can lead to unwanted transactions that will be chained in the Blockchain permanently, without the possibility of reversal, except for a hard fork. Apart from these sensitive points, smarts contracts work poorly for high rates of transaction transfers. Transaction parallelism, which could help increase Blockchain efficiency, does not work well because transactions and the order in which they occur impact the bottom line. As there are no central management queues, each transaction arrives at different orders, so each new block is also inserted in its own time. In order to avoid this chaotic process that can affect the results, transactions are only processed after their request is confirmed on Blockchain. In this context, we are only taking into account the problem of synchronization of in-chain data, but this issue grows exponentially if we insert in the context the fact that smarts contracts can receive information from the off-chain, opening a great door for the insecurity of the whole chain. Therefore, in order to prevent the development of impossible smart contracts, one must take into account the reality of its characteristics, its benefits, and also its critical points.

Allowing the integration of external data (off-chain) to the network (on-chain) is one of the most sought after challenges. By solving performance and synchronization problems, it is possible to make Blockchain and smart contracts more efficient, while solving the problem of integrating off-chain data that will make it more efficient. In a scenario where Blockchain is restricted only to its universe, that is, only to data presented on-chain, the possibility of varied applications becomes quite limited [45]. However, this integration is not trivial, since data entry in Blockchain can become a window into hackers' action, opening up the possibility of spreading false information on the network immutable. This scenario can still worsen if off-chain information is the trigger in a smart contract. Alternative paths using the off-chain concept are being explored to increase Blockchain's efficiency, understanding that the main bottleneck in information processing lies in the time it takes to achieve convergence on actions and results. This is because the network operates without an intermediary that guarantees the security, uniqueness and veracity of the information. The Blockchain network requires users to participate in the consensus process and learn about each update, so that they together maintain the integrity of the network. However, hardware restrictions and user bandwidth are a constraint to the development and efficiency of the Blockchain network. Given this scenario, projects like Raiden Network (raiden.network) and Lightning Network (lightning.network) propose instantaneous and scalable payments occurring outside of Blockchain. At first, the idea is to use smart contracts on-chain so that the participants transfer their funds and receive tokens equivalent to the amount deposited, giving the smart contract the power over the asset. An off-chain channel is established for instant and unlimited transactions, restricted only by the amount of tokens held by the user. This process does not require a global consensus, being protected through digital signatures and blocking of expenses until the conditions established in the contracts are met. When the transaction channel is undone only the final balance is published on-chain, thus preventing the publication of multiple transactions. Finally, users redeem their money with the trust of on-chain applications based on smart contracts.

The collection of data and off-chain information is quite critical, since Blockchain acts in a deterministic way to verify the originality of the data. Therefore, a node must be able to trace the origin of the information backwards in the chain at any time, just by using the chain's own data. This design is restrictive to off-chain information because it can not be deterministically verified or provide cryptographic evidence of its truthfulness. Even in a scenario with multiple sources of the same information, allowing the confrontation among them, this model does not guarantee a deterministic and verifiable security, it guarantees only a tangential reliability of the information. The case worsens in scenarios where the variety of sources of information is limited, or even an unique and exclusive source of information, making it impossible to confront divergent information. The system responsible for integrating off-chain data into the network and to the smarts contracts is given the name of oracle [46]. Revisiting the origin of the word, the oracles were responsible for interpreting and bringing messages from the gods and transmitting them to the people in the ancient Greece. The challenge of the oracles in the Blockchain network is to bring an acceptable level of trust to off-chain information, contradicting the very nature of Blockchain, which proposes to exist without trust and in a decentralized way. This paradox can be less problematic if oracles are decentralized, making them less vulnerable to manipulation, attacks, and isolated failures. Considering the outside environment that feeds the Blockchain and ensuring a reliable system that is able to tell whether a proposition is true or false is extremely difficult. The syntax and semantics in the formulation of a proposition and even the different versions of the same observed event can lead to a single system divergence on the same fact in different moments. We can see this phenomenon in the own society, however, for practical purposes, we will disregard this type of scenario. Some projects that seek to operationalize the system of oracles are:

1. Chain Link: Formed by a decentralized network, relying on reputation and reward to users who provide data feed. It acts as an information validation and certification service for smart contracts (chain.link).
2. Augur: Enables business in a decentralized forecasting market, in which users can bet and contribute their knowledge about a certain event, thus achieving the "wisdom of the crowd" (augur.net).
3. RLay: Acts through a protocol called Proof-of-Coherence. It allows customers to prove and validate propositions asserted by untrusted clients, not depending on a single source. Users receive rewards for converging statements (urlrlay.com).
4. Oracalize: Delivered data has a "proof of authenticity" based on software, hardware, or digital signature of the source. There can be more than one test for each given data, being these attested by different entities that do not have knowledge of the context to compromise it (oraclize.it).

Despite the presented oracle protocols, no consensus exists on which should be used and their potential impact. Issues such as limited number of supported applications, security, deterministic verification, financial incentive among other reasons are still obstacles to be covered until off-chain data is a reality on a large scale.

2.4 Private Blockchain

The private Blockchain is based on the concept that not every application should be open for any user to write on their records or read them. Some systems only make sense to a very specific niche of users or their information should not be shared with everyone. Thus, we are characterizing who can or can not write in the blocks when we talk about public and private Blockchain. However, we can also categorize Blockchain as open and closed to specify who is allowed to read the data. When we talk about private Blockchain or by consortium, we are talking about Blockchains that are restricted to a certain number of users or even to specific users, as well as having different contours as regards trust, anonymity, and performance [41]. Table 2 lists the types of blockchains and some examples of applications most appropriate for each specific type.

Much of what was said about Blockchain and some of the platforms covered are in the open and public Blockchain field. This type of Blockchain follows the original design of decentralization without intermediaries, anonymity and a network without

Table 2 Types of blockchain and application areas

Public and Closed	–Voting –Voting records –Whistleblower –Internet of Things devices
Public and Open	–Currencies –Betting –Video Games –loans
Private and Closed	–Construction –National Defence –Law Enforcement –Military –Tax Returns –Contracts –Genome data
Private and Open	–Supply Chain –Government financial records –Corporate earning statements –Vehicle registration –Business licenses –Certificates –Degrees –Grades –Identity cards –Pass-ports

trust among users. However, in some specific situations, we have the desire to create restrictions on these characteristics [44]. For example, when we talk about permissions policies to read and/or write data, it only makes sense if we know who these users are, so we give up the anonymity. If we now know who are the users participating in the network, it is possible to establish ties of trust if desirable, since it can be held responsible for negative attitudes. As stated earlier, Blockchain's efficiency is constrained by the time it takes to achieve convergence of results. If there is a certain level of confidence in the network, robust algorithms like Proof-of-Work are not essential. In this case, the system is still decentralized, but consensus algorithms with better performance can be used. In a public and open Blockchain, the validators are encouraged and rewarded economically for their honest behavior. Considering private Blockchain, the financial incetive for block validation may exist, even if it is not a rule to penalize unfair behaviors.

The great incentive for users to participate in the network is in the very purpose of the application. Thus, it is possible to note that public and private Blockchains have considerable design divergences. In fact, most of Blockchain platform developers consider their private use to be ideal [43], some of them are committed to the original Blockchain design proposals and others due to the belief that Blockchain loses its meaning and can be replaced by traditional database models, secured by a common trusted intermediary. However, projects such as Linux Foundation's Hyperledger, R3CEV Rope and the Gem Health network are examples of investment and interest in this type of Blockchain. Some positive examples that are only achievable with Private Blockchains are:

1. Consortia or companies with different departments that wish to integrate relevant data can, if desired, change Blockchain's rules and revert transactions. Unlike the public Blockchains where immutability is the law, rewritable chains in the private context are a valid choice. For these institutions, immutability can only be encouraged by the good behavior of its co-participants [40]. As a benefit of this design, it is much less costly to execute Blockchain and much more efficient, as the institutions jointly sign a block to corroborate its validity in the network
2. The collusion of most nodes that can subvert the purpose of the network is a possible situation in both public and private Blockchain. However, such behavior in a private environment may be curtailed by real contractual clauses. In public Blockchains, the only protection that exists is the very robustness of the network that works to avoid collusion and centralization, but once this barrier is overcome, there is nothing that can be done.
3. Transactions are cheaper and much faster because a much smaller number of validators checks them.
4. Read restriction to accredited institutions provides a higher level of information privacy.

2.5 The Industrial Revolutions so Far

Industrial Revolution is a concept used to designate certain events that leveraged and changed the means of production reality. In other words, it can be treated as an occurrence that drastically altered the concepts, practices and mentality of not only the people, devices and processes associated in the factory's environment, but also of the society in a general manner. In about 350 years, the world went through three big phenomenon of this aspect, which turned a predominantly handmade landscape into an industrialized society.

The manufacture and production processes barely altered in the period before the very first Industrial Revolution, which can be considered from the moment that the men tamed the fire or even when humans began to cultivate its own aids through agriculture and livestock until the mid-18th century. Certainly in this long era, the practices developed, yet slowly and without great technical advances. Just before the 18th century, the production of goods was mostly characterized by the handicraft, either through human work or animal traction. These agents were the main accountable to execute the tasks and transform what the seasons could offer in terms of goods and subsidies. Logically in this past, the processes' efficiency was extremely low and such practices would be feeble to supply a huge population of humans or even to grant the survival of a non-agricultural society of the period, which would rarely receive external aid due to the precarious logistics to connect two distant places and the lack of shipments reliability. In addition to this, the production was slow, mostly due to be highly dependent of seasonal factors.

This reality improved as time passed, but it was only in some time between 1760 and 1840 that happened what is called the first Industrial Revolution. Such occurrence began in England and expanded to the other European countries and the United States of America, inserting mechanized processes in the industry, especially in the textile sector, in the agriculture and in the transportation. Some of the inventions of the period can be illustrated as the mechanical loom, the steam machine, and the automatic seeder. In addition to this shift in the production, new energy sources were developed, such as the thermal, through steam and coal, which were the fuel used to boost the work of mechanical devices. In this way, the production lines began to change from a totally dependent manual labor to machinery driven factories.

From this moment on, the whole society passed through a shift with no turning back. As a consequence of this transformation prospect, the wealth concentration also departed from the traditional handicraft and craft trade to the industrial sector. Through this economical might, efficiency, effectiveness, and innovation were boosted in order to optimize the processes and triggered the Second Industrial Revolution in mid-19th century. In this event, one of the greatest landmarks can be exemplified by the creation and rise of Fordism, the basis of standardized mass production through assembling lines, standardization of products being made by specialized machines, and higher wages to the employees. Besides of this, it was embraced new energy sources to boost industrial means, such as Fossil fuels, especially petroleum to drive internal combustion engines, and Electric power in overall society.

Furthermore, new synthetic compounds, fertilizers and dyes were introduced in the industrial processes. After the Second Industrial Revolution, the world would rely more and more on industrialized goods as time went by.

At last, the Third Industrial Revolution happened after the half of the 20th century and it characterizes the current reality of most of industries in terms of practices and equipment employed in production lines. Through this occurrence, the advent of electronics and communication technologies in factories boosted by the usage of transistors and integrated circuits in place of vacuum tubes and electrical switchboards, enabled the miniaturization and programmability of industrial equipment. In addition to this, it was adopted industrial networks to interconnect devices and the generated data to automate the processes, in a way that industrial computers and programmable logic controllers can manage every single task of the production floor. Besides of these, several other clean energies sources began to be promoted, such as solar and nuclear power plant to generate electricity, along with the first records of robotics process automation used in assembling lines, the advance of biotechnology, and Genetic engineering.

Consequently, it worths to acknowledge that the industrial careers grew specialized as each Industrial Revolution unfolded, which has always been increasing continuously since the very first revolution advances. This made past practices inefficient and obsolete in new scenarios, probably fostering the bias that assumes that new technologies are "evil" and steals employees' job. Nevertheless, as much as the practices changes and new technologies are introduced into the industrial environment, it is important to recognize the other side of this situation. Throughout this period of roughly 350 years, the society has changed dramatically in terms of mentality, globalization encompassed new communities and the global population grew exponentially. This requires that the production means also change and improve to meet the new reality and satisfy a fair world quality of life of the respective period (being it good or bad). Besides of this, it must concede also the shift of the own employee's perspective, which can be aided by new equipment that can execute most of the manual work, for instance lifting heavy weights, performing repetitive tasks, or acting in hazardous environments that could permanently damage the welfare or even endanger the worker's life.

2.6 Industry 4.0

The Industry 4.0 concept was developed in the mid of 2010 through a German government strategic initiative, aiming specially to transform Germany in a pioneer country in terms of the employment of new technologies derived from Information and Communications Technologies (ICT) in the industry. In this way, it could boost the factory's process, or, at least, ensure the industrial competitiveness upkeep of their country in a global environment, along with their industries' renewal. This initiative was proposed by the German's Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung) and Federal Ministry for

Economic Affairs and Energy (Informationen des Bundesministeriums für Wirtschaft und Energie), also relying on the support of the German's academical community and private enterprises.

Comparing this proposal with the Third Industrial Revolution legacy, the industries began to apply the concept of ICT in their business, through industrial computers, desktops, electronics' development, automation employment in the production lines, and the introduction of ICT systems in the industrial environment. However, the sole Industry 4.0 concept is not fostered by a single technology movement of a single revolutionary tendency, as happened with the previous revolutions. Thus, its main approach predicts the interconnection of every single technology present in the industrial environment, enabling the process of data gathering, decentralized massive analysis of industrial data, and making the best decisions based on the knowledge base acquired from the previous operations. According to the performed research, these characteristics are empowered by nine distinct technologies, which are related to Industrial Provenance, Augmented and Virtual Reality, Cloud Computing, Big Data and Data Analytic, Simulation, Internet of Things, Cyber-Physical Systems, Addictive Manufacturing, and Collaborative Robotics. A brief overview of each technological axis, how they interact each other, and how they reshape the industrial environment under the Industry 4.0 vision is provided.

Industrial Provenance: Under the Industry 4.0 scenario, the concept of industrial provenance relates with the goal to provide the origin of applications, raw materials or products in all theirs life cycle through ICT. Therefore, the provenance ensures the knowledge associated with the overall data belonging to something of interest, such as the momentary location, whether the requirements are being met, and the quality and origin of a given good. Concerning the enterprises, this provenance represents the control over the product, ensuring the awareness of every single process that a given good has been exposed, its origin, which batch this product belonged, which set of raw material were used, if it was required to be refurbished or if there was a product recall.

Augmented and Virtual Reality: After decades of development and experimentation, the great progress in the field of digital technologies fostered the implementation of an environment committed to the Virtual Reality and Augmented Reality, which can impact in reshaping the traditional industrial model. Conceptually, the Virtual Reality aims in inserting its users into virtual environments, while the Augmented Reality focus in inserting virtual objects into real environments.

Considering the industrial segment, these technologies enables a more specialized personnel training, as well as to foster interactive design techniques of products, equipment maintenance, decision making, and security control. For instance, it is possible to make available a virtual product in full scale through the design stage, in a way that the developers can interact with it and make changes upon the virtual model without prototyping it in the physical world. Another case can be given in the personnel training sector, in which a Virtual Reality technology can reduce the required resources to train the workers, also granting the possibility to analyze the individuals' reactions when submitted to critical situations without endangering them in fact. Thus, the usage of simulators can offer a considerable cost reduction to each enterprise that contracts these services, being these due to prototyping or training, providing more accurate situations without risking the employee, and replicating this more than once and also allow the interaction of scattered places with the same virtual object. Regarding the equipment maintenance, the Augmented Reality technology can provide every needed information of a situation through virtual contents, such as graphics, 3D animation, and videos, granting a dynamical information to the operator that follows the upkeep development by means of a smart phone, desktop, or tablet remotely.

Cloud Computing: Cloud Computing is defined as a model capable to provide computational resources on demand, which can be dynamically allocated and released with the minimal management or interaction with the Cloud provider. This makes every computational processing, sharing, and storage a service. Throughout the Cloud systems automation, it is possible to manage the Cloud data centers in a way that they share "pieces" of themselves in the shape of virtual machines and networks to the Cloud consumer. Considering the industrial environment, the integrated systems with Cloud Computer can be divided in core, business, and Cloud Manufacturing.

Cloud Manufacturing has the goal to apply the Cloud Computing and its traits in the industrial manufacturing systems, so it can be highlighted three potential areas where the Cloud technology can be applied within this environment, which are the data gathering and analyze, collaboration between factories that act under the same scope, and high performance computing and simulation. Concerning the collaboration between industries, the Cloud technology can make feasible optimized services linked to the Supply Chain and Logistics, through the application of Service Level Agreement to negotiate contracts between suppliers and service providers.

Big Data e Data Analytics: The massive data growth in the industrial sector is an outstanding characteristic of the Industry 4.0 scenario. Therefore, the processing and the usage of these data in an efficient way and bound for the productive cycle improvement is one of the biggest traits that differ the traditional industrial model from the upcoming model of industries that adopt the Industry 4.0 paradigm. In this new model, the factories apply technologies to turn raw data into useful information, aiming on achieve innovative solutions. Every productive process is followed, these data are assembled and refined from the creation and manufacturing until the product prototyping. After this, the production systems can be enhanced with the acquired information, avoiding waste, errors and risks to the operators and users. Several other benefits can be highlighted when these kind of technologies are inserted in the factory environment and in the products life cycle. Some of these advantages are related to enabling the products' customization based on the final user preference, decision making more accurate and beneficial to the enterprise based on the massive data analysis of processes, preventing risk scenarios and preventive diagnosis of equipment errors, decentralized productive cycle and better closeness between clients and industries.

Simulation: Industry 4.0 is characterized by environments where dynamical changes happen, always in a fast and exponential rate, which points to the need of a continuous evolution of the technologies and work models within this situation. As a consequence, the implementation of simulation technologies can be a potential ally of industrial process. Conceptually, simulation is a technique that uses a computation modeling process to create a representation of parts or a whole process. Throughout this concept, it is possible to analyze every stages of a given procedure previously, easing the identification of potential failures, besides of aid in preventing deadlocks and fostering the search for solution before a product achieves the production phase. Considering the great complexity of current systems, the simulation helps also in preventive maintenance, providing several situations to hypothetical scenarios, anticipating solution, analyzing processes and dealing with questions that may appear during the modeling process.

Internet of Things: Alongside with the dissemination of the Internet in the most varied sectors, several opportunities arose in the technological branches and one of these can be exemplified with the advance of machine to machine communications (M2M), boosting a developed communication that integrates people, processes, data, and technologies. This made the connections more relevant and valuables, transforming the data into actions that creates new resources, also cultivating business experiences and opportunities. This concept characterizes the concept of Internet of Things (IoT), a mundane devices' network, or "things", connected to a bigger network, Internet, and interacting with each other, with processes, technologies, and people, generating data and acting in internal and external environment through this network.

Through the insertion of Internet of Things on industrial environment, there is an expectation that a massive number of connected devices, using certain protocols to communicate with each other, will enable the factory floor's equipment to be connected to the Internet, enabling that these industrial paraphernalia work in a automatized way by received commands from smart sensors and acting through smart actuators. Another branch that benefits from this addition of IoT technology is the industrial management sector, once IoT provides a great deal of data related to the most varying aspects of an enterprise. Thus, the managers can access a great diversity of information in their own hands, which assist their decision making, impacting directly in the processes and methods adopted by the enterprise. Several benefits of the usage of IoT can be pointed, such as the increase of productivity, improved control of machines, innovation in the production strategies and enhancement in the cybersecurity sector.

Cyber-Physical Systems: The premise of keeping the industries competitive and relevant, besides of providing a highly customizable, flexible, and adaptable production of Industry 4.0 demands that the industrial processes improve and adopt technologies for fostering such reality. One of the solutions that meet this proposal is called Cyber-Physical System(CPS), which employs a concept of high computational power integrating hardware, software, and the "Digital Twin," which represents a reliable digital representation of a real environment. Through the advance of simulation technologies, Internet of Things and the high connectivity between devices, processes and data, the convergence of the real and virtual worlds are granted allied to the CPS infrastructure.

In addition to this scenario, the Cyber-Physical System technology relies in a great computational power and some traits that grants autonomy to take decisions based on the combination of disruptive technologies and on the acquired knowledge from the place that is inserted (environment), which can foster aspects of self-* properties, such as self-heal, self-adaptation, and self-optimization. Thus, it is possible to achieve an extreme convergence between the real and digital worlds, in which, for instance, Internet of Things devices can supply the Cyber-Physical System with data and the later take an action based in its database of knowledge, boosted through its power. Furthermore, the Cyber-Physical Systems are a potential technology to break the industrial hierarchical levels, promoting the so called horizontal and vertical integration of the industrial environment, granting the possibility that any device of any industrial level can communicate and is available to be interacted with another device from whatever place that it can be. Thus, the data are integrated and made available to whoever is interested and is allowed to such knowledge. Besides of that, such technology can improve the industrial management, since it acts controlling the processes, has an assessment of the real data, and it can be matured as it operates. Regarding to connectivity, this can be also expanded through the Cloud Computing and encompass other scattered processes of other facilities that may be dispersed geographically.

Addictive Manufacturing: Addictive Manufacturing refers to a group of technologies that foster the creation of several products through combining materials layer by layer, which has the 3D printers as the most expressive enablers of this scenario. Thereby, this technology boosts the production of small customizable products batches that offers a great level of complexity, even operation in a mass production environment. This trend is strongly present in the fast prototyping of products, providing an evaluation of a representative model of the final good, empowering the search of design failures and easing the structural errors discovery before dispatching the real product to the assembling lines. Concerning the products production, this process can shorten some production phases and improve the economy of raw materials, which happens during the production a complex design of an item. In an industrial model where the Addictive Manufacturing is not employed, several machines and processes are required to make the final product, wherein the transition of model impacts on the resources and raw materials waste.

3 Convergence of Blockchain and Industry 4.0

This section focuses in the convergence of Blockchain within the Industry 4.0 scenario, approaching the synergy of these technologies. Besides this, it is highlighted the advantages and expected challenges to materialize such fusion, always trying to illustrate the presented concepts to contextualize what is being addressed.

3.1 Synergy Between Blockchain and Industry 4.0

As explained in the background section, the Industry 4.0 is a paradigm that is not based upon a single technology or disruptive concept. In contrast, it is supported by several trends that focus on improving current industrial traits or areas, such as fostering the vertical and horizontal connectivity and integration of facilities through Cloud Computing, Cyber-Physical Systems and the Internet of Things devices.

Whereas the integration of Blockchain on Industry 4.0, this concept contributes to the Industry 4.0 operations, encompassing the provenance of goods, raw materials, and data, financial transactions between industries, consumers and stakeholders and legislative compliance, in which the Blockchain's immutability is a pivotal characteristic to elevate the reliability of the provenance of a given item, since the involved peers are reliable. In addition to this, it is allied the transparency to evaluate the goods and data provenance in an industrial scenario, granting the traceability of not only logistics, but also fostering the acknowledgement of the compliance with the standards and registering any industrial information of interest, such as work history of a given system that can be used to gather patterns and applied in preventive maintenance. Furthermore, the own Blockchain can tear and boost the concept of Economy of Things, in which the IoT devices are aware of their roles, have enough autonomy to establish contracts with peers, and can make the payment upon an accomplished task. At last, it contemplates the improvement of the whole Supply Chain given these benefits when the Blockchain is inserted in the industrial environment.

3.1.1 Provenance of Goods, Raw Materials, and Data

As a result of the Blockchain arrangement of group of blocks evaluated by network peers, every single operation registry is stored in a perpetual manner. In this way, all data roster related to the operation is available to whoever is allowed to examine these information.

Considering a network supplied by honest peers, the registers tend to be reliable. This reflection is made because the sense of evaluation of Blockchain is lost when it is fed through off-chain data by oracles and, most importantly, by single agents without verifying its veracity. This is the most probable scenario of what will happen in Industry 4.0, when unique sources enters its data in Blockchain, just like a common database, and there is no other reviewer to judge the authenticity of data. To illustrate, this concept can be easily seen in any kind of manufacturing process, where single sensors are responsible to watch over a given scope. If there is some redundancy to ensure the same measuring, this strategy can be employed to work around this delicate fact and provide the trust promised by Blockchain through several repeated appraisals that guarantee what is being stored.

Nevertheless, the Blockchain appears as a potential solution to provide reliable provenance of a given object of interest if the data stored in it are not counterfeit. In other words, it gives the whole history related to a relevant item. For instance, if a buyer suspects of the reliability of a gold seller and its origins, this person can evaluate the data registered that grants the information archived from the moment that the mineral has been extracted and track it until the last supplier, in a way that ensures its authenticity and the sellers' trustworthiness. Analogously, this can also be applied to ensure the quality of a given product, in the case, for example, of a consumer of a high-priced product, which may want to ensure not only the sellers' reliability, but also identify the provenance of every single raw material used to make the product.

Regarding the financial transactions, Blockchain fosters scenarios of registering operations of purchasing, transferring, and selling among industries, suppliers and clients, besides of even ensuring the payment of an order through the cryptocurrency. Similarly, whenever it is enabled by a reliable and prepared network to perform such operations, it is possible to store not only the data related to the transactions, but also the quantitative and qualitative information akin to each material, as well to the ones associated with logistics. For instance, consider that a television producer wants to acquire some electronic components to make its product. In this process, it is generated a purchase order, which designates the quantity and items, agreed costs and payment method, establishing the commitment of buying from an external supplier. After this, this supplier will separate the specified components and ship them to the buyer. In this example, every single information related to this acquisition and shipment processes can be validated and stored on Blockchain and, through this, these data can be later evaluated if needed.

Concerning the registry evaluation, the scenario of auditing can exploit Blockchain in order to investigate the operation logs of a given industrial facility. In this case, if the network is made of reliable peers, this technology becomes a tool that stores every input since its first employment and hands them conveniently to the audit. For instance, this solution can be reviewed to assess the failure source in case of the occurrence of an accident or risk situation in the productive process. Through the aid of other trends, the Blockchain database can be applied to foster autonomous preventive maintenance. In other context, it also enables record history concerning the legislative compliance with the current standards. In order to illustrate this, the aeronautical sector can make use of the Blockchain in the logistics department, in which this solution can manage its warehouse, in terms of stock, but also register the processes of handling the damaged and hazardous materials that have specific guidelines to be disposed.

Aiming in one of the most profitable markets in the last years, the SophiaTX platform employs the Blockchain technology to foster solutions in the pharmaceutical industry. This project is the first developed with Blockchain with the open source ideology, integrating and boosting the multiparty collaboration between the stakeholders of this segment. In this way, it focuses in mitigating the complexity of production cycle of drugs, enabling the provenance of raw materials since its arrival in the manufacture facility until the moment that the medicine is available in the market to the consumer. Furthermore, SophiaTX developers seek to ensure the cooperation between the stakeholders, such as handling companies, suppliers, and transportation; as well as to guarantee the quality of drug composition, and the logistics of the medicines, halting the drug counterfeiting and other possible issues that may occur during this process. Briefly, this platform is initiated with the inclusion of the composition ingredients and their protocols, serial numbers, and batches, which are the responsibility of the pharmaceutical enterprises. On the other hand, the suppliers are in charge of adding the tracking protocols, status, and any other relevant data of each drug in the system. On the other side, there are the accountable enterprises to provide the transportation and storage of medicines, which must ensure the compatible conditions pointed by the manufacturer that concerns its circumstances of storage, such as humidity, temperature, and others, to maintain the perfect functioning of the compound. Thus, the information and measures must be evaluated and properly registered through the installed sensors in such areas. Throughout the compound history made by these several inputs encompassing every single stakeholder, hospitals, medical clinics and drugstores can authenticate the reliability, transportation conditions and the whole life cycle of the acquired medicine or other given drug.

3.1.2 Economy of Things

Through the advent of trends of servitization, that are transforming the software functionalities and overall computer business, allied with Internet of Things, Cyber-Physical Systems, and other technologies, there is a new economical branch called Economy of Things. This concept aims to monetize the devices' functionalities that executes a certain service to any contractor. In this scenario, one of the most potential enabler is the Blockchain.

To illustrate this concept, consider that a technology enterprise wants to develop a project to provide weather forecasts in a global scale through an app. Instead of acquiring and establishing its own infrastructure capable of assessing the weather more accurately in several locations through many sensors scattered around the world, this company can strategically close enough contracts with reliable weather stations to provide these weather data to the platform created. In a not so distant future, such weather stations are going to be made of Internet of Things devices connected to a Cyber-Physical System, enabling these to sense and interact with the environment that they are inserted, besides of integrating them in a global scale through the Internet and giving them awareness and self-* properties, such as self-adapting, self-healing, and self-management. Furthermore, in this same scenario, there will be the dissemination of protocols that will allow these devices to execute tasks in a service manner, accordingly to a Servitization trend, which are going to be managed by Smart Contracts, or software that authorize dealing and establishing autonomous contracts between hardware and software entities. These contacts are going to be negotiated by Smart Agents, or the virtual entities that represents the physical or virtual "objects" in a given scope in the Cyber-Physical System domain. In this same context, the equipment are capable of establishing, negotiating and even finishing a contract autonomously through the traits already cited without the human influence. In this way, considering the example of the weather app of the future, the own weather system can self-* to fulfill a request. For instance, after receiving a demand to provide the weather in Athens, the own infrastructure can submit a request to close a contract with the devices located in the Greek city and obtain the interested data in a autonomous manner, in a way to meet the order with the best candidates in the location of matter. However, the monetization appears once the owner of the Athens' weather monitoring system establishes fees on the sent information. Consequently, it is built an Economy of Things, in which the consumer will pay a given value to assess an information or to receive a service. Through a cryptocurrency, charges can be paid by capable devices that are under a Smart Contract, which delimits some aspects, such as the period of usage, quantity of data, and the price to receive the contracted information. Furthermore, the own Smart Contract can set a way to divide the profit to the owners of a solution, autonomously, when this is shared by more than one person, similarly to how it is done nowadays with the dividends in the stock market.

Considering the Industry 4.0 premise, the Economy of Things can be more related to the industrial Supply Chain context. Monetization makes sense even through tasks performed under the same chain of industries, in order to facilitate accountability and rigid control of OPEX. It is worth in an accounting and performance evaluation scenario where a fictional token can be created to provide a relation of production of a process. Through this, it creates a relationship that mimics an economy within an environment, supporting an easy proof of how a single entity is impacting in the whole process. For instance, it can be evaluated if an industrial conveyor belt is providing profit or loss to the assembly line through its monetary portfolio.

In the case of partnership between factories, the Economy of Things can foster the autonomous exchange systems, charging other facilities to provide a given service or granting free access to the resources of an another industry through firstly establishing a contract that delimits the partnership between them. Therefore, monetization is viewed on the case that applications improve and allow an autonomous Supply Chain, since the stock management, transportation contracting and other functions can be predicted in function of a given demand, action or task, so this can be estimated through Artificial Intelligence, Computational Intelligence or Machine Learning algorithms. For instance, if a car factory has an X product stock, the duration Y of this storage is easily calculated through the quantity Z of automobiles to be produced to meet a demand, once the assembly material list is known. Extrapolating, each process has a known average time of execution and, by means of parameters, it can be predict when a new purchase order to acquire new materials to the warehouse, avoiding the production haltage due to lack of raw materials.

In an autonomous device's environment, in which they are capable to negotiate and establish Smart Contracts and are also represented by Smart Agents, it is not hard to imagine a robotized warehouse managing its own stock and sending requests to a supplier periodically. In another scenarios, the assembling lines can have devices capable of the same functionalities, granting that the own equipment ask for materials to continue producing, calling for status or exposing its results whenever it is concluded a step to the internal environment of a facility, but also to the external world. There is also another case that an autonomous warehouse can contract self-driven vehicle to fulfill a good delivery, which can be paid through the cryptocurrency upon the shipment is completed (and this car can also pay for its maintenance and fuel through its wallet).

In the case of what has been currently being developed under this concept, it can be mentioned the Robonomics platform [18], which aims to integrate Cyber-Physical Systems with economical systems, focusing in the Industry 4.0, Smart Cities and Internet of Things areas, to foster the financial transactions and social interacts in a high automated environment and ensure the reliability of autonomous services executed within its scope. This solution is based on the integration of autonomous systems that can negotiate their contracts through a decentralized Ethereum network, improving their capacity to understand market mechanisms and contracting obligations, with the objective of creating an economic network of autonomic robots. In addition, the platform provides tools capable of measuring the quality/provenance of a given product received, since all perennial operations to this solution are recorded in Ethereum. In broader lines, the life cycle of this solution begins with the settlement of a demand or the exposure of the availability of a service, which are managed by the Ethereum network to find possible suppliers or consumers. In the Robonomics network, there are two distinct types of participants, namely Ordinary Network Participants, who have some interest in the Robonomics network, and Providers, who are interested in finding an economically significant information. When performing this rendezvous between the pair, the network aims to diminish such problem, being through someone who can use a service or provide a functionality, and, so, begins negotiating a Smart Contract to establish the Service Level Agreement between entities, or the cooperation rules. At this stage, the network itself is able to allocate requests through Lighthouses, which are autonomous workflows that distribute the execution time of the suppliers in order to guarantee the creation, when connecting a demand to a supplier, or the completion, when confirming a result of a service, of a contract. In addition, the Robonomics platform has the functionality to monitor the performance of the services provided, based on the contracted criteria that establish the verification model. Finally, according to the research conducted, this platform is capable of establishing and monitoring about 1,000 contractual obligations per day, estimating a management capacity of operations of a Smart City with more than 1 million people.

3.1.3 Supply Chain

Supply Chain are represented through a flow of information that permeates the different links of the industrial process chain, that is, it encompasses the customers' demands to the selection of the raw materials, as well as a counter flow of products that are analogous to the information of the processes, going through the entire production cycle to the end customer. As the concept of Industry 4.0 is based on the technological advances that provides smarter networks, in which machines, processes and products exchange information between one another, making possible to affirm that inevitably the ideals of this proposal directly affect the Supply Chain models employed in the current industrial scenario.

Conceptually, Supply Chain is presented through a simple horizontal model, in which interaction is maintained among a few members. In this case, their chains distance themselves from real relationships, in which the greatest deadlock lies in the tracing and investigation of events. This is due to the fact that in the real world the process chains are formed by multiple companies that are related in multilateral flows of information and products. As a contemplation of this problem, consumers are not able to validate the product or service processes in a reliable and easily accessible way, so that the price paid for a given process does not reflect the real cost of producing the asset. Another problem lies in the lack of transparency between the processes presented in the different links of the chain, and so the identification, investigation and punishment for illicit activities become extremely complex. This is evidenced by different scandals presented by the media, e.g. the misuse of assets, falsification and over billing of products, causing actions that may denigrate not only the name of the fraudulent company, but also its partners in the productive process.

Since the operation of a supply chain depends on a constant flow of information, it is imperative that the data is sufficiently collected and presented continuously to the stakeholder, so it is undeniable that the system must present a high degree of reliability, transparency, immutability of records and traceability of all operations. Through the appeal for more reliable, transparent and traceable systems, technologies such as Blockchain and Internet of Things present themselves as strong candidates for implementation. These technologies enable supply networks to reduce the number of intermediaries in the information distribution process, directly influencing in the increase of efficiency and lessening costs.

Through Blockchain's traits already mentioned in this chapter, its application in the supply chain guarantees an improvement in the transparency of the information exchanged, but it is not only limited to this, since it also guarantees the immutability of the information that can be used in the protocols of asset tracking when applied to the products.

Concerning this Supply Chain scenario, IBM is developing a solution called "IBM Blockchain Platform" that encompasses several industries under its proposal, such as Financial, Insurance, and overall Supply Chain [23]. This employs the Hyperledger Fabric, which is a project created in 2015 by Linux Foundation that involves open sources Blockchains and related tools, and IBM Cloud along with other Cloud suppliers, creating a peers' network based on the original premises of Blockchain [24]. This principles are related to the data finality, which is based on the immutability of the platform that does not fork and provides the evaluation of every data that is entered in its ledger, trust, which is possible due to the network's transparency (not in its anonymity, so every peer must be known to the network) and the chosen consensus protocol, and privacy, which is related to the platform's design and ensures that the private information remains so if the peer chooses to enter this kind of data, yet it will still be evaluated by the network [24]. Regarding the Supply Chain focus, IBM supports the "TradeLens" [26], a neutral platform that also employs the Hyper-Ledged Fabric, and employs it in a service called "IBM Blockchain" that focus in logistics, granting transparency and traceability to this area [25]. Through Trade-Lens, the logistics can register the stages during its whole process, from the purchase order until its shipment, relying in a publish and subscribe mechanism made by the stakeholders, e.g importers, to grant the transparency, security, and immutability through the solution, that also adds a shared ledger between the industrial network and establishes each process by Smart Contracts [26]. Meanwhile, "IBM Blockchain" focus in the overall Supply Chain process from the raw materials distribution until the after-sale support, fostering the transparency of data to all peers, which provides an easy overview of the whole process to any stakeholder, the traceability of data and materials, and enabling a real-time issue resolution under its platform, which are also stored perennially in the ledger [27].

In view of this scenario, the VeChain foundation proposed the creation of a new model for the supply chain processes called VeChainThor. In this model, the company will use its blockchain to perform the data storage of the whole chain in a safe and immutable way, where all process participants will access the information available using private keys. Once the chain is shipped on the VeChainThor platform, all participants will have access to the data set of their partners to address the inefficiencies of the traditional model [28]. In order to guarantee the protection of data and the privacy of companies, VeChain offers a common services platform offering interconnection between different clients. Thus, using the platform developed by the company the delegated team for the operations can carry out the business through its portable devices [29].

3.2 Challenges of the Convergence of Blockchain and Industry 4.0

Like any new technology considered in a new concept, it is inevitable that certain challenges appear as obstacles to delay an effective and efficient implementation, even more in a paradigm as disruptive as observed in trends of Blockchain and Industry 4.0 alone. Therefore, such adversities present themselves as difficulties to be overcome not only by the academic community, but also by private and governmental initiatives.

This subsection presents some challenges that have been delimited by the research made for this chapter. As Blockchain technology is maturing, it is imperative to delimit a note that not all of its potential has been contemplated by the numerous surveys conducted so far. Some claim that cryptocurrency, in the context of Blockchain technology, are compared to what the creation of e-mail was to the Internet. However, based on all the expansion that the Internet suffered after its conception and that it has not been limited to just electronic communication through e-mails, used ubiquitously in society in a way that was not thought in its origin, it can be expected that Blockchain is going to expand in the coming years and probably be employed in contexts that are not even imagined at the time of this chapter's elaboration.

3.2.1 Hype

In most of the times that a new technology arises, there is a great expectation about this topic, which, in turn, entails in its adoption without further studies to support and ascertain the benefits and capabilities of this trend in a given scenario. This can be exemplified by the trend of 3D televisions in the past years that was a potential new way to interact with its visuals, but as time gone by it was discontinued and can mostly be found restrict in some movie theaters.

One of the main reasons why many companies rashly adopt such technologies without making an in-depth assessment is the opportunity granted by joining or adopting such a trend. This strategy aims to take advantage of all the visibility achieved by this connection, due to environmental, social or simple business purposes, in order to conquer a new target public. On the other hand, few cases actually consider that the implementation of a new technology does not always imply in a significant improvement in the system, which would justify its adoption. To illustrate this, there has been several products labeled as “Smart” without even having a feature that justifies such naming due to the emergence of the concept of Smart Things, which does not even present an algorithm that optimizes their operation based on the errors made through their execution.

Regarding the implementation of Blockchain and Industry 4.0, the answer to some questions may give us an initial idea about the benefits of using it. Firstly, it is necessary to carry out the verification of the dimensions of the problem to be solved in the industrial scope and if it has the need to share information or decisions between the parties involved in a public and decentralized manner. Alongside, there are questions about the need to record the information, activities or decisions taken during the transactions between the parties and, finally, to verify if there is a need for the transactions to occur through the rules of consensus among the parties involved, ensuring compliance with the terms for the validation of the operation. If these items are really indispensable to the industrial process, Blockchain can emerge as a powerful tool for the system in question.

Besides of this aspect, there is the question of how will be the absorption of Blockchain technology by industries and how it will develop over the years. At the present moment, this is a powerful and indispensable tool in future scenarios that require the immutability, transparency and reliability of network information. However, it is expected that as the challenges begin to become clearer, some of their advocates and developers may lose their will to work with the technology and its development will begin to diminish. This aspect does not only lies to Blockchain and Industry 4.0. In fact, there is a concept that was coined as “Hype Cycle,” which consists of a graphical representation made by the technology company Gartner and takes into account the maturity, adoptability and social applications of specific technologies [31]. In [32] it is presented a study performed by Gartner in 2018, analyzing the emerging technologies of that time. Through this analysis, it can be seen on the chart that Blockchain technology is close to its peak, which proves all its potential and also all the attention that it has received in the recent years.

When researching on scientific publications that have been developed with the Blockchain proposal in the platforms of IEEExplore and Elsevier, one can see that this topic is currently a “hot topic” and it is being exhaustively researched by the world academic community. For comparison matters, Figs. 4 and 5 illustrate that submissions have continued to grow since 2014, in an almost exponentially way. For

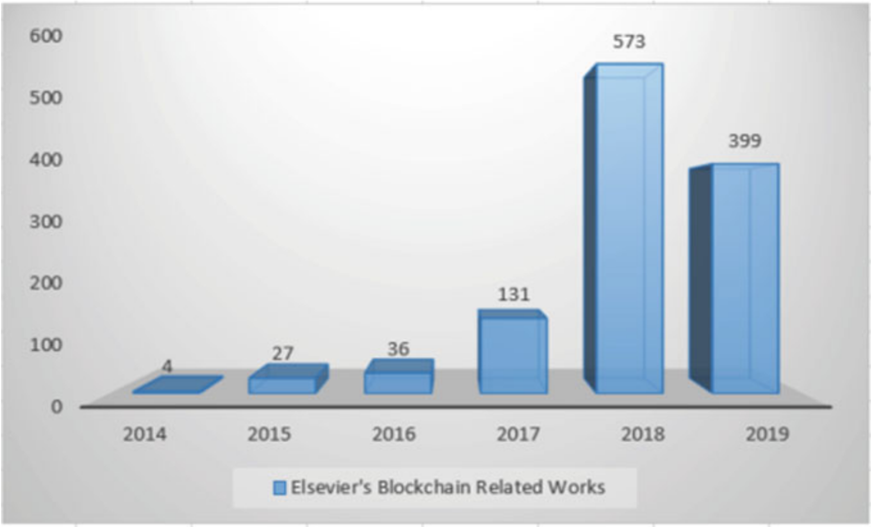

Fig. 4 Blockchain related works published under Elsevier

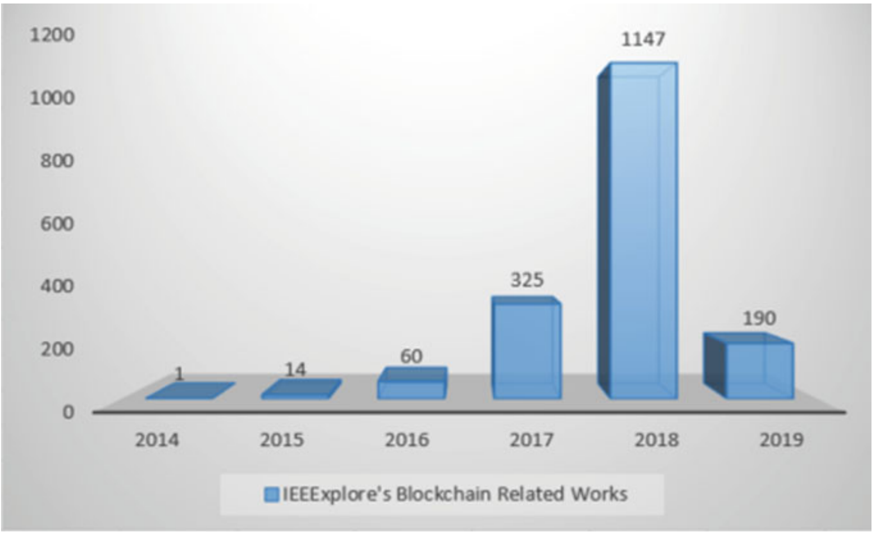

Fig. 5 Blockchain related works published under IEEE

example, publications with this theme at Elsevier from the beginning until the first quarter of 2019, at the time of this chapter's craft, had already surpassed the total number of works throughout the year 2018.

3.2.2 Cost

Another issue that challenges the implementation of any new technology is its high initial cost, which generally decreases over time, making it more popular and feasible for smaller companies. Regarding Blockchain, its large-scale implementation nowadays presents itself as something of a high level of complexity and cost, largely due to the fact that it is a technology in its maturation process. In fact, this cost can be shared and paid by the peers involved in a public Blockchains, which eases its implementation and makes it feasible. On the other hand, there is a great movement in the academic world and research centers of large companies that aim at the improvement and application of this technology in several scenarios, fostering its development and consequently impacting in reducing the cost of implementation.

3.2.3 Other Original Blockchain's Problems

Another challenges can be derived from the original Blockchain suffers. In brief, it can be highlighted that one of the biggest challenges comes from external off-chain data within a Industry 4.0 environment. As mentioned before in this chapter, it can be seen in scenarios that there are no other peers to validate an inserted data in the ledger, in the case of a single sensor feeding the records, and leads directly to the "Oracle problem." How can one ensure the trust of every single information entered in the Blockchain through devices, systems, and people, which can alter the reality to make the data conform with, for example, the audit processes?

4 Summary

This chapter presented concepts that are relevant to the understanding of Industry 4.0 and Blockchain technology. In this way, an overview was presented in which it covered what impelled the industrial model to consider the adoption of a paradigm as disruptive as that. Didactically, we tried to present a solid backgroudn in each trend, discussing the impacts and evolution of Blockchain, each Industrial Revolution since the first one and what changed in the each context not only regarding the factory's environment, but also in the social sphere. Through this, a full panorama was created and it could be drawn a parallel presenting not only the benefits of what may happen, but its social consequences in the future society due to the adoption of Industry 4.0 worldwide. All this attempts to present concepts that are important for understanding the whole chapter.

During the chapter, it was discussed not only the benefits that the Blockchain technology can present, but also the challenges that this imposes not only for its implementation in the context of Industry 4.0. In this way, parallels have been drawn with related works to each theme, in order to provide examples that ease the understanding in the exposed subject, but also to serve as evidence that they are really been explored on such questions.

Briefly, Blockchain presents itself as a potential candidate to optimize the Supply Chain in general, improving its reliability, transparency and trustworthiness of the registry. These characteristics are opportune to be explored from the traceability of goods until the actual verification that a company is in compliance with a legislative protocol, but also boosts the topic of Economy of Things and autonomy of the execution of tasks by the devices themselves, which in the future can self-organize to supply a demand and generate their own revenues. In contrast, challenges exploit the fact that technology is indeed relevant in the industrial context, so that not just another marketing tool without effective functionality or due to a hype.

5 Conclusion

Although Industry 4.0 and Blockchain technology have solid plans that guide each proposal, both trends are still immature to be actually implemented on a large scale in a real-world environment. Considering only the Industry 4.0 paradigm, it can be stated that there is a great deal of research to be done in order to address challenges that encompass not only the connectivity, security and reliability issues of devices, processes and industries. In addition, there are questions about how vertical and horizontal industrial integration will actually occur, breaking down not only hierarchical barriers, ranging from production to management, but also the barriers of the locality of an industry. In this way, any and all information generated by a factory must be displayed in a homogeneous and coherent way, regardless of the location or type of the source device that is requesting or generating such data. This in itself is a major challenge to be overcome, since each facility is currently composed of several equipment from several manufacturers that probably do not share the same protocol and data format to be presented to the upper layers. When this is solved, other factories can be connected, enabling access to disruptive features such as remote process management, and ensuring the level of autonomy that is idealized through Cyber-Physical Systems in Industry 4.0.

Nevertheless, the convergence of Industry 4.0 and Blockchain seems inevitable at this moment. At this time, both paradigms must coexist in the same industrial scope in order to optimize issues of security, transparency and data origin, which are guaranteed through Blockchain technology. However, certain questions about the real implementation are raised so that this solution is not just a marketing move to give visibility to the industries that adopt this registration system. In this way, it can achieve a Supply Chain that will completely change current paradigms, ensuring that models are efficient and, possibly, autonomous by allowing a concept of Economy of Things, in which the devices themselves will be capable of self-manage the finances and complete their activities, hiring service providers and paying by performing such activities.

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Blockchain Technology for Data Management in Industry 4.0

Madhusudan Singh

1 Overview

1.1 Data Generation

Nowadays data plays a vital role in our lives so, it should not go under negative influence other than computer connoisseur else it can lead to detrimental consequences as it enlightens with the groundbreaking knowledge. And shows an important factor about people.

The collection and survey of big data is a principal for research, management and marketing in business industry which can lead to success and failure because data miners trace every action which is basically spawned on the internet from connecting cars to smart TVs by us [1].

Climate change is one of the examples of big data, if the rampant increase of climate change was not been traced and alarmed then we would have not been aware of it. Founder of Smart-up.org cum CEO of Orchestra Networks, one of the leading companies in data management, Pierre Bonnet states, “Data knows about you more than you know about it. We could not know how much data about us is collected and where it is saved.” [2].

The two major problems data management company face are how to collect and analyze the correct data and which data is essential for their research. It is very important to understand the essentials of analysis and outcome of data to run a successful business [3]. In Fig. 1 has shown the Industrial data generation , it has

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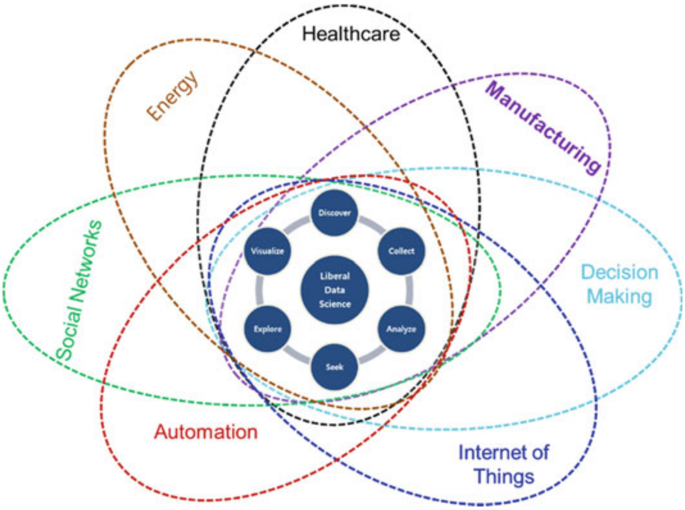

Fig. 1 Industrial data generation

shown the each and every industry has generated the data. Managing, secure and trusted those data has big challenges. Blockchain Technology can provide secure and trust data within industry.

1.2 Industrial Data

Comprehending the appropriate measure to secure and treat the data as it is the most important aspect of digital factory and data as business asset today. In the extensive study of Industry 4.0 and Reference Architectural Model Industrie 4.0 (RAMI 4.0) [3] the reference framework model like the life cycle and value stream dimension you will notice the early stage collection of data and improvising phase of the entire life cycle until the termination of it shows how the whole process is dependent upon the set of data [4].

Artificial intelligence and cognitive shows the outcome and the analysis of intellectual collection of data which gives the information and better understanding. The results and the data process is distributed across the life cycle of product and the value chain is shown in the figure given below: from ideation, prototyping and development to maintenance, production and ecosystems of information driving innovation, logistics and pretty much any industrial process, all the way to disposal or recycling. Figure 2. has shown the worldwide datacenters [5].

Fig. 2 Data centers around the world [5]

1.3 Data Properties of Fundamental Industry 4.0

This section is about the various data properties of Industry 4.0 used cases based on the real applications already mentioned in the past researches. But these real-world applications and outcomes were never mentioned in any previous researches. It shown in below image.

The produced properties of the used cases are shown below. To understand the requirements of data in the latest cases of Industry 4.0 the main motive it to extract three main properties [6]. The four important data properties are the following as shown in Fig. 3.

(1) **Data volume**
The distributed magnitude of the data in a network surrounding is the paramount to the network frame and the enablers of technology in the modern era. Different types of data magnitudes can be found in a pool of industrial network surroundings. Some example of the small size data are sensor measurements and data of big sizes are images and the biggest size of data are videos.

(2) **Data variety**
With the different types of cases another form is the variety of the data which highly affect the algorithmic and other outcomes depending upon the cases. In this, different types of data is needed as an unvarying data variety where same types of data is used

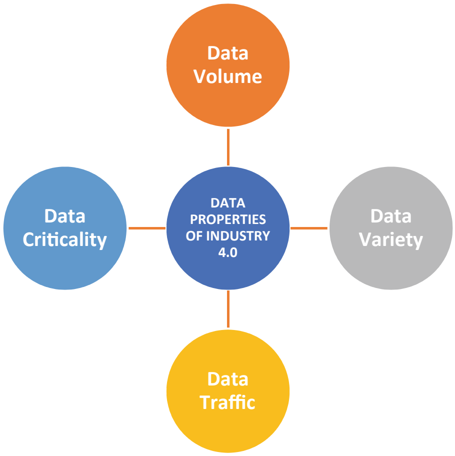

Fig. 3 Worldwide data centers

(3) **Data traffic**
Multiple traffic patterns can be affected by multiple varieties of data with multiple generational velocities. With the growing pace and maturity in technology and traffic regulations wired industry is facing profit unlike wireless side.

(4) **Data criticality**
System monitoring and safety can be highly affected if the data is carelessly analyzed. Any sort of glitch in the system should be informed as early as possible to prevent major loss of data.

2 Data Management Trends in Industry 4.0 Design

The architectural ingenious innovation is briefly explained in the section in network industrial environments with the rooted analysis of recent proposed Industry 4.0 design and by extracting the data management study as an alternative. The data management information is shows in Fig. 4.

In order to study the latest frameworks of Industry 4.0 the main properties of data have been mentioned below:

(1) **Data presence**
Data can be collected from different sources like from localized or pervasive data generators. In the localized data fixed robotic manipulators in an industry, mobile network controllers, office station, servers are the sources of it. The pervasive data generator comes under the ubiquitous data. In the pervasive data generator IoT, sensors, portable devices are the sources. Both the sources are unlimited.

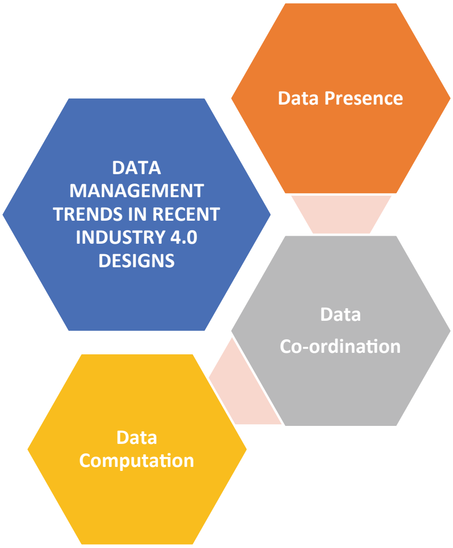

Fig. 4 Data management trends in Industry 4.0

(2) **Data coordination**
Input data can be controlled by any kind of manager irrespective of the place. Usually hierarchy system is the preferable. Global managers of the primary case are centralized. And the local managers work as hierarchical coordination.

(3) **Data computation**
Data computation are of two kinds, centralized computation and decentralized computation. In centralized computation one system is used to process the whole data on the other hand in decentralized computation multiple systems are used to process the data. Decentralized computation is more beneficial as it has more power to solve the problems in less amount of time.

2.1 Challenges in Current Data Management

(1) **Single Point of Failure**
Database is not so safe as it is not distributed among the different systems which has more chance of losing the data and shared between the group of people which cannot be traced.

(2) **Administrator Account**
Database requires a password and an administrator, that means whole database is based upon a password and if it is lost or lose it to wrong hands, it can be a major loss for the organization and if the there is no admin no updates can be made.

(3) **Security Issues**
In current data base management system is working as centralized system. Centralized system is more prone to get hacked. Centralized mechanism is the weakest problem in the current system.

3 Blockchain Technology and Industry 4.0—Overview

Today we are living in a world which is surrounded by fourth industrial revolution and it is highly affecting our day-to-day life as it is bringing machine and human together in order to have better and efficient production.

3.1 Threats to Data Integrity

There are variety of commination to the data integrity. One of the most targeted databases is the government data which is under threat of being stolen by the corrupted people. There can be different kinds of threat to it:

(1) **Threat 1**: Simply disturbing the database of the government.
(2) **Threat 2**: One member of the data federation revises the data without letting or informing other members.
(3) **Threat 3**: Database is falsely revamped by number of federation members.

3.2 What Is Blockchain?

Blockchain is the latest technology which validate the digital currency to transfer from one person to another or among the group of people with transparency in the transaction [7]. As we know Blockchain has 4 pillar whose make blockchain strong secure, decentralized and trustable networks. In Fig. 5 has explain the blockchain technology and Its pillar.

Let us take a simple example to get a deeper view of it. Assume person A wants to transfer the money to person B with the help of trusted mediator. Trusted mediator identifies both A and B for a safe transaction. But it takes some amount of money as a tariff or to charge their service out of transferred money, it takes couple of days to process the whole step.

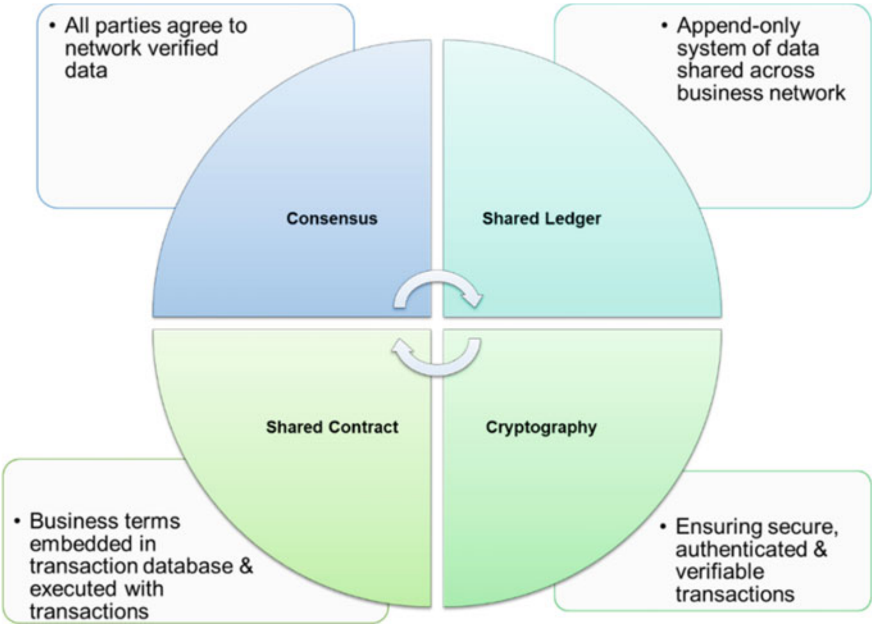

Fig. 5 Pillars of blockchain technology and it's explanation

So, what the blockchain does is to transfer money without any mediator or extra fee and do it immediately. So, the Bitcoin became the very first case of Blockchain technology. Bitcoin is a digital currency [7]. All the transactions which were legalized or approved by the miners are saved as a data and compiles it into block which makes a chain of data.

3.3 Blockchain Based Industry 4.0 Use Cases

This connection between the systems will remove the mediator from its way to have one individual to another connection. Blockchain will help the business industry in ways to transfer the data with safety. It helps all kind of sector either it is a financial sector or logistic sector [8]. Figure 6 has explain the some of examples of blockchain based Industry 4.0 use cases.

4 Blockchain Data Management

Blockchain cannot transfer digital documents, which is a common type of transaction happen between in the business industry. Digital documents can be of different

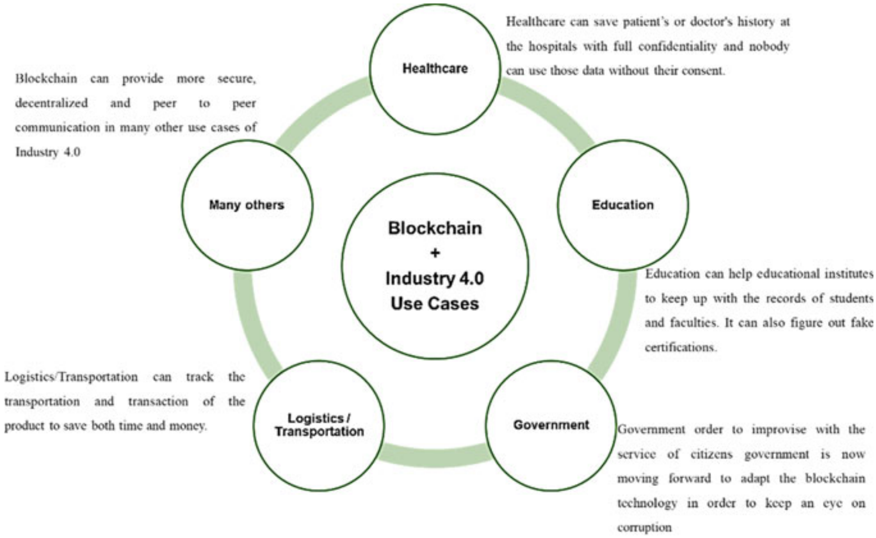

Fig. 6 Examples of blockchain based Industry 4.0 use cases

size and bandwidth which makes it difficult for blockchain technology to store and transfer. Although we can store these data in a third-party offline storage with the help of maintain their location and input sizes of the data. Giving big data to the third-party storage can be picky [9] (Fig. 7).

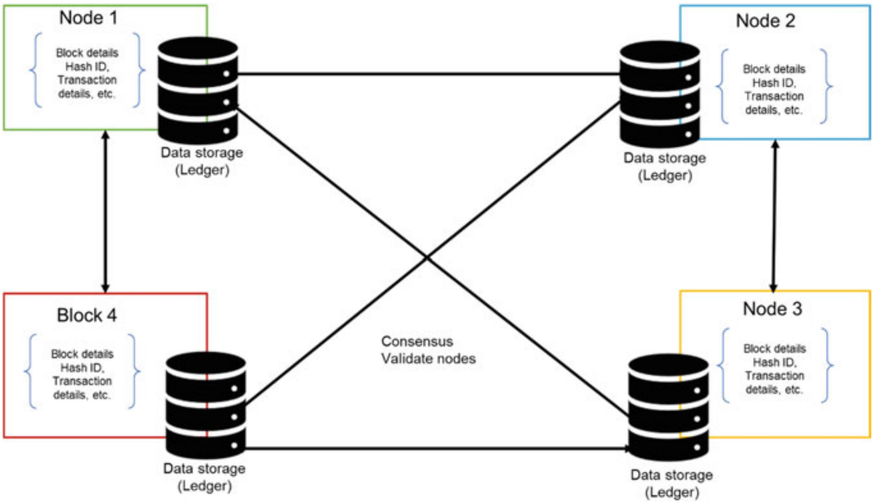

Fig. 7 Blockchain data management

4.1 Blockchain-Enabled Database

In section we have discuss the blockchain enabled data base has befits as show in Fig. 8.

(1) **Confidentiality**
Access to sensitive data require legal permission from authorities to protect the data and this not completely secure with access control as permission need to be given every time the data is being transacted. But in cryptography the data is encrypted and decrypted using public and private keys, so the data is more secure. Even though all encryption is also not secure due to interference of smart contract. Some example of safe encryption are homomorphic encryption and some type of easily influenced encryption.

(2) **Privacy**
In the past Bitcoin and Ethereum have had a not-so good experience with the privacy of the data. All the data and information are transparent in blockchain technology so when the data is carried out it has option either to save or to remove under the name "right-to-forget". It is somewhat hard for a user to change their history as per their desire because blockchain does not provide such facility.

(3) **Manage smart contracts**
By smart contract in a business means there is blockchain technology included in every aspect from designing to developing, testing to monitoring. In current scenario, smart contract is developed by the programmers accordingly the

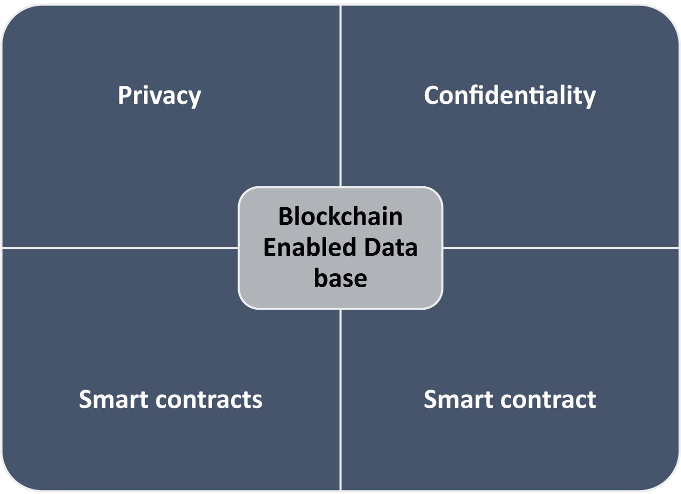

Fig. 8 Blockchain enabled data base

requirements of applications. Smart contract has a time consuming and error prone as currently no standards available till now due to its code-based contracts. Therefore, it's necessary to design smart contract self-organize in application accordingly. Smart contract has open research issue in blockchain technology-based data management.

(4) **Smart contracts**
From above we can get that, Smart contracts are not safe for blockchain data. Hence it is compulsory to design and develop smart contract according to sematic trustworthiness between the data users. Smart contract has opened the several research questions for Data management in blockchain such as, bug detection in smart contract codes [10], Deal with smart contract codes behaving erratically and maintain and update with correct codes without impacting the network [11].

4.2 Benefits of Blockchain Technology

There are uncountable benefits of blockchain technology in the business and management sector as well. It is the fastest way possible till now known for the transaction at the same time saves third-party fee. It offers a quality of legal procedure and assurance with the transparency among the group of people who are added to the network.

4.3 Uses of Blockchain Technology Within Industry 4.0

Blockchain technology can be used in many different ways in Industry 4.0. Below are some of the possible uses apart from transaction:

- **Recognizing and Authenticating IoT—**When number of devices are in network with each other with the help of blockchain.
- **Add Tamper—**It can prevent any kind of disturbance in the record.
- **Change Over to a Private Blockchain—**It can change public information into private to protect and limit down the shared information.

4.4 Blockchain: Data Integrity, Performance, Stability

Blockchain firstly emerged for Bitcoin cryptocurrency couple of years ago for a safer public transaction which is based on proof-of-work. As the name itself represents it has back-to-back blocks of chain which carry the data. Miners are special nodes in the network with higher computational power, these miners validate each transaction communicated in the p2p network to reach mutual agreement. Every time there is a transaction, it creates chain of blocks.

5 Intelligent Blockchain Based Data Base Management Systems

Blockchain Technology is now used in various fields such as Internet of Things (IoT), Intelligent vehicles [12], etc. Which is growing and improving at a very fast pace. When the data arrives, it is important for the system to recognize whether to accept and store or to dribble or drop for a better service and less traffic and unnecessary data-gathering. All the analysis cannot be done automatically so a smart blockchain system is needed in order to make the decision on its own.

5.1 Blockchain Technology-Based Data Management System Benefits

Blockchain enable database is the information data stored as a record. There are many advantages of blockchain enabled database. In below, Fig. 9 has explain the benefits of blockchain enabled data base.

5.2 Research Challenge with Blockchain Based Data Management System

As we know, blockchain new technology, even it has a lot of strong points to protect provide secure data but still it has a lot of research challenges. Till no standard has come out for blockchain technology. In below section we have discuss some open research challenges for blockchain technology-based database management system.

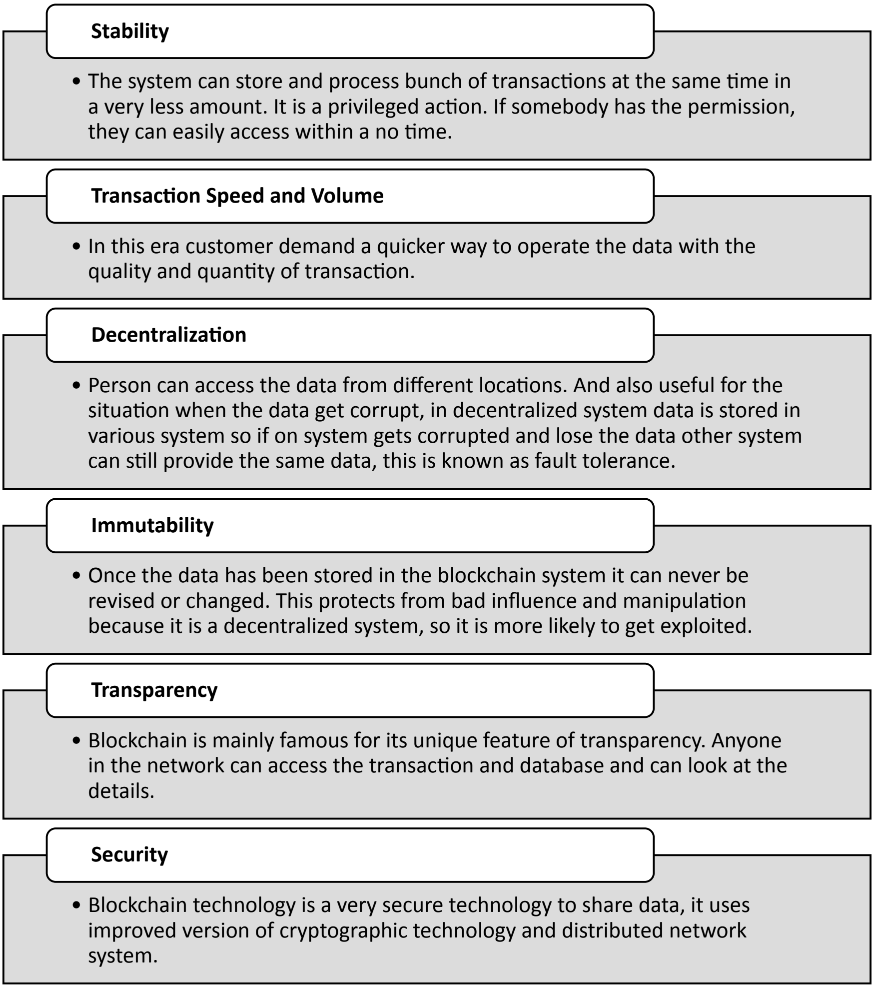

Fig. 9 Benefits of blockchain enabled database management system

Energy Consumption	The system can store and process bunch of transactions at the same time in a very less amount. It is a privileged action. If somebody has the permission, they can easily access within a no time.
Scalability	In this era customer demand a quicker way to operate the data with the quality and quantity of transaction.
Size	Person can access the data from different locations. And also useful for the situation when the data get corrupt, in decentralized system data is stored in various system so if on system gets corrupted and lose the data other system can still provide the same data, this is known as fault tolerance.
High Transaction Fees	Once the data has been stored in the blockchain system it can never be revised or changed. This protects from bad influence and manipulation because it is a decentralized system, so it is more likely to get exploited.
Interoperability	Blockchain is mainly famous for its unique feature of transparency. Anyone in the network can access the transaction and database and can look at the details.

6 Conclusions

In the whole chapter we discussed about the principal and fundamentals of blockchain, database, industrial 4.0 and data management with the help of blockchain. We have mentioned pros and cons of both blockchain and database, both the technology has its own advantages and disadvantages. It totally depends where and how these technologies are been used to manage the data in Industry 4.0.

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Secure Smart Contract Generation Based on Petri Nets

Nejc Zupan, Prabhakaran Kasinathan, Jorge Cuellar and Markus Sauer

Abstract Existing blockchain and smart contract development ecosystems do not support to design, develop, and verify secure smart contracts before deploying them. Recent attacks (see DAO hack [5]) on insecure smart contracts have caused a lot of financial loss—to avoid such issues in the future, we need better methods for creating secure smart contracts before deploying them in a blockchain. In this chapter, we present a method and a prototype tool to generate secure smart contracts based on Petri Nets. Our method allows to design and generate a secure smart contract template that can be deployed on a supported blockchain platform (e.g. Ethereum) with very little additional effort. One of the main advantages that our method brings into the smart contract development ecosystem is introducing a formal way to visually model, simulate, and verify business logic/workflows prior to the smart contract code generation. Modeling the smart contracts via Petri Nets helps the developers to minimize the logical errors—by verifying certain Petri Net properties such as deadlocks—during the modeling stage itself. Furthermore, our approach presents a technology-independent way to import and export the modeled use-case logic which can be translated into different smart contract language later.

Keywords Smart contracts · Blockchain · Modeling · Petri Nets · Security

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1 Introduction

Blockchain technology enabled the peers in a distributed peer-to-peer environment to establish the trustworthiness of data without having a trusted third-party. Recent advancements in blockchain technology allow execution of arbitrary code i.e. smart contract (SC) to implement arbitrary business logic. Blockchain and smart contracts have the potential to change how business contracts are implemented and how those contractual conditions and rules are enforced in a decentralized environment. The topic of security in blockchain systems is even more important than conventional software systems because smart contracts are used to control assets of high monetary value. As with any other software, SCs are also prone to errors and in particular, it is hard to fix an error in the deployed SC because of the decentralized nature and strong immutability guarantees that the blockchain provides. Depending on the SC design and the type of blockchain (permissionless), it might even be impossible to immediately fix the problem or temporarily set the system offline (see the DAO hack [5]), as there is no centralized authority. Therefore, we have big challenges when it comes to the creation of safe, secure, and human-understanding smart contract code as it is difficult to update (i.e., to correct the mistakes or errors) a smart contract after deployment.

In this section, we first introduce blockchain and smart contracts from a security point of view and present the problems in smart contracts. Furthermore, we discuss why securing smart contracts is important to secure blockchain.

1.1 Blockchain

A chain of blocks that guarantees the integrity and immutability of data inside every block is known as the blockchain. Each block is linked to each other using a cryptographic hash of the previous block, a timestamp, and transaction data. The first cryptocurrency blockchain introduced was Bitcoin [28], but the ideas of blockchain originated from the work of Haber and Stornetta in 1991 [13], where the authors presented a mechanism to time-stamp documents (any digital file such as a small word document or a big video file) by linking them together with the help of one-way hash function.

Blockchains are currently used in different applications, in particular, they are mainly used to create distributed ledgers that ensure the immutability of data, data redundancy, provenance and transparency of records to the participants and users of the blockchain. The records often referred to as transactions are stored in an append-only log called a *ledger*. The ledger is replicated across a peer-to-peer blockchain network where each node participating in the network maintains a consistent copy of it, thus forming a distributed database of all transactions. A consensus protocol such as "Proof-of-Work" is used to decide how new transactions are added to the blockchain and how to validate existing transactions.

The peer-to-peer network is made of different entities (node, full-node, etc) for instance, a full-node keeps a copy of all transactions of the blockchain. For the interconnection of nodes, an overlay network is used, where every network node is connected to an alterable set of neighbors in a peer-to-peer fashion. For the data distribution between neighboring peers, a flooding algorithm called *gossip protocol* is commonly used (see [30]). In general, based on the consensus protocol and the participants, a blockchain system can be categorized into two types: a *public* or a *private* blockchain. In a public blockchain network, anyone is free to join the blockchain network as a peer, and start contributing to the network by verifying transactions and maintaining a local copy of the ledger. In a private blockchain, participants are restricted i.e., only a specific set of nodes is allowed to join the network which is governed by a predefined set of rules. Developers and software architects decide which type of blockchain system (either private or public) and consensus algorithm to use based on the requirements of the use cases.

Satoshi Nakamoto in [28] introduced a cryptocurrency known as “Bitcoin” that uses blockchain to create an immutable distributed ledger for storing integrity protected cryptocurrency and its transactions. Bitcoin introduced a consensus mechanism to solve the double-spending problem without having a trusted authority (i.e., a typical banking authority) to check every transaction. Bitcoin is a classic example of public permissionless blockchain, it revolutionized the financial industry and it is termed as “Blockchain 1.0” in [34]. A very good introduction to blockchain, Bitcoin, and other cryptocurrencies based on blockchain technology is presented in [30].

1.2 Smart Contracts

Smart contracts (SC), introduced by Nick Szabo in [35], become popular with the advancements in blockchain technology, termed as “Blockchain 2.0” in [34]. Smart contracts are often written to ensure fairness between two or more participating entities without a trusted third-party. We explain the differences between a smart contract and a typical judicial system’s written contract. In the judicial scenario, two or more parties agree to a written contract and bind to those contractual conditions. In case of a dispute, the judicial system (the trusted authority by the involved parties) solves the dispute with fairness. Similarly, in the smart contract set up, the owner creates the smart contract and publishes it in the blockchain. The entities that agree with the SC conditions interact with it. The following conditions hold for any generic smart contract on a blockchain. First, the conditions written in the SC cannot be changed even by the owner after publishing it in the blockchain. Second, the SC conditions are enforced by the code written and the underlying blockchain system’s consensus mechanism. Therefore, this ensures fairness to the involved parties without involving a trusted third-party (see [10]).

Smart contracts (SC) are arbitrary computer code (similar to a programming language’s code) expressing one or more business logic. Unlike a typical computer code, a smart contract code is deployed in a blockchain network, it is executed and the results are verified by the nodes participating in the blockchain network. In Bitcoin, a simple stack language is used to express the rules and conditions for a successful transaction, validating double-spending, how new coins are produced and consumed. Therefore, it is vital that the smart contracts deployed are correct and behave in a deterministic way. There are several incidents where bugs in a smart contract code were exploited by adversaries for their benefit: one famous incident is the hack on the Decentralized Autonomous Organization (DAO)'s SC deployed in Ethereum blockchain network (see [5]).

Different implementations of blockchain exist such as Ethereum, Hyperledger Fabric, Hyperledger Sawtooth and others. They all provide a blockchain-based distributed transaction-processing platform that allows implementation of business logic as smart contracts. But they use different features such as smart contract specification language, blockchain type, and consensus mechanisms. Ethereum and similar blockchain implementations refer to the code written to enforce the business logic as *smart contract* [9] whereas, the Hyperledger Fabric refers to the code as *Chaincode*. Ethereum uses a specially designed smart contract programming language called *Solidity* [10] whereas for example, Hyperledger Fabric uses standard programming languages such as Go, Node.js, and Java to write chaincode.

In [21], the authors presented the problems of using Turing Complete languages for writing smart contracts and some methods to make SCs less vulnerable. Solidity and chaincode are Turing complete because they use Turing complete languages to write smart contracts. Researchers and organizations are working towards addressing these problems in smart contracts for example, in [4, 22], the authors explain methods to create safe smart contracts. Security start-ups and established companies are offering services to audit smart contracts and ensure that no vulnerabilities exist before deploying SCs on the blockchain network.

In this chapter, we present a method to create secure and safe smart contracts for platform-independent blockchain systems. Our approach presents a secure smart contract modeling tool using Petri Nets (PNs). Petri Nets allow to visually model a process or workflow that represents one or more business logic. Once the Petri Nets are modeled and verified, our tool allows us to generate a smart contract template. The exported smart contract template allows the smart contract developers to extend the functionality before deploying it on the blockchain. Our approach is not restricted to a particular blockchain technology. Our modeling tool can be extended to support any blockchain platform or smart contract programming language. For instance, now our tool is capable of producing a Solidity SC template which can be deployed in an Ethereum blockchain. The goal of our work is to help business owners, developers, and resource owners to create secure and safe smart contracts in a practitioner-friendly way. The modular software architecture of our tool can be extended to provide SC template for different blockchain systems.

This chapter of this book is organized as follows: Sect. 2 presents existing literature in the area of generating smart contracts and in general, the approaches to make it secure. Section 3 provides the necessary background information to understand Petri-Nets, advantages of it, and how we are using it in our approach. Section 4 presents our Petri Nets based Secure Smart Contract Generation Framework and describes how each component in our framework work and how it can be extended to support other blockchain technologies. Section 5 takes an example blockchain use case through which we describe and evaluate our approach. Finally, in Sect. 6 we present the conclusion and future work in the area of securing blockchain by creating safe, error-free and understandable smart contracts.

2 Related Work

This section presents the related work in the area of (a) generating smart contracts—with a focus on security and (b) translating business process models, state machines, Petri Nets, or similar workflow models into a generic code. The first approach (a) reviews the state-of-the-art approaches in generating smart contracts, and the second approach (b) reviews the related work in the area of code generation by translating business processes or workflows into a generic code. However, in this section, we do not cover the related work in the area of identifying existing vulnerabilities in already deployed smart contracts by symbolic code analysis or similar methods—this is out of the scope of our research.

In our research, we focus on avoiding the errors prior to smart contract generation. But integrating vulnerability analysis tools before deploying a smart contract will certainly help to find and avoid existing library or code-based security issues. In each paragraph below, we present one topic of related work and at the end, we discuss the problems and advantages of each method (if they exist). We considered the experiences, knowledge, and recommendations from the presented related works for designing and implementing our approach.

Garcia et al. in [12] presented a method for compiling a Business Process Modeling Notation (BPMN) process model into a smart contract defined in the Solidity language. The authors used the approach of the control flow of *workflow-nets* from [19] to translate BPMN to Petri Nets, to eliminate invisible transitions and spurious places, and thereby, optimizing the gas costs for the deployed Solidity smart contract in Ethereum blockchain. Nakamura et al. in [29] presented a similar approach: first, they use BPMN to model inter-organizational business processes, but it is translated into state charts and represented as State Chart XML (SCXML); second, they optimize the state chart and then produce the chaincode (using Go language) for Hyperledger Fabric. The papers [12, 19, 29] did not focus their work to build secure smart contracts, which is one of the limitations of their work.

Mavridou et al. presented two frameworks in [22–24] respectively: (a) finite state machines (FSMs) based framework called *FSolidM*, which provides a graphical editor for specifying Ethereum smart contracts as transitions systems and a Solidity code generator; (b) *VeriSolid* framework, which introduces formal verification capabilities. Their FSolidM framework provides a graphical user interface (GUI) and has the ability to integrate custom plugins for developers to add further functionality such as automated timed transitions and access control. Thereby, their approach is very close to ours in terms of correctness-by-design development of smart contracts. As this work was done in parallel to ours and also suitable to generate secure smart contracts, we complement their approach to generate secure smart contracts. A separate study is required to compare our approach, which could be future work. However, the semantics of the state machines can be hard to understand compared to the semantics of Petri Nets. Furthermore, we argue that the semantics of Petri Nets are much more suitable than FSMs to model concurrent and interactive systems such as smart contracts.

Philippi in [32] presents an overview of different code generation approaches from high-level Petri Nets. In particular, they investigated the simulation-based code generation approach. Mortensen in [26] presented a method for generating code from Colored Petri Nets (CPN) models. First, the developed CPN model is used to generate the standard ML code then, the ML code is used to generate a platform-specific code, for example, in C language. They evaluated this approach by generating code for an access control system. Their work also shows that the introduced automatic code generation method reduces the code development time and errors in comparison to the manual system development methods. Pinna et al. in [7] analyzed the Bitcoin blockchain network using a Petri Net model to find the group of Bitcoin addresses owned by the same owner, disposable addresses and explained the advantages of Petri Nets modeling. However, this approach is not related to smart contract generation, but shows the advantages of using Petri Net modeling. The approaches taken in the papers [26, 32] show the advantages of using Petri Nets such as automatic code generation, reducing code development time and errors, and evaluating the generated code for security systems like access control.

Choudhury et al. in [3] presented an automatic smart contract template generation framework that uses ontologies and semantic rules to encode domain-specific knowledge and uses the structure of abstract syntax trees (AST) to incorporate the required constraints into the generated template. The authors evaluated two use cases and presented a few examples of the generated SC code snippets in Solidity language. Tateishi et al. in [36] presented another approach to generate automatic smart contract that can be deployed in Hyperledger Fabric, their approach uses a document template and a controlled natural language (CNL) that provides a formal model which is then used to generate a smart contract with a toolchain. Both the approaches [3, 36], point out that we need human-understandable methods that can help to create smart contracts, but they do not focus on generating secure or *error-free* smart contracts.

3 Background

This section introduces the required background information on Petri Nets and provides a holistic view of research in specifying and enforcing workflows with Petri Nets.

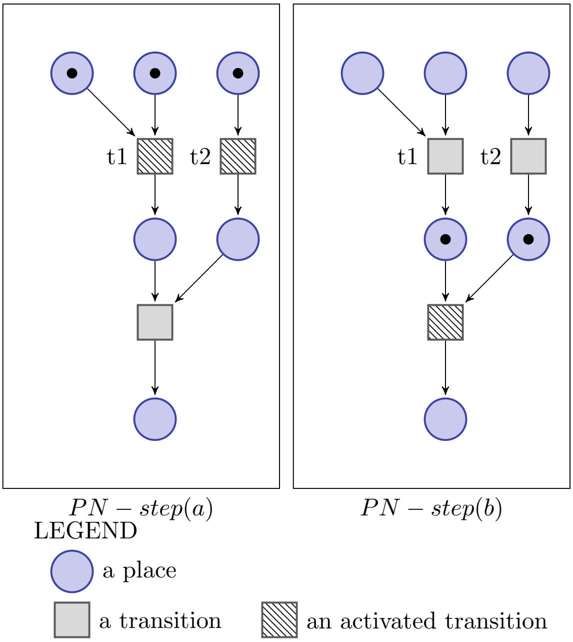

Fig. 1 PN—Step(a) shows the initial state of a Petri Net and PN—Step(b) shows the state of the Petri Net after transitions $t1$ and $t2$ have fired

3.1 Petri Nets for Workflow Specification and Enforcement

Petri Nets have evolved since its introduction by Carl Adam Petri in the year 1966 (see [31]). In traditional Petri Nets (PN) there are *places*, *tokens*, and *transitions* (see Fig. 1). Petri Nets are used in various applications such as to model concurrent systems, protocols, and resource planning in critical processes. In particular, with a Petri Net model, it is possible to evaluate and verify properties such as soundness, deadlock-freeness and livelocks, and reachability (see [8, 27, 33]). Petri Nets provide a graphical modeling tool used to specify, model processes or workflows, and to verify the properties described above in a Petri Net model.

A place in a traditional Petri Net can hold one or more tokens (also known as *markings*). A transition has one or more input and output places. A transition is enabled if its input places have sufficient tokens and as a result, it fires and produces tokens in the output places. This intuitive token-game semantics makes the Petri Nets a natural way to model and verify processes. Figure 1 shows a simple Petri Net with an action of a transition in two steps: first, in step(a) transitions $t1$ and $t2$ are activated because $t1$ and $t2$ have sufficient tokens; second, in step(b) $t1$ and $t2$ fire to produce tokens in output places of $t1$ and $t2$.

There are several Petri Nets modeling tools available that use different programming languages—a comprehensive list is maintained by the University of Hamburg.[1]

[1] https://www.informatik.uni-hamburg.de/TGI/PetriNets/tools/.

Weber and Ekkart in [41], presented an XML based language "*Petri Net Markup Language*" (PNML) for storing and exchanging the Petri Net models.

Workflow Specification and Enforcement extensions of Petri Nets such as Hierarchical Petri Nets, Time Petri Nets, and Colored Petri Nets have enabled us to model different constraints such as time and types of tokens, and so on. In particular, Workflow Nets introduced in [37, 38] enabled us to model business processes as workflows. From a workflow security perspective, Atluri et al. in [1, 2] presented safety analysis and an authorization model for workflows in a centralized pattern and Knorr in [20] used Petri Nets to model access controls.

Kasinathan et al. in [16, 17] presented a Petri Nets based distributed workflow specification and enforcement approach by introducing Oracles places, Open Petri Nets, transition contracts, and timeout transitions for specifying and validating conditions and constraints (see Fig. 2). In particular, their approach uses practitioner-friendly tools to collect requirements from the use cases and model them as Petri Net workflows. This provides a unique ability for the stakeholders to model, verify their processes and finally, to get an assurance that the entities obey the workflow and satisfy the conditions to complete the workflow. Thus, this approach provides a workflow-aware access control method that is generic to be applied to any system to have fine-grained access control.

In this work, we use the Petri Nets based workflow specification and enforcement approach presented in [16, 17] because the workflows created using Petri Nets are practitioner-friendly and less complex to model and amicable to formal verification. With Oracle places it is possible to describe the interaction with the objects/entities outside the workflow execution environment and task-specific conditions that can be written in transition functions. In particular, we see that in many blockchain use cases we need external information and this can be provided into the Petri Nets model via

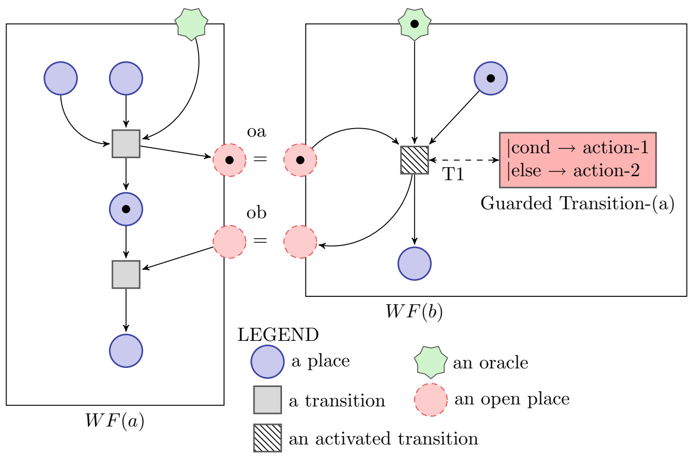

Fig. 2 Two workflows WF (**a** and **b**) show the features of extended Petri Nets presented in [16, 17]: Oracles, Open Places, and guarded transitions

Oracle places; in other cases, smart contracts might have to interact with other smart contracts where an Open Petri Net place is used to interact with other processes or Petri Net workflows. We explain in detail how we use oracles, transitions extended with guarded commands and other Petri Nets extensions with our Petri Net visual modeling tool for creating smart contracts in the Sect. 4.

4 Petri Nets Based Secure Smart Contract Generation Framework

In the previous Sect. 2, we presented various approaches to generate smart contracts. In this section, we introduce our proposed *Petri Nets based Secure Smart Contract Generation Framework* that involves a multi-step process to generate *safe, secure, and human-understandable* smart contracts. Our approach focuses on security by design approach and it is based on Petri Nets. The reasons for choosing the Petri Nets based workflow specification and enforcement framework are presented in [16–18] and explained in Sect. 3.1.

The requirements of a smart contract (SC) generation should be as follows:

- A SC should be easy to understand and write i.e., human-understandable and practitioner-friendly methods and tools should be available to model the business logic or workflows.
- A SC should be amenable to verification of process integrity i.e., the smart contract should only allow the authorized actors and restrict them to perform actions with least-privilege principle. For more information on process integrity see [18].
- If necessary, the smart contract modeling language should support human interaction, for example, to approve or reject conditions specified in a SC.

We designed our framework based on the above mentioned SC requirements. Figure 3 shows a modular architecture of our proposed framework which consists of following components: (1) a *Petri Net Visual Modeling* a graphical user interface (GUI) where user can model, import, export and store Petri Net workflows; (2) a *Simulation engine* that accepts PNML representation of the workflow and can execute each transition separately or a complete Petri Net; (3) a *verification engine* that preforms Petri Net validation and can be extended with standard Petri Net verification tools; (4) a *code translation engine* that generates the smart contract from the Petri Net model. In addition to the main components, our framework includes a SysML activity diagram modeling tool to support practitioner-friendly methods, and a smart contract expert review process to introduce a strict security auditing process within the framework before deploying the generated smart contract into the blockchain network.

The multi-step process of creating secure smart contracts starts with the stakeholders who identify the use case requirements and create the necessary business logic. To represent the business logic in a human-understandable way, we propose to use the SysML's activity diagram because it could be difficult to model complex

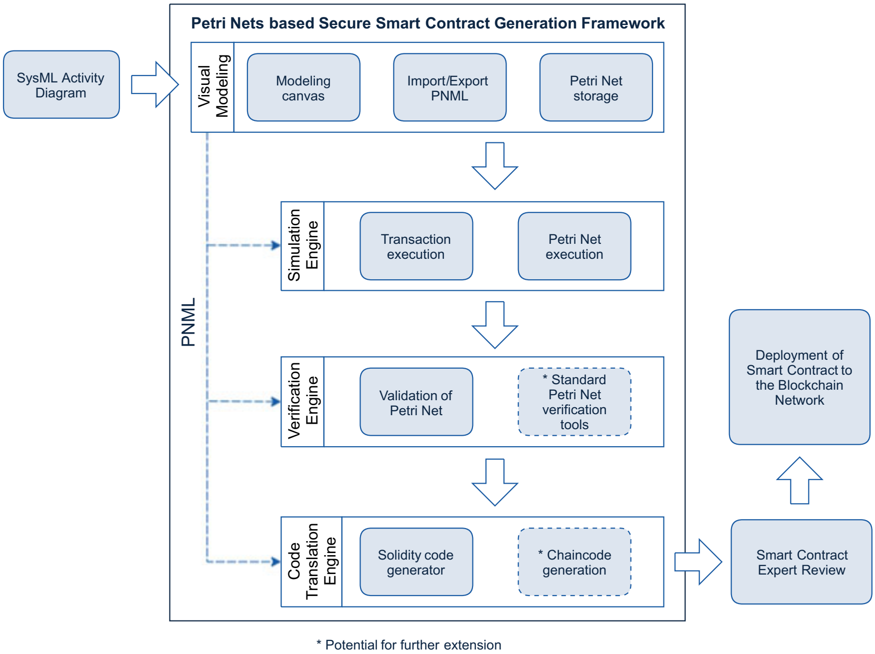

Fig. 3 Modular architecture of our Petri Nets based Secure Smart Contract Generation Framework

business logic directly in Petri Nets. Open source SysML modeling tool "Modelio" [25] can be used to create activity diagrams. Later, the SysML activity diagram can be translated into Petri Nets directly using automated tools (see cite: [14]) or by a workflow expert via our Petri Net Visual Modeling GUI as shown in Fig. 4.

A Petri Nets model can be created from scratch or can be imported from other existing Petri Net models described in the Petri Net Markup Language (PNML) which is the standard XML format to exchange Petri Net models. After importing, the PN model can be modified, extended and stored according to the needs of the workflow expert.

During the modeling process, the user can simulate the Petri Net by executing each transition separately or by fast-forwarding through the complete Petri Net. This process allows to test workflow logic already during the modeling process and allows for fast iteration.

The next step is a verification process of Petri Nets that is performed by the *Petri Net Verification Engine*. The Verification engine takes care of two main functions (validation and verification) while the user models the Petri Net workflow. The validation of Petri Net properties can help to optimize the business logic and to find and avoid errors at the modeling state itself. Additionally, the external Petri Net verification tools could be integrated that support PNMLrepresentation format.

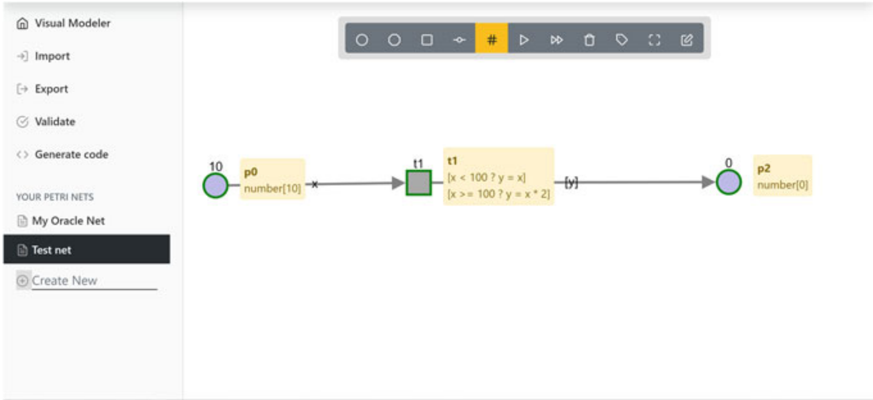

Fig. 4 The user interface of Petri Nets based Secure Smart Contract Generation Framework featuring modeling canvas, toolbar, function menu and library of modeled Petri Nets

Finally, the verified Petri Net model is provided to the *Code Translation Engine* which produces the desired smart contract template. This translation engine is designed modular and therefore it is blockchain platform agnostic. Currently, our tool supports the generation of Solidity smart contract which can be deployed in the Ethereum blockchain network but the modular design of the framework support further extension of code translation engine to support other blockchain technologies. The generated smart contract can be a standalone contract or a part of a big contract consisting of many SCs.

Below, we present a detailed description of every step. Once the template is generated, it might be necessary for a smart contract developer to complete the smart contract with necessary business-logic details that weren't modeled in the PN model. In addition, a security audit on the smart contract may be performed before deploying the SC on the blockchain.

Petri Net Workflow Visual Modeling provides the user with a visual modeling graphic user interface (GUI), allowing to model Petri Net workflows through a canvas that guides the user with tips and information throughout the complete process – i.e., from modeling the Petri Net workflow until the generation of the smart contract. Our Petri Nets based Secure Smart Contract Generation Framework can be accessed via a web browser and doesn't require any server-side dependencies. Figure 4 shows the user interface of the prototype which has four important elements: modeling canvas, toolbar, menu and workflow library. At the center of the application, there is the interactive modeling canvas used to model the Petri Net workflows. The toolbar is located above the modeling canvas in grey color, and it contains tools to add new elements to the canvas (e.g. places, oracles, transitions), connect them with arcs and to edit, rename and delete them. As you can see in Fig. 4, on the left of the canvas, there is the menu with functions to import and export PNML representation of modeled workflow, validate the workflow and generate smart contracts. Just below the menu, there is the library listingall stored Petri Net models that the user has created.

To ease the modeling process, GUI guides the user through the modeling process with visual cues and annotations, helping the user to understand and create the Petri Net workflow easily. There are three different element types that can be used in the modeling process. A most basic Petri Net workflow consists of at least two places a single transition, whereas the use of oracles is optional.

A place may represent a state of an actor in the workflow and it shall hold one or more tokens. These tokens are consumed by a transition and are moved to different places once the conditions of the transition are met and executed. Additionally, tokens can be of a different primitive data type (e.g., colored Petri Net tokens see [15]). In our framework, currently supported token can be of a type string, integer or a boolean, but the design is not limiting to only mentioned types.

The Oracles are a special type of places which represent external information that can be accessed within a Petri Net and is in the framework considered as an external parameter passed to the smart contract. Because the external parameters are tightly dependent on the use case the generated *execute* function can be modified by the smart contract developer in the review process in order to remove global variables representing oracles and pass them as variable values to the function according to the needs of the use case.

The transitions are extended with a guarded command language (see [6]) which is used to enforce business logic conditions. Each transition contains one or more guarded commands. Each guarded command consists of a proposition and a statement. A proposition is a condition and if it is true, it will lead to the execution of the statement. The conditions are checked against the input tokes from the incoming places using algebraic and boolean expressions. Those conditional statements are written in the form of assignments, for example, $x = expr$ where x must be named the same as one of the outgoing arcs of the transition. An expression (*expr*) can contain an algebraic expression that may include variables, constants, and algebraic operators. Figure 5 shows the *edit view* interface of a transition which is used to define the guarded commands. Every transition can contain multiple guarded commands. The visual modeling engine enforces that only the variables from the incoming places are allowed to be used in the expression (*expr*). The exit or output place of a transition is decided based on the execution of the statement and the transition may create new tokens, consume or update existing input tokens and push it to the output place.

Additional functionality of visual modeling engine is an option to save, import and export Petri Net workflows. This also increases the interoperability of the workflow development and allows the user to import basic Petri Net from other modeling systems. To facilitate import/export function, Petri Net Markup Language (PNML) standard and recognized format for exchanging Petri Nets models is used. PNML exchange format is extended with additional XML tags to represent additional logic that was introduced in a form of guarded commands of the transitions, additional rules, and oracles. An example PNML is shown in the appendix listing 1.

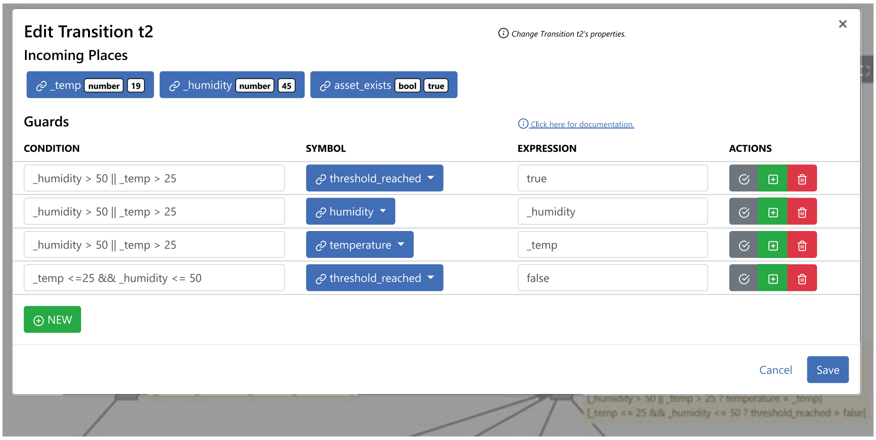

Fig. 5 Transition edit view used to define guarded commands

Petri Net Simulation Engine is introduced to ease the modeling and to quickly iterate on the workflow design during the modeling process. It consists of two main functionalities: (a) execution of a separate transition—a process which consumes the tokens from the input places of the transition based on the logic specified by the guarded commands and produces the tokens, and assigns them to the output places of the transition; (b) fast-forward of the complete Petri Net—a process which consecutively executes all transitions of the Petri Net based on the specified input parameters and guarded commands, and validates that the model does not result in a deadlock. The Simulation Engine interprets the PNML representation of the modeled Petri Net.

Petri Net Verification Engine supports the GUI by actively monitoring the Petri Nets visual modeling process and guides the user to correctly model the Petri Net by pointing out errors—an example of such error is shown in Fig. 7. Once the Petri Net model is completed without syntactic errors, then the verification engine supports validation (i.e., see validation of the PN model in Fig. 6). The verification of other Petri Net properties such as deadlocks, soundness, and liveness can be done with the help of external standard Petri Net tools such as CPN tools [15], WoPED [11], and YAWL [40]. The validation and verification of the PN model is a mandatory step and its role is to enforce Petri Net modeling restrictions by enforcing "validation" of modeled workflow prior to the generation of a smart contract template.

All enforced modeling restrictions are displayed to the user during the modeling process through the visual cues providing the reasoning and instructions on how to resolve modeling mistakes. An example of the user interface informing the user of the successful validation is shown in Fig. 6, whereas Fig. 7 shows the response with errors that were identified during the validation process. Until the user doesn't resolve all errors, the proposed framework prevents the invocation of smart contract generation.

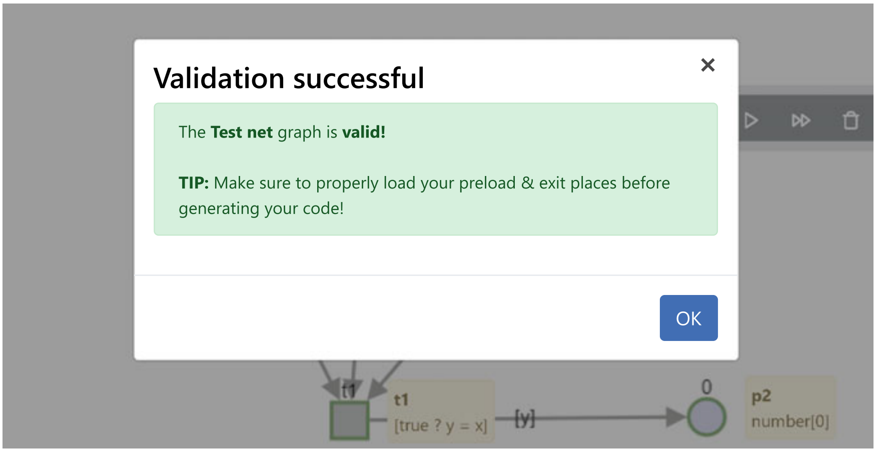

Fig. 6 Feedback of successful validation step

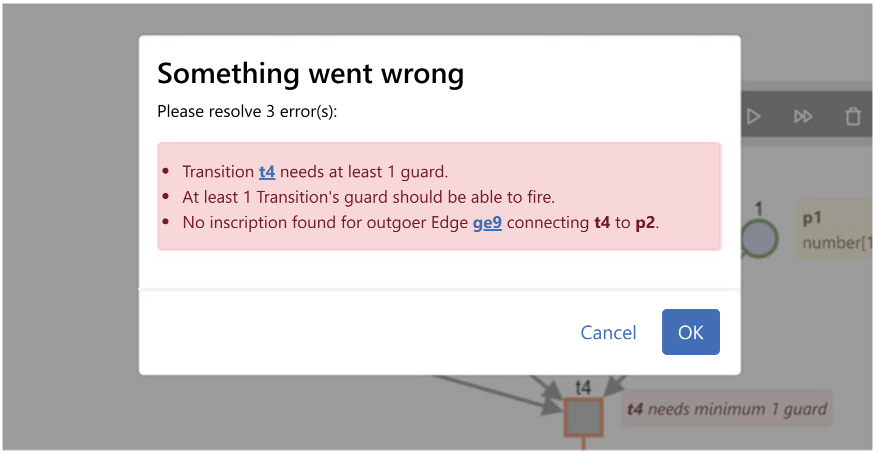

Fig. 7 Feedback of validation step showing identified errors in the Petri Net model

Petri Nets workflows are considered sound when it satisfies the following three requirements (see [37–39]): (a) *an option to complete* you should be able to reach the end state or complete the workflow from any given state of the workflow; (b) *proper completion*—when a workflow is completed no tokens (incomplete tasks) are left in the workflow; and (c) *no dead transition*—every transition in the workflow can be executed by following the appropriate path. To facilitate the soundness property the following restrictions are enforced:

– There is one start place with outgoing arcs and one end place with incoming arcs.
– All transitions and places in the workflow should be along the path from the start place to the end place.

– A transition must have at least one input and out place connected. Therefore all transitions and places need to be connected.
– Each transition must have at least one guarded command that evaluates to *true*. Note: having explicit else guard is, in general, good but not mandatory. Arc annotations are used as a reference to the incoming and outgoing places via transitions.

Once the Petri Net model satisfies all conditions, the validation process is successful. Furthermore, to validate and verify other properties other Petri Net tools such as YAWL or CPN tools can be used. Finally, after the PN model is validated and verified, the smart contract generation step (icon generate code in the GUI) is enabled.

Petri Net to Smart Contract Translation Engine helps to complete the final step of the multi-step process i.e., to generate smart contract generation from the Petri Net workflows. This step is performed by the smart contract translation Engine that takes the Petri Net Markup Language (PNML) extended with guarded commands as an input and performs a translation of the Petri Net workflow into the smart contract code. In the current version of our tool, only translation to Solidity code is implemented but the engine is extendable, thus allowing us to translate to other smart contract types such as Hyperledger Fabric's chaincode.

The proposed framework takes an approach of mapping places, transitions, and guarded commands into smart contract code. A complete PN workflow is translated into a contract consisting of global variables representing places, functions that directly implement the execution logic of the transitions. The main execution function defines the procedure that is modeled by the Petri Net based on the conditioned executions of the state variables of places.

The places, oracles, and tokens are associated with the globally accessible information where they are translated into a pair of global variables representing a value and a state. The state variable represents whether the token was consumed from a place or not. If the token was consumed, the place is considered as disabled.

Each Place of the PN, when translated into a SC code is represented with the data structure:

– a struct will hold the value of tokens which can be of the specific type (i.e. *bool*, *string*, *uint*).
– a struct will hold the *enabled* or *consumed* state of the *bool* type.

A transition of a PN workflow is written using guarded command language as proposed in [6], and each transition is translated to separate functions. Decoupling the main code from the functionality gives us several advantages such as reusability, efficient analysis of functionality by testing a small piece of the code and easier modeling of the condition statements due to the use of the guarded commands. We map the guarded command language to the smart contract language's logical and condition evaluation features such as Boolean and algebraic expressions and assignments.

The output of the function is mapped (or assigned) to the input place of next transition, and that can be achieved in two different ways:

- Approach (i): the main code invokes a function and assigns the return value (token) of the function to a variable representing the input place of the next transition.
- Approach (ii): builds on the premise that every transition of the PN can access only the places to which it is connected. The state of places is changed through assignments inside the function. In this approach, there is no need to return the results of the function to the main function.

The proposed framework implements a second approach. As the state of the place is changed from inside the function representing the transition, the translation engine ensures that the global variables representing tokens are not reused inside the functions to hold temporary states. The internal operations of a function first copy the global variable to a local variable and only if the expressions are valid, the global variable value is updated preserving the atomicity property. Therefore, we avoid any inconsistencies of state of the same places.

In both approaches, we need a lock mechanism for writing/reading the value written to a place variable. To avoid race conditions that can erase a value from a place before it is being consumed, we propose to use mechanisms used in traditional databases i.e., lock and release before writing and reading a value from such special places which are realized through the *enabled* and *consumed* state variable of the place.

Once the Petri Net is translated into a smart contract, a workflow expert reviews the generated SC code and published it in the blockchain.

4.1 Advantages of Our Petri Nets Based Secure Smart Contract Generation Framework

Our Petri Net workflows can be seen as high-level smart contracts that are amicable to formal verification, i.e., it is possible to check the workflow specific properties such as deadlock and workflow soundness properties. This supports avoiding such potential errors during the modeling phase of the workflow. Thus, translating validated and verified Petri Net models into a Solidity code will avoid those errors, therefore the generated smart contract template is considered secure and will protect the process integrity of the business logic. However, if the smart contract language has a language or platform-specific problems or business logic errors then those problems will still exist in the generated smart contract. This holds true as well for the scalability of blockchains. The process of modeling and generating smart contract through the Petri Nets based Secure Smart Contract Generation Framework doesn't have an influence on the scalability characteristics of the blockchain platform.

In particular, the advantages of using our framework are:

- When domain specialists model the workflows using our PN based framework then this will minimize the chances of business logic errors during the modeling phase

- Workflow verification with the standard Petri Net tools can help to identify errors and prevent them from appearing in the smart contract.
- Simulation of PN workflow using the token-game at modeling phase helps to understand the workflow intuitively before generating a smart contract.
- Platform independent modeling helps smart contract developers to design and deploy contracts in different blockchain platforms quickly by focusing on the modeling of business logic and not on the development process or on the programming languages.
- Smart contract generation without program development knowledge. This feature particularly helps stakeholders without programming or smart contract knowledge.

5 Evaluation of Petri Nets Based Secure Smart Contract Generation Framework

This section first introduces the supply chain use case and the advantages of using blockchain. The presented example use case is later used for the evaluation of the functionality of our proposed Petri Net visual modeling tool.

5.1 Supply Chain Use Case

A supply chain is a network of different organizations involved in the process of moving products from one or more suppliers to a customer. The products can be raw materials, small parts, natural resources (e.g. minerals), food, finished products, or even a service. Few examples of involved parties and stakeholders are the manufactures, customers or consumers, logistics companies, distributors, insurance providers, regulatory bodies, and so on.

If the participants of the supply chain are enforced to record important data on the blockchain, then the following features of blockchain reduce the chances of fraud in a supply chain process. The blockchain technology provides a single source of truth, a transparent auditability of the historic events, and proof of provenance by storing data in an immutable way. The main focus of any supply chain use case is to have an audit trail of products to track provenance. The blockchain ensures a correct and verifiable audit trail throughout the lifetime of the product.

As the use case is dynamic and depends on the domain type of the product, it is important to generate a smart contract that fits the use case. These domain-specific workflows can be modeled by domain specialists without the knowledge of smart contract development. Our proposed smart contract modeling and generation framework is designed with this focus and therefore brings all the advantages described in Sect. 4. As described earlier, after modeling, the developer or smart contract expert reviews the generated smart contract and deploys it to the blockchain network. In

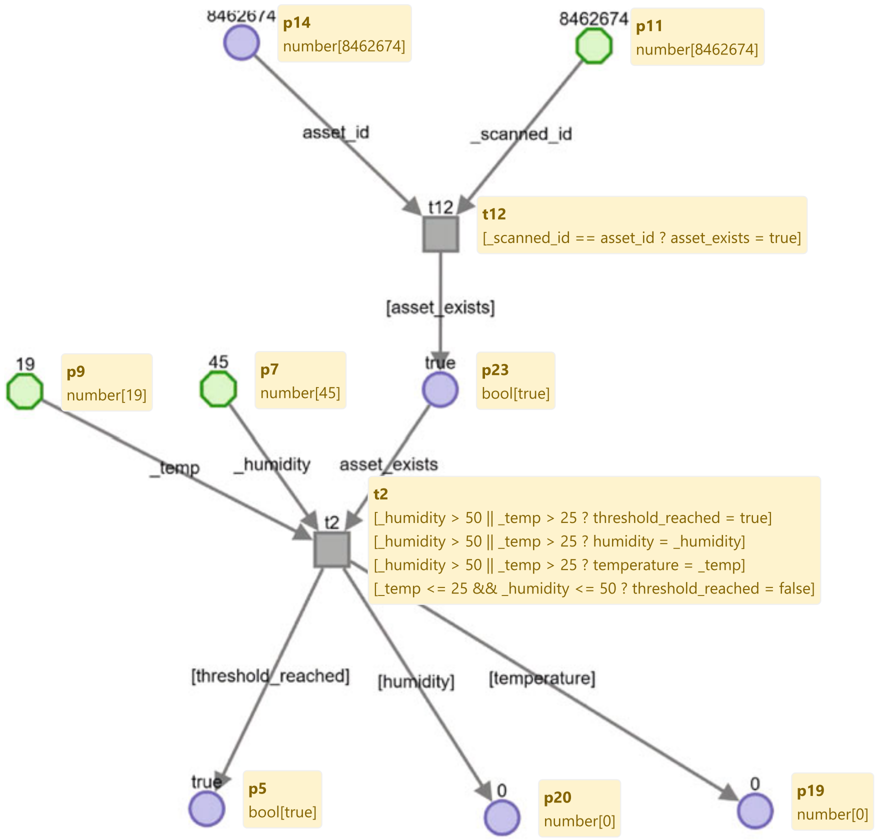

Fig. 8 An example Petri Net workflow that shows a part of the supply chain use case

this step, before deploying the smart contract code, the smart contract developer needs to perform a requirement analysis of important data that is required to on the blockchain, and define the scope of the methods (i.e., which methods should be public, private, etc.).

Our approach allows the domain specialists to simulate and test the workflow or business requirements prior to the code generation part, this activity provides the confidence that the smart contract is modeled as required. Our approach can support different blockchain technologies with one standard modeling approach, thus it minimizes the development cost, testing, and verification efforts. In particular, with our approach, we improve security by minimizing the errors in the design stage of smart contract development (correctness-by-design).

For simplicity reasons, we modeled only a part of the supply chain use case with desirable features and actions involved. An example of a part of a supply chain use case is shown in Fig. 8. The modeled Petri Net workflow consists of three Oracle places, five normal places, and two transitions. The Oracle places ($p11$, $p7$, $p9$) represent some external information that is sent by different equipment and sensors such as a scanner, a temperature sensor, and a humidity sensor. The first transition ($t12$) checks if the scanned asset ID (*_scanned_id*) from the Oracle place ($p11$) equals to the already registered *asset_id* from the place ($p14$). If transition $t12$ conditions evaluate true, then it passes a token (*asset_exists*) to the input place ($p23$) of second transition ($t2$). The transition ($t2$) has two additional input oracles named *_humidity* and *_temperature* besides the input place ($p23$). The guarded commands of the transaction $t2$ checks if the humidity value exceeds the threshold of 50 or the temperature value exceeds 25, if this evaluates true, then the *threshold_reached* boolean variable is set to true and the temperature and humidity variables are set accordingly. If the temperature value is less than or equal to 25 and the humidity value is less than equal to 50 then the *threshold_reached* variable is set to false. In either case, all output places ($p5$, $p20$, $p19$) of transition $t2$ receives a token.

The Petri Net visual modeling tool allows assigning the tokens to the starting places and oracles, which makes it possible to simulate the workflow with the arbitrary tokens and fire the transactions prior to the smart contract generation step. That way each transition can be tested with different token values to cover the complete condition space set by the guarded commands. The user can fire each transition separately, or fast forwards through the complete Petri Net model and execute all transitions.

The generated solidity code from the PN workflow shown in Fig. 8 is presented in the appendix listing 2. The generated smart contract follows the approach that was explained in the Chap. 4. The code is separated into two types of functions: one is the main *execute* function which represents the execution flow of the transitions; and, the other is the normal function which encapsulates the guarded commands and assignments written in the transitions.

The *execute* function represents the execution flow of the workflow through the conditioned execution of the functions representing transitions. These functions are executed only if all incoming places of each transition are enabled, which means that they contain tokens. To start the execution at the beginning of the *execute* function, the incoming places of the first transition are enabled.

The normal functions of the transitions have limited internal scope for the execution—this prevents the functions to be publicly executable and can only be called within the contract itself and any derived contracts. The body of the normal function starts with the definition of local variables which are created from the input and output places connected to the transition. In case of input places, the variable of the incoming input token is assigned to the local variable whereas, in case of the outgoing tokens, the variables are initialized to the default value of the output place.

Below, we explain how guarded command conditions written in the transitions are translated into the code. Every translation that holds guarded commands execute the following three steps:

- *Consume*: Each condition first starts by *consuming* the tokens of all addressed places of the guarded command and therefore disabling the place. This is done by assigning the token state variable to *false*.

– *Assign*: Next, the logic of guarded commands is translated into the code, resulting in the list of assignments to the local variables of the tokens.
– *Produce*: The last step is to produce tokens for outgoing places. This process is done by first assigning the token values of the local variables to the global ones followed by assigning the state variables of tokens to *true* and therefore enabling the outgoing places.

5.2 Limitations of Our Approach

The framework is designed to be blockchain technology-agnostic even though the first implementation of smart contract generation supports only smart contract programming language Solidity, which is specifically designed to be running on the Ethereum blockchain network. Due to the technology-agnostic design, is the modeling process not specifically tailored to optimize all unique concepts that the Ethereum introduces, for example, the introduction of *gas*, internal pricing for running a smart contract on Ethereum. The code presented in the appendix listing 2 is not optimized to minimize the consumption of gas as this was not a focus of our approach. This can have performance implications due to the higher consumption of gas. One of the approaches to minimize gas consumption is planned in the further extension, and we plan to use bit arrays to store state variables of tokens instead of separate variables for each token. This optimization concept with its advantages and limitations is explained by Garcia et al. in [12].

Another limitation of our approach is that once the smart contract template is generated by our tool, there might be the need for a smart contract developer to invest additional effort to extend the template smart contract with additional business-logic before producing a deployable smart contract. This process could introduce some generic smart contract coding errors—this topic was outside the scope of this work. We recommend the integration of smart contract vulnerability analysis tools coupled with manual expert reviews (smart contract experts with some sort of secure coding training) before deploying them on the blockchain network.

6 Conclusion

We presented an approach to design, develop, and verify secure smart contracts before deploying them in the blockchain ecosystem with a modeling tool-set for secure smart contracts generation. We presented a framework for generating safe and secure smart contracts based on the Petri Nets. The presented smart contract generation framework is designed in a modular way and it consists of four main components: (a) a Petri Nets based visual modeling engine, extended to support guarded commands; (b) a Petri Nets execution layer for executing transitions and simulating modeled Petri Nets workflow; (c) a verification and validation engine; (c) a translation engine for generating smart contract from the modeled Petri Nets workflows. We also analyzed and presented existing related work in this area of research of secure smart contract generation.

We evaluated a part of supply chain use case with our approach and presented how our framework could be used to generate a smart contract. We showed that it is easy to model, simulate, and generate secure smart contract only with domain-knowledge, and it is not necessary to have smart contract development knowledge. Even though our generated Solidity smart contract can be with little additional effort directly deployed to the blockchain network, it is recommended to be first reviewed by smart contract experts before deployment.

Future work aims at extending the smart contract generation engine to support other smart contract types and optimizing the smart contract code, for example, to minimize the gas consumption in Solidity smart contract. Additionally, further effort is needed to integrate other Petri Net verification tools with our framework. Also, it would be interesting to compare our approach versus Mavridou et al. Finite State Machines (FSMs) approach. We believe that more research in this area is required before organizations can fully adopt the benefits of smart contracts and blockchain technology.

7 Appendix

7.1 Petri Net Markup Language (PNML) Example

The exported PNML code of the supply chain use case presented in Sect. 5.1 is shown in listing 1. Some parts of the XML code are omitted for readability (brevity) reasons.

7.2 Solidity Code

The generated Solidy smart contract of the supply chain use case presented in Sect. 5.1 is shown in listing 2.

```
<?xml version='1.0' encoding='UTF-8'?>
<pnml>
  <net id='scd'>
    <place id='p9' isGlobalVar='true'>
      <initialMarking>
        <multiset>
          <item>
            <value>
              <object type='int'>19
              </object>
            </value>
            <multiplicity>1</multiplicity>
          </item>
        </multiset>
      </initialMarking>
    </place>
    <place id='p5' isGlobalVar='false'>
      <initialMarking>
        <multiset>
          <item>
            <value>
              <object type='bool'>true
              </object>
            </value>
            <multiplicity>1</multiplicity>
          </item>
        </multiset>
      </initialMarking>
    </place>

    ...<omitted for brevity>...

    <transition id='t12'>
      <guard id='1'>
        <condition>scanned_id == asset_id
        </condition>
        <symbol>correct_asset</symbol>
        <expression>true</expression>
      </guard>
      <guard id='2'>
        <condition>scanned_id != asset_id
        </condition>
        <symbol>stop</symbol>
        <expression>true</expression>
      </guard>
    </transition>

    <transition id='t2'>
      <guard id='1'>
        <condition>
          _humidity>50 || _temp>25
        </condition>
        <symbol>threshold_reached</symbol>
        <expression>true</expression>
      </guard>
      <guard id='2'>
        <condition>_humidity>50 || _temp>25
        </condition>
        <symbol>humidity</symbol>
        <expression>humidity</expression>
      </guard>
      <guard id='3'>
        <condition>_humidity>50 || _temp>25
        </condition>
        <symbol>temperature</symbol>
        <expression>_temp</expression>
      </guard>
      <guard id='4'>
        <condition>_temp <=25 && _humidity <=50
        </condition>
        <symbol>threshold_reached</symbol>
        <expression>false</expression>
      </guard>
    </transition>

    ...<omitted for brevity>...

    <arc id='ge6' source='t2' target='p5'>
      <inscription>
        <expression>threshold_reached
        </expression>
      </inscription>
    </arc>
    <arc id='ge10' source='p9' target='t2'>
      <inscription>
        <variable>temperature</variable>
      </inscription>
    </arc>
    <arc id='ge8' source='p7' target='t2'>
      <inscription>
        <variable>humidity</variable>
      </inscription>
    </arc>
    <arc id='ge13' source='p11' target='t12'>
      <inscription>
        <variable>scanned_id</variable>
      </inscription>
    </arc>
    ...<omitted for brevity>...

  </net>
</pnml>
```

Listing 1: The snippet of the PNML of the Petri Net model shown earlier

```
pragma solidity ^0.4.24;

contract Scd {

    // Template Variables
    address owner;

    // Global variables
    bool threshold_reached;
    bool threshold_reached_enabled;
    uint asset_id = 8462674;
    bool asset_id_enabled;
    uint temperature;
    bool temperature_enabled;
    uint humidity;
    bool humidity_enabled;
    bool asset_exists;
    bool asset_exists_enabled;

    constructor()
    public {
        owner = msg.sender;
    }

    // State Machine
    function execute(
        uint _scanned_id,
        uint _temp,
        uint _humidity
    )
    public
    returns(string _functionName) {
        asset_id_enabled = true;

        if (asset_id_enabled)
            fire_t12(_scanned_id);

        if (asset_exists_enabled)
            fire_t2(_temp,_humidity);

        return "execute";
    }

    // Transitions
    function fire_t2(
        uint _temp,
        uint _humidity
    )
    internal
    returns(string _functionName) {

        // LOCAL FUNCTION VARS
        bool asset_exists_local = asset_exists;
        uint humidity_local;
        uint temperature_local;
        bool threshold_reached_local;

        if (_humidity > 50 || _temp > 25) {
            // Consume
            humidity_enabled = false;
            temperature_enabled = false;
            threshold_reached_enabled = false;

            // Assign
            threshold_reached_local = true;
            humidity_local = _humidity;
            temperature_local = _temp;

            // Produce
            threshold_reached = threshold_reached_local;
            threshold_reached_enabled = true;
            humidity = humidity_local;
            humidity_enabled = true;
            temperature = temperature_local;
            temperature_enabled = true;
        }

        if (_temp <= 25 && _humidity <= 50) {
            // Consume
            threshold_reached_enabled = false;

            // Assign
            threshold_reached_local = false;

            // Produce
            threshold_reached = threshold_reached_local;
            threshold_reached_enabled = true;
        }

        return "t2";
    }

    function fire_t12(uint _scanned_id)
    internal
    returns(string _functionName) {

        // LOCAL FUNCTION VARS
        uint asset_id_local = asset_id;
        bool asset_exists_local;

        if (_scanned_id == asset_id_local) {
            // Consume
            asset_id_enabled = false;

            // Assign
            asset_exists_local = true;

            // Produce
            asset_exists = asset_exists_local;
            asset_exists_enabled = true;
        }

        return "t12";
    }
}
```

Listing 2: The generated Solidity smart contract for the Petri Net model shown earlier

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Blockchain for Machine to Machine Interaction in Industry 4.0

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1 Introduction

Internet of Things (IoT) has already widely adopted for industrial applications in tasks such as automation, diagnostics, and management of industrial machines and the processes inherent in the formation of supply chains. Such devices have unique characteristics, such as reduced processing and memory, low bandwidth for data transmission and data collection, and limited autonomy, as they are usually battery-powered.

The popularization of these devices and in the face of such restrictions, it was necessary to develop new types of communication protocols, designed to deal with these limitations. For the most part, the protocols used by IoTs currently work with the Publish-Subscribe paradigm, which enables the availability of data for multiple consumers. Besides, some devices can communicate with each other, directly or through some intermediary. This form of communication between machines is called M2M (Machine-to-Machine) [18].

IoT applications have many gaps because of their heterogeneity, poor interoperability, and resource limitations. Insufficient update cycles often also make IoT

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devices vulnerable to security issues. One way to complement the IoT applications, improving interoperability, privacy, and security is to use Blockchain.

Using Blockchain to store data from these IoT applications provides high reliability and scalability. Information such as transaction logs, static and temporary files, after being converted, processed and extracted, are stored and protected by Blockchain, guaranteeing its immutability. This data is stored as Blockchain transactions, that is, encrypted and digitally signed by cryptographic keys.

Technologies integrated with Blockchain such as Smart Contracts give power and increase the security of M2M Communication, besides allowing the application of routines and payment automation between machines without human intervention unprecedented, all combined with complete traceability and reliability of the information.

The data entered in the Blockchain are identified and verify anywhere and anytime, resulting in secure and unchanging transaction history. It allows the creation of IoT applications with guaranteed traceability and audit since it is remote the possibility of altering or falsifying inserted and stored transactions in Blockchain.

A classic example would be a retail IoT application that provides traceability of vendor products based on Blockchain transactions while maintaining the quality and originality of products that can be inspected and verified at any time without the possibility of fraud due to the immutability of embedded information.

M2M has been gaining ground in new applications aimed at Industry 4.0, where there is a search for complete automation of processes, as well as the removal of repetitive tasks, often dangerous and critical to the business of the responsibility of people.

Industry 4.0 encompasses disruptive technologies and standards that lead to complete decentralization of process control—having as a crucial feature the proliferation of intelligent devices interconnected throughout the chain of production and logistics of factories. The basis of this industry is to connect machines, systems, and assets to create intelligent networks that assist in productive control, and the expected impact on the adoption of this new concept in the industrial sector compared to what the Internet has provided modern society.

Precisely because it has immediate potential in industrial applications, M2M communication has shown promise, especially when it comes to Industry 4.0. In summary, M2M Communications is a concept that describes the technologies that allow networked machines to exchange information and execute actions without any human intervention—leading to full industry digitization. This technology is potential can be used in large part of the existing network infrastructure, which also makes it flexible and can be used to communicate with new or legacy applications for various purposes.

2 Blockchain

Blockchain is a key technology for decentralized encryption platforms, Bitcoin has given rise to this innovative and disruptive design and is currently the big bet of solution for most FinTech (Financial Technology).

Its initial proposal comes from the complexity or even impossibility of relying on financial transactions without audit mechanisms, as in the case of Bitcoin virtual currency.

Although widely used successfully in new decentralized financial transaction systems, we can already find some proposals for using Blockchain for applications other than currency encryption, such as IoTs in Industry 4.0 [5].

Concerning security, one of the main problems of the current applications of the IoT platforms is to have a centralized cloud-based infrastructure. A decentralization of M2M transactions using Blockchain would overcome many of the problems associated with a centralized approach because it did not have a single point of failure or vulnerability [15].

The Blockchain form a structure as a chain of blocks (chained list) where each block has a set of transactions that occur at a given time. This data structure is expandable and shared by multiple clients in a peer-to-peer (P2P) architecture, and because it built with cryptographic tools, it is not possible to modify its data without the private keys. The blocks are linked by the previous block hash, as a reference, forming a chain in which any modification occurred are public for all and forever. To support and operate Blockchain, network peers have specific features like routing, storage, and mining.

In the Blockchain the chain o can be consulted wholly and openly, this procedure allows access to the transactions that have occurred since the first block (Genesis), allowing a complete verification and grouping at any moment.

New blocks of the chain generate through mining, in which the mining nodes make computational use to find a solution to create a new block, this search is called PoW (labor proof). This solution must satisfy criteria, which can easily be verified by the other nodes of the network, and once PoW is completed, the block publishes in the network order to be validated and added to the chain.

3 Blockchain Propositions

3.1 Ethereum

Ethereum has become a popular platform for Blockchain applications, providing more features than Bitcoin because it includes Smart Contracts in its structure, which significantly contributes to generating new application possibilities [23].

Smart Contracts for Ethereum are full Turing and can write in languages such as Solidity, compile into a bytecode that runs on an EVM (Ethereum Virtual Machine), enabling the creation of own arbitrary rules, transaction formats, and state transition functions.

EVM is the environment where smart contracts execute in Ethereum. The Ethereum nodes run EVM as a sandbox and provide an isolated execution environment, and all Blockchain nodes can run the same code. It provides redundancy in the execution of smart contracts.

In Ethereum, all calculations and transactions have rates, which measure in units of Gas, and each transaction must not specify a maximum Gas limit that can use during the execution of a transaction. Using this mechanism ensures that Smart Contract does not run forever [21], but some research claims that this may bring some problems, and to mitigate. To try to mitigate some of these problems we have propositions like BOScoin.

In 2017 born the [13] EEA (Enterprise Ethereum Alliance) with focus on open-source developing and standards-based Blockchain specifications, to propose globally standards for the betterment of all businesses and consumers. In the memberships are Microsoft, Santander, JPMorgan, Accenture, BNY Mellon, and many others.

3.2 Hyperledger

Open source, Hyperledger is a global collaborative effort among leaders that dictate the development efforts of technologies that involve the Industry 4.0 concept. This effort has allowed community developers to contribute and share development efforts to the Blockchain [4]. Hyperledger started in 2015 when many companies interested in the Blockchain decided to gather their resources and create a Blockchain of open source and public use, and for this was placed under the tutelage of the Linux Foundation, counting since its publication with more than 230 organizations as members, an existing framework called Fabric and more than seven projects related having IBM as a premier developer member. Unlike Ethereum, Hyperleadger is not a public Blockchain where all transfers are public to all party nodes, and it is as a consortium network, where only authorized participants can provide transactions in the network in complete privacy and confidentiality. Unlike Ethereum that uses its Ether currency and Gas fees, Hyperledger allows to use of Smart contracts with rewards rules, and transactions in the way need them. Unlike Ethereum that has adherence to B2C (Business to Consumers) Hyperledger proves to be a business-to-business or B2B (Business to Business) solution because of its characteristic.

4 Smart Contract

Smart Contract is a concept introduced or the first time by Nick Szabo in 1994. Its adoption brought innovation to Blockchain implementations, making it possible for developers to write routines at their top, making the Blockchain a platform capable of performing procedures as well as transactions contracts are also encrypted to prevent manipulation in their data entry and exit routines.

Smart Contracts already include in most Blockchain implementations, and it allows components to add to the Blockchain according to the needs of the application. Companies such as IBM, JPMorgan, Intel, and BBVA already contribute to the popularization of this technology, key to those who need reliability, immutability, and audibility. Of the Blockchain technologies, we have Ethereum as one of the pioneers to include smart contracts in its implementation.

When deployed in the Ethereum Blockchain network, there is an address to each smart contract. In which any user who knows the contract address and the contract interface definition (ABI definition) can send a transaction to the contract. The transaction is sent to the Blockchain network and combined with other pending block transactions. The miners validate the block. Blockchain network nodes validate the transaction and reach consensus to add the block. The new block then is transmitted to the entire network, and the smart contract is running at the end of the transaction mining.

4.1 BOScoin

Blockchain OS coin is what stands for the acronym BOScoin [8], being the "OS" acronym for the operating system, and suggest the use of "Trusted Contracts." Trust contracts are called so because their result can be known long before they execute, allowing writing and recording in the Blockchain by ordinary users. This option is considered more democratic than the complete Turing, challenging to read by non-programmers, and it is not possible to know the result of the contract before executing it.

In this democratic governance, BOScoin is not governed by consensus rules as in other crypto-coins, established by miners and us. In BOScoin there is a cryptocurrency of the same name and denominated by the acronym BOS, it acts as means of payment, gives voting power and determines rights on the creation of dynamic blocks with an interval of 5 s. The BOS then becomes used to power all operations performed on the platform.

5 Why Use Blockchain for M2M Communication Security

Currently, most of the implementations in this concept use the centralized model, and cloud communications used as a base infrastructure for on-demand access to resources. This strategy is requiring a reliable intermediary for reliable transactions between the machines. The use of Blockchain technology in M2M communication would allow a decentralized peer-to-peer network to e used without the need for a trusted intermediary.

M2M applications that act independently or without user interference need to be transparent, secure, and traceable. Without this, users cannot verify the actions of their applications that request purchases and actions on their behalf.

IoT devices that reused in places where they are expected to have a long life need to work on an infrastructure that supports it without exposing them to vulnerabilities. [6] The machines that exchange goods or services need to trust, M2M transactions which involve financial cost or use of third-party resources require trust and to be viable they need to work without risk [24].

Some features make Blockchain a potential tool to ensure M2M [19] communications in applications for Industry 4.0.

- Decentralized and without trust, Because it is a public ledger in which all transactions replicate among the other nodes of the network. Blockchain allows the existence of a decentralized and unreliable peer-to-peer network since the network nodes do not need a trusted intermediary to be able to exchange messages with each other or the figure controlled by a central authority. Transactions have method d verification by consensus of nodes without the need of trust between them.
- Resilient and scalable, Blockchain has excellent resilient to failures since a decentralized peer-to-peer network does not have a single point of failure, being an immutable and durable ledger in which transactions, once registered in the Blockchain and after a consensus among the cannot be changed or deleted. By being a peer-to-peer network, it has a highly scalable nature.
- Auditable and secure, All transactions are encrypted, and as a public ledger, this ensures transparency and making the Blockchain network secure and auditable, because everyone on the network knows about all transactions.
- Standalone, The Blockchain can allow IoT devices to communicate with each other and make transactions autonomously, as each device has its Blockchain account and there is no need for a trusted third party

In the literature, research work on M2M IoT and Blockchain security is limited, with most of the work being focused on Blockchain and Smart contract technology to benefit communication, and the challenges for identity in IoT. These works focus primarily on discussions of how to provide ownership and identity relationships, authentication and authorization, data governance, and privacy about IoT and Blockchain.

6 Smart Contract Scenarios

In scenarios of shared-economy applications, we note that some scenarios are favorable for the use of the Blockchain suite of solutions for IoT, where this union makes secure the business viability of this model. A union of financial and machine tools using M2M brings new possibilities enabling even payments of products and services with cryptocurrency [14]. To illustrate, let us now explore some possible scenarios

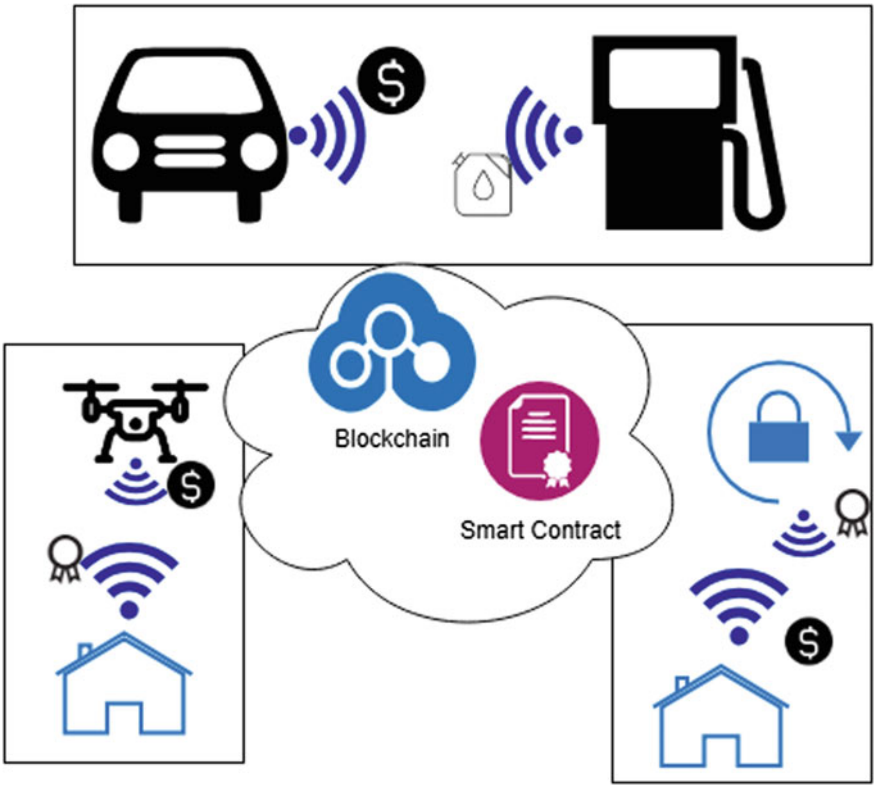

Fig. 1 IoT in a communication using blockchain and smart contract

in our daily lives for smart contracts. We note that they have in common the fact that they use established protocols and promises, and none of the parties involved can manipulate or change the agreed-upon financial and operating parameters.

Figure 1 shows three M2M scenarios using Smart Contract and Blockchain, a payment for a gasoline pump, Drones paying a toll to fly properties and houses with smart locks.

By integrating IoT and Blockchain into the payment system of private urban transport applications, autonomous payment scenarios become viable and secure. It is a union of disruptive technologies, transport and M2M or machines talking with machines, represented by the smartphone of a passenger and the car. The car automatically synchronizes with the standalone smartphone payment service of the passenger in a payment model that provides security and confidence when using for smart contracts and Blockchain financial transactions and making use of an autonomous payment system.

Another scenario of free payment and financial transaction without the use of an intermediary is the payment of fuel through a gas station. In a traditional scenario without the use of Smart Contract, the application stores the user's credit card and the exchange of information between two machines the intelligent vehicle and the intelligent petrol pump enables the mutual identification between the vehicle and the fuel pump. Then, the credit card stored by the cloud service charge after the user refills. In this same scenario, only using smart contracts to pay for fuel, we do not need a centralized entity that manages the state of the application. Instead, a vehicle running a decentralized application can interact directly with the public Blockchain to send cryptocurrency to the smart contract. Likewise, the gas station can interact directly with the Blockchain through its application to determine if a vehicle has paid and to record how much gas has purchased.

The application can even extract data from the vehicle and identify in advance that the car is running low on fuel, and then automatically plot a convenient route to the gas station announcing fuel at competitive prices. After fueling and paying automatically and receiving gasoline in the car, the user receives a message confirming the transaction.

In another stand-alone payment scenario, a user receives a message stating that their grocery shopping application has identified based on their daily shopping list, local retailers with the best prices, paid for everything, organized through M2M transactions and arranged for their delivery at an opportune time for the user.

The smart contract of a machine or as in the previous example a car can vary per user. A classic example of this would be a vehicle where the user is allowed to pay a supply or park in his office, but his son does not, so the smart contracts are customizable for each member of the family.

A project called Aigang has implemented smart contracts in Ethereum to contract and process service requests for this insurance automatically between IoT devices [2], such as maintenance, warning of payment, and its payment. This project uses the virtual currency to AIX, to negotiate investment opportunities in different products and at different levels of risks and gains.

Some potential applications of Aigang include claims handling, fraud detection, reinsurance, and new payment methods, and better determination of the price of insurance, reducing in industrial environments such as administration costs of these insurance, and delay for service requests.

For distribution of digital assets, Smart Contract and Blockchain can count on a new ally, the IPFS (Interplanetary File System) [3]. Each file and all the blocks inside it receive a unique fingerprint represented by a cryptographic hash, guaranteeing its uniqueness and preventing its duplication in the network. This disruptive way of serving distributed files by not having a central information storage agency prevents content-tracking agencies from governments and cloud companies. In a Blockchain structure, it possible create monetary incentives and rewards for the node to keep copies of files on the edge of the network. It is possible for criteria, allow access to all file changes using the versioning, a resource of the solution.

IPNS (Inter-Planetary Name System) is one of the propositions for creating and updating IPFS links that, because they are content-assignable objects, are mutable. In short, IPNS is a hash associated with a record containing information about the hash to which it is linked. Other propositions use DNSLink, faster than IPNS, and some communities explore ways to use Blockchains to store humanly legible names.

Digital media industries could benefit immediately from a network with these resources, because in the case of a book, music, photos, movies among others it would not be possible to duplicate it in the network but to consume them, and with the presence of a contract.

Another option that is becoming quite popular for deploying distributed storage is Swarm. The Ethereum Foundation already has implemented Swarm in Etherem test network stack. Swarm is in short as well as IPFS, a distributed storage platform and content distribution service in a decentralized and redundant way with a service native to Ethereum web3. To resolve names ENS (Ethereum Name Service) is the system used to permit content to be referred to by a human-readable name or another application.

7 Using Blockchain and M2M in Industry 4.0

Some M2M decentralized industrial applications can be proposed using Blockchain and Smart Contracts.

On-Demand Manufacturing: In the manufacturing services market, users are able, through smart-contracts, to create pre-established agreements for machines to execute autonomous requests to other machines directly, to take advantage of manufacturing services in an on-demand model, such as 3D prints.

Diagnostics and maintenance of machines: Intelligent diagnostics and self-service to the machines, can allow autonomy in the state monitoring, enabling preventive action and diagnosis in operational problems, such as requests to replenishment stations and requests for replacement of service providers maintenance.

Traceability: Smart contracts can help keep track of interactions between machines, facilitating the traceability of processes and assets, allowing a complete record of the production process. This traceability would facilitate the identification of defective products through analysis of the entire production chain from the history of M2M interactions. In a supply chain application, for example, it is even possible to know who owns the asset and when it delivered.

Authenticity: In M2M communication, it may be necessary to prove the authenticity of a particular machine. Information such as manufacturer, specifications, date of manufacture, expiration date, maintenance dates, can be stored in smart contracts in the Blockchain, for inventory or possession purposes, reducing and even eliminating physical certificates. This possibility of verifying authenticity can further improve security and reliability, and it is possible to mitigate falsification and adulteration during the production process and consequently, in the interactions between the machines [27].

Subscription Services: the consumer can purchase services that require the participation of more than one manufacturer or machine, this signature governed by a smart contract, allows requests and manufacturing or service to request through transactions between machines.

Quality and reputation of Fencers: Smart Contract can cause machines to execute orders and automatically negotiate with other machines, based on reputations in the public quality parameters of the vendor available, such as delivery time and ratings provided by their other customers [10].

Stock control: Smart contracts may be responsible for informing details such as manufacturing date models and other data that identify the machine and these details can be read by machines that have smart contracts that coordinate audit or stock control transactions.

8 Adoption Challenges

Bitcoin is the most successful digital currency in the world. It uses a public distributed ledger called Blockchain to maintain transaction history on the network. It employs a Proof of Work (PoW) consensus protocol for miners to add more transaction blocks to the chain to ensure transaction integrity and reach consensus on the state of the network. However, nowadays, in the consensus mechanism used, the miners are not given any notion of their progression. To solving a PoW problem, its nodes using the search strategy by brute force, unaware of how far they or other miners are for a solution, or whether it is necessary to devote more resources to such a resolution, being an inefficient, slow and highly energetic consensus process.

The key to the consensus algorithm is its efficiency, security, and convenience. The most widely used consensus algorithms have many gaps, most of which are designed to solve the inherent problems of Blockchain. In PoW miners make much computational effort, and an energy-saving alternative is PoS (Prove of Stake). Instead of requiring users to find a nonce, the POS requires people to prove ownership of the amount of money because it is believed that people with more coins are less likely to attack the network. Some critics of the PoS consider this selection based on the balance of the account quite unfair because it would give dominion of the net the rich person. Compared to PoW, PoS has better energy efficiency by having many Blockchains adopting PoW and migrating to PoS gradually as the Ethereum.

Another approach is the (PoA) Proof of Authority. In PoA-based networks, transactions and blocks are validated by authorized accounts, known as validators. The validators run software to allow them to place transactions in blocks. The process is automated and does not require validators to monitor their computers constantly. However, it is necessary to keep the computer (the authority node) unused. In the PoA, individuals gain the right to become validators, so there is an incentive to maintain the position they have won. By attributing a reputation to identity, validators are encouraged to maintain the transaction process as they do not wish to have their identities associated with a negative reputation. PoA is considered more robust than PoS. The PoA allows only non-consecutive block approval of any of the validators, which means that the risk of severe damage is centralized at the authority node. The PoA model suggests certain egalitarian notions involved in weaker consensus models, replacing them with cryptographic signature evidence and commercial contracts imposed and supported by the network. The authority in this algorithm is a agreement among the various parties based on the commitment of one set of assets against another whole set. Thus, if one party falls outside the consensus, the other parties will automatically assume the party's assets and liabilities without consent, so that end users are not affected.

The PoC (Proof of Capacity) miners have to allocate ample hard disk space to mine a block.

Bitcoin introduced the concept of cryptocurrency in Blockchain, and Ethereum in conjunction with its Smart Contract shows value and ease in building distributed applications, but for these applications to be viable, high transaction rates are required, and propositions for this problem begin to publish, the article [20] presents a model for free transactions in the Blockchain. Instead of spending tokens by transaction fees, a token-holder client blocks the tokens to generate new tokens as a reward for the miner that includes the transaction in a block. This token-locking reward model eases congestion on the Blockchain in the same manner as the fees of Bitcoin, but without forcing clients to sacrifice their tokens.

Although it is a promising way for M2M communication in Industry 4.0 applications, there are some gaps in the Blockchain that need to work on for massive adoption of the solution.

Blockchain has great potential for building future Internet systems, but to get a grip on M2M applications, it will still face several technical challenges. A primary challenge would be its scalability, the bitcoin block size, for example, is limited to 1 MB and a block is extracted every ten minutes limited at a rate of 7 transactions per second, insufficient for applications per instance of a high frequency of negotiations. On the other hand, increasing the blocks means the need for more storage space and longer time for propagation in the network. This will lead to centralization gradually since users would like to keep such a Blockchain. Therefore, switching between block size and security has become a challenge. Also, current consensus algorithms, such as POW (Prove of Work) and POS (Prove of Stake), face criticism. POW wastes much electrical energy, while the POS is power saving but would promote a wealth-enriching phenomenon.

The Blockchain has a blocking time, time that a new block takes to confirm in the Blockchain network, to guarantee the distributed ledger consistency so that the nodes see the same ledger. When we are comparing the blocking time of the two most popular Blockchains, we note the Ethereum network has 17 s and bitcoin has 10 min of POW. It is the reason why that many industrial applications do not have this wait tolerance for a transaction. The security of Blockchain technology is this consensus process, and a smaller blocking time is lower Blockchain security.

Criticisms about the lack of regulation and public privacy as well as awareness of the very limits of technology affect confidence in the adoption of other sectors outside Fintechs such as Industry 4.0 applications, in addition to the legal questions and applicability of Smart Contracts.

These challenges need to be resolved quickly for the development of Blockchain technology.

9 FrontEnd

IoT M2M applications with Blockchain combine business rules and sensing with Blockchain, and can be used as a means of storing data or calling a Smart contract. Front-end applications float to Blockchain through the Blockchain Client API libraries [25]. Some approaches to IoT interaction with Blockchain can be explored. In the first case, each IoT node has an address and a Blockchain account. Since transactions to Blockchain can be sent from this address, transactions are signed, and access to the keys provided by a key manager. In possession of the key, the device and its application can then autonomously make transactions in Blockchain. In the second case, the IoT device does not have an individualized account in Blockchain; it is passive and functions as a sniffer. It acts as a verifier of the events created by Smart contracts in Blockchain. For example, it allows a sensor to perform actions (for example, switch on a relay) or see transactions recorded in the chain (for example check a value of a Blockchain address). This strategy is simple and can work with most simplified critical storage security systems in terms of secure storage of keys.

For communication and these frontend approaches to be feasible, it is necessary to have some functionalities in the devices and clients of the IoT application, and some possibilities can be explored. An Ethereum client such as Go-ethereum or geth has the full function of a Blockchain node and is responsible for running the entire stack of protocols, communication, block and transaction management in addition to chain monitoring, account management, and mining. An API exposes all the functionality of Blockchain Ethereum and can be accessed through standard programming and communication interfaces structured an RPC HTTP using JSON, this library is web3.js An essential feature of these local clients is the local wallet, which maintains and protects access to user accounts and keys, and allows you to sign outbound transactions. This feature is essential for the development of IoT Blockchain applications because it allows accounts to be managed by code without user interaction. Without this feature, it is not possible to automate transaction calls since user confirmation is required for a new outbound transaction, a procedure not applicable to autonomous embedded devices and applications.

Client APIs provide transaction signing and transmission functions for Blockchain. The web3.js library, for example, implements the sendTransaction() function that receives a structure in JSON format, creates the appropriate signature, encodes the results in a raw transaction, and transmits it to Blockchain. SignTransaction() creates a raw transaction that can then be passed to the network. In order for these transactions to be signed, access to an Ethereum account already unlocked is required.

10 Implemented Models and New Propositions

The use of Blockchain in applications that communicate M2M is very recent, and this union can think of origin to many scenarios and applications [26].

10.1 Smart Cities

When we evaluate its applicability in Smart Cities, we see that Blockchain can make the concept of the smart city a reality [7]. Smart cities use IoT devices to extract information from the urban environment, and when we use the concept of M2M communication, we evaluate the possibility of IoT devices working autonomously, allowing the integration and coordination of these devices safely and reliably [19]. When we add the possibility of creating rules in the interaction between the machines, with Smart Contracts, it is possible to realize that this autonomy would facilitate the emergence of disruptive applications and new markets focused on management, control, and extraction of knowledge of the urban environment.

Some projects such as Chronicled have focused on providing maximum security for IoT devices and integrating it with various Blockchain systems such as Ethereum and Hyperledger using a synchronization server so that Smart Contracts perform their registration and identity verification.

10.2 AERO Token

AEROToken [1] is an Ethereum-based Blockchain technology that proposes to enable a drone highway infrastructure within the United States, coordinated by Smart Contracts.

In the United States and some countries, drone operators need permission to fly at low altitudes over private property and sometimes even with other restrictions, for reasons of security and invasion of privacy, but we already have a significant demand for service of commercial drones [28].

AeroToken enables real estate owners to authorize their properties for commercial drone operations. By notifying the Blockchain that his airspace is available, making him business and generating income.

10.3 The Chain of Things

The Chain of Things (CoT) [11] is a research lab that develope Blockchain and IoT projects to come up with innovative and futuristic solutions. Among its security use cases, we can highlight Chain of Security, which provides security for IoT using Blockchain technologies; The Chain of Solar, which connects solar panels to the network of control panels and the Chain of Shipping.

The Chain of Shipping proof of concept has a mechanism to mitigate fraud and to address the inefficiencies of management of the traditional roles used in shipping (BoL) Bill of Lading systems, and even if often used digitally they may be currently duplicated or hacked. This project proposes the creation of a Smart BoL in which it eliminates the roles and risks of fraud using Blockchain.

It would allow creating a digital enforceable BoL contract and title, and this one must be not replicated and secured in a way that exists the distributed ledger shared with the contracted parties and stakeholders. Using Smart contract, it allows the execution term in BoL that can start and send alerts if any have hacked.

Some ongoing concept projects such as Liquidstar and Blockpass show commitment from The Chain of Things to create M2M solutions with Blockchain.

Liquidstar is developing a Decentralized Autonomous Utility that enhances the existing generation and network infrastructure with smart, portable, and battery-powered batteries, called “Solar Buckets.” Replacing expensive traditional grids and liquid fuels with Mobile Virtual Networks, it is the future of energy for 1.1 billion people the world that has no electricity and the many more that do not have reliable energy.

Blockpass is a Blockchain-based identity application designed for industrial and Internet (IoE) applications, created to be an identity layer, a protocol that allows interaction between essential identity, human, industry, object, and device profiles. This interaction provided by Blockpass allows the development of new applications that depend on a reliable connection between various entities.

10.4 IBM and Samsung ADEPT (Autonomous Decentralized Peer-to-Peer Telemetry)

ADEPT is an IBM project in partnership with Samsung that uses Blockchain to build a distributed network of IoT Internet of Things devices in a decentralized way [16].

The project uses three protocols—BitTorrent for file sharing, Ethereum for Smart Contracts, and TeleHash for p2p messaging.

The proofs of concept of the ADEPT are of use cases based on domestic environments, where networks of devices can maintain autonomously. Moreover, these home appliances signal operational problems and make software upgrades on their own. They are able in an M2M communication to use the ADEPT to communicate with other devices nearby to control the energy efficiency [27]. In the proof-of-concept of an intelligent washing machine that uses smart contracts to buy detergents from resellers, ADEPT has demonstrated how to make semi-autonomous device manage its supply of consumables, perform self-service and maintenance, and even negotiate with devices to optimize the home environment. These autonomous tasks happen without a central controller orchestrating or mediating between these devices [12]. In this proof of concept, the Samsung W9000 washing machine used smart contracts to issue commands to the detergent dealer to receive new supplies. With this smart contract, it was possible to pay for the order itself and receive notification from the seller that the detergent was paid for and shipped to the washing machine owner’s smartphone because this device participates in the house network. Just as most IoT use cases the biggest challenge of the solution is the scalability, according to the authors, although the current results are promising, the project does not yet have a clear strategy for incorporating billions of devices [30].

10.5 Slock.it

Slock.it [29] is a German startup that develops applications for embedded devices with Blockchain, IoT, and Smart Contract. They have developed a concept of intelligent locks that link to the Blockchain of Ethereum. The idea is that a user can use his Slock to rent, sell, or share property, for example. By having a smart contract built into the solution, is possible set a deposit amount and a price to rent a property, and a renter, for example, pays through a Blockchain Ethereum transaction to be able to open and close the property through an application on SmartPhone. Collection of rental values, refunds of values and discounts are managed without interference from third parties [9], allowing shared rental models to be able to be operated by any users without the help of companies, who can rent, share or sell anything that can block.

These smart locks provided by Slock can use on cars, bikes, and gondolas. Cars, for instance, could be parked at any point in a city and wait for a next customer, located with a phone application, rented by the hour and unlocked by an application. This business model comprised of smart locks could threaten large shared businesses such as Uber and Airbnb, and Smart contracts would make them irrelevant.

In transportation solutions, Slock.it even works on a project to provide charging infrastructure for electric vehicles, called Blockcharge. Its uses a smart plug-in enabled by a mobile application to control billing and payment for service through Blockchain and smart contracts.

10.6 MyBit

MyBit Network is a Blockchain-based solution that promises to revolutionize the asset management industry. Where the infrastructure, tools, and financing model change the way as assets currently manage. MyBit [22] combines Ethereum with MyBit SDK (MyBit Software Development Kit), a funding model known as the Decentralized Development Fund.

The MyBit network uses Blockchain and Smart Contract to control shared-economy design. Its provide a service that shares the gains and revenues proportionate among groups of IoT asset owners, such as drones, scooters, bicycles, cars, machines, providing trust without the need and an asset manager, all being passed on to rules and financial gains of the group of investors manage by Smart Contracts.

11 Conclusion

In this chapter, we discuss some of the significant benefits and projects Blockchain Industry 4.0 in M2M communication, and we try to tackle some of the similarities with conventional technologies. We have seen that by addressing a decentralized structure, some applications already reduce operating costs, reduce risk, and increase trust among new business partners.

The possibilities for developing industry 4.0 Blockchain-based applications such as those for Smart cities are very promising, and countries like the United Arab Emirates, the US, and the UK already use in government and the public sector. Dubai, for example, plans that all public services be Blockchain-based by 2020 [17]. Moreover, in the context of M2M communication, we can highlight the following applicabilities, people and assets identity management, decentralization and automation of payments between assets and users, property control, records and asset history, proof of transactions and events. The combination of these features enables the generation of next-generation applications in which message-to-machine reliability can be a solution and no longer a security problem, uniting immutability, resiliency, and transparency in a transaction.

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Blockchain-Based Crowdfunding

Hasnan Baber

Abstract Crowdfunding has disrupted the way of financing and allowed the startups to raise funds without much hustle and bureaucracy. In the existing model, Pool of people contribute small amounts of money towards a project or cause and expect some financial or non-financial returns. A crowdfunding platform takes a commission and matches the needs and expectations of funders and fundraisers. Blockchain technology is a decentralized ledger, more efficient, safe and tamper-proof system of nodes in connection. Introduction of blockchain in crowdfunding will make it more reliable, transparent, trusted, decentralized, cost-efficient and convenient. A crowdfunding platform which was acting as an intermediary before will only provide the technology and name is its own crypto-currency which will act as a medium of transaction and exchange. Fundraisers will generate their own currency and everyone on the network will be notified about the project. Funders will buy this crypto-currency to claim its share in the project and can withdraw any time by selling the currency and losing the share in a project or transferring it to another project. Blockchain can further improve this unique and contemporary way of raising funds by making out more reliable and transparent.

1 Introduction

Blockchain technology is a dispersed technology-oriented ledger recording [54]. It records all transactions in an efficient, transparent, secure and decentralized manner [48]. The blockchain is the decentralized transparent ledger with the transaction histories and the database that is pooled by all network nodes, well-run by miners, observed by everyone, and owned and controlled by no one. It is like a colossal collaborating spreadsheet that everyone has access to and updates and authorizes that the digital transactions transferring funds are unique. The central level of the stack is the protocol which is the software system that transfers the money over the blockchain register. Then, the top layer is the digital currency itself, Bitcoin,

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which is denoted as BTC or Btc when dealt in transactions or exchanges. Blockchain technology was the originating technology for Bitcoin [40]. There are numbers of digital or cryptocurrencies like Litecoin, Dogecoin, Ripple, NXT, and Peercoin. Though, Bitcoin is the first and largest.

Jenik et al. [29] explained crowdfunding as a mechanism of raising funds from a pool of contributors in a systematic way for a business model or cause through online application or platform. Contributors back a project or fund a project in return of financial (e.g. equity and interest) or non-financial (e.g. donation or reward) benefits [3] Kirby and Worner [31] attributed the financial crisis of 2008 for the birth of crowdfunding. A crowdfunding portal bought convenience and effectiveness for raising funds with the help of technology advances while doing the same job of traditional intermediaries [11]. Heminway and Hoffman [26] proposed the definition of crowdfunding as a process where start-ups and companies raise funds from a pool of normal people, which called a the crowd, with the help of intermediary known as a crowdfunding platform, which is supported by social networking and viral marketing as shown in Fig. 1. Ordanini et al. [41] studied the impetus of individuals to use crowdfunding applications and also inducements for service providers to offer such services. Crowdfunding is water in the desert for financially inaccessible firms and individuals to raise funds effectively and efficiently without much hustle and red-tapism.

The crowdfunding platform is a which matches the services between the contributors and fundraisers. Investors are usually normal people who want to save and invest; they don't need to be experts in the financial market, they just have to make a small contribution which makes it less risky. Dorfleitner et al. [21] stated that

Fig. 1 Diagrammatic representation of crowdfunding

Crowdfunding is actually a part of the financing application of FinTech. Baber [8] in his study about applications of FinTech in banks mentioned crowdfunding as a subcategory of financing, which is one of the four broad applications of FinTech. Increasing crackdown on lending after the crisis of 2008 by banks made borrowers look for substitutes and less interest rate at the bank on savings made investors seek for other ways to invest which will offer them better yield [20].

As per the report of Statista, 2018, crowdfunding has reached to US$5,250 m in transaction value in 2018. The average funds raised in the campaign has raised to US$818 in 2018. China records highest transaction value of US$4,105 m in 2018 in comparison with the rest of the World. Aveni and Jenik [7] suggested that China's peer-to-peer (P2P) lending sector will continue to expand and credit goes to some reputed crowdfunding platforms like CreditEase, Yooli.com and many more. One of the success factors which is reasonable for such exponential growth of crowdfunding is a reducing the number of agents and which led to a reduction in commission fee as money is directly transferred from contributor to the project owner through crowdfunding platform [51]. Another success factor for its growth is that people who were finding it difficult to raise funds through traditional methods can easily raise funds with much trouble and bureaucracy [30]. Boitan [13] credited the lower interest rate for its growth as these platforms charge lower rates than bank or institutions that too more conveniently and swiftly so people prefer to raise funds here through crowdlending.

Many scholars only considered equity-based crowdfunding application [19, 49] or lending-based crowdfunding [5, 10, 12, 38, 44]. Some studies categorized crowdfunding into only two categories-lending and equity-based [14, 16, 27, 47]. Lawton et al. [33] mentioned three types of crowdfunding- donation based, loan based and equity-based. Most of the researchers segmented the crowdfunding features into four main categories- donation based, reward based, loan based and equity-based [1, 9, 35, 36, 42, 46].

1.1 Donation-Based Crowdfunding

Donation-based crowdfunding is a sub-segment of crowdfunding where investors participate or donate money in return of no benefit or pay-off. They may get indirect benefits through donations [4]. In donation-based people simply donate to feel good about helping the project or they believe in the cause [53]. A donation-based crowdfunding platform can act as intermediaries for charity and NGOs. Donation-based crowdfunding is a voluntary act where the donor does not expect any financial and tangible benefit [13]. Alonso [3] stated that donation-based crowdfunding is funding to a cause with no expected benefits. In Islamic finance, donation-based crowdfunding can be helpful in disseminating Zakkah and Sadaaqa [52].

1.2 Reward-Based Crowdfunding

Investors in this kind of crowdfunding will essentially buy products of the business in which they contributed. The reason to contribute to a cause may come from non-financial returns like free sample products for supporting an idea [2, 34]. Bradford [15] stated that in reward-based crowdfunding contributors take pride in supporting the cause and feel good having their name in the list of contributors.

Reward-based crowdfunding can reduce the risk of damages with no financial pay off in favor of fundraisers and make contributors become spokesperson and ambassadors of the products [11]. Social entrepreneurship can be encouraged with the help of Donation-based or reward based crowdfunding as investors do not want monetary rewards [6, 24].

1.3 Crowdinvesting

In crowdinvesting, investors get equity shares, financed through debt or both. Klohn and Hornuf [32] stated that mezzanine instruments are used for equity participation by contributors in crowdinvesting. Equity crowdinvesting helps an individual or firm to invest in legal entities which are not listed in stock exchanges and this kind of crowdinvesting is mostly employed by SME's and startups. Crowdinvesting portals charge their commission for successfully financed firms. In Germany, crowdinvesting portals charge 8% of the raised amount on an average [28]. These portals continue to innovate and as a result, different business models have evolved [23].

De Buysere et al. [18] stated that this type of crowdfunding has opened a new route to raise funds for any business and offering equity though there will be risks associated. Accessibility of data and symmetrical information available makes this method of offering equity less risky than the traditional one. Also the nature of peer evaluation and peer references, as well as prompt feedback and making all necessary project details and documents available to a large pool of potential contributors, risks are mitigated. Agrawal et al. [1] have observed the social benefits of equity-based crowdfunding due to private benefits from trade (exchanging equity for cash between creators and funders). De Crescenzo [19] proposed that equity-based crowdfunding is not only available to new companies and start-ups but also to the old business models. Meanwhile, equity-based crowdfunding can also help in social entrepreneurship, which is focused on business models for providing solutions to social problems profitably. Social enterprise projects are likely to pull at the heartstrings, providing social benefits like eradicating poverty, employment, or educating vulnerable social class [45].

1.4 Crowdlending

Crowdlending provides a podium that helps individuals and business firms to get a loan from a pool of people and it is the largest sub-segment of crowdfunding. Loans are provided at a fixed interest rate [15]. Peer to peer lending companies has lowered the cost of borrowing for consumers [13]. Also, it is similar to traditional lending except it is borrowed from many people and at lower interest rates. Kim and Moor [30] suggested that this sub-segment of crowdfunding is the most useful application as it will help to reduce financial exclusion by getting the poor and low-income customers under its umbrella. Credit ratings can be added to borrowers depending upon the adherence to the repayment schedule. Bruto et al. [16] stated that crowdlending has the ability to decrease the gap between demand-supply for entrepreneurial finance. Some researchers found that customers who are good-looking and trustworthy can obtain a loan easily and on lower interest rates [22]. Female customers are likely to obtain loan faster [43].

Hartmann et al. [25] studied the difference between conventional blockchain ad crowdfunding blockchain and suggested that companies which are entering in blockchain based crowdfunding should first understand the success factors and regulatory framework. Cai [17] suggested that the market may see new financial products and business models in the coming years with the integration of blockchain in FinTech. Muneeza et al. [39] studied the ability of crowdfunding to propagate inclusion policy and found that crowdfunding can help in inclusive policies and blockchain will help crowdfunding platforms to mitigate the risks and work effectively. Zhao and Coffie [55] studied the application of blockchain technologies in crowdfunding and found that issues related to security, investor abuse and, illegal transactions that could plague crowdfunding contracts and blockchain is the optimum solution for all these issues.

2 The Blockchain Explosion

Investments in blockchain and crypto-currencies have seen a boom from the last few years. There was an abrupt surge in the investments from 2017 and in deals count last year. The capital investment in blockchain and crypto-currencies remains under one billion dollar from 2013 to 2016 as the concept was new and not much popular among the masses. Capital Investment in blockchain technology has seen a sudden explosion in 2017 with 4.8 billion investments as shown in Fig. 2. It was actually the birth year for crypto-currencies as people start recognizing its potential and started investing in digital currencies. There was a steady and sustained investment in the year 2018 at 4.5billion dollars. With an increasing focus on innovative and start-ups, equity-based crowdfunding has been in limelight.

The United States was the epicenter of blockchain investments in 2018. There were two big blockchain deals in Switzerland in 2018—One valued 103$ million

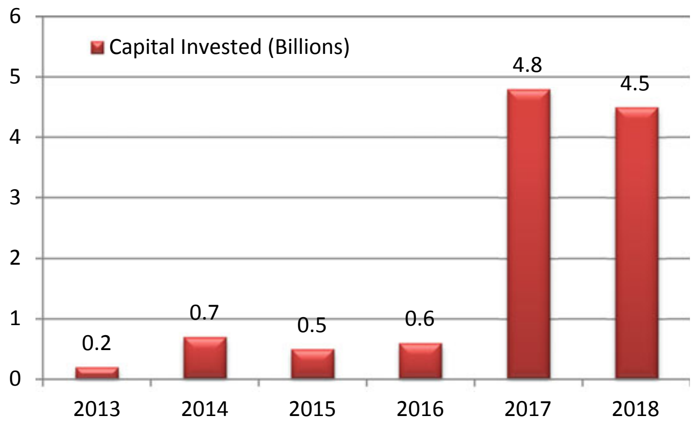

Fig. 2 Capital invested

raised by SEBO crypto and Definity raised 102$ million. China also witnessed 90$ Million deal by WeShare. France, Bahrain, and Dubai also evolved significantly in blockchain investments. Singapore also supports blockchain technology and aiming to be one of the development hubs in the world. Blockchain technology is actually a parallel system and it requires time to build infrastructure and trust. There were 494 investment deals in 2018 which is highest so far as shown in Fig. 3. Though the quantum of investment in 2017 was more than 2018, the number of deals signifies that more people and organizations are showing their trust and interest in blockchain technology.

Blockchain technology is a disruptive technology which replaced a centralized database with a decentralized one. As ledger of records is available on the internet, it enables the user to access it from anywhere, resists any forgery or tampering and provides high safety and security of data. Swan [50] stated the various potential areas where blockchain technology can bring innovation. First is a digital currency which

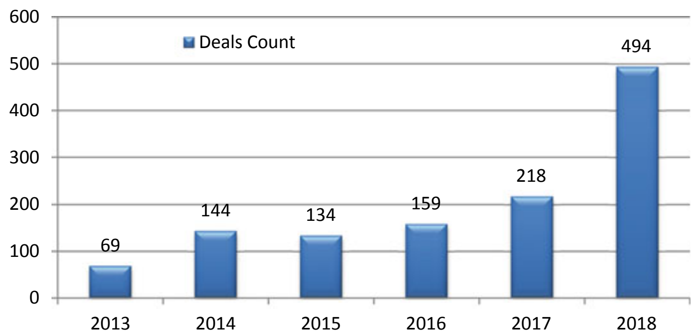

Fig. 3 Deals count. *Source* Pulse of Fintech 2018, Global analysis of investment in FinTech, KPMG

has already started in the shape of Bitcoin and other crypto-currencies. Digital or smart contracts can also be secured and distributed through blockchain technology. The blockchain can be utilized for any form of asset registry, inventory, and exchange, including contracts in finance, economics, and money; hard assets (physical property); and intangible assets (voting, sharing ideas, reputation, intention, health data, and information). Blockchain technology opens its way to multiple segments of application across all sections of businesses involved in money, markets, and financial transactions. The blockchain-encoded property becomes a smart property that will be transferable via smart contracts.

3 Integration of Blockchain and Crowdfunding

Blockchain technology can change the experience of equity-based crowdfunding for investors. In centralized crowdfunding, papers such as contract or shareholder list or any kind of information are stored on a crowdfunding platform and only a few people have access to it. The features of blockchain crowdfunding technology like anti-tempering, anti-fraud and decentralized ledger system will help to make information and data secure. Blockchain will be helpful in eliminating the tiring job of signing on a number of papers, postage issues, registration, authorization, and certification. This feature can increase the reach of the crowdfunding platform as the rights of investors are secure and accessible from anywhere. The rights of investors are secured and recognized all over the world through a digital or smart contract. Blockchain technology is transparent and can help the crowdfunding platform to gain trust and credibility among the funders and fundraisers. The credibility of the crowdfunding platform is really important for the success of campaign and platform itself. Blockchain technology will also eliminate the double payment record issue as each equity transaction will be recorded once and uniquely.

In the peer-to-peer lending model, digital money can be directly transferred from funders to fundraisers and thus eliminating the passive member which is a bank or financial institution in the existing model. At the time of fundraising, the documents are stored in the blockchain and will be proof for the shareholders to claim their rights in the company. Shareholders can be located in the different regions of the world and e-voting feature of blockchain can help shareholders to exercise their power of decision making. Shareholders can also share their views, ideas, and arguments and get to know each other through blockchain technology. Traceability feature of blockchain technology will help to fight against black money and money laundering. In all aspects, blockchain technology based crowdfunding can bring more discipline to this innovative and more effective form of crowdfunding.

The most commonly acknowledged application for the blockchain technology is in the field of finance, as it certifies the much-treasured transparency between the trading parties. Every contract in public or private equities, stocks, bonds or derivatives could be transcript in the blocks and later be established by the local authority for its validity. From this point, it's easier to sense scam cases or money laundering through stock exchange moves. Apart from finance in the conventional form, the blockchain could also develop the existing forms of financing. Another principal example of how financial services are being innovated with blockchain-based decentralized models is crowdfunding. The idea is that peer-to-peer fundraising models such as Kickstarter can replace the need for customary venture capital funding for startups. Where previously a centralized service like Kickstarter or Indiegogo was needed to enable a crowdfunding campaign, crowdfunding platforms are driven by blockchain technology remove the need for an intermediary third party. In the existing framework of crowdfunding, there are three active players and one passive member. There are three parties actively involved in crowdfunding process i.e. funders, fundraisers and crowdfunding platform. The fourth one is a bank where the money is deposited, acts as a passive member. With the help of blockchain, the bank can be replaced and contributors in a crowdfunding campaign accept tokens that epitomize shares of the business startup they support. Blockchain-based crowdfunding platforms will help startups to collect funds by forming their own digital currencies and selling "cryptographic shares" to the early contributor.

Swarm is one of the prominent "crypto-currency" crowdfunding platforms funding startups which focusses on incubator of digital currency had raised $1 million in its own crowdfunding, completed in July 2014. The company's own crypto-currency was given a name Swarmcoin, which gives investors the right to the dividends from the startups. Whirl is another crowdfunding platform, powered by the Ethereum blockchain, started in 2018. The platform works on the principle of 'pay now, get later'. Backers donate cryptocurrencies to the campaigns and in return, they receive Points known as Karma points, which help their own Campaigns in the future. Campaign Owner receives the raised crypto's after the moderator's sanction when it reaches its predetermined goal. The Platform is a donation based platform; i.e. a Backer does not receive any financial benefits but backer can start its own campaign with the collected Karma Points. The platform doesn't accept any legal tender to be exchanged, only Karma points can be bought through currency and then exchanged. Only registered campaign owners who have already backed few campaigns and earned the Karma points up to 500 can start their campaign which will be backed by the backers or other campaign owners to collect Karma points for starting their campaign in future.

Crowdfunding can be enriched through blockchain adaptation. As an alternative of a platform that collects donations and distributes them to the campaign runners, it could turn to a decentralized platform that manages the money from the benefactors and if the campaign is positively completed gives the money to the fundraisers or otherwise returns the contribution back to contributors. This cracks the confidence problem that many new crowdfunding platforms may face.

Crowdfunding is an eminent topic at Bitcoin industry conferences, and researchers are worried over its legality. Critics of crowdfunding always complain that there is presently no legal way to do crowdfunding whereby one actually owns shares in the underlying organization, and there are several ways in which crowdfunding infringes securities laws. To overcome problems in equity-based crowdfunding, offered by crowdfunding platforms like Swarm is to sell non-financial items, such as early access to software, subscription, free samples and other non-financial rewards. However, this is somewhat deceitful because in many cases the marketing still looks a lot like selling shares.

4 The Framework of Blockchain Crowdfunding

In an existing crowdfunding process, there are three parties actively involved i.e. funders, fundraisers and crowdfunding platform. The fourth party is a bank where the money is deposited, acts as a passive member. In blockchain based crowdfunding bank will be replaced with the crypto-currency wallet. Crowdfunding platforms make a profit by charging a percentage commission on funds paid out to fundraisers. This commission is usually calculated from the total funds raised, and/or based on achieving a “fully-funded” goal. Majority of crowdfunding platforms adopt two funding options—“all or nothing” or “keep it all”. Most widely used crowdfunding model is “All-or-nothing” model (AON). This model is grounded on the idea that a project can only be started when the target investment is reached else funds will be returned to the funders. In blockchain based crowdfunding crypto-currencies can be mined and retained by funders till they find the relevant project. As the system is decentralized, fundraisers will pitch the relevant project to the currency holder which suits its needs and returns. This model is more likely to accomplish as projects will either start or don’t take off at all. As the blockchain system is transparent so funders will trust the platforms in all the aspects like the start of the project, follow-up returns, and contract clauses.

Although the existing crowdfunding system has a touch of decentralized essence as compared to the traditional model of fundraising, most of these project campaigns are however centralized, and therefore controlled by giant intermediary stand-in as the reliable third party liable for matching funders and fundraisers. Blockchain-based crowdfunding eradicates the need for these intermediaries, by allowing the formation of decentralized crowdfunding platforms, which operate independently on the grounds of a peer-to-peer network. However the technology is still in its infancy stage and not build enough to carry out campaigns on large scale There have been attempts and work is still going on to build a decentralized crowdfunding platform like Swarm, Koinify and lighthouse.

Though the existing model of a crowdfunding platform is somewhat decentralized however, the real innovation which blockchain brings into crowdfunding is the way of raising funds by eliminating the bank and legal currency. Fundraisers can create their own type of equity which is known as crypto-equity which will signify the stocks of the project which is being funded. In some application of crowdfunding, funders are promised predetermined returns like non-financial rewards or interest rates. In the existing model, funders are only given what was promised to them in spite of the project grand success. Oculus Rift raised $2.4 million on Kickstarter and provided the contributors all reward which was promised to them and then afterward was bought by Facebook for $2 billion. Crypto-equity will help the funders to be the real shareholders of the project and funders can be remunerated with a share of and bestowed interest in the project they have supported and thus benefit from any supplementary revenue that might derive from the ensuing appreciation in the value of these shares. So in a crypto-equity crowdfunding campaign, funders are investing in the project which they believe and trust will succeed and they become true shareholders of the project. Their investment returns depend on the success or failure of the project. Blockchain solves the double payment issue, ensuring the uniqueness of equity deals and transfer. Also, the digitization of equity eliminates paper documents, reduces labor costs, and improves the effectiveness of equity transaction and transfer.

Only 36% of projects are successful so far on Kickstarter and 54% on the start next covering the years 2011 till mid-2017. This means that only half of the projects succeed on Startnext and more than one in three projects on Kickstarter. Therefore, it is good to know about aspects that define the success of a funding campaign in order to increase the probability to get funded. Trust of funders and transparency of the platform plays an important role in crowdfunding success. Among the various success factors for crowdfunding, the project itself holds much important but trust and transparency which can be enhanced by the application of blockchain technology. This means that funders assess the quality of the product, the team and the likelihood of success. Mollick [37] pointed out certain mistakes which startups make while campaigning on the crowdfunding platform. Mistakes like spelling errors on websites and in documents signal a low project quality for funders. As the documents will be decentralized now on the blockchain, it will be more important for the fundraisers to keep contracts and documents error free. "Keep-it-all" (KIA) model transfers all funds in the account of fundraisers whether the target is achieved or not. Such projects may face a shortage of funds in the future and may turn failure.

In Blockchain crowdfunding each fundraiser can create its own currency and value it against other currencies on the blockchain. Funders will buy currency and relative share in the project. If the project succeeds and results in appreciation of the currency, the currency holder can sell it at the appreciated value to get its money back or buy any other created currency on this or any blockchain. There will be the updated value of each currency with other currencies on the blockchain and hence users can buy and sell their currencies. In the existing crowdfunding model, the crowdfunding platform has to do matching service between funders and fundraisers to increase the profit of the platform. In blockchain based, there will be no such matching service needed. Each funder will have access to all projects, currency values, and a number of existing funders, history of currency, project documents, contracts and fundraisers as shown in Fig. 4. This decentralized system makes it more transparent and removes the control from one entity. Many blockchains can be coordinated together to form a bigger web for more diverse currencies and projects which is called as consortium blockchains, which will be suitable for crowdfunding. During the fundraising process, contract documents can be stored in the blockchain. After the fundraising, investors are listed as registered shareholders by blockchain. Smart contracts help investors receive proofs to confirm that they own equity in the crowdfunding project. A smart contract will be generated whenever the fundraisers will have to spend the

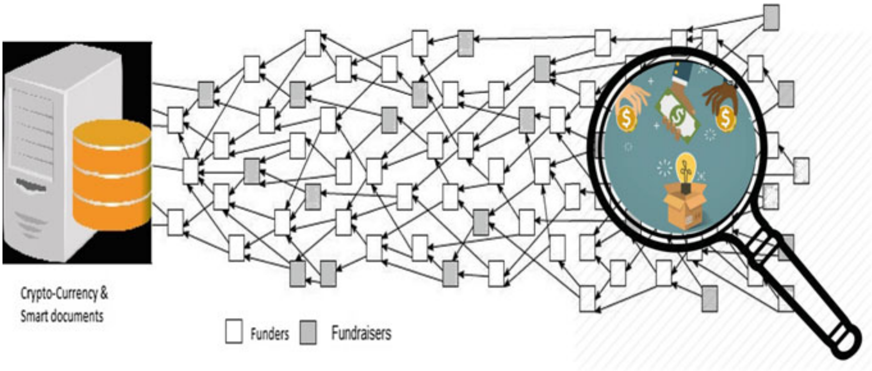

Fig. 4 Blockchain-based crowdfunding

raised money so funders will be able to track the spending. In this way, funders will be confident that their money will be spent in the right place while having the record of each spending. Because money does not go through the platform or bank, a capital pool will not arise. So models like "all or nothing" and "Keep-it-all" will not be relevant to blockchain based crowdfunding. The blockchain based crowdfunding will work on "Buy Crypto-Own Equity" model. This will solve the issue of security of funds and compliance with regulations. Implementation of blockchain technology to crowdfunding platform provides more transparent transactions. As a result, users can feel more confident about the project and can donate freely to a campaign. The application of smart contract on spending request also can help funders to know how their money is being spent.

5 Conclusion

Crowdfunding has made it easy for new companies and startups to raise funds without going through traditional means. Presently, the crowdfunding platform controls the process of raising funds and matching the funders and fundraisers. The intrinsic and inherent feature of blockchain is decentralization which can be applied in crowdfunding to make it more cost-effective, transparent, efficient and secure. Fundraisers present their project and upload all documents related to the project which are accessible to every member. Project owner creates a crypto-currency which also acts as share in the project. Funders who buy this currency are actually buying the share in the project and start supporting it. The value of a currency with other crypto-currencies depicts the health of the project. Shareholders can sell their currency and shares anytime at the existing rates. With the help of blockchain technology, paperwork will be reduced, there will record of every transaction so it will enhance trust and reliability in the project, contracts and documents will be secure and accessible and shareholders can take part in the governance of project while being miles away. Therefore, Crowdfunding already disrupted financial capital markets and with the help of blockchain technology can take it an extra mile.

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Engineering 4.0: Future with Disruptive Technologies

Pooja Khanna and Sachin Kumar

Abstract Revolutions in technology in past few decades have generated complete transformations in natural orthodox processes owned by industry, education and healthcare, disrupting work flow processes and generating out of box solutions and processes. Industry 4.0 has increased the demand for revolutionary changes in education and pedagogical approach in education. Engineering education is directly affected by the revolutionary demand of industry. Disruptive technology has directly affected all the core branches: Mechanical, electrical, electronics, civil engineering. Exponentially evolving technological innovations are described as Volatile, Uncertain, Complex and Ambiguous and to make students industry ready, changes in engineering curriculum are required. The current work is sincere effort to analyze the issues and challenges required in all branches of engineering for industry 4.0. The objective of the work is to analyze and identify the major disruptive technology with their influential effect on core engineering branches. The work also discusses the necessary changes required to incorporate concept of engineering 4.0.

Keywords Disruptive technology · Industry4.0 · Flexible learning · Education 4.0 · Massive open online course (MOOC)

1 Introduction

Knowledge and Information have been the driving force of technological innovations, and the library has been the resource for this for decades, although the functional definition, structure, and orientation of knowledge, information, and library have been completely transformed; knowledge and information have become key drivers of business data analysis, and the library is now an electronic library. The industry has gone through 4 revolutions and in parallel the academy that generates raw resources for the industry must be in synchronization.

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Engineering education is highly affected by the influence of disruptive technology on industry. Industry 4.0 (I4.0): The fourth industrial revolution is due to the fact that all this disruptive technology directly affects industrial processes. Industry 4.0 has great potential and expands with a high growth rate. It is estimated that by 2035 most jobs will be self-sufficient; few jobs based on personal skills will exist in almost every field. Industry processes based on disruptive technology are more connected, reliable and predictable, thus providing the basis for economic power. This revolutionary change in industry processes is creating a huge demand on specialized skill sets and therefore requiring major changes in the teaching-learning pedagogy of the engineering education system [1, 2].

Restructuring of engineering education is always necessary with every revolutionary change in the industry. With the study, it is being analyzed that all major changes in the industry have created a demand for specialized skills to meet current requirements. Engineering education therefore requires major changes in pedagogical style. The introduction of disruptive technologies is the main reason for the resonance effect in engineering education. Technologies such as AI, additive manufacturing also known as 3D printing, spatial computing as augmented reality/virtual reality, IOT, 5G have changed the traditional way of handling processes in different engineering domains such as production line, operations, design, manufacturing, construction. etc. While it appears that such technology will increase the demand for IT professionals, a greater mastery of knowledge of specific skills will be required. To resist this industrial revolution, engineering education needs a major redirection, as there is now a high supply of multidisciplinary and practical learning materials. Massive online courses, apprenticeship systems, online diplomas are replacing the traditional classroom teaching methodology. With rapidly changing industry needs, it is difficult to meet and generate specialized skills requirements with traditional, slowly moving learning systems. The education revolution aims to engage students in creative and innovative academic activities rather than result-centered orthodox education systems. Transforming the role of trainees, change in trainees' interests including classical programs, improved cooperation, the structure of commercially relevant training programs, the use of ICT tools and Internet technologies are all factors that increase efficiency and bring an improved educational impact. The current work is a sincere effort to explore disruptive technology with its influential effect on the core branches of engineering. The paper also discusses the changes needed to incorporate the concept of engineering 4.0.

Volatile, Uncertain, Complex and Ambiguous (VUCA) is the new definition of technological innovations, called disruptive technologies, which provide new and unexpected possibilities for change that this generation may encounter. Change is the one constant and keeping pace, an accepted one to mix with it. The industry went through four major revolutions, the first steam engine revolution was used to automate production, the second introduced electric power for mass production, the third brought electronics and information to automate production, and the fourth was in addition to an enhancement of the third industrial revolution, which blurred the lines between the biological, digital and physical worlds. New technologies evolve at an exponential rate, with no historical precedent marking the beginning of evolution, being called disruptive technologies, as shown in Fig. 1. These revolutions are led by technological innovations and the emergence of parallel flows such as AI, IoT, robotics, self-assisted vehicles, nanotechnology, 3D printing, quantum computing and energy storage.

Standard 4.0 of industry revolves around six diversified design criteria:

i. Inter-Operability
ii. Transparency in Information
iii. Technical Assistance provided
iv. Data in real time
v. Acquisition and Processing of Data
vi. Modularity and Parallel Decision capability.

Industry 4.0 aims to ensure that machines, devices, sensors and people are in simultaneous communication, especially with IoT enabled, with additional decision

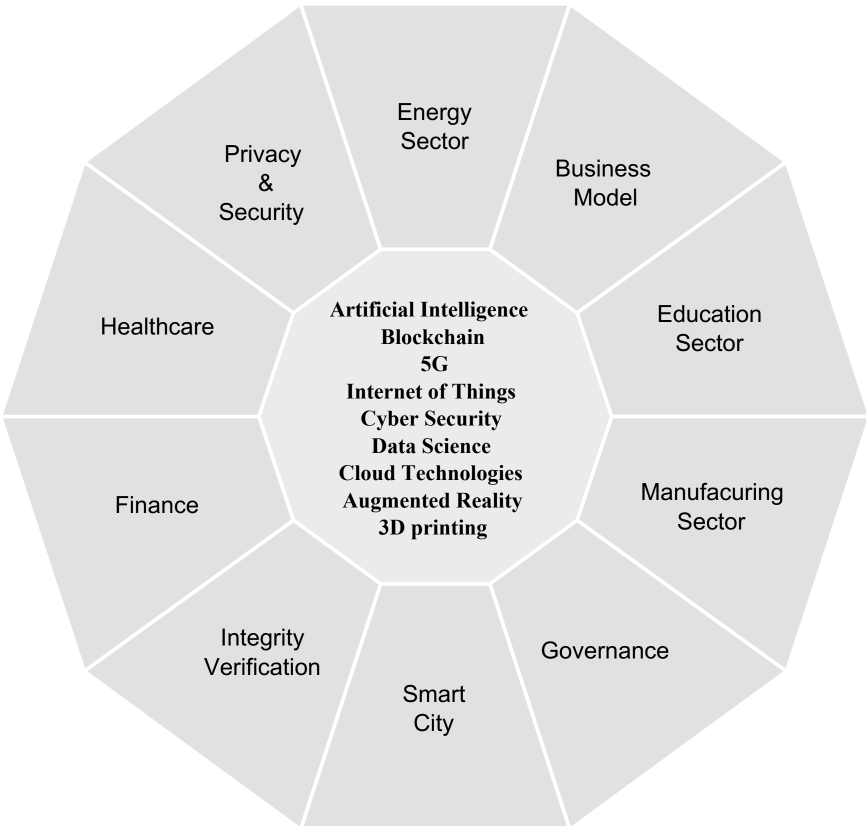


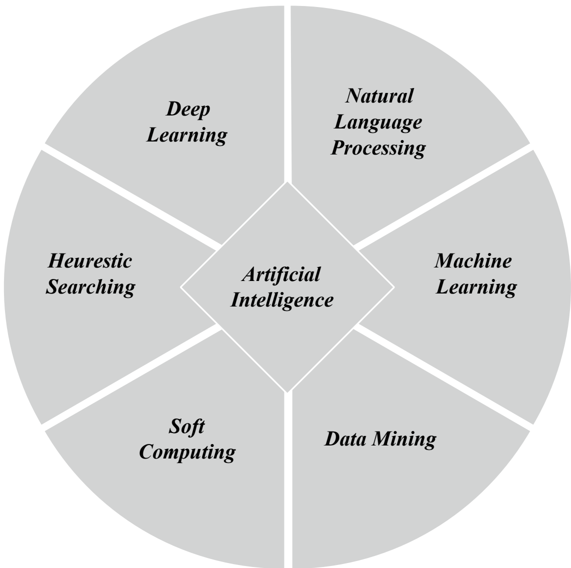
Fig. 1 Application areas of disruptive technologies

making capability. This suggests that production is transferred to cyber physical systems. Cyber physical systems are systems that have all the elements, from production to consumption in communication with each other [3–6]. As technological innovations are taking place, terms such as obsolete and outdated have become the order of the day. Disruptive technologies have had a huge impact on the way the world spins [3–7].

1.1 Artificial Intelligence

Artificial Intelligence was introduced to incorporate human behavioral and cognitive decision-making capabilities into the software system. In recent years, the use of artificial intelligence has increased tremendously in almost every domain, including finance, business, manufacturing, medical science, media, entertainment, etc. Artificial intelligence has added new dimensions to creative thinking and innovations. The focus of any AI-based system is to incorporate three basic characteristics that are considered for intelligence in any human being: reasoning ability, decision making power and self-learning environment. AI is a concept and there are several techniques and technologies behind its implementation in real world problem solving. These technologies include: heuristic searching techniques, natural language processing, machine learning, soft computing techniques, data mining, as shown in Fig. 2 [8, 9].

Fig. 2 Artificial intelligence and allied technologies



1.2 3D Printing

3D object printing is a collective name for the process used to create three-dimensional objects in the computer control environment. The journey of 3D printing began in the early 1980s under the name Additive Manufacturing Technology. 3D printing is a three-step process that begins with object design. Design scanners or CAD printing can be used to project the object. The next step is to choose the right material (glass, plastic, ceramics, metals, polymer, textile, biomaterial, food and lunar dust) for the printing of the object. Once the object is created, it needs to be completed before actual delivery.

i. Fused Deposition Modeling (FDM) Technology: The most famous 3D printing technology with a large number of affordable printer options. The process involves input material being melted and extruded through a nozzle for 3D printing. Cross section of sculpted input objects from each layer one at a time. The foundation lowers so that each new layer is processed and the process repeats until the object is completed. Carved layer thickness decides the quality of 3D printing. FDM 3D printers have two or more different color print heads and use a support system for hanging complex 3D print parts.
ii. SLS: Laser sintering is a 3D printing system for article manufacturing, fusing consecutive layers to design the desired article. The technique can make it easier to create complex and interconnected shapes [10, 11].

1.3 Cloud Technology

Cloud technology is a collection of all the technology needed to access resources (infrastructure, software and platform) over the Internet. Cloud computing applications are diverse and have therefore become a center stage for people in academia. Organizations are employing a variety of cloud-assisted applications to ensure students and industry perform well in academic and business tasks. Academic organizations are now employing a combination of AI, Cloud, and IoT technologies to host a number of student-centric platforms, such as cloud-embedded learning management systems (LMSs) such as Moodle and Blackboard. A large number of online portals for learning solutions are available, from commercial to open source. The database and support for these courses is maintained at the cloud level. Using cloud applications, it is possible for both trainers and trainees to access individual information through a browser on a tablet, system or mobile phone at college, market, home or any other desired location, enabling fast, reliable, efficient interaction, and shared information and notes, as well as links to other information. Using cloud applications enables instructors and learners to be on the move while driving their learning goals through connected devices [12].

1.4 Blockchain

Blockchains are a heterogeneous group of diverse and decentralized blocks, or rather records that are interconnected through a cryptology element known as hashing; transactions happen between these blocks in terms of data, the blocks have unique hash identities that can be distinguished using a public key [5, 6]. Each transaction is validated by other blocks using public key, an authenticated hash key is required to create a new block. Generation of new blocks are achieved by a process between blocks in the network through consensus and competition. There are several consensus mechanisms that can generate a block in the chain, the mechanisms that are used by the most famous currency encryption network are known as 'proof of work'. Other consensus mechanisms available are 'Proof of Stake', 'Proof of Elapsed Time' and 'Proof of Authority'. Blockchain grows to become a diverse and decentralized network of data records. Interactions happen peer to peer without authority or intermediate control, and all transactions that take place in the block chain are validated by other blocks in the network, and all transactions are recorded in every block. The algorithm has had security, decentralization and transparency enhancements. Advantages of the block chain are a better level of security, transparency and traceability; others include higher efficiency, transaction speed and cost effectiveness. Figure 3 shows the functional elements of Blockchain technology [9, 13].

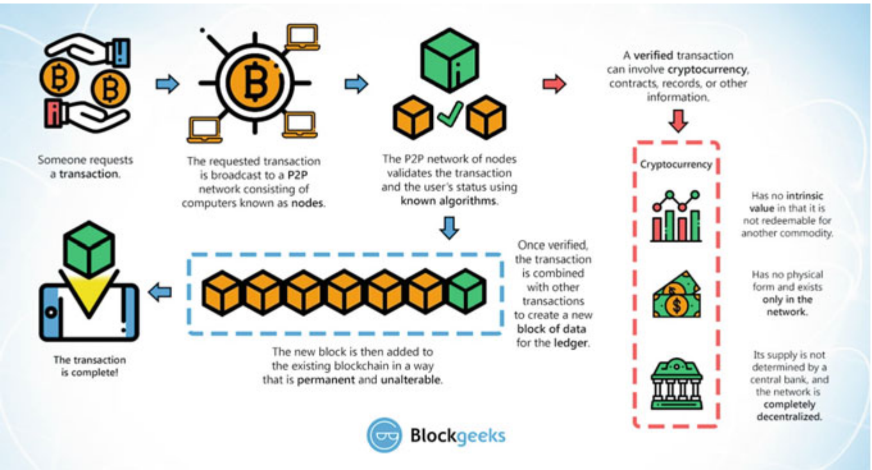


Fig. 3 Functional elements of blockchain technology [36]

1.5 Augmented Reality

Augmented reality is an effort to recreate an interactive experience of a real-time situation by enhancing computer-generated projection of objects as they would appear in the real world, often assisted by a number of sensory modalities, integrating visual, audio, haptic, somatosensory and olfactory. Manufacturing sector employs technology in similar shape and form. The surprising part is that it can be used to present more than digital characters, images or content. Projections can be impregnated with characters, statistical information, and data relevant to current applications. It is much easier to view through a virtual prototype and can be easily used where working conditions are extreme. Possible applications include:

- Streamlined Logistics

Augmented reality can virtually recreate environment with all necessary details, this feature can be efficiently tapped workers into a connected system to identify position and condition of products and goods, assisting them in early decisions at a faster pace.

- Product Design and Development

The orthodox idea of designing, prototyping and implementing can be a very time-consuming process. The complete process also requires various round-trip interactions between the relevant sections. Even before the product reaches production and manufacturing, it also requires a second opinion until a final stage of production is reached. Augmented Reality can undo the tedious process through virtual visualization of the actual product being designed and finalized in real time.

- Healthcare

Technologies such as AI, Augmented Reality, IoT, Block Chain and 5G have completely transformed the health care functional flow chart. Consultations, tests and surgeries are now very technology dependent. Services are no longer restricted to medical centers, but now an app is available or a Call Away. These technologies can dramatically improve the quality of health services being provided in terms of expertise and latency.

The virtual world is not only helping medical experts learn about human anatomy, but it is also redefining the way patients are most effectively diagnosed. The first telesurgery, known as the Lindbergh operation, was performed under the direction of Dr. Jacques. Marescaux, Director of the European Institute of Telesurgery. Moji Ghodoussi, project manager at Computer Motions, Inc., and communications specialists at France Telecom [12], demonstrated in 2001 that the surgeon was present in New York, USA, while the patient was a 68-year-old woman present in Strasbourg., France, which was at a distance of 4,300 miles or 7000 km. The surgeon successfully performed an operation using the satellite link to remotely control a surgical robot to remove the patient's gallbladder (laparoscopic cholecystectomy).

Telesurgery has become possible due to the advance of artificial intelligence assisted application in the field of assisted medicine with the augmented reality scenario. Robotic telesurgery is endowed with 5G-supported infrastructure, tactile internet, augmented reality and artificial intelligence. These technologies assist the physician in performing surgery on the patient, can be present remotely anywhere in the world and thus reduce the resource scheduling problem [14, 15].

1.6 5G

With the multiple number of telecommunications users increasing, 4G will soon be replaced by 5G technology, functional in beam division multiple access (BDMA) and Non & Quasi-orthogonal filter bank multiple access (FBMC). 5G communication will likely be present in the market by 2020. It is expected to significantly improve QoS in terms of data volume and expansion in service variety. The number of machine-to-machine (M2M) connections to mobile operators is expected to exceed 15 billion by 2020, double the current rate, and by 2022 operators will have more than 26 billion machine-to-machine connections.

The need to delve into 5G communication is related to current data service and latency drifts, challenges that are not effectively addressed by 4G. That is, higher capacity, higher data rate, lower latency, device connectivity, cost effective and quality of service are being carefully handled with 5G.

- Immersive Gaming—Reduced latency and high data rates open new boundaries with 5G related to games and especially augmented reality and virtual reality. 5G is likely to make virtual reality effective. 5G will completely transform the immersive experience into augmented reality, turning virtual creatures into smart and intelligent games with zero-time real-time communication.
- Autonomous Driving—Connectivity with the environment is the key to making autonomous decisions, this explains the importance of 5G for the already growing field of autonomous driving. 5G is the "oxygen" and driving force for autonomous cars. With the concept of smart cities fully connected with technologies like IoT and AI, speed won't be important, but security will. Suggested autonomous vehicles may interact with vehicles and surrounding people.
- Remote Robotic Surgery—5G will take telehealth to a new level. Several telesurgeries have already been performed, equipped with technologies such as AI, IoT, 5G, Tactile Internet, Robotics and Augmented Reality, with patients located in remote locations and specialists in different locations. The entire process is carried out through technology support with specialist physician and patient located in different locations. The process solved the problem of resource scheduling in terms of scarcity of health professionals. Even regular prescriptions and consultations can be achieved.

Production—Robots can manipulate, manage and reach places with extreme environmental conditions, where human intervention is probably not possible; therefore, in the robotics line, as IoT expands powered by 5G communications capabilities, the robots on the production line willget hard impact. 5G, due to its continuous connection capability, will be able to perform complex calculations and real-time information transfer with ease and reduced latency. The process flow and supply chain perspective will be completely transformed and it is expected to be a change in the game [16, 17].

1.7 Internet of Things (IoT)

IoT is made up of three components that enable continuous connectivity:

i. Hardware: comprised of sensors, actuators and built-in communication support hardware;
ii. Middleware: storage and computing tools for data analysis;
iii. Presentation: User friendly, easy to understand and view smart cities, smart vehicles and smart devices. Smart is the key. This key is being built by technologies such as IoT, where each device is communicating and interacting with all devices for resource scheduling and decision making. Everything is connected to everything, interacting and communicating through pending processes, resource scheduling and optimized solutions [18, 19].

2 Industry Engineering Integration Model 4.0 (IEIM-4.0)

The progression of any society, to a large extent, is based on the path that the educational system develops in conjunction with technological advances. Higher education is shaped primarily based on student choice of major and secondary subjects. Numerous diverse courses are offered at university level, ranging from commerce, engineering, biotechnology, medicine, arts, humanities, mass communication, law, fashion technology, pharmacy, education, hospitality, languages, business and architecture. Innovations in technology have revolutionized the educational process and transformed the learning process into an experiential learning process. Education 4.0: is characterized by virtual platform courses with an interactive presence in the form of blended learning and AI-driven issues as key challenges, described in Fig. 4.

The skills development methods of the industrial revolution 4.0 need to meet the next generation workforce requirements in terms of employees and designers, who have given adequate exposure to the digital world and can reach 4.0 with totally new and changed skills. Technological innovation and the development of cyberphysical systems will need scientists and networking professionals to work with specialists in diverse disciplines.

Engineering is among the most dynamic higher education disciplines, offering around 45–60 courses over a 4–5 year period, ranging from humanities, basic sciences to basic courses specific to the chosen field. The integration and overlap of several important disciplines are shown in Fig. 5 [20–22].

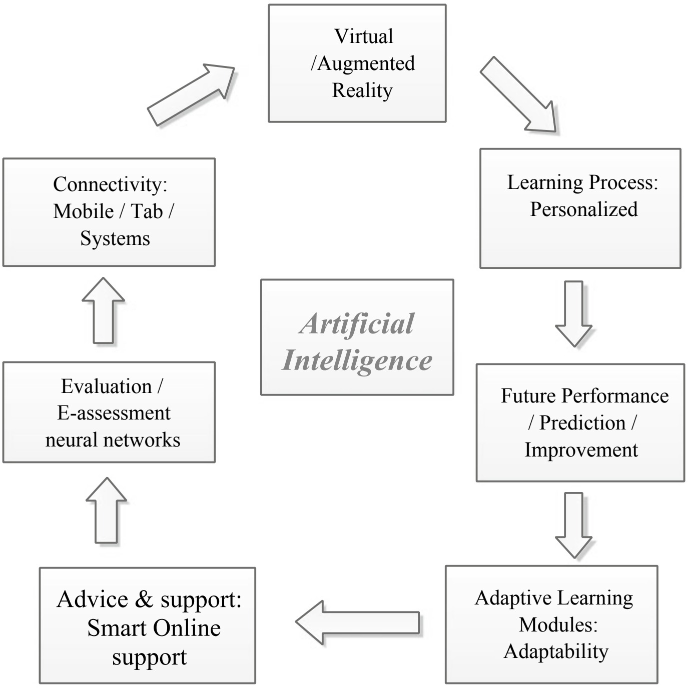


Fig. 4 AI driven features as significant challenges

The main features of the engineering discipline can be summarized as:

- Integrates area-specific technologies depending on the specialization chosen. Courses are distributed over a 4-year period (in some locations the course may extend to 5 years);
- First year generally covers foundation courses, second year involves undergraduate elementary school courses, third year involves advanced technology courses, and fourth and final year have courses that integrate the concept studied into application-oriented courses, but the student can choose by specialized courses also in the last year;
- In addition the student has to go through internships, industrial training, smaller projects and a major dissertation during the engineering program;
- Almost all Engineering disciplines have Soft Computing as part of the curriculum, data preparation technology for query processing and storage. For the design of complex systems to be successful, it is highly dependent on how design data is represented, managed and retrieved;
- Engineering flows prepare learners to design processes based on understanding dynamic resources so that the end product behaves in a desirable manner;
- Numerous multidisciplinary branches and specializations are offered to meet industry standards, enabling a graduate engineer to process initial project work

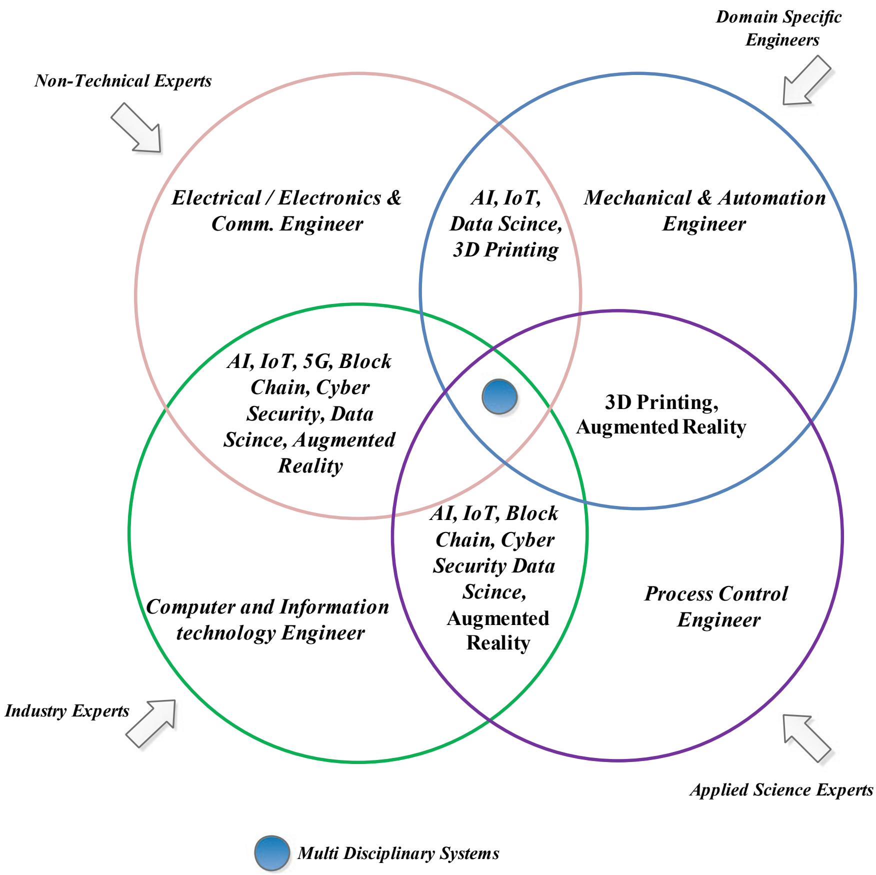


Fig. 5 Integration and over-lapping of various major disciplines

and communicate effectively with specialized project engineers from diverse disciplines;

- Universities need to change, model, modify, and update their engineering curriculum to prepare students for industry.

To successfully prepare our students for the future, we suggest redesigning, inventing, and reorganizing according to industry needs 4.0, concepts such as E-Learning, Lifelong Learning, Learning Management Systems (LMS), Blended Learning, Reverse Classrooms, Learning Analytics, or Massive Open Online Courses must be integrated with technologies such as Artificial Intelligence, Block Chain, 5G, IoT, Cyber Security, Data Science, Cloud Technologies, Augmented Reality, and Printing. 3D. incorporated into the engineering discipline. For successful integration between industry and academia 4.0, the following suggestions are proposed [23–25].

2.1 Flexibility

Flexibility in terms of interdisciplinary collaboration, big data management and data security; issues that have been growing with technological advances. Therefore, people with the responsibility of designing the curriculum for initial and advanced skill training should definitely be included in the Industry 4.0 strategic processes in the nascent. Attention should be given to dual degree flexibility education and training programs so that students can choose from major and minor across a wide range of related, connected and relevant skills, with the goal of providing industry-based technical occupations for all with a relevant skill set. Industry 4.0 will play a number of interdisciplinary roles that will require an information technology workforce and manufacturing knowledge. Several academic organizations are offering time-tailored training programs to meet specific industry needs. To further facilitate interdisciplinary programs, universities, in consultation with industry, should implement programs that integrate information technology and engineering, built on existing business requirements programs. The suggested hybrid platform must be introduced intentionally to fill the academic-industrial gap to increase employability [26, 27].

2.2 University-Industry Cooperation

The educational organization must identify gaps in existing educational training programs and address them in order to prepare specialists with the skills required for I4.0. The identified skill set usually requires detailed technical training and usually cannot be obtained through the help of colleagues in the same project or through requalification. The academy, along with industries and government organizations, should encourage students to pursue courses in disruptive technologies to address the trends the industry is taking. Fields like Artificial Intelligence, Blockchain, 5G, IoT, Cyber Security, Data Science, Cloud Technologies, Augmented Reality, and 3D printing will completely change the courses and classes that are running. Consistent with the goal of broadening the technical mix, the Academy must integrate computing elements into other diverse areas, especially in business [28–30].

2.3 Open Learning Sources

The Academy should support the education system for the re-qualification of the industrial workforce by accepting the need for disruptive technology training in traditional off-site locations. Support can integrate online learning platforms and access to free educational courses on open platforms. Massive open online courses may be offered to postgraduate engineers and credits may be included in the curriculum. Academy should work with business leaders to identify specific technology training needs required. Concepts such as MOOC and Flipped Classroom should be prepared keeping in mind the requirements of Industry 4.0 standards. Suggested collaboration can lead to new business education models, such as short-term instructional programs aimed at improving skills rather than awarding a degree. The suggested Cyber-Physical Factory is the end product of our modular and progressive system to learn in competition with Industry 4.0. The training program module is flexible, Cyber Physical Factory maps a number of Industry 4.0 features, including [31, 32]:

1. Manufacturing divisions integrated with digital production;
2. Automated Assembly;
3. Logistics in autonomous systems;
4. Industry based production techniques 4.0;
5. Intelligent maintenance to verify systems and their status;
6. Quality Assurance;
7. Prepare factory smart modules for teaching and research purposes;
8. Industry 4.0 modular and expandable structure to represent the value chain;
9. Open interfaces that are concurrent with industry standards;
10. Cyber Physical Factory with Industry 4.0 applications: CPS, RFID Technology, NFC, SOA, MES4 Software, Augmented Reality;
11. Cyber Physical Factory as a flexible modular factory;
12. Cyber Physical Factory Robotic module for robotics skills in the industry.

2.4 Shift in Communication Processes

Industry 4.0 is working with a goal of Smart Manufacturing. Effort is to use technology intelligently to design systems with simplicity and scalability. Smart Manufacturing involves a paradigm shift in communication between human-machine and machine-machine interface procedures. Achievements that are undefined and are showing unpredictable growth will require expert intervention for optimized solutions, enhanced security, and interactive clouds working simultaneously. The required skill set will be more optimized and formative in nature, increasing the need for student capacity and instructor capacity. Today's existing educational platform is based on knowledge acquisition and has so far not opened the door to skills integration [33, 34].

1. What is required as a prerequisite to achieve integration?
2. Policies that govern education need to be flexible and futuristic to facilitate improved learning.
3. Exam and assessment schemes need to be articulated differently to validate students' core competencies and aptitude.
4. Technology in vocational courses shall be redesigned and restructured in accordance with I4.0 requirements to improve student capacity, student growth, and student expression of knowledge and skills.

5. Attention to positive encouragement for entrepreneurial initiative and creativity with risk coverage should be given to the student.
6. Horizontal and vertical mobilization of knowledge and skills acquisition should be incorporated into professional courses.
7. Industry-academy networks and learning centers should be established with online and offline support for multidisciplinary learning experiences.
8. Multi-skill certification programs established by governmental and educational organizations in collaboration with industries and business houses should be initiated to ensure reliable and relevant skills.
9. "Mass Marathon Syndrome" needs to give way to "growth of targeted technical skill set".
10. Quality idea needs to be at the apex.

2.5 Flexible Learning

The academy on principle should focus on technology trends and student choices about how, where, and when they want to learn. The foundations of flexible learning must be student-centered. By setting new requirements in education programs that appear as prerequisites for Industry 4.0, one can simply address by incorporating flexible learning into the program structure. Flexible learning plays a vital role as it can meet the requirements of learners in many fields. Interestingly, the Industry 4.0 philosophy is now spreading its wings in the university environment, as technological innovations and research are almost on the same platform [35].

2.6 Sustainable Development

With innovations in technologies that are disrupting the entire work flow of business and thought process for tackling problems, sustainability becomes a big question. Innovation needs prerequisites and technical backups in terms of experts, experimental setups and infrastructure to support innovations, globe is divided into under developed nations, developing nations and developed nations and in additions neighboring countries may be allies or enemies further technical support offered must be cost effective and in subsidized rates for wide exposure, even to unprivileged but deserving lot. Technology, Expertise and infrastructure support and transfer across may not be at same threshold of technology and available to all, therefore sustainable development at same level becomes questionable. However academia and industry should focus onto two main questions—what kind of skill development programs can suffice the needs of technological advancements and what should be the support system so that maximum can attain the skill set with limitless boundaries, further resources generated in terms of technologically supported education should be free and omnipresent.

There has been a paradigm shift in all forms of education systems across the world, especially after the inclusion of experiential learning concept for effective and efficient curriculum implementation. The whole focus has been diverted towards creativity, out of box solutions and exposure to implementation based learning. Industry Engineering Integration Model 4.0 (IEIM-4.0) proposes to implement engineering 4.0 with inclusion of flexibility in programs, University industry interaction, open learning courses, shift in communication processes, flexible learning and optimum support for sustainable learning, though number of academic organizations have already started working on it, concepts such as choice based flexible credit systems, flipped class rooms, MOOC courses, flexible major and minor curses and online LMS modules. However with advent of disruptive technologies era, utilization of virtual environments for real time applications, real time functional prototype models and optimized decision in extreme environments could be very well incorporated in engineering curricula to raise the bar at par with industry 4.0 standards.

3 Conclusion

The proposed work is the study towards the exploration of disruptive technology, with its influential effect on the main engineering branches. The study also discusses the change needed to incorporate the 4.0 engineering concept. Many studies are suggesting TAM (Technology Acceptance Model) for industry 4.0. But each change in the industrial process produces a resonant effect on the educational level. Each industry-level change requires a specialized generation of engineer-level skills. Now a huge structural change is needed in teaching core engineer courses, as the focus should be on graduate production with a broader vision and thinking process to deal with problems. By studying current trends in industry and education, the gap is analyzed between industry and academia and for industry-academia 4.0 integration, and the proposals are: Flexibility, University-Industry Cooperation, Open Learning Sources, Changing Communication Processes Flexible learning, sustainable development. As an extension of current work, the author is working on the Industry Engineering Integration Model 4.0 (IEIM-4.0).

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The Opportunities of Blockchain in Health 4.0

Prateeti Mukherjee and Dhananjay Singh

Abstract The next definitive step into the future is expected to involve a shift towards a fully automated environment that utilizes exponential technology such as Artificial Intelligence (AI), Internet of Things (IoT), Sensor Networks and Blockchain paradigms. We are immersed in the Fourth Industrial Revolution, that is fundamentally changing the way we live, work and interact with one another, and with technology. Industry 4.0 is an emerging era of connectivity and interaction among parts, machines and humans that have the potential to create enormous production and efficiency dividends, in addition to improvements in the quality of life and sustainable environmental outcomes. The Healthcare Industry is in the process of adopting technologies that allow digitization of health records and automation of various plausible clinical procedures. The field has undergone an evolution of its own, and is now standing at Healthcare Version 3.0, the extension of Web 3.0, that involves greater transparency of healthcare data to individuals, personalized to optimize their experience with the interface. The amalgamation of the two revolutions to realise the new era of Health 4.0, is where the emerging Blockchain Technology could play a major role. The need for interoperability across clinical departments within the same hospital, the necessity of updated set of records for reference across multiple healthcare facilities, and the exigency of trusted and transparent documentation of individual health data, urge the use of Blockchain concepts in our attempt to transform healthcare services. This chapter explores the transition of the Healthcare Industry, the drawbacks of previous versions, and the opportunities of Blockchain concepts that would aid the medical field in keeping up with Industry 4.0.

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1 Introduction

The healthcare industry has witnessed a steady progress in terms of digitization. As a trillion dollar industry spread over hospital care, clinical services, dental care, elderly assistance, medications, and research and development, healthcare has and will continue to greatly benefit from digitization of services. A consistent set of digitally stored medical records for every individual, with multiple levels of security and restricted access schemes would undoubtedly result in better coordination among healthcare providers, departments, and clinics, despite the distance between them. Further, modern technological advancements in the field promote better patient compliance and inclusion. The age-old one-way conversations where doctors prescribe medications and patients follow their recommendations religiously shall become a thing of the past. Through digitization, and the influence of Industry 4.0 concepts, healthcare practitioners are encouraged to hear patient concerns and carefully craft remedies to ensure positive patient experience. In certain cases, the diagnosis of a medical condition may depend on the way the patient's body reacts to prescribed experimental medication. Through technological intervention, healthcare practitioners could easily facilitate round-the-clock monitoring and provide medical support when needed. Employing ubiquitous healthcare services, the patient could even be responsible for their own health, reaching out for assistance at their own discretion. The list of revolutions brought about by digitization in the healthcare industry seems endless. However, a breakthrough in the field of digital medicine is yet to be accomplished. The aim is to create patient-centric applications that present the promise of better, more personalised care to every individual.

Industry 4.0 is the current age of digital transformation that relies heavily on the optimization of computer systems, and automation of various processes. This technological wave encompasses Cyber-Physical Systems, 5G Technologies, Internet of Things, Cloud Computing, Big Data Analytics, and Cognitive Computing, among others. The key concepts governing the fourth Industrial Revolution, as suggested in [13] are as follows:

– Interoperability
– Virtualization
– Decentralization
– Real-time Capability
– Service Orientation, and
– Modularity

As evident from the list, applying these concepts to the Healthcare Industry shall immensely elevate the quality of healthcare services across the Globe. Decentralization of services is essential for the creation of a distributed system involving patients,

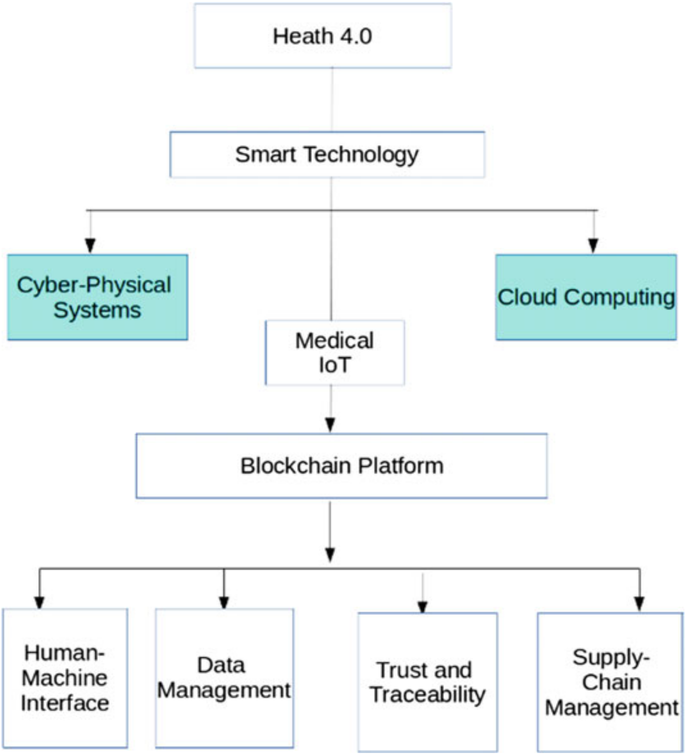

Fig. 1 Industry 4.0 healthcare extension

healthcare practitioners, and caregivers. This, however, is a challenging feat, since medical records constitute sensitive information and distributed storage of such data seems unappealing to participants. Distributed patient-centered care requires a continuous and reliable data flow across diverse networks and spheres, incorporating best Industrial standard security measures to protect patient privacy. This is where Blockchain comes into play. This emergent technology is capable of providing a solution that not only helps secure recording and sharing of medical records, but also ensures that the patient has complete ownership of their own data, while others can view the same only when sanctioned by this owner.

The scope of Industry 4.0 notions in Health 4.0 is depicted in Fig. 1.

Blockchain technology is an important distributed ledger architecture that has significant applications in the realisation of Health 4.0 abstractions. The chapter is organised as follows: Sect. 2 lists notable research papers in this domain, while highlighting the novelty of our chapter. The evolution of healthcare services over the past few years is explained in detail in Sect. 3. Section 4 provides an in-depth analysis of the opportunities of blockchain technology in this movement, with emphasis on

Industry 4.0 principles that are scalable to the medical domain. Finally, conclusions are drawn in Sect. 5, and the key concepts of the emerging framework that find use-cases in this technological revolution are discussed.

2 Related Work

Despite the enormous potential of blockchain as an innovative technology to combat several persisting issues in modernised healthcare schemes, the field remains immature with few real-world examples that have gone into production till date. In [10], the trends of blockchain popularity are studied. The authors suggest that the technology is in a 'hype cycle' characterized by stages of innovation triggers, inflated expectations, disillusionment, enlightenment, followed by a final "plateau of productivity". The authors suggest that,at present, healthcare and life sciences lie squarely in the middle of phase one and two of the curve.

A notable contribution to Health 4.0 is the extensive survey provided in [9]. The authors deliver an in-depth analysis of Industry 4.0 concepts that are applicable to healthcare service development, while discussing the potential of Health 4.0 to extend, virtualize and enable new healthcare-related processes such as home care, personalised remedies, and remotely triggered pharmaceutical treatments. Commenting on the scalability of Industry 4.0 concepts into the health domain, the authors suggest the implementation of Cyber Physical Systems to monitor real-world processes, use of Value Chain Organizations (VCO) that benefit from Industry 4.0 standards to boost productivity in the presence of budget pressures, and Big Data Strategies for custom healthcare schemes. Healthcare decentralization is presented as a challenging affair since it fails to appeal to a substantial number of underdeveloped nations, considering security concerns, governance, and liability issues. While healthcare is leaning towards a distributed, patient-centric model with patients, specialists and caretakers as its participants, the authors express their concern for the increased count of sophisticated needs in network design and communication providers. However, the work does not mention the enormous potential of Blockchain technology in this regard. The latency and security issues mentioned in the paper could easily be solved through a carefully designed network employing blockchain concepts, as discussed in detail in Sect. 4.

Another work [1] addresses the critical issues encountered in the process of sharing data across authorized parties. The authors express their apprehension, with particular focus on confidentiality and integrity concerns. They suggest blockchain technology as a revolutionary tool that shall ensure data integrity and privacy in any system, and proceed to conduct a literature review to identify research gaps and future directions in Blockchain applications for the healthcare domain. The authors provide a systematic view of the challenges in terms of people, processes, and technology, while reviewing the advantages as well as disadvantages of employing blockchain techniques to solve said challenges. The open-source framework promises high-level security and transparency in financial and data sharing applications, and has hence exponentially increased interests in adopting blockchain into electronic healthcare schemes. Despite the growing popularity of such architectures, intense data traffic handling and security concerns, along with cost affairs must be considered before implementation and investment, as suggested by the authors. However, several improvements to blockchain network design have since been witnessed, that are capable of handling security threats and intense traffic, without imposing colossal financial implications. The legal and regulatory challenges of a unified data storage mechanism might still persist, however, once the potential of the technology is realised and trust is built within the community, such issues would cease to exist in a few years.

A similar paper [14] discusses the current landscape in blockchain for healthcare. The authors highlight the issues of healthcare that stem from the complex network of intermediaries and lack of traceability of transactions, resulting in fragmentation of data across several silos. The potential of Blockchain in solving these trust and traceability issues is extensive, gathering significant interest in the healthcare industry. The paper provides a comprehensive review of major use-cases of blockchain in healthcare such as data management, billing claims, data analytics and telemedicine. The work also surveys related projects that target a varied set of health-related aspects including General Electronic Health Records (EHR), data modalities such as genomics and dermatology, and pharmaceutical research. The existing challenges are also discussed, concerning technical aspects, regulatory concerns, and business trials. The authors bring to light an interesting point—while a multitude of companies and research groups advocate the implementation of blockchain in the healthcare sector, most projects are in the white-paper or proof-of-concept stages, with very few readily available products backed up by relatively small user bases. However, the increasing quantity, quality and maturity of such projects accords hope for a propitious future of blockchain in the medical sector.

Several other review papers exist in this domain, with comparable content. [16] provides a comprehensive literature review, while discussing directions for future applications. Views concerning blockchain conceptualization, development, and deployment from a multidisciplinary group of practitioners to understand whether the technology is fit for purpose in the healthcare industry is discussed in [17]. The emergent blockchain solutions for modernised healthcare infrastructures is discussed in [26], where the authors emphasize the need for the medical community to understand fundamental concepts behind blockchain, and recognise its potential impact in the industry. As evident from our survey, a number of related works exist in this discipline, with little variety in content. However, none of these works mention the momentous potentials of Industry 4.0 standards that, when hybridized with blockchain computing, could transform present day healthcare practices. Exploration of the opportunities and challenges when interweaving these emergent technologies constitutes the novelty of our work.

3 Healthcare Evolution

3.1 Health 1.0

Health 1.0 was set in a world of unfettered physician autonomy and sacred doctor-patient relationships, coupled with incredible focus on the art and humanity of medicine. The glorious 'good old days' functioned in the absence of crucial evidence-based medicine, adopting consensus and intuition instead. Due to the nature of payment services, and the venerated position held by doctors in society, healthcare practitioners were incentivized to do things to people, instead of for people. The hallowed relationship between doctor and patient were often marred by pernicious practices to benefit the former. The system was clearly broken, and collective realisation of the fact paved the way for Health 2.0.

3.2 Health 2.0

Introduced in the mid 2000s, Health 2.0 is a subset of healthcare technologies that stemmed from the Web 2.0 movement. Inclusion of social media, user-generated content, cloud-based applications, Software-as-a-Service (SaaS) schemes and mobile technologies form the basis for this movement. Health 2.0 emerged as a response to the aforementioned shortcomings of Health 1.0, empowering patients to have greater control over their own healthcare. Medical Paternalism, where the physician determines whether the patient's choice regarding their treatment methodologies shall be honored or not, was a booming practice in early to mid 20th century. Heath 2.0 challenged the modus operandi, initiating the era of Big Medicine.

However, this new-age system was loaded with flaws. Instead of ceding authority to clinicians and medical practitioners, patients cede authority to the government, administrators, and faceless algorithms. An appropriate analogy is considering the Health 2.0 system as a machine, with the entire healthcare team, as well as the patients being treated as mere commodities and raw materials. Although the power that previously existed in the arms of the physician is now devalued, it is not granted to the patient, but to large firms and authorities instead.

This discouraged physicians, eventually leading to a crisis in the field. Considering the disparaged reputation of the profession, the new generation avoided a career in medicine, while nurses marched in protest. Although certain principles espoused by the movement were crucial in development of the field, the heart and soul of medicine was lost along the way.

A blend of the concepts prevalent in this movement and its predecessor led to the inception of Health 3.0.

3.3 Health 3.0

Health 3.0 was set out to restore the strong human bonds of trusted relationships at the heart of healing, while invigorating medical practices with a patient-centric approach. In [20], the term mobile social networking is used extensively to define Health 3.0. The author is concerned about the influence of the cyberspace in healthcare, wherein the patient relies on information available on social media platforms, forums and blogs for diagnosis. He fears second guessing on the patient's part, seeking advice elsewhere, with increased risks of declining health standards and improper use of drugs. However, while highlighting the positive effects of the movement, the authors lists the following:

- Daily support system to comply with a prescribed medication regimen
- Better disease and care management along with early detection of symptoms
- Real time support, regardless of distance between healthcare provider and patient
- Reduced feeling of isolation and helplessness for the patient
- Improved doctor-patient communication
- Care customized for specific needs and requests of the patient
- Culturally sensitive care

Hence, this revolution, drawing inspiration heavily from the concept of the semantic web [18], makes use of social media and other virtual tools for enhanced interactions between healthcare providers, caregivers, and patients. The movement showed great potential in transmuting disease management, medical research, and the entire healthcare industry.

3.4 Health 4.0

A shift in the demographics and socio-economic patterns in large parts of the world has prompted healthcare systems to evolve through the years. With the emergence of fundamentally new strategies such as Industry 4.0, the field of medicine cannot be left behind. As suggested in [1], Health 4.0 is a strategic concept for the healthcare domain that derives from the Industry 4.0 movement. The concept aims for virtualization of services, decentralization of records, and personalization for patients, professionals and other stakeholders leading to overall improvement of services, through technology. Driven by networked Electronic Health Record (EHR)systems, Artificial Intelligence (AI), real-time data from wearable devices and body sensor networks, and improved data analytics, Health 4.0 is set to completely metamorphose the healthcare industry.

The transformation from the typical architecture prevalent in traditional hospitals and poly-functional clinics to Health 4.0 standard architecture is depicted in Fig. 2. The traditional framework includes the patient, but does not solely function to serve their needs. In other words, the system is not patient-centered. While the patient is the

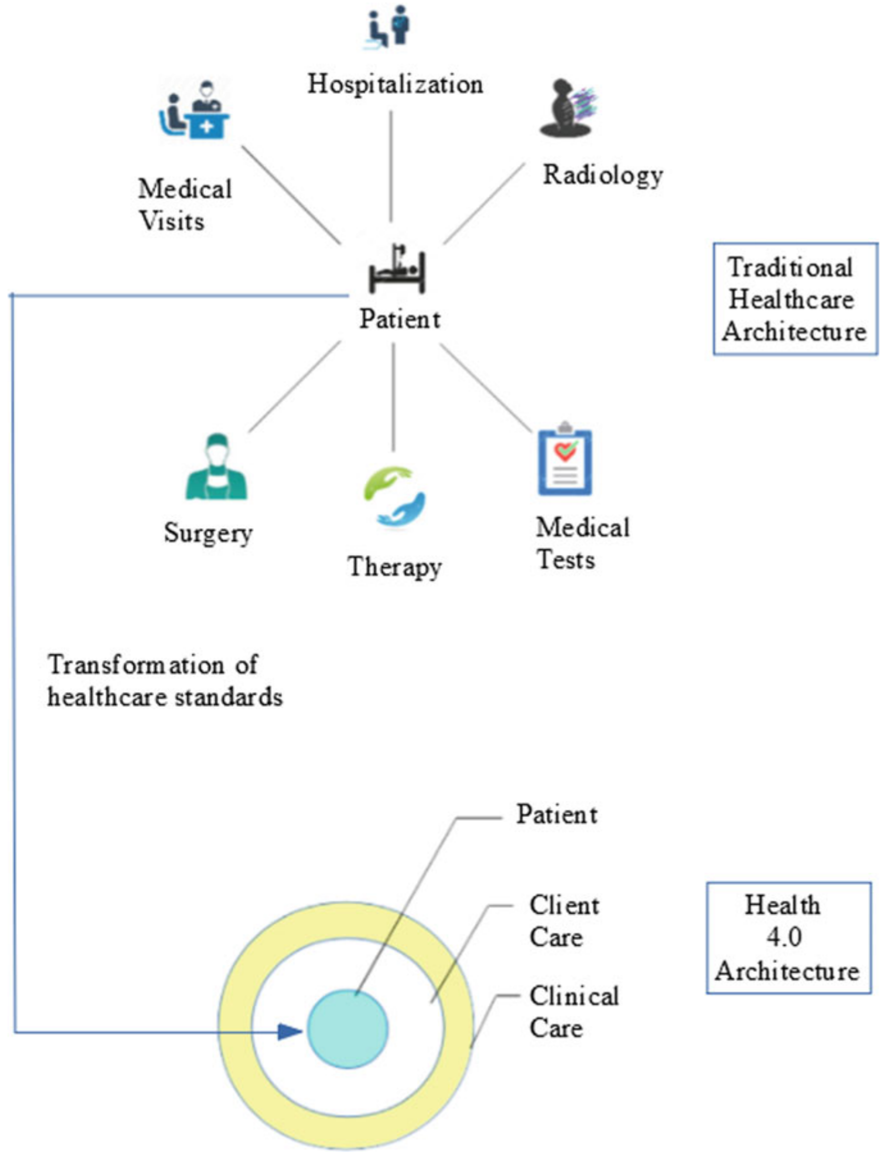

Fig. 2 Transformation of healthcare architectures

connecting element in the architecture, the other services merely involve the patient in their functioning, as opposed to revolving around the patient's requirements, desires and medical circumstances. The Health 4.0 standards for a hospital differ from this architecture, as is evident from the figure. Here, the recipient is the client of the service and lies in the center of the framework. Other elements surround this client, with their sole aim being provision of the best medical experience to the patient. Health 4.0 focuses on collaboration, coherence, and convergence amongst participants and stakeholders, to make healthcare more predictive and personalized.

Health 4.0, with its advanced concepts derived from emergent technologies and modernised, patient-centered design opens doors for enhanced patient care and improved healthcare outcomes, while creating notable value for stakeholders.

4 Why Blockchain in Health 4.0 ?

Health 4.0 realises the importance of data management. The movement understands the need for consistent, secure, and effective data storage and analysis schemes for successful operation of a patient-centered system and improved user experience. In compliance with Health 4.0 standards, the burden of maintaining medical records and keeping track of scheduled checks is lifted off of the shoulder of the patient and is instead digitized and secured. Further, this data can be transferred between caregivers free of hassle, if permitted by the patient.

Execution of such a mammoth task is no easy feat. Blockchain, by design and definition, belongs to a class of databases. Data stored in the blockchain decentralised ledger is termed transaction and requires a space of 1 kB or less. This data has a restricted access mechanism, by virtue of which only the owner, holding the private keys, is granted access. The owner can transfer this data from one computer system to another using the Inter-Planetary File System (IPFS). This transfer is fast and secure, and economically superior to a traditional centralized database. The rationale for the application of blockchain technology in the context of medical record storage is the fact that maintenance of a typical healthcare information system involves various operations, including backup storage services, maintenance of fail-safe recovery mechanisms, and ensuring the data is up-to-date. In a blockchain setup, the data is distributed across the network, thereby reducing the chances of failure by a significant amount, since there is no single point of failure. Further, a single, most recently updated version of the data is copied on every node, greatly reducing the volume of transactions that occur between information systems. These factors collectively diminish the burden on the healthcare ecosystem, enabling better analysis of data and provision of healthcare solutions to the clients of service. The blockchain architecture, applied to the healthcare industry, is depicted in Fig. 3.

The following is a list of Industry 4.0 concepts that constitute major Health 4.0 standards, achievable through blockchain technology.

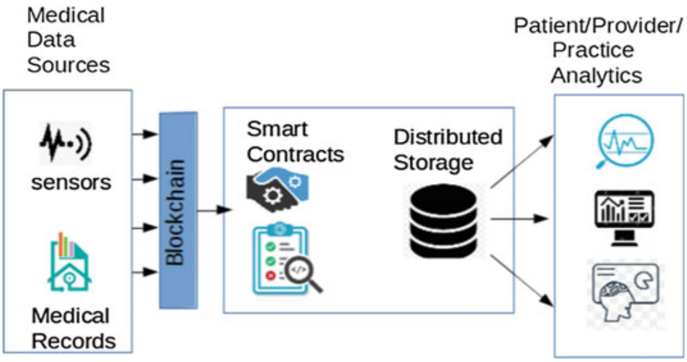

Fig. 3 Blockchain architecture for healthcare applications

4.1 Decentralization and Data Management

A distributed, decentralized architecture is desirable for Industry 4.0 applications when their computation loads lie in the mid to high range. Centralized servers are expensive in the first place, and the costs keep soaring considering deployment and proper maintenance of these structures. The healthcare industry is a complex system of interconnected entities that function under heavy regulatory boundaries. In the traditional framework, patient data is highly fragmented and the cost of proper delivery of healthcare services escalates rapidly due to several inefficiencies within the system and dependence on third party personnel and intermediaries. The already expensive healthcare sector, if augmented with centralized solutions, shall discourage potential collaborators from participating in the movement due to the exorbitant price of medical services.

The most exciting aspect of blockchain technology, often used to define the concept in literature [4, 27] , is its decentralized architecture. Blockchain-enabled decentralization promises to curtail the vendor lock-in problem that has tormented the healthcare industry for centuries. In cloud frameworks, the vendor lock-in problem arises when the customers are dependant on a single cloud provider and cannot easily migrate to a different vendor without having to endure substantial costs, legal issues and/or technical incompatibilities. When it comes to the medical field, a similar issue arises when the patient can only avail services at a particular healthcare center. Once the patient decides to migrate to a different clinic, transfer of prior records, billing data, and other information is cumbersome, and legal issues are often encountered, resulting in delayed care and unpleasant patient experience. Often, crucial data is rendered inaccessible due to fragmentation and multi-level authentication from intermediaries and authorities, and valuable information is sequestered at a time of urgent need.

Blockchain introduces the Health Information Exchange (HIE) scheme that employs a trusted, decentralized database. Through this framework, a one-stop access mechanism is established, wherein the entire medical history of a patient is made available for review across all healthcare providers and medical practitioners. The participants and stakeholders can only view the data when the activity is sanctioned by the owner. Digital Decentralization through Blockchain concepts is set to revolutionize healthcare extension of Industry 4.0 in a multitude of ways.

- Real-time information sharing among patients, caregivers, medical practitioners, physicians and stakeholders.
  - Practitioners prescribing different medication to patients with similar symptoms could collaborate and exchange data, resulting in steep learning curves and enhanced medical research.
  - Decentralized applications (dApps) link hospital data systems across a shared network, enabling real-time exchange of information from one end to the next. Patient data is constantly updated and stored on the distributed ledger, aborting the vendor lock-in problem entirely in the context of healthcare.
- Secured storage of sensitive medical records.
  - Decentralization through blockchain concepts offer a much safer paradigm for the storage and distribution of digital information, when compared to traditional record systems. Hospitals and Clinics that use discrete and isolated central servers are easy targets for cyber-criminals and hackers. Despite this advantage, a blockchain network presents a new set of security ad privacy concerns that are addressed through careful design of consensus mechanism and cryptographic protocols deployed at the nodes.
  - The major advantage of a decentralized architecture in this regard is the sharing of information across multiple network nodes, and the absence of a single point of failure. This makes the storage system robust and fault-tolerant, rendering it difficult for hackers to compromise the network.
- Improved hospital administration.
  - Decentralized applications are expected to streamline communication among caregivers, practitioners and the staff at healthcare organizations. Easy access to a patient's data, when granted permission, would keep everyone involved in the medical procedure well informed. This aids daily process management and overall administration through simplified patient verification and facile revision of insurance claim policies, among other benefits.
- Electronic Medical Record (EMR) management.
  - Decentralized applications empower patients to collect, own, and manage their own data rather than storing the same in remote Electronic Health/Medical Record systems owned by physicians, clinicians, or third party agencies. Modern wearable devices powered by Internet of Things (IoT) paradigms gather relevant information regarding the individual's health and update the database regularly, while sharing this data with medical practitioners in real-time, when permitted to do so. Patient-centered schemes are greatly supported by this technology,

granting absolute ownership of delicate medical information to the concerned individual.
– Alternatively, instead of storing patient data, the application could store access control specifiers decided by the individual. The concept essentially produces the same effect as the preceding framework, with the actual data being stored in the remote EHR. Flexibility in design enables survival of certain traditional healthcare elements to allow a slow transition to Health 4.0 standards.

4.2 Trust and Traceability

Accurate data analytics and digital trust are the founding pillars of Industry 4.0 [8]. The industrial revolution is expected to introduce major alterations to business formulae. With such prodigious changes in store, the one area that companies cannot afford to ignore is digital trust. A technology-enabled ecosystem can function efficiently only if all parties involved have faith in the security of their data and communication, and trust the digital framework with protection of intellectual property. Protecting a business, while ensuring digital trust requires substantial investment and a clear set of guidelines for data integrity and security. In the healthcare industry, trust and traceability are of paramount importance. Healthcare institutions are data driven, and the volume of data generated in the era of wearable sensors and pervasive monitoring techniques is growing significantly [23, 24]. Secure transfer and storage of delicate records and privacy concerns discourage the populace from switching to the Health 4.0 standards of medical service. Violation of security by illicit users has destroyed the reputation of many institutions and have struck massive blow to their capital. Different participants in the healthcare network play a varied set of roles. The Health 4.0 scheme requires appropriate provision of access privileges, based on these roles and their importance.

These trust and traceability concerns could easily be solved though Blockchain concepts. These are, in fact, the two basic promises of the network, solving generic trust issues at the public, federated, and organizational levels. Extensive research has been conducted in the field of cryptographic protocols and consensus mechanism in hopes of building a robust, fail-proof system.

Several attacks on blockchain networks have been studied in literature. Popular attack mechanisms include the Majority Attack which is secured using a hybrid machine learning and algorithmic game theory-based approach [6], and the Distributed Denial of Service Attack (DDoS), mitigated through a Proof of Activity [3] protocol or by continuous monitoring of network traffic using discrete browsers such as Tor or any other user-defined web service. An Eclipse Attack [12] is when a majority of a node's peers are malicious and prevent the node from connecting to the main network. The purpose of this attack is to obtain sensitive information about transactions of interest. This attack usually targets a single user, and to combat these malicious nodes, additional procedures are adopted to store the trustworthy IP addresses in the network, along with deployment of special intrusion detection mechanisms at the nodes. Sybil attacks [7] affect the whole network. When a single adversary controls multiple nodes in the network, the phenomenon is termed as Sybil Attack. The network remains unaware of the activities of the adversarial entity in gaining control over these nodes. In the Bitcoin network, Sybil attacks are avoided by setting thresholds to the block generation abilities. For Bitcoin [19], this value must be proportional to available computational power through a Proof-of-Work mechanism, thereby limiting the number of blocks an adversary can generate. Several other cryptographic protocols may be employed, such as zero-knowledge proofs [5], White Box Cryptography [11], Identity-based Broadcast Encryption (IBBE) [22], and Incremental Cryptography [2], among several other schemes.

Pairing distributed ledger technology with such advanced security protocols ensures provision of trust, traceability, and a privacy-preserving contract design, that form the core building blocks for critical Industry 4.0 applications, including healthcare and supply chain management.

4.3 Supply Chain Solutions

Supply Chain Management (SCM), under the Industry 4.0 standards, is designed to include the best practices of the Industry to streamline the entire delivery process, from ordering of goods to delivery of the same [15]. In the healthcare industry, SCM is a challenging prospect, and immensely crucial to ensure transparency of the pharmaceuticals manufacturing and tracking of medical distribution. The issue lies in the scattered ordering methodologies prevalent in traditional medical markets, with fragmented information regarding bulk orders of surgical equipment, drugs, and critical resources. Compromising the supply chain process could directly impact patients' health and safety, and must be taken very seriously for appropriate framework design.

Recent concerns in this domain lie in the illegal selling of counterfeit drugs. According to a study conducted by the World Health Organization (WHO), more than 100,000 deaths in Africa are linked to improper dosage of counterfeit drugs that were ordered from unknown vendors [21]. The Drug Quality and Security Act (DQSA) [25], first enacted by the Congress in 2013, outlines steps to build an electronic, interoperable system to identify and trace certain prescription drugs as they are distributed in the United States. This system is expected to enhance the FDA's abilities in terms of consumer protection against exposure to counterfeit, stolen, contaminated, or otherwise harmful drugs. The system shall also enable timely detection and removal of potentially dangerous drugs from the supply chain networks in the States. Blockchain, through its trusted and traceable architecture coupled with the transparency of transactions, shall ensure he authenticity of prescriptions for compliance with the Drug Supply Chain Security Act.

In addition to product and drug counterfeiting, lack of product registry in a trusted database and packaging errors could disrupt the entire supply chain network and cost the care facility a hefty sum in remedies. Blockchain is capable of monitoring the entire process, tapping into every transaction and movement of product along the chain. Whenever the product changes hands, the transaction is recorded on the public ledger, and is copied onto every node. The systematic procedure, with no single point of failure, makes it easier to verify the origin of the drug, the vendor credentials, and distributor identity. With enhanced awareness of the activities within the supply chain, and necessary authentication procedures brought into play, pharmacies and healthcare providers will be able to ensure flow of authentic drugs from source to destination, without fail. Furthermore, blockchain technology promises significant enhancement on other aspects of SCM such as, demand forecasting, data provenance, fraud prevention, and transaction.

5 Final Remarks

Industrial leaders are digitising essential functions within their internal vertical operations processes, as well as with their horizontal partners along the value chain. In addition, they are enhancing their product portfolio with the introduction of innovative, data-based applications to provide best possible service to the consumers, while increasing company revenues. The Smart Industry, or the Industry 4.0 revolution is not only the next big thing, but it represents an ongoing evolution, a necessary step towards the inevitable digital transformation.

At the end of this transformation process, successful industries shall transfigure into true digital enterprises, with physical products at the core, augmented by digital interfaces, decentralised frameworks, and innovative services. These entities will work together with customers and suppliers in industrial digital ecosystems. These developments will fundamentally alter the industries, as well as transform market dynamics across the Globe. The healthcare industry shall experience this exciting technological mutation as well, emerging as a patient-centered service that caters to the need of every individual in need, as opposed to the fee-for-service scheme rife in traditional frameworks.

As discussed in this chapter, blockchain technology presents a promising infrastructure that is flexible, adaptable, agile and secure, to aid healthcare in keeping up with the rapid progress in Industry 4.0 principles. The decentralised management architecture, almost synonymous with blockchain computing, provides a platform for collaboration and coordination among the multitude of stakeholders in healthcare administration. The technology provides immutable audit trials, suitable for applications such as insurance claim records, where the database holds critical information, that must not be altered. Further, data provenance and traceability is a key aspect of blockchain technology, finding applications in digital asset management and preservation of patient consent forms. The robust nature of the network, along with ready availability of relevant data could potentially save lives in extreme emergencies, and save patients from the hassle of running around with sensitive records in hand, when they should be receiving treatment instead. Advanced encryption algorithms and attack-resistance schemes provide greater security and privacy of data than remote centralized databases, with third party interventions.

While the initial focus of Blockchain technology was on applications in the finance sector, several other industries have witnessed the far reaching potentials of this framework. Blockchain technology enables new business models, innovative organisational forms and work processes, fundamentally changing the paradigm from hierarchical organisations to self-organising economies. The technology has opened doors for the healthcare industry to a world of possibilities, and is set to transform medical services as we know it, elevating the quality of service and patient experience by a colossal amount to meet Health 4.0 standards.

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