Industrial and Artificial Internet of Things with Augmented Reality

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Abstract Internet of Things (IoT) is a concept that proposes the inclusion of physical devices as a new form of communication, connecting them with various information systems. Nowadays, IoT cannot be reduced to smart homes as due to the recent technological advances, this concept has evolved from small to large-scale environments. There was also a need to adopt IoT in several business sectors, such as manufacturing, logistics or transportation in order to converge information technologies and technological operations. Due to this convergence, it was possible to arrive at a new IoT paradigm, called the Industrial Internet of Things (IIOT). However, in IIoT, it is also necessary to analyze and interact with a real system through a virtual production, which refers to the use of Augmented Reality (AR) as a method to achieve this interaction. AR is the overlay of digital content in the real world, and even play an important role in the life cycle of a product, from its design to its support, thus allowing greater flexibility. The adoption of interconnected systems and the use of IoT have motivated the use of Artificial Intelligence (AI) because much of the data coming from several sources is unstructured. Several AI algorithms have been used for decades aiming at "making sense" of unstructured data, and transforming it into relevant information. Therefore, converging IoT, AR, and AI makes systems become increasingly autonomous and problem solving in many scenarios.

Introduction

The industry is part of an economy that produces materials through mechanized and automated processes. In the past, there were several industrial revolutions that led us to the world we know now. The first one began with the introduction of mechanisms that produced energy from water and steam. The second one introduced electric power allowing the creation of first-line assemblies. And, the third one came with the introduction of automation and the appearance of the first programmable logic controllers. Based on this, we can say that there has always been an interest in increasing productivity and efficiency in industrial processes and, as a result of the recent advances in information and communication technologies, the fourth Industrial Revolution, also known as *Industry 4.0* or *Industrial Internet,* commenced. This new revolution was initiated by the German government aiming at increasing its competitive and sustainable advantage. The concept of *Industrial Internet of Things* (IIoT) was an adaptation of the industrial revolution with the concept of the Internet of Things (IoT), hence being used interchangeably [1].

The latter concepts, i.e., IoT, proposes the inclusion of physical devices as a new form of communication and connecting them with various information systems. The most frequent use cases in IoT generally refer to devices with certain integrated functionality, whether simple or not, such as controlling an environment through actuators or obtaining sensor values from a machine [2]. Nowadays, we cannot reduce IoT to smart houses, and because of the recent advances in hardware and cloud computing, this concept has evolved from small to large-scale environments. There was also a need to adopt IoT in several business sectors such as manufacturing, logistics or transportation in order to converge information technologies and technological operations [1]. IIoT initially referred primarily to a structure in which a large number of devices or machines that were connected to each other were synchronized through software or existing Machine-to-Machine (M2M) technologies in industrial environments. However, at the moment, this concept is no longer only applicable to machines, but also to intelligent computers and people that enable intelligent industrial operations through advanced data analysis. In IIoT, IoT bases are used where data obtained from machines also play a fundamental role, as it was necessary to increase the level of automation, thus introducing intelligence into devices. Technologies such as ubiquitous computing, large storage systems and M2M connections have led to the creation of Cyber-Physical System (CPS) [3] in IIoT capable of deciding and triggering actions to be able to control these systems autonomously. To achieve this autonomy, it is necessary to interact with the physical and virtual worlds simultaneously. This interaction enabled a better communication between humans and machines, forming connected machine networks that follow the social paradigm, therefore creating new paradigms in product creation and, finally, services based on intelligent systems [1]. In addition, these technologies enabled the adoption of new concepts such as Artificial Intelligence (AI) and Augmented Reality (AR) in the industry.

Artificial Intelligence

IIoT has become increasingly dependent on big data and consequently AI, creating a new paradigm called *Artificial Internet of Things* (AIoT). When we speak of AI we are talking about computer-based techniques that use a lot of unstructured data to process, interpret and visualize aiming to obtain credible information. Both big data and AI enable predictive historical analysis and to obtain information about what is happening inside a machine. Furthermore, because of this analysis, there is the possibility of having machines and services that are more efficient, predicting failures and reducing unnecessary inefficiency or maintenance costs. Hence, an IIoT system that incorporates this type of intelligence can collect data from sensors and, if necessary react faster than a human. There are three AI techniques that have been proposed for IoT [4], namely supervised learning, semi-supervised learning, and unsupervised learning. The integration of AI-based algorithms into the different IoT architectures to process data in a way to take autonomous decisions caused the appearance of interconnected intelligent IoT systems. These systems allow combining innovative technologies such as AR.

In the context of IIoT, the cloud offers an accessible and elastic infrastructure in order to allocate resources necessary for the system to scale. This is an important point that differs from traditional databases because we do not have to worry about the resources available for storage. For example, if we need a system with the ability to increase or decrease the storage needs, the cloud is a good example, which made it quite an interesting technology to adopt in IIoT services. In addition, the cloud provides development environments to its users, enabling accelerated development of applications. For instance, Microsoft Azure provides support for .NET applications and big data tools. Nevertheless, there are not only advantages on using a cloud-based system. Latency, which is the time difference between the start of an event and the time when this event is received, is very much a problem when using the cloud. In systems where the goal is to store data for use in big data, that is not a problem; however, in industrial systems where real-time information is required, latency can greatly affect the system's performance. Cloud systems are usually located on the Internet, where traffic can be affected by network quality, and where IIoT data are subject to latency. So, what will be the best methodology to satisfy storage requirements and to solve the latency problem? The answer is to use fog or edge computing. Fog and edge computing are cloud infrastructures located closer to the edge of the network [1]. In fog computing, the "intelligence" is transferred to the local network, and a pre-processing of the data is performed by an IoT node or gateway.

Augmented Reality

Since the late 1960s, the use of computer-aided design (CAD) has provided major advantages to industrial sectors such as automotive and aeronautics. The integration of CPS in the industry made possible to create and model any system or equipment in 3D, giving rise to a new concept called Cyber-Physical Equivalence (CPE) [1]. The latter refers to the fact in which the virtual and physical can interact simultaneously in real time. This new concept is also related to the concept of Digital Twins, where there is a virtual simulation of the system with the ability to update and change according to the changes at the physical level. A digital twin is not just an exact virtual copy of a product, but a combination of the two worlds allowing to analyze data, to monitor systems, to test new configurations, and to control the life cycle of a product. Thus, how could it be possible to add value to this combination? It is now possible to take advantage of this virtualization and use technologies that make use of AR to visualize these digital systems.

According to [5], AR is defined by three fundamental requirements: (*i*) combine real and virtual content, (*ii*) interactive in real time and (*iii*) accurate alignment of real and virtual objects. These three characteristics also define the technical requirements that an AR system must have. An AR system can combine real objects with virtual ones allowing interactions with the user, and a tracking system is able to find the position of users and virtual object. The convergence of the concept of digital twins with technologies that make use of virtual or augmented reality can increase the value of this combination by enabling the latter systems to visualize data in real time where, for example, one can operate a piece of equipment without being close to it, or even have the ability to predict a problem.

Considering the enormous potential of AR and IoT, several challenges have arisen to integrate both technologies. AR has as one of its objectives to provide an intuitive interface for IoT, using a virtual overlay of information. Therefore, one of the main challenges for those developing IoT or AR applications is to understand how this connection can be made more intuitive, enabling consumers to interact in a natural way with the virtual object, thus causing state changes in the same object. Service providers using AR also have the challenge of using real-time IoT data to debug and repair faults, hence providing a higher quality of service (QoS) and shorter response times.

More and more companies are taking advantage of the “power” of AI, IoT and AR in intelligent factories to reinvent themselves and gain competitive advantage. For example, mining companies are adopting strategies based on IoT, AR, and AI to increase their effectiveness in mining operations. They can obtain the extracted quantity in real time, perceive the fatigue of their employees or make a daily analysis of the equipment available in addition to these functionalities [6]. Companies in the energy sector use real-time data acquisition and analysis to optimize energy consumption and create sustainable smart cities. Moreover, because of the need to interconnect all components of a factory or a city, companies are forced to improve and innovate through this convergence. Converging IoT, AR and AI make systems increasingly autonomous and problem-solving in many scenarios.

Industrial Internet of Things

The impact of IoT in our lives is increasing as most devices already connected in a network to communicate with each other. IoT-based technologies adopted in many sectors such as medical care, security, surveillance, and product management allow many new services to meet the needs of their users. An IoT system must take into account characteristics such as heterogeneity, scalability, interoperability, ubiquitous data exchange, security and privacy, among others due to the plethora of different devices and protocols [7].

As previously stated, IIoT brings together advances of two revolutions that have emerged over decades, that is, the industrial and internet revolutions. These revolutions together with the technological evolution have given rise to three key elements that define IIoT: (*i*) intelligent machines, (*ii*) advanced analytics and (*iii*) people at work. Intelligent machines allow machines to have software and sensors connected to the Internet. Advanced analytics make use of physical data and AI algorithms capable of analyzing data. The last element is to connect people in the office or in an industry so that they can interact with each other at any time or even provide support remotely [8]. The combination of these elements offers new business opportunities, enabling a new perspective and analysis of data that traditional methods did not have. IIoT makes use of IoT applied in the industry since it is based on the characteristics such as heterogeneity, scalability and interoperability [7], that a system must consider. In addition, it uses a large amount of aggregated data, where it is crucial to get better visibility and perception of systems that are often linked to the cloud. Because of the adoption of IoT in the industry, we have been able to transform business operations or processes through analytical mechanisms used in big data and AI. These processes are optimized through gains in operational efficiency, productivity and automation of the equipment, thus generating more profit. Although what was initially said may seem like an M2M system applied to industry, the difference with IIoT is in the operation scale as it is necessary to consider large data streams stored in the cloud in real time and massive data analysis. This analysis thus allows obtaining information and statistics from data aggregated through AI algorithms. In many industry sectors, the introduction of AI into an IoT system has enabled the systems to perform predictive maintenance, i.e., through certain data patterns, events or problems that could stop a piece of equipment have been predicted.

IIoT can be seen in layers. Sensors and devices of pieces of equipment can be found in the lower layer, and gateways or communication hubs, which are responsible for communications between the sensors and the cloud (that will be the third layer), can be found in the layer above. In the fourth layer, there is big data and AI software, which can be utilized to analyze and optimize the desired information. At the first tier, we can integrate customer relationship management (CRM) software, which cannot only help to plan and control processes that are happening at the factory more efficiently, but also inform a customer if changes on the product are required.

In Figure 1, we can see the elements that are currently present on IIoT. These elements are the result of a constant evolution that happened in both the information systems and hardware since this was the only way to create the concept of IIoT. Systems such as CPS, Industrial Automation and the cloud are already known and part of the IIoT concept, however, due to their development and integration with other systems over the years it has been possible to introduce technologies such as AR and AI in order to evolve the IIoT concept. Various business sectors' digital transformation also provided the need to converge technologies already present in IoT with others such as AI and AR. Therefore, the emergence of the IIoT concept is a consequence of the need to innovate and obtain new business models for the benefit of companies.

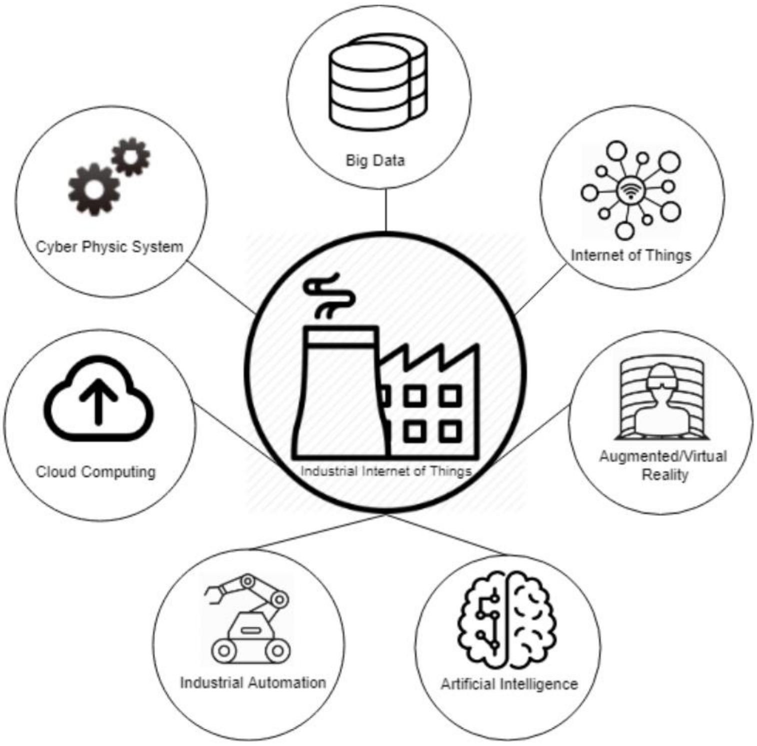

Figure 1 - Elements of the Industrial Internet of Things

Cyber-Physical Systems

As we can see in Figure 1, one of the main components that constitute IIoT is a CPS. Initially, embedded systems were used in small scales and independent of each other, but with advances in technology and communication, it was possible to adopt networked devices. This adoption gave rise to a new concept, called CPS, which functions as the link between a system/equipment and the real world. The term CPS appeared in 2006 and there is no clear definition, however, it is important to note the difference between an embedded system and a CPS. In an embedded system, only information systems are incorporated into physical devices meanwhile CPS are automated systems that allow connecting processes that occur on the physical world with computing and communication infrastructures, whose purpose is to control these same processes and adapt the system to new conditions [9]. CPSs are the integration of computing, networking, and physical processes capable of monitoring and controlling them. Unlike embedded systems, CPSs are designed to be connected in a network with all devices integrated with physical actuators that by acting change the environment. CPS permits the digital world to interact through computers and software with real-world processes. This interaction makes it possible to manage and control processes running in real time. To simplify, one can think of a CPS as containing embedded systems, but giving importance to the domain of communications with the physical world.

With these systems applied to IIoT, industries do not only see what happens but also interpret data through their analysis. Consequently, a CPS has the ability to do predictive analysis, as it was possible to create different scenarios where the probability of an occurrence in a piece of equipment could be estimated. It is also important to consider that these systems can take adjustment measures at any time without human intervention. The introduction of these systems can also be very advantageous, for example, in hazardous environments such as mining that requires constant analysis of workers' biometric data, and intervene promptly if necessary. The ability to expand the interaction of the physical world by means of computer-generated interactive systems such as virtual and augmented reality is a key factor in establishing a two-way link between the physical and digital. To connect a CPS with other computational elements as intelligent mechanisms or 3D models of a system, makes it possible to increase efficiency, usability, autonomy and adaptability.

Industrial Augmented Reality

Since the 1960s, computer vision has been very important in the industry sector, especially when it was adapted to the control and projection of equipment and products. It is not imperative that an IoT system has integrated visual computing, however, IoT systems using CAD have integrated systems that allow the development of new solutions. It is hence possible to make the system more complete and integrated and to create new business models.

As stated before, a CPS "bridges" the physical and digital worlds by building greater flexibility in the virtual simulation of products or processes before and during an operation. This flexibility together with CAD allows simulating all processes that cover the Product Life cycle Management (PLM), from the design phase of the product where the customer has difficulties in realizing the necessary requirements until the maintenance part. The simulation of a process permits the reduction of production errors or even increase the efficiency of the product development since there is a constant simulation during PLM phases. This modeling/simulation was only possible with the appearance of the CPE [1]. Differently from CPS, CPE is an approach where the virtual world and production environments are synchronized, and not just create a production process in a digital image. The creation of CPE is directly linked to the concept of digital twin. A digital twin is a virtual model of a process, product, or service that overlaps the virtual world with the physical to allow data analysis and system monitoring to avoid problems, optimize maintenance costs or even the planning of future processes. A digital twin can update the system as changes occur on the physical level. According to [10], "Digital twins are becoming a business imperative, covering the entire life cycle of an asset or process and forming the foundation for connected products and services". In an early phase of PLM, this model aims to help companies improve the customer experience by better understanding the needs or requirements of a product, reducing future errors. In the final phase, workers can be assisted with monitoring and analysis capabilities. GE Renewable Energy has developed a digital wind farm with the aim of improving performance, reducing risk and costs [11]. This was made possible through the simulation of a digital environment so that each wind turbine could be configured before construction, thus gaining 20% efficiency by analyzing data from the real environment.

Due to the constant evolution and increase of computational power in technologies such as smartphones and smart glasses, there has been an interest in using both technologies in the industry. Because of this interest, there was a convergence between the digital twin and AR applications, making it possible to create new use cases in the industry. AR enables the visualization of a virtual object in the real world through a device. In 2019, IDC estimates the world's augmented and virtual reality expenditures of almost $20.4 billion [12]. Just think how virtual simulation models can accelerate the entire production chain, or even maintenance processes, from the visualization of the 3D model in AR applications. Furthermore, a virtual layer integrated into the IoT system to obtain and visualize information in all types of industry and environments through AR devices could be added.

The simulation and control product life cycle is also one of the main uses of AR in the industry and is defined in five parts: product design, manufacturing, commissioning, and inspection and maintenance [13]. The first phase, the drawing, is focused on realizing the idea and the requirements that a product should have. Initially, when requirements are specified a user may not have the perception of what they really want, and this phase is important because through AR he can visualize the product or project and change according to the imposed requirements. Consequently, it can significantly reduce error costs that may arise in the future. In the assembly stages, AR and IoT together can assist the assembly processes instead of using typical traditional systems (i.e., manuals). For example, the AR system can show hidden structures (i.e., wires) inside the walls. After the creation of a product or process, it is necessary to verify if there were modifications during the assembly process and AR there could help to verify these requirements. In the maintenance step, a product or system having the ability to use IoT and AR data can make the response shorter in the event of a problem or even provide remote maintenance. In addition to these examples, AR also has another important role in interactive machine maintenance training. AR can provide hands-on training where users are given visual instructions of actual objects. Previously, technicians needed to participate in training courses in order to be able to solve equipment problems. However, with AR it is possible to accelerate the training phase, since manuals are not used anymore, and they were replaced by 3D drawings where you can view the instructions or see where each part is located. Machines and production lines generate a large amount of data that must be read in seconds in order to obtain relevant information in real time. This requires not only new technologies that enable the exchange of large information flow but also new ways of visualizing information. In this context, virtual analysis has come together to “separate” technologies such as big data, IoT, the cloud, and AI algorithms in order to contradict problems previously difficult to solve and analyze or reveal hidden patterns that were not obvious at first sight.

For example, Boeing developed one of the first industrial applications of AR [14], which aided airplane assembly processes to increase worker efficiency and reduce costs. Another example of applications where it is possible to converge AR with IoT is in emergency services. Firefighters are already using devices and equipment built into helmets that receive data such as temperature smoke detectors, and presence status. This information allows a firefighter to see if there are people in a building during a fire.

AR does not only depend on IoT but also on AI to be effective, because only through this convergence it is possible to predict, for example, which interface is shown to the user depending on the surrounding environment. This is possible thanks to the implementation of AI for object recognition and tracking as well as gestures recognition. Recognition and tracking allow people to interact with objects in the virtual space or even move an object in the real space. They do not only recognize an object, but also the gestures or interactions of other objects. For instance, transport companies can use AI to predict weather events in order to divert routes and display information to the driver through AR [15]. The combination of AR with AI also provides users in retail or marketing areas, where users can get information on what they are buying, with a digital representation of the products before they buy or even to obtain recommendations based on their preferences. The purpose of this experience is to enable the customer to reduce uncertainties when they want to buy a product and to allow the company to collect data about the customers themselves.

In summary, all these examples of applications that support industrial processes have given rise to a new concept called Industrial Augmented Reality (IAR). This definition began in the early 1990s with the Boeing project but the convergence of the latest advances in electronics, sensors and paradigms, such as IoT and AI, have led to the development of more advanced applications for industrial systems. IAR has proven to be a widely used tool across several business areas, enabling smart factories where workers monitor and interact with real-time systems. Although there are already some examples of applications that use AR as technology to support industrial processes, IAR is still very early in its development. Computer graphics, AI and object recognition are examples of technologies that allow the use of AR in the industry.

In [41], a project was designed with the goal of training people in the process of assembling and maintaining equipment through a multimodal AR system. In this project, it was possible to conclude that an AR platform could reduce learning and training time compared to traditional methods. Moreover, people made fewer mistakes and achieved better performance times. Accordingly, specific training strategies based on AR benefited not only people that were learning new skills but also reduced costs associated with those processes.

IoT Communication Systems

Wireless networks play a key role in IIoT as they interconnect devices present in the industry. They are also responsible for making the traditional industry more “connected”, along with technologies such as CPS, the cloud, AI and AR.

At the beginning of the third millennium, wireless networks generated a growing interest from an industrial perspective. However, they were considered slow and insecure and many security departments avoided their use. This initial wireless technology only allowed limited bandwidth and coverage, and although security was not yet a priority, it was an important issue to consider in the future. The wireless medium is “open” and because of that, anyone can listen to any frequency as long as it is transmitted through the air, being this the main reason for them being discouraged in the industry. Another important aspect of this technology was the need for an Access Point (AP) to have a network identifier (SSID) so that wireless devices could identify and connect to the network [16]. The first APs were open, i.e., without authentication credentials, and the data was either unencrypted or protected by a very weak security protocol called the Wired Equivalent Protocol (WEP). With the improvements in security, specifically Wi-Fi Protected Access II (WPA2) encryption and authentication [17], and speed over time, these types of networks became essential in many industry sectors.

In M2M communications, sensors capture events that are transmitted over the network to a system that converts these events into information. Due to enhancements on Wi-Fi technology, M2M communications are no longer just one-to-one being also possible to transmit data to multiple devices. However, what happens when there are no Wi-Fi networks available, that is the case, for instance, of remote areas? To answer the latter, please consider sensors whose key requirements are low power consumption and long-range data transmissions. Most IoT applications use short-range frequencies, about 10 to 100 meters, and in many use cases, this range is not enough, as sensors might be located in distant areas. Traditional communication technologies such as Wi-Fi, Bluetooth or ZigBee, can only easily handle applications with a reduced transmission range. Conceptually, radio wave indicates that the reach is inversely proportional to the frequency, that is, the lower the frequency, the higher the reach. Hence, if a lower frequency is used, the range increases and the signal penetrate obstacles easily. The latter motivated the creation of low-power wide area network (LPWAN) such as IEEE 802.11ah, SigFox, and LoRa, which scatter large scopes and consume very little energy, thus meeting the requirements imposed by IoT systems. The main benefits of LPWAN are of being able to transmit a signal through dense locations and having reduced power consumption, which permitted sensors to have a longer "life" (i.e., 5 to 10 years). These networks use low frequencies allowing optimizing energy. LPWAN besides having a good range, is also better than Wi-Fi as the signal is not interrupted if there are obstacles in front [18]. There are other wireless technologies that met IoT requirements such as IEEE 802.15.4, low-power Bluetooth, ZigBee-IP NAN, and cellular M2M.

On the other side of the spectrum, there is also a variety of mobile networks that have gained attention in IoT applications, as they are far-reaching and do not use much energy. That is the case of 2G, 3G, and 4G mobile networks. Although the latter were not optimized for this purpose as they were not prepared for Machine Type Communication (MTC) [19], there was an interest in adapting them to IoT systems, thus, creating the NarrowBand-IoT (NB-IoT). This standard was created by the Third Generation Partnership Project (3GPP) [20] to address the need for very low data rate devices that needed to be connected to mobile networks. Despite being similar to Sigfox and LoRa, NB-IoT uses a faster modulation rate consequently requiring a higher power consumption [21]. With the emergence of 5G this problem can be overcome, given that it provides faster data rates with low latency and improved coverage for MTC communications, hence enabling the adoption in IoT applications. 5G networks are still in their infancy being the successors of 4G LTE network [19], nonetheless, they will not be affected by Wi-Fi signals, buildings, etc. Additionally, 5G networks will significantly contribute to IoT by linking billions of smart devices where they can interact with an intelligent environment, without human intervention through faster communication links, increased frequency range, and guaranteed energy efficiency. This network will have speeds faster than the current ones (4G LTE), that is, speeds up to 10 Gbps and will allow to connect numerous devices at the same time.

It is not easy to attain a network frequency that can have characteristics such as speed, long distance, transmission power, reliability, and latency, because while some give priority to range and latency other cherish speed. In IIoT, there are still many challenges related to the type of communication necessary in a system, because one may have to consider technical aspects that can be deterministic for a system to be able to respond to all eventualities.

Artificial Internet of Things

Nowadays, AI is not only reduced to the ability to imitate human thought or to act as such but rather as a complete set of operations resulting from the computational capabilities available today. AI can take advantage of information technologies, including data collection and processing (i.e., machine learning, natural language, etc.). The concept of IoT is essentially to get data from connected devices and take advantage of them to transform data into information that can be used by people or devices. However, the great challenge is when we analyze data to obtain information after data analysis. The adoption of interconnected systems and the use of IoT have motivated the use of AI because much of the sensor data coming from several sources is unstructured. What would you do without the ability to automate information? Would it be possible to analyze large amounts of data without using AI, given that old information management approaches cannot manage unstructured data?

Several AI forms have been used for decades, with the aim of "making sense" of unstructured data, transforming it into relevant information. Therefore, the combination of IoT and AI is no longer surprising. Nonetheless, the big challenge is to analyze data and acquire information.

Big data refers to a large set of structured or unstructured data from various data sources that cannot be stored in structured databases [16]. This information coming from big data increases the efficiency of machine learning and AI algorithms, as the greater the amount of data, the greater the reliability of the information generated. In addition, it is thanks to big data and its data analysis enabled the efficiency increase of AI and its commercial value. IoT systems have sensors that interact with the environment through data analysis, hence deciding to send an event to an actuator that will act faster than a human. In many industry sectors, the time a machine is inactive causes a reduction in productivity as well as costing a lot of money. The fact that IoT and AI exist mainly in industrial environments makes it possible to create computer systems with the ability to perform predictive analysis and reduce maintenance costs. Predictive maintenance makes use of AI analytics with IoT data aiming to predict in advance equipment failure and scheduling a maintenance procedure. A suitable approach to converge AI with IoT is the development of robots or systems whose purpose is to supervise independently tasks or events without human intervention, or even to create concepts where intelligence can be part of a network of sensors. There is a need to give machines the ability to understand the information they collect in order to create patterns that allow them to act in case of problems. Future AI trends include solutions where there is integration with IoT technologies, security, and cloud computing. AI techniques and IoT systems along with cloud computing can be used to provide analytics and decision making in a more efficient and autonomous manner. The integration of AI-based algorithms to process data and make decisions in different architectures of an IoT system allows combining new technologies like bots and AR to create new solutions [22]. An IoT system that does not integrate these technologies in which it can learn, interact and increase its capabilities to respond to an event, is a system where there is only data transmission without any meaning.

Bringing intelligence to the data

As we attempt to make machines take autonomous and more efficient decisions than a human, AI inevitably becomes a necessity. In the fourth industrial revolution, industry systems are transformed into digital systems. IoT and big data assume an important role to enable companies to deal with the large volume and variety of data coming from the equipment. Here, IoT describes a network of interconnected devices constantly sending data, making it primarily responsible for the big data concept. In the year 2020, it is estimated that around 50 billion devices will be connected to the Internet [23]. The digital transformation in the industry from sensors to IoT systems fostered the creation of new business models. Emerging technologies, e.g. the cloud, enabled major analysis hence providing ubiquitous access to information. In addition, it allows companies to adopt IoT systems, big data, and AI to increase their competitiveness through predictive analytics. One of the main challenges that today is imposed from the analysis of big data and AI algorithms is the visualization of results, since the latter is considered during decision-making.

Big data can be characterized by three concepts: volume, variance, and velocity [24]. The volume refers to large amounts of data that are generated from multiple sources. The variety refers to the use of various types of data from different sources to analyze a situation or event. The velocity corresponds to the time that a system takes to interpret the data and give a response. In IoT, a system can have multiple devices generating a flow of constant data that not only result in a large volume but also incorporates several events. As more IoT systems decision-making depends on data, its velocity is also a factor that influences decision-making. Some data, e.g., the one obtained from M2M sensors, require real- or near-real-time analysis, therefore placing additional pressure on storage systems and big data algorithms. An example of the importance of the latter is the stock and financial market data, where answers in milliseconds are required. This is a decisive factor in the Industrial Internet because devices tend to send values to a processing domain and wait for the response. This response can sometimes be influenced by several factors on the network such congestion which may influence response times.

AI has become imperative in IoT systems because they both depend on one another and cannot exist without big data and intelligent data analysis creating a new concept called *Artificial Internet of Things*. AI technologies rely not only on large amounts of data but on the quality of these data since a better quality is related with a better prevention or detection of patterns. The growth of AI is proportional to the growth of big data as the availability of data volume is what permits the implementation of AI in IoT systems. The greatest benefit in adopting the concept of AIoT is the possibility of creating a cognitive computing system capable of detecting patterns in the data and consequently predicting flaws or anomalies that a human would have difficulty detecting.

There are several types of AI algorithms that are used to label information from unstructured data. Supervised Learning is an AI algorithm that assumes that the data used to train an algorithm is labeled with its information and is typically used in small-scale systems. The data provided do not need to be labeled but require more accurate learning techniques [4]. Clustering or semantic analysis are examples of algorithms where data is not labeled and can be applied depending on the problem. These techniques allow unstructured data to create standards or to group automatically data following a degree of similarity, where this criterion of similarity is part of the definition of a problem. By creating this pattern of data from sensors, an anomaly occurrence can be prevented since data being received does not fit the pattern, or vice versa, or even the data may be within a pattern that will eventually create a problem.

Although IoT depends on big data and AI to add commercial value to both technologies, visual analysis through AR could help in the convergence of these technologies. The industry can be a very a demanding and challenging scenario for visual analysis because modern machines and production lines can generate many data simultaneously and the only way to make sense of this data is through their convergence.

Edge and Fog computing

Given a large amount of data generated by IoT devices, the cloud architecture often cannot handle all sorts of information. While the cloud provides us with services such as computing, storage, and communication, these features when centralized can cause problems such as latency or poor performance. Both problems can be determinant when asserting a system's efficiency. Aiming to address both problems, two concepts are presented, namely edge and fog computing.

Edge computing is not a new concept but has generated a growing interest as it helps industrial organizations to turn large amounts of data, e.g., from sensors, into intelligence, but closer to the data source. Edge computing is a decentralized computing infrastructure in which computing resources can be used "at the edge" of the network [25]. The edge is a logical layer rather than a physical one, therefore, this concept can be implemented depending on business logic. The key benefits of edge computing are to improve performance, decrease data privacy and security concerns and reduce operational costs. Edge is not only a way to collect data before you send it to the cloud, but also a way to analyze, process and act on these data. Thus, it is important to optimize industry data. Only the aggregate data should be sent to the cloud, hence reducing bandwidth and improving the response time.

For instance, in a wind farm, if wind speed changes direction, the edge software can analyze this data in real time and adapt the turbines to optimize production. This data could also be sent to the cloud. However, the latter data could be less productive and costly. Another important point is privacy and security. Edge computing allows businesses to reduce Internet connections, thereby reducing security risks by using local computing. The last point emphasizes the reduction of operational costs. Bandwidth and latency are expensive features, and this is where edge computing comes into play by reducing these costs as well as by minimizing communication needs. If a company is located at a remote location and it needs to ensure that it has control over the production rate, the alternative is to build an edge computing infrastructure, where it is possible to process data in real time, maintaining the flexibility that this approach offers [25]. So, it is possible to increase operational efficiency and reduce maintenance costs. Edge computing creates an infrastructure to handle a large amount of data by allowing reducing events response times, and by avoiding being constantly dependent on the cloud. In short, it is possible to avoid large bandwidth requirements, which also allows to analyze data locally, and at the same time, to ensure data security.

Fog computing is a concept in which intelligence can also be introduced close to the edge, being sometimes confused with edge computing. However, both concepts are different. Fog computing is a standard that defines how edge computing should work or be implemented thus facilitating computing, storage and network operations between cloud computing devices and data centers [26]. From a different perspective and depending on the requirements, fog can even be a cloudlet, an edge device or a micro-datacenter.

In 2016, Bombadier, an aerospace company, chose to use sensors in its aircrafts [26]. This innovation enables real-time performance data and efficient problem solving without needing to land the aircraft. By putting edge processing closer to sensors, one can reduce the need to send constantly data to the cloud or server. It is, therefore, possible to identify urgent problems that may arise, minimizing response time. Although being possible to process data on the edge when there is a need to do a predictive analysis based on data previously collected to determine whether an equipment can or not fail. Though, sometimes this analysis should be done in the cloud. The reason behind is the analysis and algorithms that require a tremendous amount of data.

Both concepts have their disadvantages because by putting too much processing at the edge, it is easy to overload devices or storage. Moreover, the limited redundancy is another problem. Both edge and fog computing are providing IoT architectures with more options, removing the boundaries of centralized servers, in addition to making IoT more distributed and flexible.

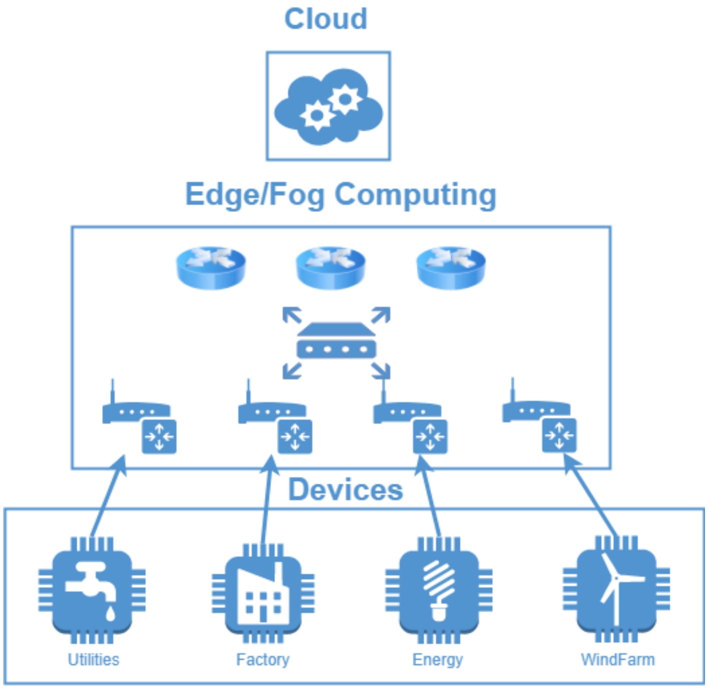

Figure 2 - Edge and Fog computing

Figure 2 shows a possible architecture of edge and fog computing to facilitate the perception of the difference between them. The cloud features are at the top layer. In the middle layer, we have the architecture complexity, as it includes nodes in the network attached to other nodes in the fog network. These nodes consist of various devices on the network such as gateways and switches. Finally, the lower layer represents sensor devices of an infrastructure. The lower layer sends data to the middle layer where it is processed by the network nodes. This processing is performed near the devices, hence reducing a transmission step that the network is subject to. After this processing is performed data is sent to the cloud [27].

In [28], an architecture called EXEGESIS is presented, which focuses on the concept of edge and fog computing. EXEGESIS is composed of three layers (mist, vFog, Cloud), where in the lower one are located the devices (i.e., sensors, actuators, mobile devices, etc.) that create connections between them forming a "neighborhood". This layer follows a hybrid peer-to-peer (P2P) approach consisting of regular nodes (RMNs) and supernodes (SMNs). SMNs create a logical fog topology along with the features provided by RMN and interact with the virtual fog (vFog) located in the above layer, and allow dynamic interconnections between various neighborhoods. Finally, in the upper layer, there is the traditional cloud that establishes connections with vFog, in order to provide computing resources and facilitate interconnections between various vFog elements. With this architecture, one can take advantage of existing cloud architectures just by changing the edge of the network to make the best it.

Applications

Although many IoT solutions are consumer-oriented, this trend is changing since the growth of IoTs is dramatically changing various industry sectors. This trend gives companies access to AI systems, communication mechanisms and new ways to interact with the digital world so that there is an improvement in the efficiency of their services and productivity.

Manufacturing sector

The manufacturing industry is one of the sectors that benefited most with the introduction of IoT. Manufacturers in all areas, including automotive and electronics, invest in embedded devices to control and automate their equipment. Imagine, for example, that a customer could point a camera to a mobile device and see the digital model of an equipment and its associated values or problems.

Caterpillar (CAT) [29], a manufacturer of construction machinery equipment, has transformed its business by introducing IoT, AI and AR technologies and solutions. The company began equipping their machinery equipment with sensors as well as integrating software tools and analysis based on the cloud. This software helped its customers to reduce operational costs, decreasing maintenance time, and performing predictive analytics by making their machines autonomous. Bucklar, which is a CAT customer, saved about $600,000 in production costs through predictive maintenance. Another customer in the construction sector increased the use of their machinery equipment by 15% through analysis of data coming from the equipment [30]. Caterpillar Liveshare is an example where one can use AR as a collaboration tool allowing remote technicians and experts to connect through video and audio to solve a real-time problem. This AR video platform uses voice, 3D animations, annotations where users can draw, highlight and place cues on real-world objects and share screens [29]. Video streaming via Wi-Fi or mobile phone is also possible. If Wi-Fi or mobile coverage is low, technicians can send instant images instead of video streams, therefore reducing bandwidth. CAT has developed this platform to reduce the time to solve problems, increase service revenues, and increase customer satisfaction.

In 2014, *Bosch* Automotive Service Solutions introduced a platform called Common Platform Augmented Reality (CAP) that provided a multi-platform system capable of creating AR applications. The Bosch CAP allowed the integration of visual and digital contents in the creation process, through live images and a database in which content corresponding to the AR application was extracted [31]. This visual overlay is done through 3D models, photos, texts (information and explanations) and the tracking of objects. For maintenance, servicing or repairing, the CAP is used to view hidden cables or components and repair instructions that permitted to view the required work steps and the relevant tools. It was also possible to check the status of parts with real-time information. The CAP allowed to magnify and rotate objects and provided additional information such as training videos. Its main goal

was to reduce time by taking faster decisions and to increase the assembly process, save costs and reduce error rates.
ThyssenKrupp is one of the leading elevator construction and maintenance companies in the world and makes use of AI, AR, and IoT in their equipment. The constant pressure of Asian markets has led the company to create new services such as predictive maintenance, automation of warehouses and assistance to the maintenance processes in order to be able to differentiate itself from its competitors. ThyssenKrupp's primary goal is to reduce significantly maintenance costs, to ensure that their elevators worked properly, and independently control their inventory. Working alongside Microsoft, the company was able to connect sensors in their elevators to the Azure cloud [32]. Through this system, they were able to capture data such as engine temperature, shaft alignment, speed and door operations. When a technician heads to a place, through the HoloLens mixed-reality headset, he is able to visualize all the equipment and the values of its components. Tools like AI enabled the perception of certain patterns in values that could cause problems in their equipment, hence accomplishing a predictive analysis.
Moreover, as part of the company's digital transformation, the need to control everything that goes in and out their warehouses arose. This transformation has eliminated physical inventories saving hours of work, and a virtualization of the warehouse where each piece could be easily located. This virtualization brought a new concept, called digital warehouse, which enabled a 30% improvement in terms of materials processing efficiency [33].

Aerospace sector
The acceptance of IoT technologies in the aerospace industry has been slow because of the existence of complex systems whose costs are hard to estimate. However, the interest of airlines in these technologies increased due to their apparent benefits. An aircraft that has a system that could predict problems before they actually happen would save maintenance costs. The goal of aerospace IoT is to establish an integrated sensor infrastructure with computational intelligence, reliable information and component manufacturing in a more conscious manner. For this, the large volume of data produced by sensors is used to provide alerts or give information in real time through a descriptive (what happened) and predictive analysis. It is also necessary to take into account network latency and data security. Therefore, in IoT, edge analysis is being used, thus avoiding the need to send data continuously to the cloud.
Airbus is the largest aeronautical company in Europe and is responsible for assembling aircrafts and helicopters in various parts of the world. In order to create a new aircraft production process by means of digital tools, the Mixed Reality Application (MiRA) was created in 2009. MiRA is fully integrated with its information systems and combines real images with digital models on a tablet equipped with a camera. This application increases productivity on production lines using AR to visualize parts and detect errors. Equipment such as tablets and sensors, and AI software specially designed for this application were used to reduce the time required to check,

recover and mount most probably damaged parts. With this application, it was possible to reduce from 300 hours of fuselage (that is, the main carcass of the aircraft) support to 60 hours. With the use of IoT, it is possible to increase efficiency, safety and control of flights, because of a better data interpretation.

Logistics sector

Logistics is one of the areas that continually needs improvements to support the growing demand for products. Logistics companies depend on networks to manage large amounts of data volumes, allocate assets and keep track of deadlines. AI can organize and optimize these networks for levels of efficiency that a human cannot do so effectively. AI is able to adjust behaviors in the various sectors to reduce costs, time and increase productivity with cognitive automation [34]. Cognitive automation refers to the combination of AI and robotic processes for intelligent process automation, where AI can extract, perceive and learn unstructured data, and the robotic process executes rules-based workflows.

Logistics companies often rely on third parties such as sub-contractors, airlines, etc., leading accounting departments to process millions of invoices. AI technologies can make this work easier by extracting account information, dates, and unstructured data and inserting it directly into accounting software. Another important point related to logistics issues where AI can be useful is in customs. Customs clearance processes usually require many documents, tax returns, invoices, brokerage costs, etc. that need to be validated by employees. In other words, they are complex processes that require a lot of effort over many hours of work, because it is difficult to maintain the level of concentration at the end of the day, and, consequently, there are errors that can be costly. The solution to this is to use AI to facilitate these processes. Through training algorithms, one can use legislative materials, standards, and manuals to automate customs declarations [34].

As an example of the logistics sector, please consider DHL. *DHL* is an international logistics company that is trying to implement AR and AI in its industry, in areas such as storage operations, transportation optimization, delivery and assembly/disassembly services. According to [35], any paper approach is slow and prone to errors, and because of this, an AR-based software was created to allow real-time object recognition, barcode reading, internal navigation and information integration for a warehouse management system. With this system, each worker can visualize the best route to the location where the object is, and use bar code for automatic readings and recognition of places. It is also possible to visualize a storage process in order to understand how the warehouse is organized. The AR can optimize the transportation of cargo through its verification, therefore allowing knowing if there is available capacity in a truck to transport. An important point in the delivery service is to minimize transportation time, as it is many times affected by transit. Recently with the new cities infrastructures, it is possible to have digital maps with traffic patterns that allow improving the overall routing. As a result, the DHL group has implemented a feature to optimize transport using both AR and AI, allowing the driver to view an outdoor navigation system with real-time traffic information and if necessary to optimize this route. In the delivery service when using AR, it is possible to perceive which driver is appropriate to a given cargo and to calculate and visualize the free space in each transport. DHL is responsible for storing Audi components as well as for assembling their components. To optimize this assembly process and reduce error rates, an AR system powered by AI can provide an intuitive way to visualize the process to provide instructions for each step of work.

Water sector

Thames Water is one of the largest British water-recycler companies that, through the implementation of sensors, remote communications, and big data algorithms can anticipate equipment failures and respond more efficiently to any critical situation that may arise due to adverse weather conditions. Additionally, it has installed smart meters for customers have access to water consumption through the telephone and gain control over their spending. With the water monitoring, it is possible for consumers to inform the water company quickly if there is a problem and most probably reduce consumption.

The company believes that it has found a way to adopt intelligent systems through IoT to make simpler and more efficient measurements. The goal of adopting IoT technology would be to make water consumption more sustainable and to have a closer relationship with the customer, and to provide more accurate data, hence, being able to improve the company's water supply system knowledge, for example, to where the water goes, or if leaks exist. The company estimates that by 2025 the number of readings per day through these meters rises to 35 billion.

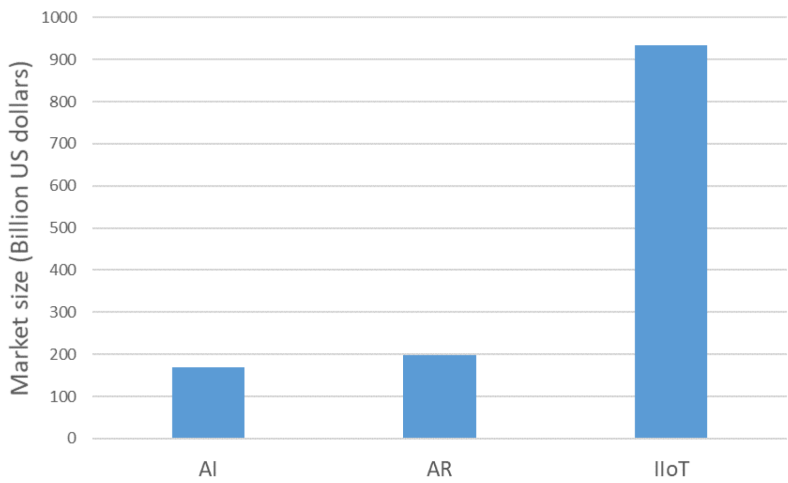

Figure 3 – An estimate of the global market size in 2025

The idea of combining computers, sensors, and networks to control systems has been around for many years. Usually, technologies such as IoT and AR are associated with applications for personal use such as home automation, and not so much with the industry. However, these technologies together with AI can create new business models or improve existing ones.

As was seen in the examples above, there are several industry sectors in which the adoption of systems where IoT, AR, and AI converged was notorious. In these same examples, it can be seen that there are several industry sectors where this convergence is more pronounced. From manufacturing to logistics, new solutions based on current market technologies were implemented fostering even more the digital transformation. The convergence of IoT with AI and AR allows solving problems that used to be hard, optimizing costs that were formerly invisible, and more importantly, to predict future problems. IoT leverages on AI to become efficient because the IoT concept alone, i.e., without a system that interprets data, seems weak. AR benefits from IoT and AI to display intuitively necessary information, also enabling a better interaction between physical and digital systems.

The latter examples have shown that there is a great deal of concern with the adoption of new technologies such as AR, IoT and AI by the industry. However, despite the increasing tendency in adopting them in various industry sectors, Figure 3 indicates that this tendency will become even more prominent over the years [36]. Artificial intelligence has been one of the fast-growing technologies in recent years[37]. The development of cloud and big data infrastructures, and AI-based solution have led to a strong growth of the AI market, which has grown due to the significant impact that AR has had on industrial applications. Industry such as logistics, manufacturing, and aerospace are taking advantage of what this technology can provide to increase operational efficiency. It is estimated based on this growth that the market size will be close to 200 million in 2025 [38].

Future directions

The digital transformation forced industry and companies to create their business models based on a competitive strategy and with this transformation, there was a need to create new or converge existing technologies.

Initially, both IoT, AI, and AR emerged as separate concepts to address various problems. However, there was a need to converge them to create new business models. In addition, this convergence leads to a greater connection between customers and companies, product innovation, new business models, process automation, labor replacement, and more efficient decision-making. Although there may be a need to value IoT data, in the future it is expected that AI algorithms can be further embedded in IoT system architectures and subsequently create more AIoT applications.

Future trends are based on creating autonomous decisions through AI along with IoT systems combining with new technologies such as bots and AR/ VR. Thus, IoT applications can continuously learn, interact, ensure security and then carry that knowledge to edge processing [39]. Apart from the industrial sector, where there is already a convergence of IoT and AI, it is also in projects of intelligent cities that arise paradigms in which the goal is to optimize energy consumptions.

IoT systems are widely used in projects where there is a need to implement AI in edge and fog computing systems to address the enormous amount of data generated by devices. An example of this is in [40] in which an energy management architecture with edge computing based on a deep reinforcement learning (DRL) network is presented, in which both the cloud and edge servers implement machine learning algorithms. Network delay (jitter, latency) in data delivery, e.g., during data transmission, is a problem in disruptive systems and affect these systems' QoS [41][42]. To address the latter, cloud services have been moved to the network edge. However, this may not fully solve the problems of IoT systems in environments such as factories, buildings, and smart cities where resources such as bandwidth are sufficient to be able to respond to large amounts of data. Many of the network technologies available today are not appropriate for the future, so the solution is to rely on the introduction of future mobile networks (e.g., 5G) [43]. In the coming years, IoT systems will be even more complex being that the reason why 5G will affect these systems by allowing data transfer rates faster than 4G. It will also support a large number of devices at the same time over a period of time.

Edge computing, big data, AI and AR along with IoT will certainly be among the major developments in the coming years. The ability to take advantage of large amounts of data, combine AI methods and to be able to view this information intuitively with AR, making convergence important for a new digital transformation.

Conclusion

The business world as we knew it a few years ago is not the same as today. There are industry sectors such as logistics, manufacturing, etc. that already started adopting IoT, AI, and AR. The combination of the latter technologies in the various sectors is no longer so surprising because of the digital transformation, and their introduction is nearly a requirement as it allows creating value, that is, new products and services. Some of the main concerns of companies will always include improving productivity, reducing costs and time, as only then they can become competitive in face of market demands. As these technologies are adopted, more data will be generated and consequently, it will be possible to improve many business processes. By analyzing these technologies separately, one may see how they depend on each other. Although IoT together with the power of the cloud has already made a global impact on the industry by allowing thousands of devices to be connected, the IoT concept alone seems weak. At a basic level, it is just a system with sensors that sends data to a storage system. Thus, there is a need to converge IoT with AI because data that is sent from several sources can increase the efficiency of machine learning algorithms. AR is a complement to extend information and interact with a digital system more efficiently. From the choice of articles in a warehouse to aiding a maintenance process, AR can take advantage of the information from IoT systems with AI. As mobile devices become smaller and more capable, it became possible to adopt AR in the industry as a means of visualizing a system. Some argue that this convergence may have negative consequences such as job cuts; however, that does not seem the case. Converging these three would only allow to optimize various factors in the industry, reduce manual work that no one wants to do, and above all increase human potential with their help.

According to the International Data Corporation (IDC), we are on the third evolution platform, which relies on pillars such as mobile, big data, analytics, cloud and social technologies [44]. However, some companies claim that they are already reaching the fourth platform with the convergence of these technologies. The fourth platform is the consequence of companies always trying to innovate in order to make their business models more productive and more differentiated from their competition. This is why the elements illustrated in Figure 1 are already the consequence of this desire to innovate. Even though AI and AR belong to the “supposed” fourth platform, they are already being introduced in some sectors of the industry.

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