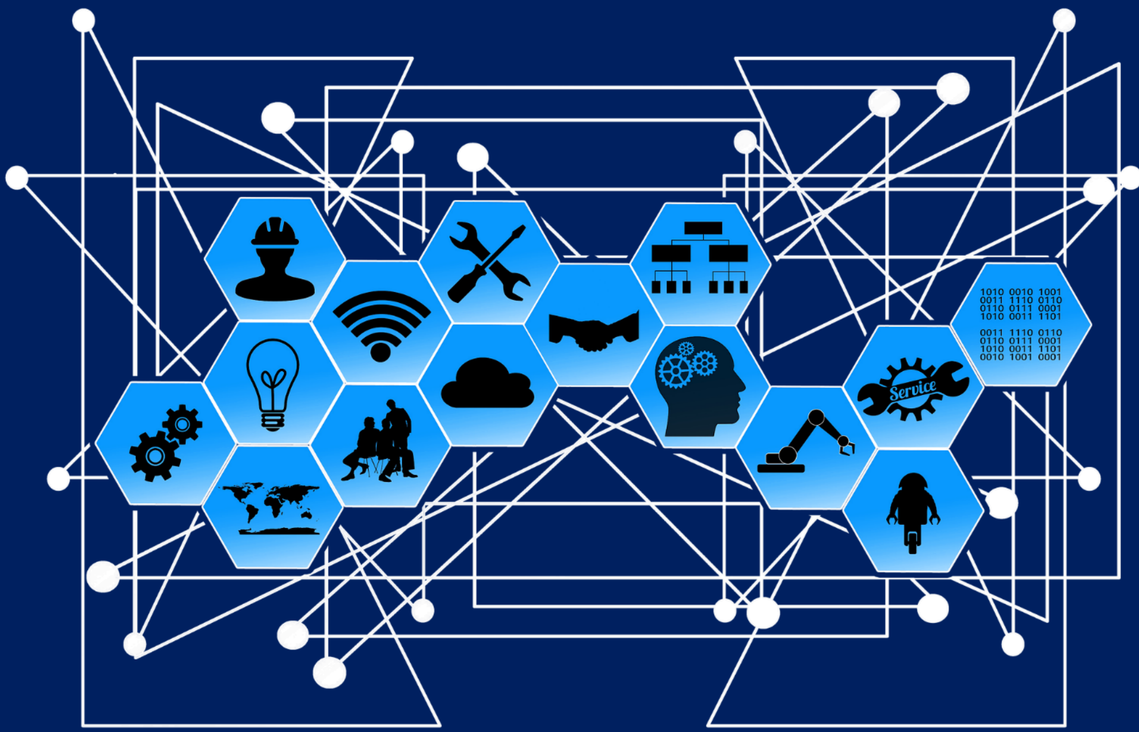

Symbiotic Autonomous Systems
White Paper III

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OVERVIEW

This document represents the third White Paper produced by the IEEE Symbiotic Autonomous Systems (SAS) Initiative that in 2019 merged with the IEEE Digital Reality Initiative to further foster the Digital Transformation and continue the work of the first two years of the SAS Initiative.

The first White Paper provided the vision and the framework of symbiotic autonomous systems, and the second White Paper addressed the roadmaps that will pave the way to the fulfilment of the vision and the creation of the framework, applied to both technology and considerations of economics and societal aspects.

The evolution window considered by the second White Paper spans 20 years, from 2020 up to 2040, getting fuzzier as the horizon is pushed further out in time. However, one of the outcomes of the second White Paper was the recognition that several steps are now underway and that most, but not all, of the technologies considered have passed the stage of theoretical research into preliminary experimentation, industrial application research, and in some cases, to leading-edge products that are already in the market.

The first section briefly summarizes the first two White Papers. Those familiar with them can skip over it, although it has been written in a way to provide a synthetic overview of the implications of the studies presented in those first two White Papers and as such it can make for a useful starting point in reading the following sections. Additionally, the first section provides a brief outlook at the general aspects of the Digital Transformation, leaving the specifics to the single market and industry sectors. A more comprehensive presentation of the Digital Transformation is attached as Annex 1.

Industry Focus

This third White Paper focuses on today's application of (Symbiotic) Autonomous Systems, the industrial application research, and the feedback coming from leading edge products, since these are the stepping stones to foster the evolution. Notice that at this time, and considering the observation timeframe of this White Paper, the focus is on Autonomous Systems. Symbioses will not materialize in the coming two years, at least in a significant way from the point of view of implants and more generally of symbiotic technologies. However, symbioses at a societal level is already here (for example, we are in a symbiotic relation with our smartphones) and is addressed in Section 4.

The target audience of this third White Paper includes professionals, industry leaders, public institutions, and government decision makers on whom lies the responsibility of investing resources and delivering to the market, affecting the society and wellbeing of citizens as well as creating business wealth.

The focus on market and wellbeing of citizens requires an in-depth consideration of societal issues and the factors leading to their evolution. Societal and cultural aspects are becoming more intertwined with the market, by being both affected by the offerings and affecting the offerings by shaping the demand. Hence, societal and cultural aspects are a powerful lever in steering investment, that in turn, steers technology evolution and market offerings.

A significant part of this report looks at these aspects connecting them to industry strategies in the medium term. Because of this, several industry players have contributed to this White Paper, bringing their specific point of view and experience. Although this third White Paper is clearly targeted to this audience it can be most valuable to academia, connecting their studies to the reality of the industry and market in a rapidly evolving landscape.

After the overview of the first two White Papers, the next section outlines the expected market evolution, considering it from various aspects and taking 2018 as the base year, whenever data were available, and forecasts the following in the years 2023-2025:

- **Technology**: a number of the technologies identified in the second White Paper have been addressed. It should be noted that the figures provided have been taken from several documents published by a variety of market intelligence studies and for each technology one can find different estimates in different studies, even when those market values refer to the past. The reason, often, is in the different boundaries that are chosen for a given technology. In reporting the market value, and estimate, there is always a reference to the source, and it is appropriate to refer to that source and read the data in the full context of the source to appreciate the boundaries. This applies to all market values and estimates, although in the case of technology it is basically impossible to separate the market value of a technology applied to a specific field to the global value, independent of the application field. Unless specifically indicated, the market value provided for a given technology refers to all of its possible applications. The technologies have been clustered under machine augmentation, human augmentation, and symbiosis, this latter focusing on Digital Twins since all other aspects of symbioses presented in the second White Paper fall beyond the horizon of this one.
- **Manufacturing**: manufacturing plants will become fully autonomous and intelligent leveraging edge deployments with a high degree of intelligent automation on the factory floor and its ecosystem. This includes equipment, computing resources, processes, workflows, safety, and security. Manufacturing workflows will include autonomous processes and will be autonomic in nature – have the ability to self-configure, self-optimize and self-heal due to any business change or failure. Robots and cobots will be used extensively in such plants and concepts like Digital Twins – at least for certain equipment in a plant – will be the norm. Most of the focus is placed on robots for industrial applications with the addition of the growing segment of cobots that are becoming an important component in the industry 4.0. Use of robots in logistics (like warehouses) has also been considered.
- **Health care**: the markets for robots in assistive, rehabilitation, humanoid, delivery, implanted, surveillance and security sectors are considered. Additionally, market value for artificial intelligence (AI), as engine for hard and soft robots in the healthcare space, is considered. Market estimate for medical apps is included although it is not possible at this time to separate the market of apps that can be considered as (soft) autonomous systems from the others. The healthcare market for autonomous systems is tightly connected with wearables and with sensors but the related market value is addressed in the technology section.
- **Retail**: autonomous systems in the retail space are already widely adopted, with different degrees of autonomy. The main driver has been cost reduction and the "wow" factor. and this is likely to keep growing in the next five years. This is also an area where there is a strong coupling with digital twins and augmented reality (AR) in the years to come. The evolution in those technologies is going to have a significant impact in the retail space.
- **Finance**: AI is dominating the landscape along with autonomous agents. These two technologies are slashing cost and shifting decision-making from human experts to computers. A cohort of new companies providing data analytics are on the rise, and half of the operational cost savings (leading to significant headcount reduction) will become revenue for these companies. The autonomous agent technology will become a commodity, applied to a variety of sectors, while AI and data analytics are crafted to fit this specific area. Neobanks are a new market that is briefly addressed.
- **Transport**: autonomous systems will play a significant role in this market segment, however most will not be deployed in the timeframe of this White Paper. The market overview looks into autonomous vehicles, cars and trucks, autonomous ships, and drones outlining the perspective and the first estimated uptake in the market.
- **Education**: this represents a crucial area for the future. IEEE is committed to keep leveraging new technologies, including autonomous agents, cognitive digital twins, AI, AR and VR to deliver knowledge to professionals, academia and industry. The education market is in the hundred billion dollars, and it will continue to grow. However, the biggest challenge

is to have efficient access to knowledge, knowledge as a service and not necessarily to expand the "value" of the market in terms of dollar value. The knowledge gap is real, and it cannot be fought with the tools of the past. Investment in new tools is needed.

Section 3 of the White Paper considers industry adoption of autonomous systems within the following industries:

Industry Vertical Sectors

- **Manufacturing**: it is not surprising that manufacturing is leading the adoption of autonomous systems. The section considers in detail, drawing from contributions provided by a number of industries, how autonomous systems have been adopted and how this adoption is spreading as Industry 4.0 is being deployed. Digital Twins are becoming a mandatory technology in manufacturing as they are bridging the digital design/workshop floor with the products manufactured, and they are connecting the various players on the value chain, extending to the end user and enabling the delivery of services as add-ons to products. Significant attention is given to additive manufacturing that is becoming a more important component in the digital transformation of manufacturing.
- **Health care**: autonomous systems applications are presented clustered under the three main areas of disruptive transformation currently affecting health care, i.e. delocalization, personalization and digitalization. Autonomous systems are helping to deliver health care to patients in remote locations and to provide more extensive out-patient support (increasing quality and decreasing cost). Soft autonomous systems (AI, data analytics, digital twins) are shifting healthcare from the application of statistically certified paradigms (like drugs approved after extensive trials) to personalized protocols taking into account the patient (genomic) specificity. This growing digitalization is exploiting data generated by a variety of monitoring systems (including wearables) and leverages big data at community, country, and transnational ensembles levels.
- **Retail**: only robots "manning" the point of sale, either a store or a department store, a mall, providing concierge service at a hotel, providing services to office customers and so on are considered. In particular, robots involved in the retail "operation" –like inventory or shelf replenishment- are considered more concrete examples of applications of autonomous systems while the ones used to interact with customers as application examples that can have a potential growth in the future. The main issue in retail is to have affordable robots, given the limited application in small scale retail. Robots operating in warehouses are considered as part of manufacturing (sections 2.1 and 3.2) since manufacturing is evolving along the Industry 4.0 paradigm, thus including the supply and delivery chain, and robots are playing a big role in this.
- **Finance**: Autonomous systems are already widespread in the financial sectors in the form of softbots. The whole area is based on data, actually big data, and data analytics and AI are used to make decisions. Some of these decisions are completely autonomous since the response times need to be measured in milliseconds, and speed can make the difference between making or losing money. Specific application areas, like Credit Risk Assessment, Investment Banking, Financial Crime and Fraud Detection, and Personalized Insurance Products are addressed.
- **Transport**: the general framework adopted by the EU commission in this area is used to discuss the emergence and deployment of autonomous systems. A first point is the integration among different transportation siloes that is becoming possible through the digital transformation. These siloes are both about different transportation means (trains, cars, airplanes…) and different areas (cities, end-to-end, private, public). Digital Twins are addressed as possible omni-comprehensive (360°) approach in this area, integrating the transportation means with the "goal", e.g., a car that can be aware of the need to take a passenger to the hospital for an emergency procedure.
- **Telecommunications**: Autonomous systems are a "historical" reality in telecommunications, in the sense of autonomous networks (60,000+ of them in today's

internet structure). However, the focus in this part is on the use of autonomous systems (mostly drones) in infrastructure maintenance and on "soft" autonomous systems. The latter have already permeated the telecom business, under the names of chatbots or softbots, and a few comments are made on the potential offered by digital twins to the business of telecommunications providers.

- **Security**: As autonomous systems are being deployed, security is becoming a critical concern. A general approach to security, resilience and self-healing is followed by consideration of threats and cyber-attacks. A brief look is given to security in the defense area (although not extensive information is obviously available). Finally, and this makes for a good transition to the next part, system trust and self-awareness are addressed.

Societal Aspects

The final section of the White Paper is on Societal aspects. These are provided after considering the market and the industry because the main influence is clearly derived from people's perception of what is available (steered by marketing pressure). Given that the Societal Aspects are affected by the growing seamless interplay of the physical world with the digital world, one of the reasons that led to the merging of the IEEE Symbiotic Autonomous Systems Initiative into the IEEE Digital Reality Initiative, this section is introduced by a discussion on Digital Reality vs Reality. Then the section continues by considering:

- **Personal level**: the digital transformation is not just about machines, processes and businesses. It affects people and is changing the culture and creating a personal reality that is a mesh of the physical and digital. The possible emergence of personal digital twins raises ethical and societal issues. If the digital twin becomes the interface to the perception of the digital reality who is responsible for the outcome. Will the reality shaped by the personal digital twin become the one that matters? Notice that this is nothing really new, the perception of reality has been mediated, influenced and transformed by media in the last century. Yet, media have been a reality "outside of me"; will that be the same for my digital twin or, more likely, will my digital twin become part of my "self"?
- **Community level**: Digitally driven social disruption has already happened and continues to transform society and governments in a dramatic way. An emotion-driven connective and collective social limbic system operating at viral speeds has turned local gossip into global clamor allowing dangerous private agendas such as terrorism and electoral manipulation to disrupt virally and globally an already fragile social order. Autonomous systems are instrumental in these changes. Social credits are becoming an asset and the web a tool to assign and keep social credits.
- **City level**: pervasive and seamless (no latency) communications, as the one promised by fifth-generation wireless (5G), can transform a city into a living entity. The application of the Digital Twin concept accelerates the transformation of cities into living entities where all parts are connected and mutually influence one another. A few cities have already implemented the digital twin model, and this is creating a ripple effect on other parts of the city, forcing them to interact with the whole and impacting their relationship to other cities. It is also instrumental in creating awareness in the citizenship, thus connecting to the personal and community level.
- **Impact on jobs**: Technology has always impacted jobs, changing existing jobs, creating new ones and making some unnecessary. What is new, at least in perception, is that technology is now providing alternatives to what we have taken for granted as human characteristics: intelligence and decision making. Symbiotic autonomous systems are becoming an artificial enhancement for us. The keyword is "symbiotic", the capability on both sides, human and machine, to take advantage, seamlessly, of the other to perform a task or to reach a goal. AI devices can support physical tasks, but also liberate us from (some) decision-making.
- **Ethical aspects**: this section explores some aspects of ethics and particularly technology ethics applied to autonomous systems as well as mixed reality (virtual reality, augmented

reality, etc.). It is meant to be indicative of areas of further development and shows current thinking on these topics, since the whole landscape is in rapid evolution and new ethical questions are created on a daily basis. Three pillars are considered as fundamental in ethics of symbiotic autonomous systems: 1) Universal human values, 2) Political self-determination and data agency, 3) technical dependability. To exemplify the application of these pillars the case of truly fully autonomous vehicles is considered.

Digital Transformation

The main point arising from this third White Paper is that the Digital Transformation is affecting more and more sectors of industry and society and is accelerating the symbiosis between the world of atoms and the world of bits, between the knowledge created by humans and the one created by machines, eventually leading to the symbioses of humans and machines. The symbiosis is fostered and supported by progress in the areas of Augmented, Mixed and Virtual Reality, acting as a technology and market bridge but, more importantly, also resulting in an emergence of a more complex form of reality where the boundary between cyberspace and the physical world gets blurred, eventually disappearing.

A corollary is that industry and market are now in the driver’s seat of this transformation; however, this does not diminish in any way the relevance of academia and theoretical studies, rather it provides researchers with a clearer blueprint and framework for their activities.

1. SYMBIOTIC AUTONOMOUS SYSTEMS

This section is largely based on the similar sections "Evolution and Definition of Symbiotic Autonomous Systems" provided in the first and second White Papers of this series, published in 2017[i] *and in 2018 respectively. It is a revised version; however, those familiar with the SAS Initiative and the first two White Papers may skip it since it is intended to familiarize new audiences with the IEEE SAS Initiative providing context to this white paper. It has also been expanded to include the basic concepts of the Digital Transformation.*

To a certain extent, human cultures have been characterized by the tools they made and used to the point where, starting with the Stone Age, these cultures are named after the predominance of a specific material used for tools. Notice that the idea of a tool is related to an artefact, more or less sophisticated but still manufactured by a human being to serve a specific purpose. The Stone Age was a time when our ancestors learned to shape stones in order to fit a specific purpose (to cut, drill, hit, scrape, etc.). Subsequent cultures have shown an increased capability to deal with additional materials (like bronze) in order to make new and more effective tools.

Tools as body extensions

Until the 18th century, tools were primarily an extension of our body powered by our muscles. While levers could trade displacement for strength, human power was limited by our muscle power (note that water and wind mills predated steam, but their application was constrained by the particular location).

With the invention and wide distribution of the steam engine, humanity quickly acquired the capability to use external power in ordinary fabrication methods. The issue for the culture of the 18th and 19th century became one of how to control this power.

At the end of the 19th century, electricity provided a new and different source of energy that was easier to control and use. As a consequence, electricity became the dominant way to manufacture products, including tools.

In the second half of the last century, the invention of computers made available a new *quality* of tools. Computer-controlled automated processes are improving the effectiveness of *control* and more recently have become outstanding tools for improving our reasoning and thinking capabilities.

Computers as tools for mind extension

We are in the Computer Age because many of our tools are directly or indirectly tied to computers. However, we are starting to see the emergence of a Digital Age in which the material to be manipulated and used for construction is no longer (just) atoms but also bits.

Spectacular advances in brain monitoring and in various forms of brain-computer interface (BCI), including deep brain stimulation (DBS), have proved the unification of *soft* (thoughts) and *hard* (neurons and neuronal circuits) in the brain. Notice that BCIs, similarly, are composed of a hard and a soft part with technology evolution in both. The former detects brain electrical activity with electrodes and affects brain activity using technologies like optogenetics; the latter interprets the detected activity creating "meaning" and commands specific actions to affect the brain.

At the same time, SAS creates new challenging questions about the emergence of shared thinking and shared awareness with profound ethical issues. This digital technology evolution is moving us towards the availability of a seamless integration (at different levels) of these computer/digital tools with us, the users. These tools are becoming a seamless extension of our body and mind, as the hoe was an extension of the farmer's arm. This seamless integration is very important, because it implies that these new tools are fading from our consciousness, we take them for granted, and they become an integral part of our life.

Think about the many times we use our smartphones to Google a piece of information. When we do this, we are extending our brain's memory and knowledge using a prosthetic device without giving it a second thought.

The symbiotic relationship with tools leads to humans 2.0

We are slowly entering into the age of human 2.0 or (or, as some have called it, transhumanism), and we are doing this through a symbiotic relationship with our digital tools. These new tools have become complex entities that are probably better referred to as *systems*.

Actually, the proposed change of name, from tools to systems, is the consequence of a new qualitative dimension of modern, computerized tools.

While today's computerized tools are far more complex than what was used just 100 years ago, this is not the most important factor. Rather, today's tools are starting to operate autonomously and without our direct intervention, due to a growing flexibility and an improved awareness of their environment and decision-making capabilities. They are operating to fulfil a goal and take what they consider are the required actions to pursue and achieve that goal. Clearly one point is *who* sets the goal - can it be set by the SAS itself, or can the SAS change the goal on its own as the context changes and experience is gathered?

Self-evolving, autonomous decision taking, advanced interaction capabilities

Never in human history have we had tools with these characteristics. Robots are the first example of these types of tools that comes to mind. They come in many shapes and operate in different ways and for different purposes. They may differ significantly from each other, in terms of shape, dimension, functionality and cost. However, what matters most in the context of SAS is the varying degrees of autonomy they have, their capability to evolve (e.g., to learn and adapt), and their ability to interact with their environment, between themselves, and with humans.

We are therefore interested in SAS because of these three aspects: autonomy, self-evolution and human interaction. As SAS developments continue to progress at an ever-faster pace, they will change the landscape of industry and life itself. They may even change what it means to be human.

Like all life on Earth, we have evolved to adapt our behavior to the context in which we live. However, by becoming able to change the environment to better suit our needs, humankind went a step further than simple adaptation. As a result, in the coming decades we will see that for the first time, artefacts that we have created will start to adapt themselves and their behavior based on their ecological context. In short, we will be part of *their* context.

Hence, starting in the next decade and even more so in the further future, we will live in a dynamically changing world where we will be responding to the behavior of machines, machines will be responding to our behavior in a continuously changing fabric, and it will become progressively more difficult to distinguish cause and effect between man and machine.

From symbiotic relationship to emergence of new entities

What is happening is the establishment of a symbiotic relationship among (autonomous) systems as well as between them and humans. A recent example is the development of smart earphones[1] able to focus the amplification on a conversation that is of interest, shielding it from other conversation. In order to make this possible the earphones intercept the electrical activity in the brain and through artificial intelligence are able to identify the conversation the brain is interested in. This is a clear example of symbiosis between a prosthetic device (the earphones) and the human being.

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[1] https://www.sciencedaily.com/releases/2019/05/190515144001.htm

There is yet another aspect of these trends that will become apparent over the next decade. The interaction of several systems, each one independent from the others but operating in a symbiotic relationship with the others—humans included—will give rise to emergent entities that do not exist today. However, we are recognizing the abstract existence of something like a *smart city*, a *digital marketplace* or a *machine culture*. These entities are seemingly abstract concepts, although they are rooted in the interoperation of independent systems.

As an example, a smart city is the result of the interplay of several systems, including its citizens as a whole, as well as individuals. We can design individual systems and even attempt to design a centralized control system for a complex set of systems, such as a city. However, a smart city cannot be designed in a top down way, as we would do with even a very complicated system such as a manufacturing plant where everything is controlled. Just the simple fact that a city does not exist without its citizens and the impossibility of dealing or controlling each single citizen, as we would control a cog in a manufacturing plant, shows that conventional design approaches will not succeed.

In the past we felt that we could fully control a robot as we would a cog in a factory. However, as robots become more and more autonomous, aware, and able to self-evolve, they will become increasingly similar to human citizens, thereby requiring different strategies for management and control.

Digital Twins

This emergence of novel abstract (although very concrete) entities created by and leveraging these complex interactions is probably the most momentous change we are going to face in the coming decades. We have called these entities "Digital Twins" and they are characterized by three aspects:

- the capability to model a real entity, to be its "digital mirror";
- the capability to keep in synch with the real entity status, becoming its "digital shadow";
- the capability to record the history of that entity and its relationships as they evolved over time, creating a "digital thread".

As such a Digital Twin represents a sort of bridge between a real entity and cyberspace. It is traditionally associated to a 3-dimensional model of a physical device, but that is not necessarily the only option. A digital twin is a mathematical model that replicates behaviors or patterns of physical devices and is useful in order to manipulate those entities in a space where that is a task much easier, faster and cheaper than in the physical domain.

Notice how the possibility of creating:

- a "digital mirror" is becoming part of the industrial process of designing an entity (using CAD instruments that by their nature work on digital representations);
- a "digital shadow" is becoming possible through the extensive use of IoT and pervasive connectivity that allow an almost real time monitoring of an entity. This monitoring is both exploited for operation and maintenance as well as for distributed architectures to deliver services, partly residing in the entity itself and partly in cyberspace. In this sense the "shadow" can become an active component in the control of an entity;
- a "digital thread" is resulting from the aggregation of data over time linking the present of an entity to its past and to the various actors that have been interacting with it. The digital thread, along with the digital mirror is also leveraged for simulation and predictive analyses.

Digital Transformation

Digital Twins are part of a broader shift in the business and social evolution brought forward by the Digital Transformation, that is the use of bits to replace atoms (in part) and to flank them, making it possible:

- to execute, and create business in cyberspace and with cyberspace, thus decreasing transaction cost, increasing efficiency by overcoming space barriers and enabling the participation, cooperation and competition, of many more players;

- to blur the perceptive boundaries at the social level between cyberspace and the physical world, first by seamlessly linking the Digital Reality with Reality and then blurring the boundaries between the two resulted in an extended Reality that embeds both.

The Digital Transformation is happening: in several areas it has already changed the landscape, like in the music and travel areas; in others it is rapidly growing and taking the lion's share, like in the entertainment area; in other it is steering the evolution, like in Industry 4.0; and in others it is expected to become a disruptive force in the next decade, like in the healthcare area.

An in-depth view of several Digital Transformation aspects are given in Annex 1. A course on Digital Transformation[2] is available through EIT Digital (in Europe) and through IEEE world-wide.

Virtual, Augmented, Mixed Reality

Notice the increasing role played by Virtual, Augmented and Mixed Reality technologies, services and devices. These are expected to be the physical bridges between the world of atoms and the world of bits while Digital Twins are the virtual bridges among these two worlds. Virtual, Augmented and Mixed Reality are addressed in this third White Paper under the Market, Industry and Societal points of view.

SAS with human participation

The symbiosis of artefacts with humans will move by little steps and has already begun. For example, prosthetic hands are becoming more and more sophisticated, and part of their increased functionality stems from the autonomous nature of the prosthetics. When we pick up an object, several control systems are at work, even though we are normally unaware of their operation. For example, we can effortlessly pick up a nut or a raspberry, and we know to modify the pressure for the nut versus the raspberry, which is easily crushed. The decision process involved is quite complex, and it requires the cooperation of different systems; sensorial, touch, sight, motion, decision-making at the brain/cortical level, fine grading coordination by the cerebellum, immediate response by the spinal nodes, and more.

Prosthetic hands are now able to sense and interoperate with the person's neural system; they can also make local decisions (like the level of pressure to exercise). To a certain extent, these hands are *autonomous systems*, and they enter a symbiotic relationship with the person wearing them. Notice that this development is a continuously evolving process resulting in increasingly advanced symbiotic relationships currently involving evolution slanted towards the person who is slowly learning to adapt his or her actions and reactions to achieve a better control of the prosthetic. Most recently, we are seeing the emergence of a co-learning, or symbiotic learning, approach where both the person and the prosthetic are engaged in a learning process that results in a distributed knowledge.

From shared to distributed knowledge

Note this knowledge is not shared, where every component has the same knowledge, but distributed, where each component has its specific knowledge and the symbioses generate the required overall knowledge.

A leading edge prosthetic hand, different from the first model that did not have sophisticated interaction capability, would not fit a different person because over time a very specific symbiotic communication will have evolved, mostly on the part of the person—today—but we are now seeing learning and adaptation taking place in the prosthetic hand as well.

[2] Digital Transformation Course: offered by EIT Digital : https://professionalschool.eitdigital.eu/professional-courses/digital-transformation-social-challenges/ Offered by IEEE beginning early 2020.

Embedded Internet of Things (IoT) devices are also becoming more common (think of sensors to monitor chronic pathologies, smart drug dispensers like insulin pumps, and home connected devices). IoT devices are getting more and more sophisticated. In a short while, these IoT products will communicate with each other through body area networks—and in the longer term, they are likely to create distributed decision points with an emergent intelligence. Shortly after this, a symbiotic relationship will be established with the person wearing the devices, first improving the person's well-being and then the user's physical performances and ultimately their intellectual performances as well. In this latter area, DBS and the progressively more sophisticated chips controlling it create a new way of interacting with the functioning of a person's brain, changing the way it works. This is the path leading to augmented humans, human 2.0, or transhumanism.

Augmented Humans, Humans 2.0, Transhumanism

Although these three terms are sometimes used interchangeably, we take the view of a progression where the first step is leading to augmenting the physical abilities of a person (imagine having a wavelength converter embedded in the eye that allows that person to see in the infrared or UV spectrum), then reaching a point where many persons are markedly different from natural people because of their extended capabilities. These could include specific "improvements" like a permanent, seamless, connection to the web, made possible by advanced BCIs. This stage would characterize the development of human 2.0, and its main difference from augmenting the physical abilities of one person is the generalization that it will involve many people.

Humans 2.0

While in the augmented human we are likely to see an evolution that starts (as it is already happening) to address some disabilities and then move on to provide augmented advanced functionality to very few people, in the development of human 2.0 we have a generalized adoption of the technology probably due to decreasing cost for implementation. (Note that it has been said that we are already at that stage because of the generalized and systematic use we make of the smartphone to pair the web to our brain-based memory.) What we have in mind with our interface with devices like our smart phones is not the full human 2.0. We might concede to call this Human 1.5 insofar as in the nearer future, human to machine interfaces will remain visible. The transition to human 2.0 is marked by a seamless, often invisible, interface where you are not going to interact with the smartphone in an explicit way by typing or calling on Siri or Alexa but you simply think of something and related information pops up in your mind's eye after having been retrieved seamlessly from the web (or a local storage device that you may carry with you).

Augmented Humans

Transhumanism carried to the extreme may signal a transition to a new species not driven by evolution, but, rather, by technological development. Although transhumanism is rooted in the concept of leveraging science and technology, it is looking not at a symbiosis between us and our artefacts but to the possibility of changing, at a fundamental level, the characteristics (or some of them) of humans.

Transhumanism

We think that artefacts will evolve in a way that in some respects resembles the organic evolution of living creatures. The rapid development of technology enables this artefact evolution. It is therefore a natural step to extend the concept of symbioses one step farther applying it to the relationship between artefacts as well as living creatures.

Artefacts in a symbiotic relationship

Interestingly, we have examples in nature where these properties do not belong to individual components in a relationship but tend to emerge when many of these interact with one another as an ensemble. This is the case, for instance, for swarms of bees with a behavior as a group that is very different from that of individuals. Similarly, we can expect similar emergent behavior for swarms of robots. There is therefore a focus on two categories of symbiotic relationship only involving the interaction of artefacts with each other:

- Firstly, where each artefact demonstrates awareness-autonomy-evolution
- Secondly, where the ensemble demonstrates these properties as an emerging property

In the former case, the symbiotic relationship may occur among only a few artefacts. An example is the area of robotics where as individual robots increase their awareness capabilities through better sensors and context data analysis, they become more and more autonomous with technologies supporting analysis and problem solving using AI/Deep Learning methods that evolve over time. This type of symbiotic relationship impacts several verticals—for example, Industry 4.0 (manufacturing and retail) and healthcare.

Local interacting Intelligences

In the second type of symbiotic relationship, there is a need for a significant number of artefacts to create a symbiotic relationship with enough complexity that emergent behavior results. There are no defined thresholds for complexity above which these properties emerge, although in general, the simpler the entities involved, the more of them are required. We see this in nature where a flock of starlings gives rise to amazing choreography in the sky with hundreds of birds while in the case of a swarm of bees the number is in the order of several thousands.

Emergent Behavior

These aggregations can be studied with the science of complexity along with other technologies in the domain of AI. These aggregations and their emerging properties will be a topic of growing interest in the domain of IoT, although very few studies have focused on that. The interest derives from the fact that we are moving towards billions of IoT loosely connected with one another.

AI technologies can use data from the devices to extract emerging properties and direct the behavior of the IoT in the cluster.

This completely new domain will come into play in the next decade, as the number of connected IoT will reach a threshold above which awareness-autonomy-evolution can take place. 5G is likely to be an enabling technology in this domain providing the communication fabric for the ever-smarter IoT and clusters of IoT.

IoT Swarms

The growing connectivity is an enabler of increasingly complex systems, provided that each (or several) of the various parts have some autonomous characteristics. In turn, the studying of various technologies and application areas will require the SAS view.

The evolution towards human 2.0, the issues related to Transhumanism and the possibility of a superhuman intelligence lay in the fourth and fifth decade of this century. They have been addressed in the second White Paper to provide a horizon whose perception can impact actions in the next decade, particularly for regulators and public institutions that need to understand how the technological building blocks being researched today could be assembled in the future.
However, some of the aspects that we might be facing in the long term will already emerge, actually some are already emerging, in these years. An example is the symbiosis of human workers, both blue collars embedded in exoskeletons and white collars depending more and more on cognitive machines, is part of the Industry 4.0 evolution. Another example, in the mass market, is the symbiosis of car drivers with their semi-autonomous vehicles that has in some cases led to fatal accidents because the human is losing the perception of control and is actually handing over control to the machine even when told that the machine cannot have full control in any situation. These emerging issues are being addressed in this third White Paper through the magnifying (and polarized) lens of industrial players and of sociologists.

As William Gibson observed, the future is already here, it is just not evenly distributed.

The aim of this third White Paper is exactly along this line: as it should be for a white paper produced by IEEE Future Directions, it is about the future, but about a future that is already among us.

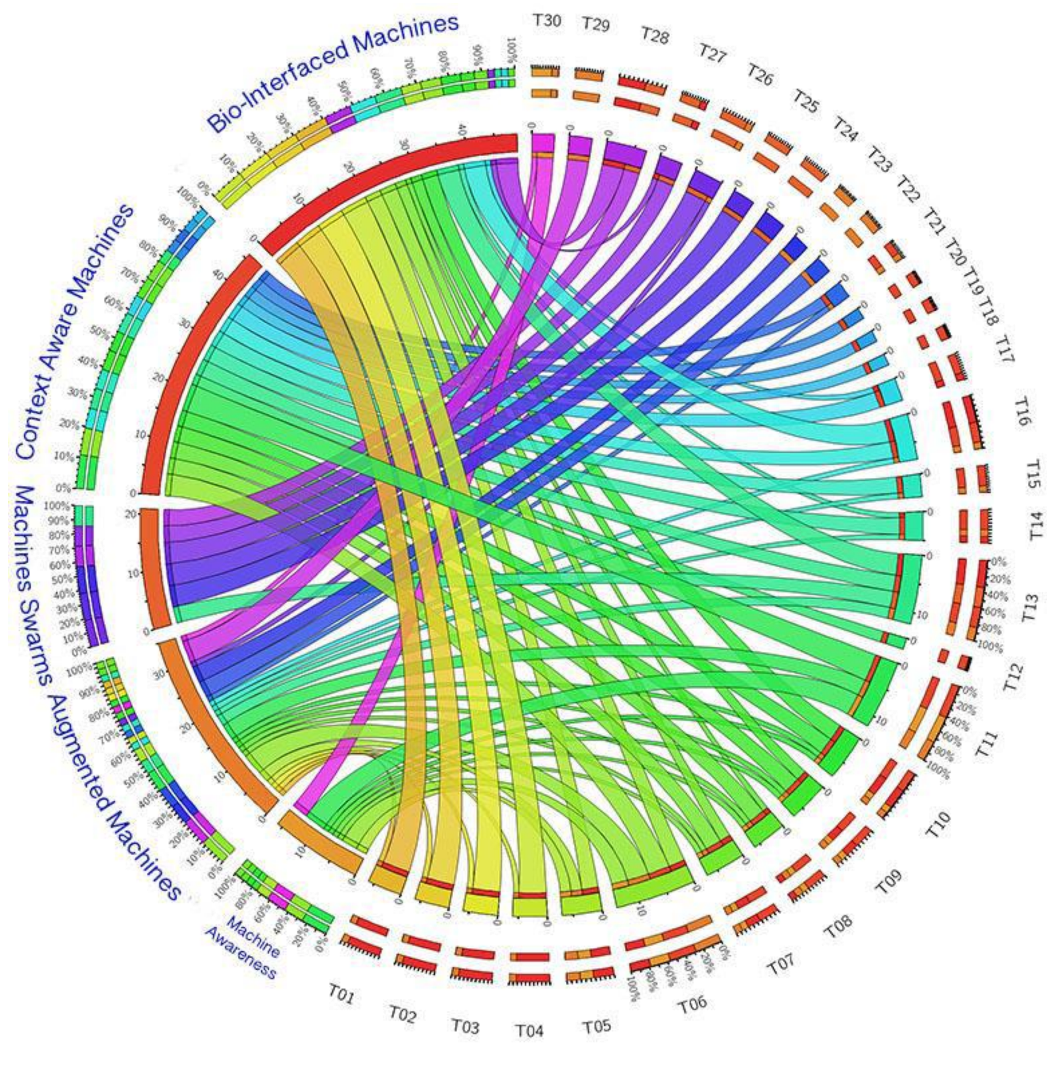
2 MARKET EVOLUTION

This section presents the expected market evolution first in the technologies supporting autonomous systems then in several application areas. This overview can provide an indication of the expected evolution since a growing market stimulates investment in research and industrial innovation.

2.1 Technologies market trends

Autonomous systems, as shown in White Paper II, are leveraging several technologies that are weaved into the fabric supporting autonomy in general and domain specific operations. To make the reading easier this White Paper follows the same structure of the Technology Roadmaps presented in the White Paper II. For reference to those technologies' expected evolution please refer to it. Notice that several of the technologies considered in White Paper II were and still are in the academia research stage and as such they are not considered here.

2.1.1 Machine Augmentation



T01	Bio-nanotechnologies	T11	AGI	T21	Biometric Clues Detection

T02	Nano-biotechnologies	T12	LIDAR	T22	Affective Computing
T03	Optoelectronics	T13	Sensors	T23	Self-Replication
T04	Optogenetics	T14	Image Recognition Understanding	T24	Small Worlds
T05	Signal Processing	T15	3D Recognition	T25	Complex Systems
T06	Artificial Intelligence	T16	Pattern Recognition/Understanding	T26	Self-Orchestration
T07	Deep Neural Networks	T17	Intention Recognition	T27	Low-Latency Communications, 5G
T08	Recurrent Neural Networks	T18	Sound Signature	T28	LPWAN
T09	Convolutional Neural Networks	T19	Empathic Machines	T29	Autonomous Machines
T10	Machine Learning	T20	Social Robots	T30	Sentient Machines

2.1.1.1 Optoelectronics

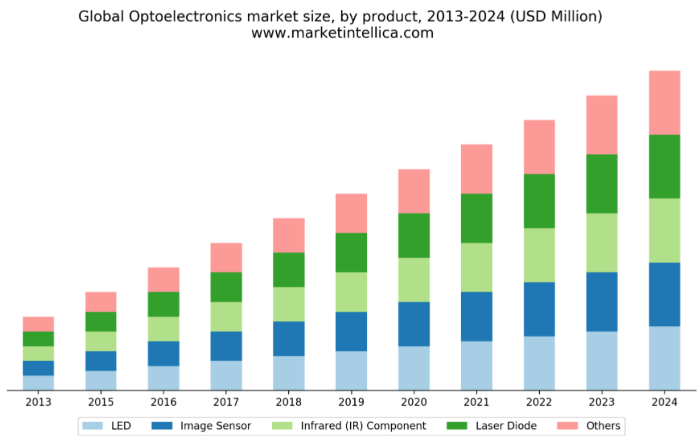


Figure 1 Global Optoelectronic Market. Historical data 2013-2017, base line year 2018, forecast 2019-2024. Market analysis by MarketIntellica

As shown in the graphic, the area of optoelectronics has seen a significant growth in the last five years, and this trend is expected to continue in the next decade. The market[3] can be split into LED (illumination), image sensors (photography, video and general image capture), infrared (IR) component (in which a significant growth is stimulated by use in autonomous cars) and laser diode (similar to LED but generating a laser beam) with application in telecommunications, medical, consumer electronics, and storage devices.

In terms of industry split, consumer electronics and automotive are capturing each close to 25% of the market with telecommunications capturing around 20%.

All these market areas are relevant to Autonomous Systems with the IR market being particularly relevant to autonomous vehicles since IR sensors are used to capture the environment and provide data to machine learning and machine awareness software that, in turn, generates digital models of the surroundings.

2.1.1.2 Signal Processing

Although signal processing is a technology that is often not perceived by the lay person, it is one of the most important in making the digital revolution possible. It has clearly leveraged the increased processing power (Moore's law) over the last sixty years and is now fueled by the huge amount of data generated by IoT. In 2018 the market value has exceeded $10 billion worldwide with an expected growth (CAGR) of 8.7% in the next decade[4].

[3] https://www.marketintellica.com/report/MI80801-global-optoelectronic-material-market-research-report
4 https://www.reuters.com/brandfeatures/venture-capital/article?id=45993

The market value of Digital Signal Processors (specialized chips that process signals) mirrors the growth of signal processing with a market value of $9.5 billion in 2018 expected to grow to $19.5 billion in 2025[5].

The three main sectors[6] of digital signal processing, with basically an equal share of market value are industrial (24%), automotive (24%) and consumer electronics (21%) applications with the remaining market taken up by a variety of applications.

2.1.1.3 Artificial Intelligence

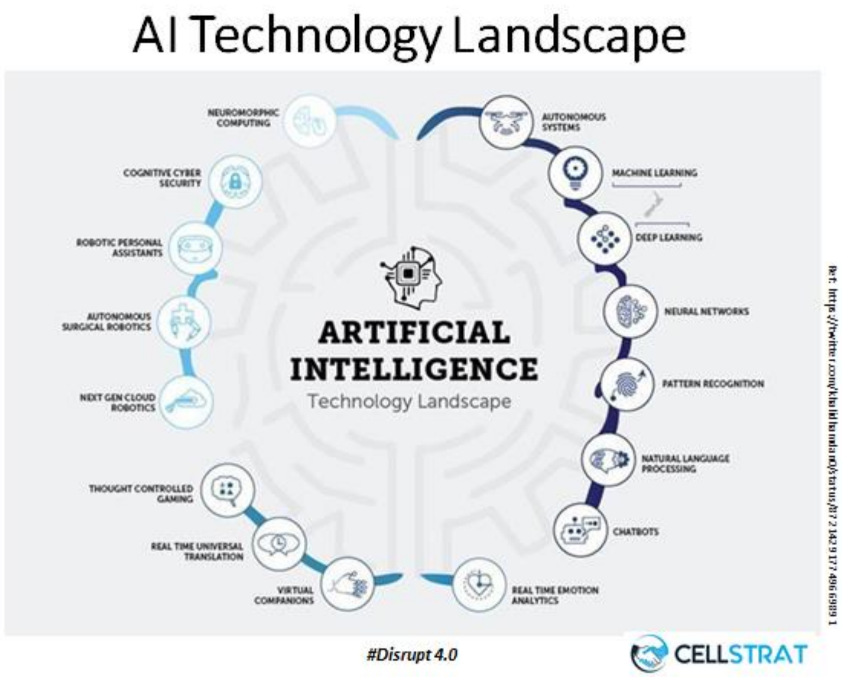


Figure 2 Source: CellStrat

The Artificial Intelligence market comprises a very broad landscape, including hardware, software and services, see Figure 2[7]. It can be split in a variety of ways (machine learning, deep neural networks, neuromorphic chips). There are plenty of reports[8] addressing these various aspects (as well as regional splitting). The general consensus expects an exponential growth in the next decade.

The AI software market reached a value of $9.51 billion worldwide in 2018 and is expected to reach 118.6 billion $ in 2025[9]. It is also important to notice that the indirect market fostered by the application of AI has roughly the same size of the AI market itself.

Machine learning is becoming pervasive (although there is a lot of hype in this area, and most of what is claimed as machine learning is actually the application of some neural network algorithms on a very limited set of data that does not result in real artificial intelligence). The market value of machine learning is expected to grow worldwide from $2 billion in 2018 to $8.8 billion in 2022[10].

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[5] https://www.themarketreports.com/report/global-digital-signal-processors-dsp-market-research-report
[6] https://industrydailyobserver.com/digital-signal-processing-dsp-market-tracking-current-trends-opportunities-challenges-and-swot-analysis-of-top-key-player-forecasts-to-2024/257006/
[7] http://www.cellstrat.com/2017/12/18/ai-technology-landscape/
[8] https://infotechlead.com/artificial-intelligence/latest-artificial-intelligence-ai-trends-and-forecast-reports-57324
[9] https://www.statista.com/statistics/607716/worldwide-artificial-intelligence-market-revenues/
[10] https://www.marketsandmarkets.com/Market-Reports/machine-learning-market-263397704.html

Gartner estimates the market impact on global worldwide business to reach $3.9 trillion in 2022 (notice that the worldwide market of technology companies is around $35 trillion, hence the Gartner forecast implies that 10% of this market will be affected by AI) with companies spending, according to IDC, $77.6 billion on AI (hardware, software and services) in 2022[11].

The neuromorphic chip market (Brainchip, General Vision, IBM, Intel, Invidia, Qualcomm, Samsung, Waymo) is growing rapidly, although it is considerably smaller than the software and service market[12]. In 2018 the market hit $2 billion and it is expected to grow to $10.8 billion by 2026.

2.1.1.4 Sensors

The sensors area is so large that it makes little sense to provide a single market value aggregate. There are estimates on sensors for smartphones (a huge market that is levelling out as smartphones are reaching a maturity point in terms of penetration, expected CAGR 2019-2023 of 2%[13]), in automotive (expected to grow significantly as vehicles increase their autonomous level), in healthcare (rapid growth as wearables are gaining consumer interest), in industry (Industry 4.0 is largely expecting a pervasive fabric of sensors[14]), and in retail[15] (significant growth as the supply and delivery chains becomes automated).

Normal (non-autonomous) cars already have over 100 sensors, and that number is increasing with every new model. By 2020 new cars will embed over 200 sensors[16] leading the number of sensors used in the automotive sectors to reach 22 billion.

Figure 3 Many companies are providing products and services in the retail space deploying and making sense of sensors' data. Source: CB Insights

Industry is already making extensive use of sensors, with a market in 2018 of $16 billion USD expected to grow to $21.6 billion in 2023[17]. A further increase is expected by the spread of the Industry 4.0 paradigm that will involve manufacturers of smaller components often forced to adopt sensors to provide data for the whole value chain.

It is important to notice the growing interest on sensors fusion (using data from a variety of sensors to discern semantic information, of particular relevance in AR applications) with a CAGR 2019-2024 close to 20%[18], resulting in a market growth from $3.29 billion USD in 2019 to $9.45 billion in 2024. Notice that these values, although representing large amounts, are insignificant when compared to the overall value of the sensor market that is in the trillion-dollar range worldwide.

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[11] https://www.forbes.com/sites/louiscolumbus/2019/03/27/roundup-of-machine-learning-forecasts-and-market-estimates-2019/#4cb74ca37695
[12] https://www.mordorintelligence.com/industry-reports/neuromorphic-chip-market
[13] https://www.businesswire.com/news/home/20190617005349/en/Global-Sensors-Market-Smartphones-2019-2023-Emergence-Sensor
[14] https://www.manufacturingtomorrow.com/article/2018/10/the-role-of-sensors-in-industry-40/12293
[15] https://www.cbinsights.com/research/internet-of-things-retail-market-map/
[16] http://www.automotivesensors2017.com
[17] https://www.prnewswire.com/news-releases/global-industrial-sensors-market-to-2023-growing-industrial-4-0-and-iiot-increasing-industrial-wireless-sensor-market--rising-demand-for-industrial-robots-driving-market-growth-300760546.html
[18] https://www.mordorintelligence.com/industry-reports/sensor-fusion-market

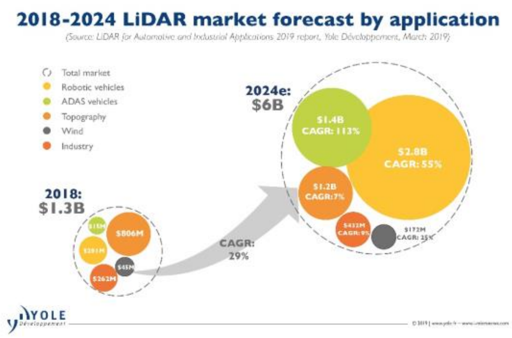

Figure 4 The growth of LIDAR market over the coming four years. Source: Yole

2.1.1.4.1 LIDAR

LIDAR is a sub-category of sensors that is worthwhile to single out for its specific application in autonomous vehicles (mostly, see Figure 4).

Today this technology is favored by several autonomous vehicles manufacturers (Waymo leading the pack) in spite of its high cost. Other manufacturers rely on normal radar and video cameras with image recognition and analysis software because of the lower cost (Tesla is leading the pack).

In the coming years, the emergence of fully solid state based LIDAR may substantially decrease cost making it more attractive. However, use of neuromorphic chips and better software for image recognition and analysis may shift the adoption towards these latter technologies in the area of autonomous vehicles (including industrial robots).

The growth is expected from $1.3 billion USD in 2018 to $6.4 billion in 2024[19].

2.1.1.4.2 Image Recognition

Image recognition has moved from being academic research to becoming a consumer feature, seen in many digital cameras (the camera triggers the shot when everybody is smiling and may take several shots to avoid blinking eyes, and software can change a closed eye with one that is open taken from another picture in the sequence).

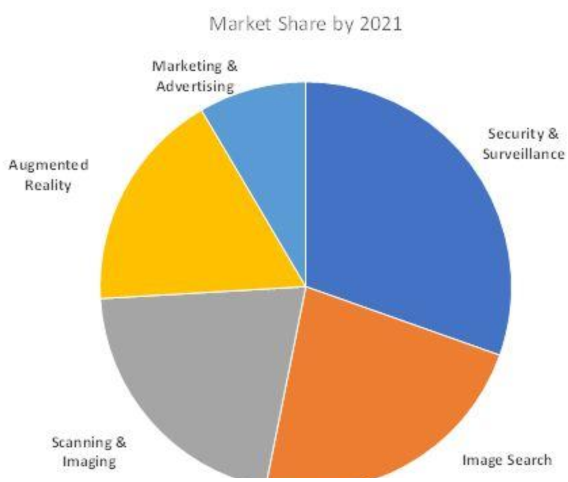

Figure 5 Various segments in the image recognition market. The segments most relevant to autonomous systems are the ones of Augmented Reality and security / surveillance. Source: Markets and Markets 2017

These features have become common but of course image recognition is much more: it is about identifying an object and, there are a few apps[20] that can tell you the name of a plant or flower; and it is about understanding what an object is and therefore what it could do, something that is crucial in autonomous vehicles needing to navigate a complex environment (a tree is unlikely to step out from the sidewalk and cross the street, not so a toddler). There is still plenty of research needed in this area but today's technology is available and used in industrial and consumer applications.

Image recognition is based on computation on data provided by an image sensor and often makes use of artificial intelligence techniques, like neuromorphic chips, neural networks, and machine learning. Because of this we are discussing its market under the sensors' area.

The image recognition market is quite broad, including biometrics (fingerprint, iris-scan, veins patterns, and face characteristics) object identification and object "understanding", and photographic editing.

[19] http://optics.org/news/10/4/19

[20] https://theplantguide.net/2017/08/23/best-plant-identification-apps/

All together this market has been valued at $1.41 billion in 2018 and is expected to grow reaching $5.32 billion in 2024[21] (a CAGR of 24.7%).

In the area of autonomous systems, image recognition is a prerequisite to achieve an understanding of the environment and the capability to interact and move around. Notice that the type of image being detected by an autonomous system may be quite different from the ones our brain needs to make sense of its surroundings. Radar scans can provide data that are seen as images by software that decodes the meaning. An autonomous system tasked with analyzing medical exams, like radiographies and fMRI, is not looking at the image in the same way a medical doctor does using her eyes. This, by the way, can allow higher precision in detection.

It is also worth mentioning the growing market flanking the area of image recognition, the one of emotion recognition software largely exploiting image recognition. The worldwide market reached $599.91 million in 2018 and is expected to grow to $7.2 billion by 2027[22].

2.1.1.5 Social Robots

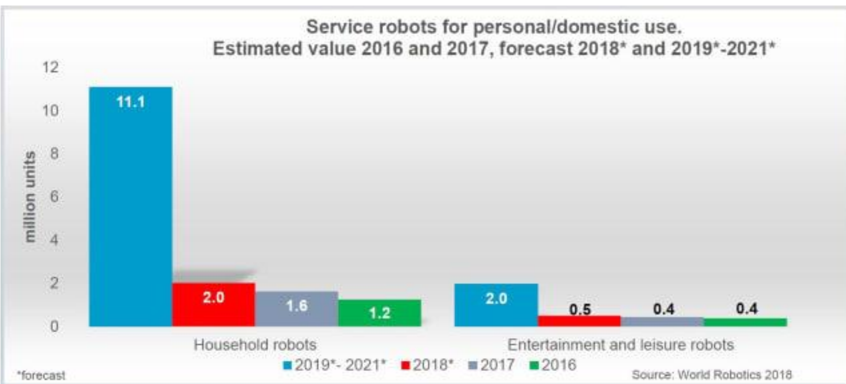

Figure 6 The market of social and entertainment robots is growing but not as much as might be perceived from the graphic. The blue bar represents the total volume over 3 years and should not be compared to the others representing one-year volume. Source World Robotics 2018

Social and entertainment robots are yet to demonstrate a clear value by graduating from being a curiosity and a gadget to becoming useful partners at home. The market[23] has doubled in the last 5 years in terms of robots sold (from 1.7 million sold in 2015 to the 3.67 million estimated in 2019), although the value over the same period has increased by less than 50% (from $1 billion in 2015 to the expected $1.46 billion in 2019). Over the next five years the pattern remains the same, doubling the number of robots sold to reach 7.43 million and $2.03 billion by 2025.

Social robots are expected to embed ever more sophisticated technologies as their price drops, and this is fueling adoption but lacking killer applications their adoption will remain, relatively speaking, marginal. They are providing an indication of automation and intelligence reaching the consumer market.

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21 https://www.mordorintelligence.com/industry-reports/ai-image-recognition-market
22 http://resource.affectlab.io/2019/03/25/emotion-recognition-market-is-set-to-grow-at-a-cagr-of-32-56-over-the-forecast-period-2019-2027-says-absolute-markets-insights/
23 https://loupventures.com/social-and-entertainment-robotics-outlook-2025/

2.1.1.6 Low Latency Communications (includes 5G)

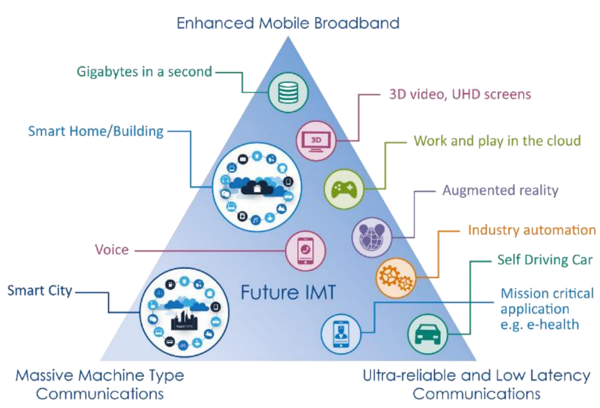

Figure 7 The well-known graphic representing the three selling points for 5G: larger bandwidth, high density and low latency. Source: ITU-R Recommendation M.2083

Demand for low latency communications originates from autonomous systems' requirement to react promptly to changes in the environment and to unexpected situations. Latency is tied to the technology used and even more to the overall architecture adopted. 5G has this requirement etched in its specifications and low latency, as indicated in the figure, is one of the three main selling points for 5G. However, the question is what is the size of the market, i.e., how much the market is willing to pay for low latency.

As shown in Figure 7 the areas that demand, or at least benefit from, lower latency communications are autonomous vehicles, industry automation (collaborative robots), and some health procedures[24] (like robot assisted surgery requiring haptic feedback). To a lesser extent XR applications and gaming may require low latency (and surely benefit from it).

Describing the actual market[25] in this area, however, is tricky. The global market for those segments is in the hundreds of billion dollars (medical robots $15 billion, connected cars $100+ billion, media, entertainment and XR $200 billion, robotics in manufacturing $15 billion), but how much of those market would be captured by low latency communications is highly debatable. Even more uncertain is the market captured by 5G because of low latency performance.

It is worth noting that recent trials[26] carried out by Deutsche Telekom and Nokia indicate that to ensure low latency in the 5G architecture one would need to enable computing at edge (i.e. move DB and processing to the wireless tower). This would also push for autonomous systems to embed communications network functionalities, effectively becoming network nodes and creating networks at the edges.

2.1.1.7 Low Power Communications

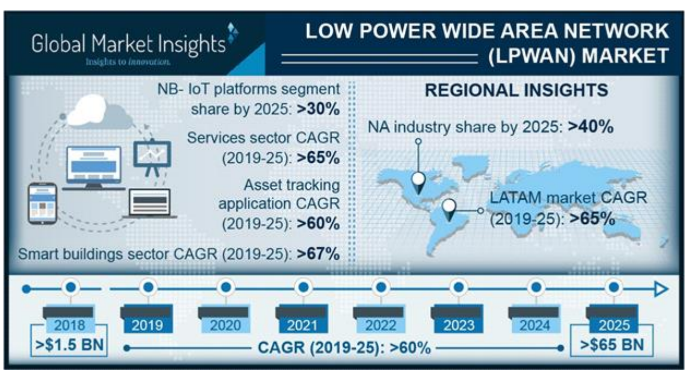

Figure 8 Growth of the Low Power Wide Area Networks Market. Source: Global Market Insights

The low power communications, including wide area networks (LPWAN), is expected to grow[27] exponentially from the $1.5 billion of 2018 to $65 billion in 2025.

As shown in Figure 8, the market can be split in several areas: communications platform, services, asset tracking, and smart building (installation and operation). Actually, the Low Power communications can use a number of different communications protocols and systems, from Narrowband (NB) IoT,

[24] https://arxiv.org/pdf/1703.09434.pdf
[25] https://www.researchgate.net/publication/315683979_Business_Case_and_Technology_Analysis_for_5G_Low_Latency_Applications
[26] https://enterpriseiotinsights.com/20190322/channels/news/edge-is-the-only-way-to-make-5g-v2x-safe
[27] https://www.smart-energy.com/industry-sectors/business-finance-regulation/lpwan-market-to-reach-65-billion-by-2025/

LoRaWAN[28] (Long Range Wide Area Network), SigFox to LTE-M and in a few years 5G (see Figure 9). Among these, LoRaWAN has the bigger market share (50% in 2018) because it uses unlicensed spectrum and is suitable for applications generating low traffic volume (which is typically the case for IoT).
The rise of interest and market is due to the increasing penetration of IoT and Industrial IoT, from 2019's 3+ billion of (directly) connected IoT to the 14 billion expected in 2025.

Among the many technologies enabling autonomous systems, low power communications is one of the most important to foster their dissemination and operation in any environment. Besides, low power communications support pervasive IoT which in turn generates data that can be used both by autonomous systems to make sense of the environment (emerging intelligence and awareness) and by ambient orchestrators. These data are also feeding into the digital twins, making shadowing more accurate, again, a feature that enables more autonomy and better performance to autonomous systems.

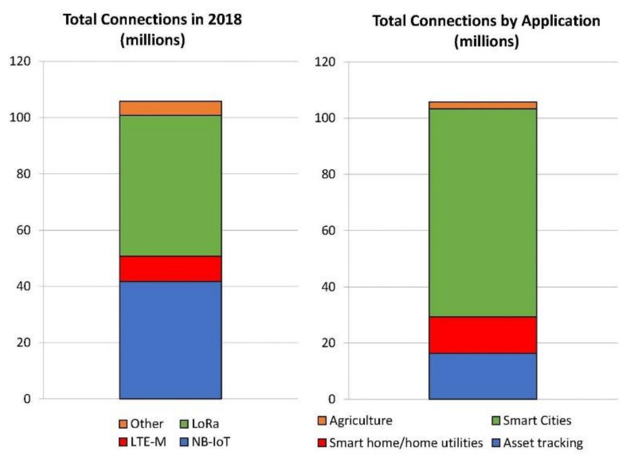

Figure 9 Split of low power communications in terms of connection technologies (left) with LoRa taking the lion's share, and in terms of application areas (right) with a predominance of smart cities applications. Source: IDTechEx

Significant areas of application for LPWAN are the healthcare sector with a 65% CAGR till 2025 and industrial/smart cities application with a 50%+ CAGR.

The area of smart cities[29] is grabbing most of the market, and it is also, along with industry and health care, the one that will see most growth in the next five years in relation to autonomous systems.

Unlicensed spectrum dominates; it remains to be seen if there will be a shift towards licensed spectrum once 5G becomes pervasive and chips drop in price beyond 2025. It is expected that the trend towards the use of unlicensed spectrum will continue also in the second part of the next decade.

[28] https://lora-alliance.org
[29] https://www.idtechex.com/zh/research-report/low-power-wide-area-networks-2019-2029-global-forecasts-technologies-applications/614

2.1.1.8 Autonomous machines – Drones

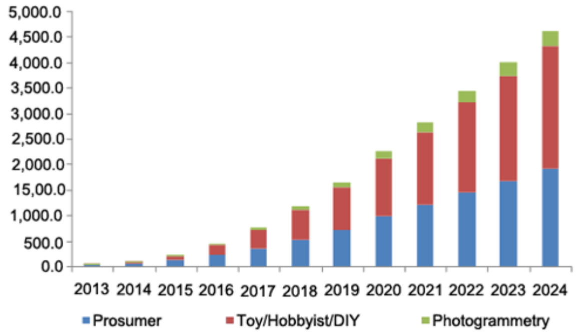

Figure 10 The rapid growth of the drone market in the last 5 years is expected to continue well into the next decade. Source: Grand View Research

Drones are a relatively recent technology, product, or service. Drones in the military area have been a reality for several decades but their price tag made them just beyond affordability for the commercial market, and this is the market that is generating big numbers. Military drones are not addressed in this white paper.

The drone market includes several technology providers, both hardware and software and has created an impressive number of companies[30]. The technologies at the core of the drone systems include sensors, artificial intelligence, processing, material science, storage, motors and actuators, wireless networks, navigation systems, energy management and storage, and digital cameras. They represent the typical example of autonomous systems.

In 2018 over 274,000[31] drones were sold worldwide with a market value of $5.8 billion, and there is a foreseen 56.7% CAGR expected over the next five years. The whole drone market (equipment and services) was valued $13.2 billion in 2018[32], and the growth will continue, with a market value expected to reach $141 billion in 2023 with the commercial sector totaling $17 billion. The small drones market in the 5-25 kilogram payload is expected to reach $40.31 billion by 2025[33].

There is a growing number of fields of application with filming and photography that have taken the lead so far with a market value of $1.86 billion in 2018 and is expected to continue to take the largest share of the market for the next five years. It includes amateur photographers although it is also becoming of interest to several industries for inspection of infrastructures (for example, utility industries).

Drones have been under the focus of the Federal Aviation Administration (FAA) to create possible regulation and determine possible threats due to the impact they can have on commercial flight, and in their forecast for the coming two decades, drones are indicated as the single most rapidly growing market, expected to triple in unit numbers over the next 3 years[34] (2023). Despite the request of registering drones and growing restrictions to their flight the market keeps growing.

Drones used in transportation will be considered in the transportation section of this White Paper; those used for delivery or supply chain are considered in the retail section.

In addition to the above segments (and military) drones are being used in:

- search and rescue[35],
- agriculture with a 2018 market value of $9.9 billion and a 7.13% CAGR up to 2024;

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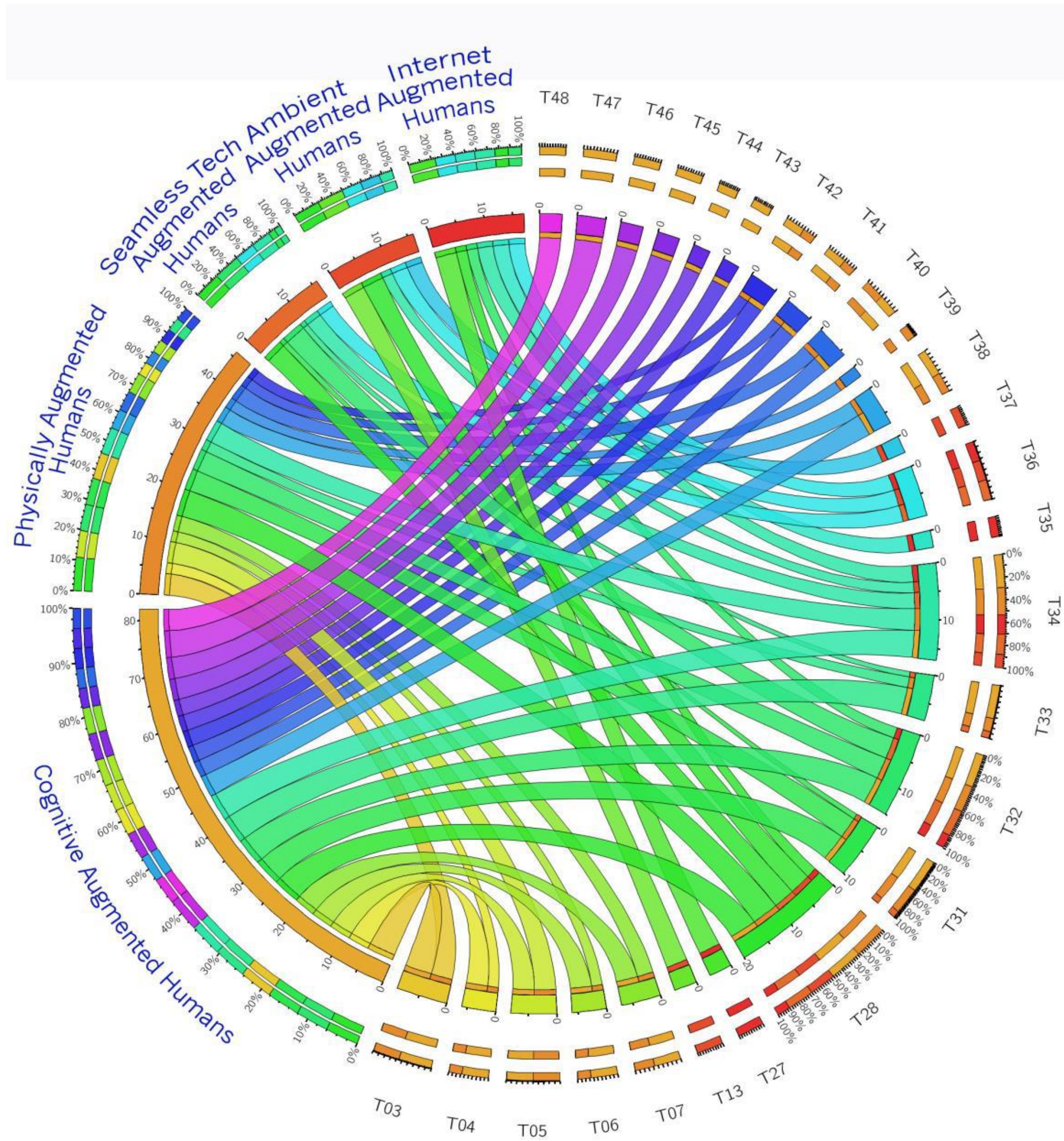
[30] https://www.droneii.com/drone-market-environment
[31] https://www.grandviewresearch.com/industry-analysis/global-commercial-drones-market
[32] https://www.globenewswire.com/news-release/2019/05/10/1821560/0/en/Drones-Market-will-grow-at-a-CAGR-of-40-7-to-hit-144-38-Billion-by-2025-Analysis-by-Trends-Size-Share-Growth-Drivers-and-Business-Opportunities-Adroit-Market-Research.html
[33] https://www.reportlinker.com/p03665911/Small-Drones-Market-by-Application-Size-Payload-Type-Propulsion-Systems-Region-Global-Forecasts-to.html
[34] https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2019-39_FAA_Aerospace_Forecast.pdf
[35] https://www.aeroexpo.online/aeronautic-manufacturer/search-rescue-uav-557.html

- inspection[36] - these are specialized drones usually having a long range, over 600 kilometers, and long flying hours, up to three days in flight. They are produced by specialized companies, and their price tag is obviously high;
- police monitoring - these are different from the drones used in inspection and have, in general, lower range and sometimes higher speed. They are also raising privacy concerns, and needs for regulation have been voiced by several parties[37];
- real estate - use of small drones for aerial views of real estate is becoming normal in the US and expanding to other countries.

[36] https://www.transparencymarketresearch.com/inspection-drones-market.html
[37] https://resources.infosecinstitute.com/privacy-and-security-issues-with-drones/#gref

2.1.2 Human Augmentation



T03	Optoelectronics	T32	Smart Materials for long term Implants	T41	DNA modification
T04	Optogenetics	T33	Neuroimaging	T42	RNA modification
T05	Signal Processing	T34	BCI	T43	Deep Brain Stimulation
T06	Artificial Intelligence	T35	Virtual Reality	T44	Transcranial magnetic stimulation
T07	Deep Neural Networks	T36	Haptic	T45	Cognitive prosthetics
T13	Sensors	T37	Smart Materials	T46	Neural Engineering System Design
T27	Low-Latency Communications, 5G	T38	Implantable chips	T47	Smartphones
T28	LPWAN	T39	Exoskeletons	T48	Symbiotic Intelligence

T31 Fluorescent proteins T40 CRISPR/Cas9

2.1.2.1 Optogenetics

Optogenetics provides the means to affect very specific areas of the brain at neuron/neuronal circuit level. It is an invasive procedure, and as such its application thus far has been in research and is just starting to be applied in very limited cases as a way to control brain activities as an alternative to electrical stimulation with implanted electrodes.

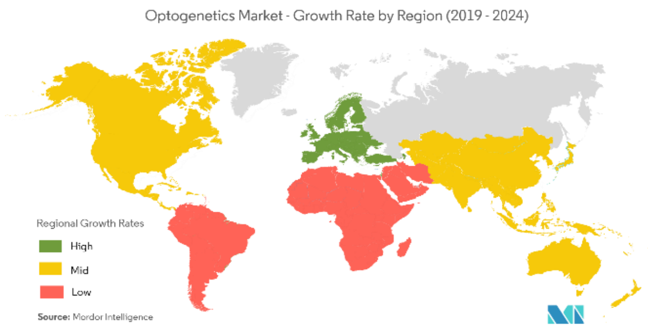


Figure 11 Europe is the region with the most rapid growth followed by North America and the Far East and Australia. Source: Mordor Intelligence

Applications to achieve human augmentation are not foreseen within the next ten years. In the next five years (2019-2024) the market is expected to grow[38] at 16% CAGR, with an expected market value growth from $20 million in 2019 to $46.82 million in 2022[39]; beyond 2025 the growth may increase significantly, depending on results achieved by the flagship projects on the brain. The technology hurdle that is limiting the market growth is related to the difficulty of coupling the LED to the optical fiber (basically the tip of the fiber should embed an LED to activate the light sensitive protein in the neuron).

Although Europe is the region with the most rapid growth expected, North America is leading the market in terms of technology and product offering through companies like Addgene, Cobolt Inc., Coherent Inc., Gensight Biologics, Laserglow Technologies, Noldus Information Technology, Scientifica, and Thorlabs Inc.

2.1.2.2 Smart Materials

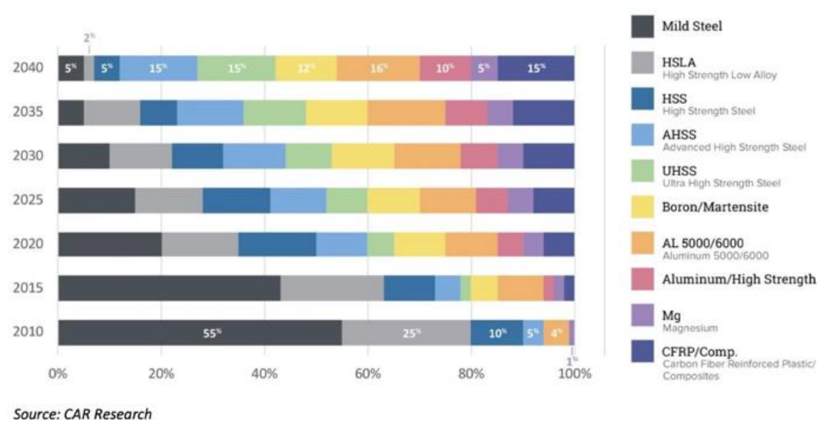


Figure 12 Change in the composition of materials used in vehicles in the US over the period 2010-2040. Most of materials expected to be used in 2040 will be designed, composite/smart materials Source: Center for Automotive Research

Science and technology have progressed to the point that it is now possible to design materials from the bottom up, starting from the desired characteristics to create a material with the right atomic and structural composition to deliver them. There are already several "smart" materials that have been created through design and the variety and applications will grow in the next decade.

As an example, Figure 12 shows the change in materials expected to be used in car manufacturing[40] over the next 20 years. These changes will reshape several industries, enabling new products as well as modifying the players in the supply chain.

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[38] https://www.mordorintelligence.com/industry-reports/optogenetics-market
[39] https://www.reuters.com/brandfeatures/venture-capital/article?id=11462
[40] https://www.cargroup.org/wp-content/uploads/2017/07/Technology_Roadmaps.pdf

The global market for smart material will be huge, since it will impact the market throughout the whole supply chain. For autonomous systems one can segment the market into the several areas where smart materials are (will be) used, including implant material, sensors and actuators, structural materials, shape memory, smart fluid, alloys, as well as by type of material.
As an example, advanced ceramic materials had a global market value[41] of $72.74 billion in 2018 and are expected to grow over the next 5 years to $122.66 billion. This class of smart materials will include sensors, electric/dielectric specific characteristics, shape memory and more.

The bio-implant market, close to $100 billion in 2018, is expected to reach $161.32 billion by 2024[42] (by far most of these are for human applications, although a minority is for use for sensing in robotics).

Another class of smart materials is the so called 4D materials, having a structure that can modify its shape, memorize the shape and return to it after deformation. These materials are created through 3D printing. It is a market that is just starting in 2019 and is expected to reach $537.8 million by 2025[43].

An interesting subset of these materials are the so called "shape memory alloys" based on nickel, copper, titanium, aluminum and a few others. Advances in metallurgy, computer analyses and design of alloys has opened the door to an unlimited class of materials, where software is used to explore the potential characteristics of an alloy before it is manufactured. The market value was around $9 billion in 2018 ($3.4 billion in the US[44]) with the largest share taken by Nitinol (a Nickel Titanium alloy used in biomedical implants, aerospace and even in space exploration[45]) and it is expected to reach $19 billion in 2022[46].

[41] https://www.grandviewresearch.com/industry-analysis/advanced-ceramics-market
[42] https://www.medgadget.com/2018/09/bioimplants-market-is-expected-to-reach-us-161-39-billion-by-2024-according-to-new-research-the-research-focuses-on-cardiovascular-bioimplants-dental-bioimplants-orthopedic-bioimplants-spinal-bi.html
[43] https://www.marketsandmarkets.com/Market-Reports/4d-printing-market-3084180.html
[44] https://www.gminsights.com/industry-analysis/shape-memory-alloys-market
[45] https://technology.nasa.gov/patent/LEW-TOPS-99
[46] https://www.marketsandmarkets.com/Market-Reports/shape-memory-alloy-market-83856907.html

2.1.2.3 Brain Computer Interface (BCI)

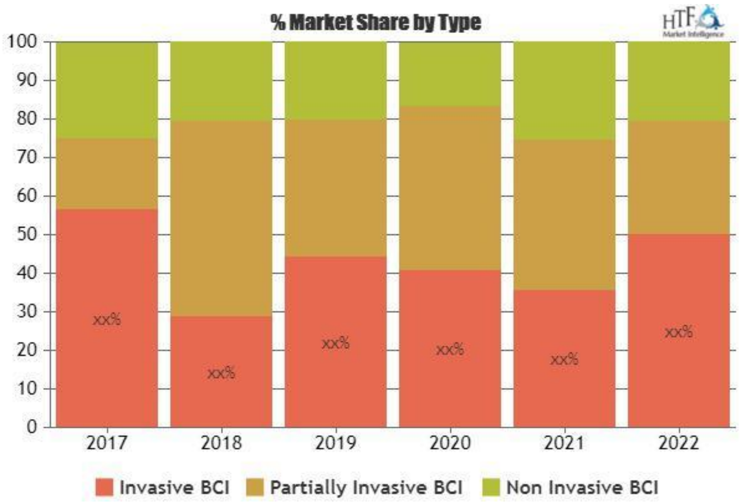

Figure 13 The ratio between invasive, semi invasive and non-invasive BCI. Notice that the lion share of the market is taken by invasive and semi invasive interfaces. These are used chiefly in medical applications. The evolution of technology, but we are well beyond the horizon of this White Paper, may increase the sensitivity of non-invasive interfaces and this, in turns, may stimulate adoptions in other markets, including gaming and industrial applications. Image Source: HTF MI

The Brain Computer (invasive) Interface (BCI) market is relatively small, $125 million in 2018, with a 12% CAGR[47] until 2025 when it is expected to reach $283 million globally[48].

The actual growth of the market, that by far is based on medical applications to treat brain disorders or nervous systems impairment (apart from military applications that are beyond the scope of this White Paper), will be dependent on research results, particularly those expected from the flagship brain initiatives. Progress in technologies already mentioned, like signal processing and smart materials, will also play a significant role.

The path towards establishing a symbiosis between human and machine, what is also known as Mind Machine Interface (MMI), through a seamless brain computer interaction is bordering on science fiction, at the moment, and it does not have any market impact.

The use of BCI in areas like equipment control and gaming or entertainment is very limited because of the crude results delivered by today's non-invasive BCI. Hence, the market is limited[49]. In the longer term, progress in signal processing and sensors may increase the sensitivity of non-invasive technologies and this may capture a larger market.

An interesting area of evolution is sensors capturing muscle movement coupled with related signal processing able to understand the intention behind that movement. These new technologies[50] are being used in smart prosthetics (e.g., in controlling a prosthetic hand by detecting limb muscle movements). An interesting market analyses[51] in this area has been prepared by NIST.

[47] There are more optimistic growth expectations, from 17% up to 28%
[48] https://www.prnewswire.com/news-releases/global-brain-computer-interface-bci-market-projected-to-be-worth-us283-04-mn-by-2025-with-high-incidence-of-brain-disorders-300863252.html
[49] https://www.openpr.com/news/1080301/How-Brain-Computer-Interface-BCI-Market-will-grow-in-the-upcoming-year.html
[50] https://www.researchgate.net/publication/328784260_A_Novel_Flexible_Sensor_for_Muscle_Shape_Change_Monitoring_in_Limb_Motion_Recognition
[51] https://www.nist.gov/sites/default/files/documents/2017/04/28/239_limb_prosthetics_services_devices.pdf

2.1.2.4 Extended Reality

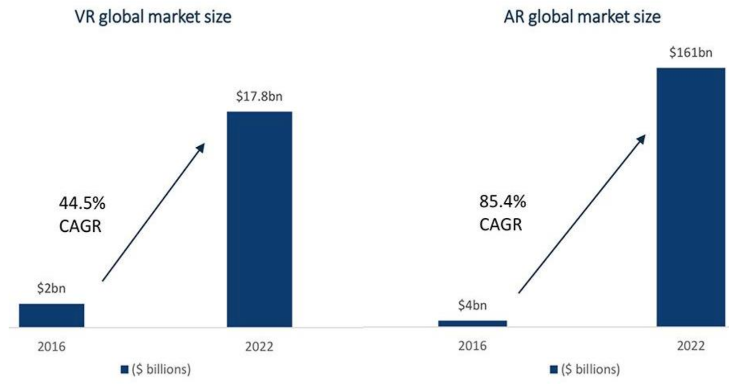

Figure 14 Augmented Reality is growing much faster than Virtual Reality and is already dominating the market in 2018. It is expected to become almost 10 times bigger than VR in 2022. Credit: Consultancy UK

Extended reality (includes augmented, virtual and mixed) has permeated several businesses, like entertainment, manufacturing, marketing, medical, military, training, real estate, remote working, transportation, and tourism[52]. Figure 14 comprises all the above areas and includes both hardware and software (content).

It is interesting to note that AR has already taken the lion's share of the market in terms of software (apps and content), with $4.91 billion vs the $1.84 billion of virtual reality (VR) (both figures represent worldwide spending expected in 2019[53]). These numbers are expected to grow to $8.03 and $2.81 billion respectively in 2021 (near doubling in two years). Figure 14 depicts the spectacular rise of the AR market[54], including both software and hardware, that is expected to reach $161 billion worldwide in 2022, almost ten times bigger than the VR market value ($17.8 billion in 2022).

Notice that the expectation is for rapid growth of the software market to reach $35 billion in 2025, led by gaming[55] (see Figure 15). The figure does not include the VR/AR (Mixed Reality) market in public education that is expected to reach $9.9 billion by 2023[56].

Hardware will keep the lion's share of the AR/VR market for the next decade, also because devices supporting AR/VR are expected to continually increase their functionality (and form factor, becoming more seamless), hence a relatively short life time and rapid replacement can be foreseen. Add the market expansion in terms of users, and it is clear that hardware is leading the market value.

52 https://www.visualcapitalist.com/extended-reality-xr/
53 https://www.statista.com/statistics/828467/world-ar-vr-consumer-spending-content-apps/
54 https://www.consultancy.uk/news/17876/virtual-and-augmented-reality-market-to-boom-to-170-billion-by-2022
55 https://www.businessinsider.com/goldman-sachs-vr-and-ar-market-size-and-segmentation-2016-4?IR=T
56 https://markets.businessinsider.com/news/stocks/global-mixed-reality-learning-market-surges-to-9-9-billion-by-2023-1017567232

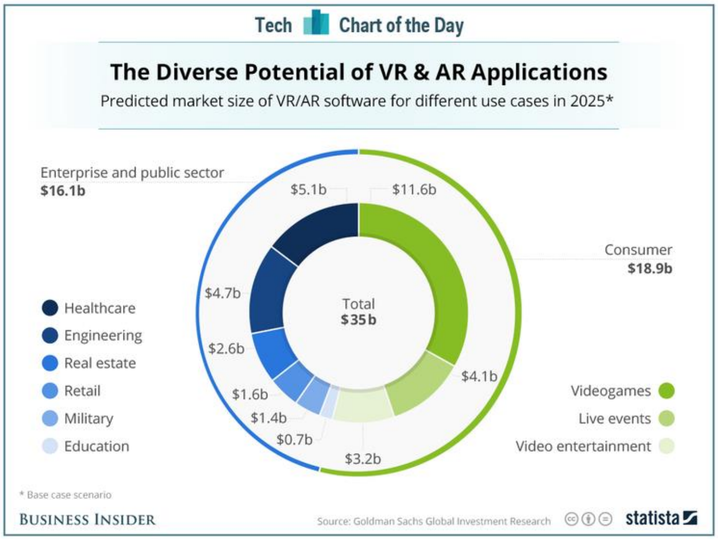

Figure 15 Split of the market value, expected in 2025, over consumer and enterprise related to software. Interestingly, the consumer market is expected to exceed the enterprise market (in 2019 is the reverse). Also, of particular interest, the large share of AR and VR application in the Healthcare and Engineering areas. Source: Statista

Specialized hardware for enterprise applications is also expected, further increasing the market volume. Including the hardware, the enterprise market is expected to exceed $30 billion in 2025[57] (notice that volumes are smaller in the enterprise market than in the consumer market).

It is also interesting to note (even though this does not fit with human augmentation) an emerging trend of using VR in the training of autonomous systems before they are confronted with the real environment. VR spaces are used to train the artificial intelligence embedded in robots, drones, autonomous industrial vehicles, and for simulation and assessment of autonomous cars.

2.1.2.4.1 AR/VR trends

The current trends of AR and VR devices highlight how the companies are trying to segment the market in two parts:

- Devices and software aimed at the enterprise;
- Devices and software aimed at consumers.

Enterprise solutions

Figure 16 The Varjo XR-1, commercially available in the 3rd quarter of 2019, supports the blending of real and virtual allowing the display of photorealistic images. It can seamlessly switch between VR and XR, integrating a 20/20 Eye Tracker. Inage credit: Varjo

Enterprise AR/VR solutions aim at improving the production processes of companies, offering high-cost, high-end hardware. Some key features required by companies are the high quality of the product, the comfort for letting workers wear it for many hours, easy cleaning for maintaining high hygiene standards and high possibility for customization.

XR devices for enterprise usually cost at least $1000 and offer functionalities that cannot be afforded by general consumers. Companies, though, can find the competitive advantage given by these devices worth the high price tag.

One example is the virtual reality headset Varjo[58] VR-1, that is able to present the user with a very vivid virtual image, with a resolution so high that the eye of the user cannot discern the pixels. This headset is perfect for companies that operate in fields where the visual fidelity is critical, like industrial

[57] https://www.globenewswire.com/news-release/2018/04/03/1459315/0/en/Global-AR-in-Enterprise-Market-Will-Reach-USD-30-520-million-by-2025-Zion-Market-Research.html
[58] https://varjo.com

prototyping (in fact Varjo has partnered with Volvo[59]). The Varjo headset costs around $6000; only big corporations may afford it.
Another example is the HoloLens 2 AR glasses that were released by Microsoft in 2019. The $3500 price tag is not suitable for mainstream adoption, but the big technological leap offered by this headset, due to a very natural user interface, a wide vertical field of view, and a suite of software dedicated to satisfy the needs of companies, is making companies very intrigued by this device. It is being employed in the maintenance field by big industries and the US Army.

Premium headsets with high-functionality and high cost will continue to be offered in the future.

Consumer solutions

Average consumers have very different requirements than industry. They are looking for products that are affordable, trendy, comfortable, user-friendly and offer software that is useful (e.g., Words on PC) or entertaining (e.g. gaming).

AR and VR companies are working especially on the price point, lowering the entry level for adoption of the technology, and regarding user friendliness, offering devices that don't require technical skills to be set up. The recent release of the Oculus Quest summarizes all of this: for only $399 the user is able to have a virtual reality headset that can be used out-of-the-box to play VR games. This can be compared with the Oculus Rift CV 1 that was commercialized in 2016: the headset with the controllers cost around $800, required a PC worth at least $1000, and the setup consisted in installing 3-4 USB cameras in the user's room.

All-in-one headsets like the Oculus Quest, called "standalone" devices, are the current trend of VR, the one that will take the technology close to mainstream adoption. The reasons are the one described above: affordability and ease of use.

Regarding AR, the current trend in the consumer space is to offer light and trendy headsets that are connected to smartphones via an USB-C cable. In 2020, the Chinese company nReal[60] is going to release $499 AR glasses that are very similar to fashionable sunglasses. It is also rumored that very soon Apple may release its own AR device, that, given the commercial power of the company in Cupertino, will probably disrupt the market.

The advent of 5G should resonate with these trends: due to the power of the cloud and the high bandwidth offered by 5G, it is very possible that in the future the AR/VR headsets will just be light, cheap and trendy shells featuring only one display and an antenna, with all the heavy rendering and calculations happening in the cloud.

While on the hardware side the future trends seem clear, on the software one there is much more uncertainty. Companies do not yet understand what kind of immersive content can actually drive the adoption of these technologies. Currently they are betting on gaming, but they need to determine useful applications to attract non-gaming people to these devices, similar to the ones that drove the adoption of computers (email, Word, Powerpoint) and smartphones (social media, ubiquitous access to the Internet).

2.1.2.4.2 Data Visualization

IoT and simulation systems gather a big quantity of data. There is a common saying: "companies have collected a big amount of data, but now they have to understand what to do with those data". Corporations need to determine a good use of this data, and one of them is of course creating

[59] https://venturebeat.com/2019/05/29/varjo-teams-up-with-volvo-to-enable-safe-driving-with-ar-headsets/
[60] https://www.nreal.ai

statistical graphs. By looking at the graphs and charts of the data collected during a simulation, it is possible to analyze this data and use it to improve the processes of a company.
While this operative flow makes sense, the limited dimensionality of graphs restricts their application. Graphs are two dimensional entities, but often they must represent data that spans multiple dimensions: the resulting images appear incomplete or cluttered, and thus sometimes difficult to be used.
For this reason, with the advent of AR and VR technologies, companies are trying to port the representation of the graphs and charts to XR environments, evolving them to exploit the bigger number of dimensions. These companies are creating solutions to visualize data in augmented and virtual reality. This has the following advantages:

- AR and VR solutions live in three dimensions, so charts can exploit one more dimension to show the data;
- Since the human brain is trained to live in a three-dimensional world, it is able to understand 3D objects better than 2D ones. It has been demonstrated that the human brain is able to detect patterns in 3D representations of data better than those in 2D ones. This means the user can extrapolate the meaning more easily and more efficiently by analyzing an AR/VR graph;
- The ability to manipulate the data with the hands, using the controllers of XR devices, also triggers some cognitive processes that help in understanding and retaining the data better;
- Since the data is in the physical space, the user can rotate around it and analyze it from different points of view, finding in the end the optimal view to spot patterns and trends;
- VR can present an infinite virtual space around the user, where the data can be positioned in a preferred representation. For example, charts that may have a correlation can be moved closer together to try to see some patterns. 2D screens have usually a limited size, and this is not possible;
- There is also a "fun" component in using AR/VR to visualize the data: as investor Eduardo Siman points out[61], it appears less "serious" than 2D graphs on a piece of paper, and so can appeal more to people.

There is more than one approach to data visualization in AR and VR, and different companies are taking different routes. Virtualitics[62], for instance, has a very academic approach and is trying to offer the VR version of 2D graphs and charts to companies and universities. BadVR[63], on the other hand, is trying to pursue a more artistic approach, offering data visualization solutions that don't resemble graphs and charts at all, but that immerse the user in environments (e.g., a stadium), where the data is shown in a more creative way.

[61] https://skarredghost.com/2018/12/28/interview-to-eduardo-siman-virtual-reality-makes-data-visualization-fun-we-should-all-work-together-to-make-ar-and-vr-to-succeed/
[62] https://www.virtualitics.com
[63] https://www.badvr.com

2.1.2.5 Haptic

Haptic devices fall into two categories: cutaneous or tactile and kinesthetic. Cutaneous or tactile relates to touch sensations, and kinesthetic relates to manipulation sensations. They are often used in conjunction with AR and VR systems to enhance the experience. Another growing field of application is the interfacing with (semi) autonomous systems such as steering wheel vibration that autonomous cars generate to alert the driver. The global automotive market segment of haptic systems is expected to reach 6.97 billion $ by 2021 (fueled by the need to avoid driver distraction).

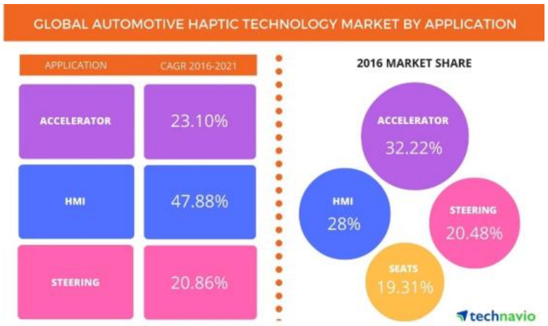

Figure 17 The adoption of haptic system in the automotive market is growing in the four areas of seats - vibrating to warn of collision threats, steering - vibrating to alert the driver, HMI with various touch feedback and accelerator – with haptic feedback on the pedal. Source: Technavio

Using haptic interfaces on mobile devices to provide touch sensations on a touch screen of a smartphone/tablet, named surface haptics, is an important sector growing the market. Piezoelectric technologies are predominately used, along with new microfluidic and electrostatic technologies that will grow in the next decade (piezoelectric will continue to lead also in the next decade[64]).

Another growing area of haptics is enabling robots interacting with an object or environment to sense and the transmit the sensation to a person. The deployment of 5G with its low latency will support remote haptics, fostering a human augmentation by extending the sense of touch.

All together the haptic market is expected to reach $22 billion in 2023 with a 16% CAGR in the period 2017-2023[65].

2.1.2.6 CRISPR

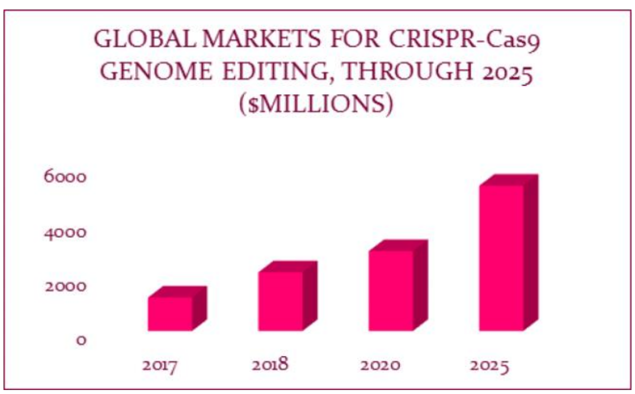

Figure 18. The CRISPR market will keep growing significantly. Source: AheadIntel

Genome sequencing has already reached the edges of the mass market and is expected to become ubiquitous in the next decade. The market for DNA sequencing was over $6 billion in 2017 and is expected to exceed $25 billion in 2025[66]. The largest part (40%) of this market is for consumables used in the sequencing. The largest application area today is in diagnostics and will most likely remain so in the next decade.

The market is dominated by Illumina and Roche (with 25 and 20% of the global market), followed by Thermo Fisher Scientific and Agilent Technologies, with a number of other companies capturing the remaining 30% of the market.

The availability of millions of sequenced genomes will foster the application of artificial intelligence tools to extract meaning, and this in turn will prompt the use of genome editing tools, of which

[64] https://www.globenewswire.com/news-release/2013/08/06/920723/0/en/Driven-by-Touch-Screen-Devices-Haptics-Market-to-Grow-16-Fold-to-13-8-Billion-in-2025.html
[65] https://www.marketresearchfuture.com/reports/haptic-technology-market-4011
[66] https://www.alliedmarketresearch.com/press-release/dna-sequencing-market.html

CRISPR-Cas 9 is currently the leading one. Genome editing can support curing of disease in humans, but it is not expected to result in a significant market in the next decade.

The CRISPR-Cas9 market was estimated in $1.22 billion in 2017 and is expected to reach $5.3 billion in 2025[67]. Most of the market growth is expected to be sustained by genome editing in agriculture.

2.1.2.7 Deep brain stimulation

Deep brain stimulation is becoming an accepted procedure in a number of pathologies (see Figure 19), with the majority of the market in the US (65% of the global market in 2018) although Europe will see the greatest growth in the 2019-2024 period[68].

Parkinson's disease is affecting 2.5 million new people every year, and statistics are showing an increase worldwide (possibly as result of longer life span). Deep brain stimulation is implanted through surgery and is effective in only some of the Parkinson's cases (it is not advised for patients with signs of memory loss or dementia). It results in benefits on movement control and reduction of tremors[69].

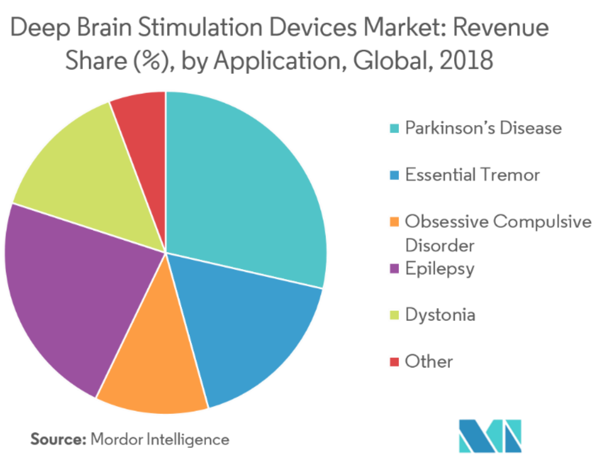

Figure 19 Split of market share for deep brain stimulation in the treatment of various pathologies. Parkinson and Epilepsy treatment are the major users followed by Essential tremor and dystonia. Source: Mordor Intelligence

At present, there are no real applications of deep brain stimulation to augment human performance, although some studies seem to indicate a possible reinforcement of memory.

Deep brain stimulation uses transcranial magnetic stimulation, a non-invasive procedure with coils placed on the scalp generating magnetic fields that can be focused in a specific area of the brain, and is mostly in the stage of clinical trials. Here, as well, the application is focusing not on human augmentation but on decreasing some neurological symptoms in depression, obsessive compulsive disorders, schizophrenia, and post-traumatic stress[70].

The market size is small, estimated in $71 million in 2019 to reach $130 million in 2024[71].

67 https://www.aheadintel.com/product/crispr-cas9-tools-global-market-and-patent-landscape-report-till-2025/
68 https://www.mordorintelligence.com/industry-reports/deep-brain-stimulation-devices-market
69 https://www.michaeljfox.org/news/deep-brain-stimulation
70 https://www.transparencymarketresearch.com/transcranial-magnetic-stimulators-market.html
71 https://www.marketwatch.com/press-release/transcranial-magnetic-stimulators-market-size-is-set-at-104-cagr-to-reach-usd-130-million-by-2024-2019-03-06

2.1.2.8 Smartphones

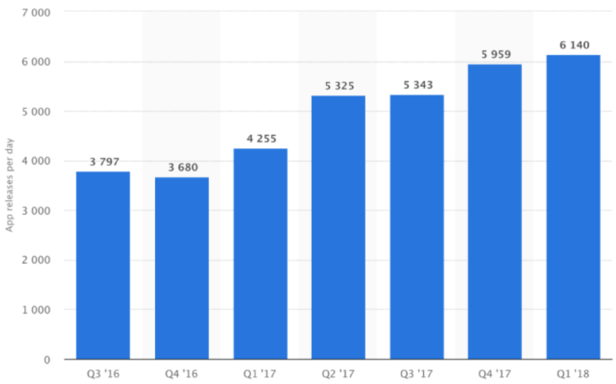

Figure 20 Average number of apps released every single day on the Android store. Source: Statista

Smartphones are clearly augmenting human capability by creating a seamless link to data in the web and providing a variety of applications and services supporting a broad range of augmentation, from overcoming distances to understanding a foreign language.

Every single day new applications are available, meeting needs in millions of niches. As shown in Figure 20, over 6,000 apps were released on the Android store[72] every single day in the first quarter of 2018. The number of apps released every day on the IoS store (Apple) was "only" 1,434, one fourth of those released on the Android store but still a mindboggling number.

Even more important from the point of view of impact on human augmentation is the usage: on average we use ten different applications every day and 30 different applications every month. The smartphone has become an extension of our brain.

The app market is increasing from $88 billion in 2016 to the expected $188 billion in 2020.

2.1.3 Symbiotic Technologies

2.1.3.1 Digital Twins

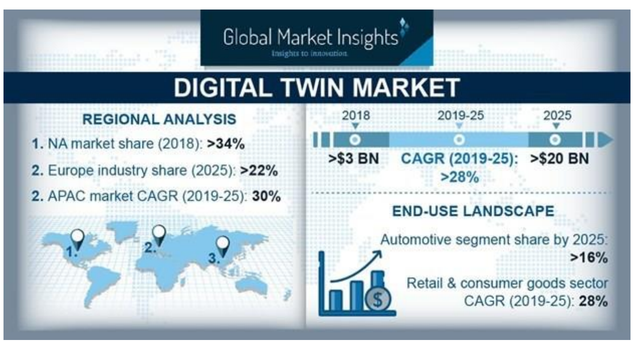

Figure 21 The Digital Twin market is expected to grow at a 28% CAGR till 2025 with strong uptake in North America, Europe and Far East Asia. Source: Global Market Insights

The Digital Twin market is possibly one with the highest growth, partly because it is both fueling the digital transformation and it is fueled by the digital transformation. Another reason is that the success of digital twins in areas like manufacturing and operation is pushing their adoption in other areas, with healthcare expected to adopt them in the next decade and education knowledge management following suit. In a way, digital twins are both a consolidated technology and an emerging one, both in terms of application areas and in terms of technology. Standardization is ongoing[73] and will play a role in their adoption and in market development.

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72 https://www.statista.com/statistics/276703/android-app-releases-worldwide/
73 https://www.iso.org/standard/75066.html

The global market value, as of 2018, is around $3 billion[74] (actually, digital twins include several software and hardware components, and there is no unanimous agreement on what to include - e.g., are CAD systems to be included? - , so different boundaries result in different market estimates) and is expected to grow to $26 billion by 2025[75].

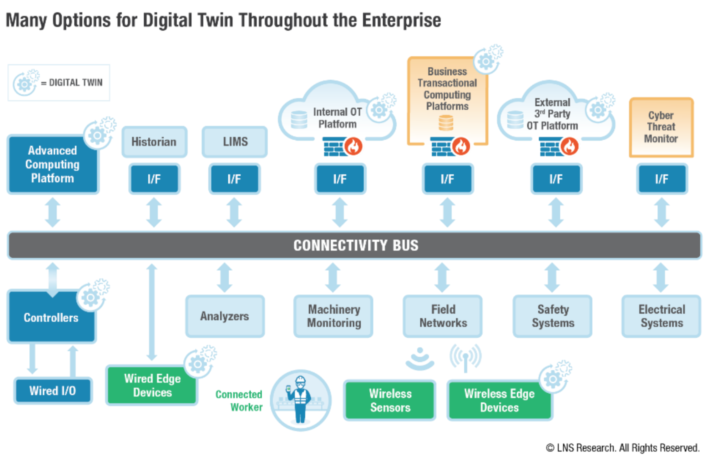

Figure 22 Digital Twins apply and support a variety of activities in the enterprise processes. In the figure are shown as mirroring controllers, wired and wireless edge devices –associated to operation activities- and computing platforms, internet IoT Platforms, Business Transactional platforms, and third party platforms. Source: LNS Research

Currently, in 2019, digital twins are becoming a consolidated reality in several enterprises in the value chain of product manufacturing, as shown in Figure 22. Notice in the figure[76] how digital twins can mirror the operation through mirroring sensors (and most IoT devices are now expected to be connected to cyberspace through digital twins) and on the other side digital twins can mirror enterprise processes. Several industries are now developing and providing platforms that become aggregators of third party applications by sharing services and data through digital twins (like Siemens Mindsphere[77]). This is important since these platforms stimulate adoption of digital twins and demonstrate the value of digital twins fostering the growth of the market.

Main players as of 2019 in the digital twin market are: Allerin, Altair, Amazon Web Services, ANSYS, Aucotec, Autodesk, CADFEM, HP, CoSMo Company SAS, Dassault Systems, DNV GL, FEINGUSS BLANK, GE, IBM, Mevea, Microsoft, Oracle, Bosch, SAP, Siemens, Sight Machine, TIBCO Software, Toshiba, and Virtalis.

Autonomous systems are already mirrored by digital twins (for example, a Tesla car), and it can be expected that most, if not all, autonomous systems in the coming years will be associated with a digital twin. In the next decade, digital twins can move to stage 4, where they become an integral part of a product delivering part of its functionality through cyberspace.
Eventually, the digital twins will reach a final stage where they detach from their corresponding physical entity and start having an independent life. While this may seem a science fiction possibility, there are already companies working on this feature.

Somnium Space[78] is the most famous example in the mainstream social VR ecosystem. It is a virtual world environment that is becoming available on all major VR and non-VR platforms, where ownership of virtual land and items is determined by blockchain technology. While the mix of XR and blockchain is not something new in the field (the reader can think about the examples of Decentraland and High Fidelity, for instance), the approach of applying AI/ML analysis on the behavior of its users is quite unique.

Users of Somnium Space can opt in for the "Live Forever" feature. When this modality is on, the system records and analyzes the behavior of the user in his/her own virtual property, feeding all user actions to a machine learning system. The AI engine will learn across the months how the user

[74] https://www.reuters.com/brandfeatures/venture-capital/article?id=68154
[75] https://www.grandviewresearch.com/press-release/global-digital-twin-market
[76] https://blog.lnsresearch.com/digital-twin-diverse-players
[77] https://www.plm.automation.siemens.com/global/it/our-story/glossary/digital-twin/24465
[78] https://www.somniumspace.com

behaves, what is his way of talking, what are his usual actions and so on, and in the end, it should be able to replicate exactly what the user does in the virtual space, even if he is actually not present anymore. The avatar will not be just a virtual puppet that the user can move anymore, but can become his alter ego, that can take action at his place. Even when the real person dies, the avatar can continue living in the virtual world, replicating his behavior, hence the name "Live Forever".

2.1.3.2 Simulation support

Part of the value of digital twins lies in the support of simulation. This is widely used in manufacturing and product design (discussed later in the White Paper in vertical industrial applications of digital twins). It is also becoming mainstream in the area of enabling virtual reality animation.

One of the most interesting startups working on simulations in virtual reality is Improbable[79]. The company is currently focused on offering SpatialOS, a framework to support the creation of multiplayer virtual worlds, but the same solution is also being used for running simulations of cities and other complex systems. The peculiarity of Improbable is that it can run a simulation of an environment including multiple AI and human-controlled entities in a way that is close to how a real complex environment works. For instance, the virtual world maintained by SpatialOS is persistent. If a player changes something in the environment, all other players will see it, not only some instant after the action has been taken, but also days or months after.

A virtual world flanking the physical world

The simulation is also continuous. Even when all the players have exited the game (e.g., at night), the virtual world continues being alive and evolves. This means that the virtual world has its own life, exactly as a real place, that continues evolving even if all people have stopped interacting with it. The third incredible feature is the quality of the simulation; it is able to combine the effects of every single entity on all the other entities and on the environment. SpatialOS is able to obtain the so-called "ripple effect": a little change in one of the entities in the world may create huge consequences in the future of the whole virtual environment. All these features combined together are very powerful and make the simulations offered by Improbable very realistic.

What Improbable has been able to obtain is incredibly complex and at the same time incredibly useful, not only for gaming. Imagine running a similar simulation on a city: the designers define the roads of the city, the traffic lights, and all people inhabiting it, along with their behavior patterns. Then they let the simulation run for (virtual) days and can examine if that particular urban scenario performs well, or if over time it creates problems, like too many accidents or traffic jams. The tools offered by Improbable are crucial to be able to predict the consequences of a particular design of a virtual world.

An example of simulation application to AR/VR is provided by I-see[80], an Italian company that offers solutions to simulate, preview, evaluate and analyze the effects of radiation produced by equipment in specialized therapeutic centers on human tissue. These simulations allow the creation of therapeutic centers (e.g., radiation rooms) that are the safest possible for the people that should utilize them. Since the simulation is all conducted virtually, it is possible to spot problems in the design of the room or the devices utilized before having even started constructing them, sparing much money that would be wasted if a problem would have been detected after the construction.

[79] https://improbable.io

[80] www.i-seecomputing.com/

2.1.3.3 AR Cloud

One of the most important technologies for the future of augmented and mixed reality will be what Ori Inbar calls the "AR Cloud", and other names such as "Mirror World", "Cyberverse", "MagicVerse", and "Metaverse".

These many names express the same single concept, that is a virtual world that:

1. Has a one-to-one matching with the real world;
2. Is persistent;
3. Is shared between people.

The AR Cloud is how everyone of us envisions the future of AR: a virtual overlay on the real world that every person shares with all the other people. It overcomes the current limitations of AR, that at the present time is an experience mostly confined to room environments and shared only between selected people (e.g., our friends or colleagues). With the AR Cloud, the whole world becomes the stage for AR applications, and the elements of the augmented reality applications will be pinned to exact locations of the world.

As an example, consider the power of the AR Cloud that matches the virtual world with the real one: one person wearing a pair of AR glasses can wait for the bus at the bus station, only to discover that no bus is passing by. He can leave an AR message in that place, so all people approaching that bus stop may see that that stop had been suppressed and so go to another one. As you can see, the virtual elements left by the first person are fixed in a physical location and are shared between all people, even the ones that don't know each other. This is the power of the AR Cloud.
Realizing the AR Cloud is very difficult, but many companies are working on it. It requires solutions problems like:

- **The creation of a digital twin of the real world.** To create a one-to-one mapping between the real and the virtual world, a full mesh of the real world is required, so that the two worlds can be registered one with the other. When a user puts a digital element on a street, he is not putting it in the real street, but in the virtual replica of that street that must exactly match the real one, to make the mixed reality coherent. Creating such a mesh is a complex task, but companies like 6d.ai and Scape are developing it. 6d.ai is exploiting the rear cameras of all the smartphones used by its users to reconstruct the mesh of the environment around them. All these little meshes get sent to 6d.ai servers which stitches them together until all the mesh of the world is obtained. Google and Apple are instead working on a more top-down approach by directly scanning the places of interest;

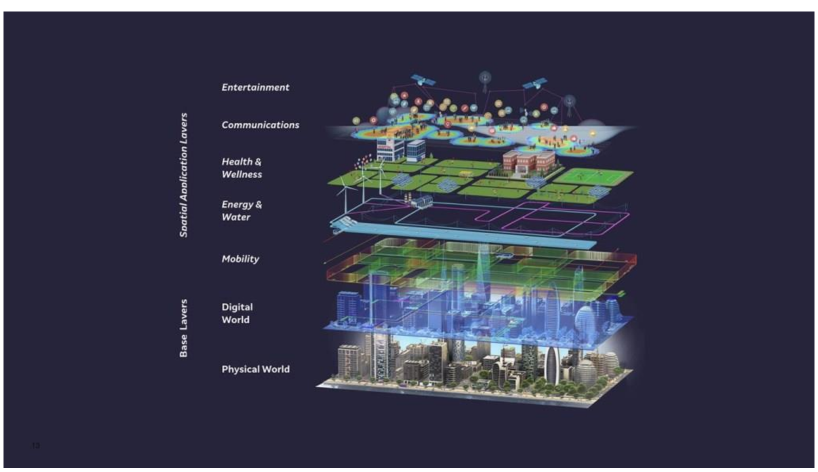

Figure 23 A layered approach to rendering. The physical layer can be overlaid by information created/available in the Digital World. This ensemble is then displayed according to the vertical application needs. Image credit: Antony Vitillo

- **The creation of digital layers inside the virtual world.** In every single real place, there could be many virtual applications running. A bus stop, for instance, may be running the AR applications of the public transport company, to show information to the passengers; may be running some games like Pokemon Go, where some Pokemons may be located; may be running some map apps, that show routes to users. Each one of these applications belong to a different layer of AR applications running all in the same physical place. There is a one-to-many mapping between a physical place and its corresponding virtual layers (see Figure 23);

- **The ability to filter content.** No user wants to see too many notifications. If every physical location corresponds to many virtual layers and thus many AR applications, every location is full of associated AR elements. To reduce the possible cluttered mixed reality, the system needs to filter AR content depending on the requirements of the user. There should also be the possibility of blocking dangerous and offensive content;

- **Privacy concerns.** Always-on cameras that record the environment and send information to a central location are dangerous for our privacy. These cameras could also be inside our houses, sharing details about our personal life with external companies. This should be regulated;

- **Glasses damage.** In a future where people will always live in a mixed reality world, what will happen when glasses won't work anymore and one needs to live without the precious digital information shown in front of the eyes?

According to market analysis agency Gartner and John Gaeta who is working on the Magicverse at Magic Leap, the AR Cloud will need 5 to 10 years to be fully realized[81].

2.2 Manufacturing (including related logistics)

The digital transformation has started to change the whole manufacturing industry. Devices, machines and computers on both the shop floor and the office floor are connected, communicate with each other and produce a huge amount of data. Increasing computational power combined with new and improved technologies like AI and digital twin allows decision making without or at least with less human involvement. Machines become smart and act autonomously, supported by sensor data to perceive the environment and by several communication channels to get context information of neighboring software systems and Cyber-Physical Systems. These smart machines intentionally act and in return provide information to other machines and systems. Data analytics, machine learning and enhanced simulation skills are examples of technologies which allow decision making and improved operation on higher system levels. The economical goal behind these developments is not only the improvement of the golden triangle, costs, quality and time, but also a new dimension in flexibility, often referred to as mass customization or lot size one. This increased flexibility addresses both product development and production topics.

Initiatives in many Countries to transform manufacturing

This transformation has already started, beginning in 2011 under the name Industrie 4.0 in Germany and comparable activities worldwide like Industrie du Futur in France, Made in China 2025, or Robot Revolution Initiative in Japan. The business value is huge; in a study of Roland Berger[82] a gross increase of +25 percentage points in ROCE is expected following the transition to Industrie 4.0 for an industrial business through 2035. In the same time 10 million jobs could be recreated or shifted with a positive net effect. The digital transformation will affect all areas of production (discrete manufacturing, process industry as well as hybrid industries) and related domains like logistics. In a digital factory we will see integrated approaches to enhance the product and the production engineering and manufacturing processes - the product will control its production, enabled by autonomous production machines and cells which cooperate in a symbiotic way.

[81] https://skarredghost.com/2019/09/04/augmented-reality-mature-gartner/ and https://skarredghost.com/2018/10/31/magic-leaps-john-gaeta-talks-about-the-future-of-cinema-storytelling-and-mixed-reality/
[82] https://www.rolandberger.com/de/Publications/The-Industrie-4.0-transition-quantified.html

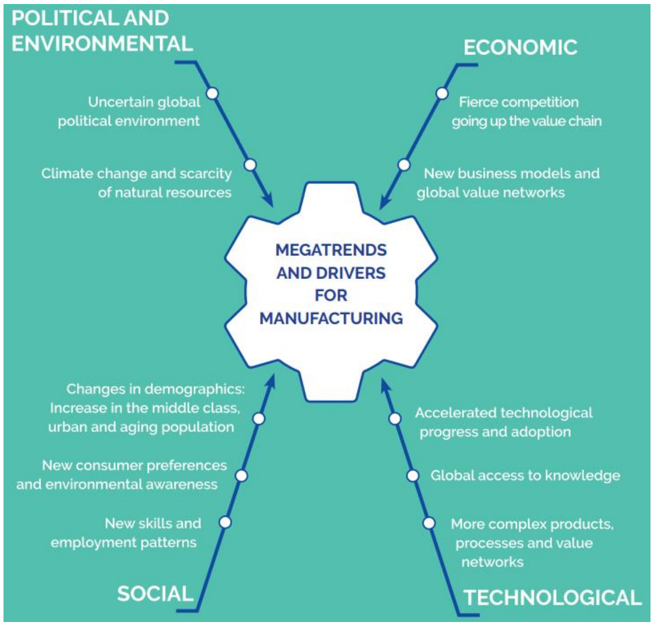

Figure 24 Megatrends and main drivers in manufacturing. Source: ManuFuture

The progress in technology is important but there is a shift in business models as well. Value creation is increasingly shifting from production to services[83] with two different perspectives, including first, production as a service and services like diagnostic functions and second, predictive maintenance which is based on measurements from an increasing number of sensors. Digital artefacts and models (also called digital twins) will become an asset and form a new ecosystem. The figure from ManuFuture[84] (Figure 24) shows the megatrends and main drivers for manufacturing.

Increased autonomy in all areas of manufacturing and all hierarchical levels (from devices, machines to production networks and logistics) is the key technological lever for manufacturing of the future. The synergetic and symbiotic behavior of these machines and systems will be a decisive factor in the digital transformation.

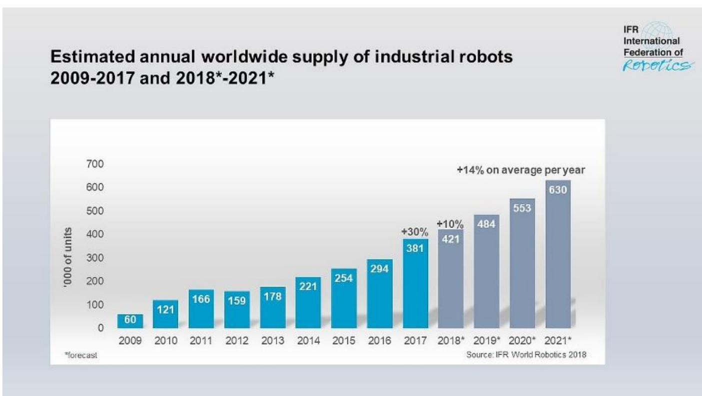

Figure 25 Industrial robots deployed in manufacturing plants worldwide. Source: IFR World Robotics 2018

Robots are impersonating the idea of autonomous systems in our imagination. The first robot to enter a manufacturing plant was back in 1961 where it started working at the General Motors assembly line in Ewing. In these last roughly 60 years, robots have become pervasive in most manufacturing sectors and in many cases production will not be possible without robots (particularly in most consumer electronic products). They have increased in number, in flexibility and in autonomy.

The major areas of application are automotive, electronics and metal industries[85]. In terms of geography, Far East Asia is leading (4 times the European market and over 6 times the North American market), with China being the biggest market, followed by Japan and South Korea. In Europe Germany is leading followed by Italy and France. In the Americas, US is leading with Mexico growing rapidly.

The pharmaceutical and cosmetics industries are seeing a significant uptake of robots followed by food processing industry.

[83] https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/digitale-geschaeftsmodelle-fuer-industrie-40.html
[84] http://www.manufuture.org/strategic-research-agenda/vision-2030/
[85] https://ifr.org/downloads/press2018/Executive_Summary_WR_2018_Industrial_Robots.pdf

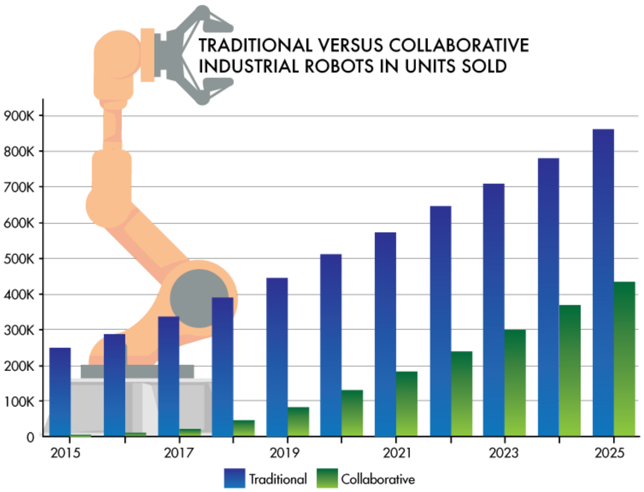

Figure 26 Cobots are starting to be deployed and their growth is foreseen to be faster than the growth of robots. In the longer term they may be replacing today's robots. Image credit: Kuka

In 2017 there were 2.1 million industrial robots in operation; the expected figure for 2019 is around 2.778 million. In 2017 there was a robot density on average of 85 robots per 10,000 workers worldwide, with Europe showing a higher density (106 robots per 10,000 workers) but South Korea having a record of 710 robots per 10,000 workers (Germany has 322 robots per 10,000). Notable is China increase from 11 robots to 97 per 10,000 over a period of 8 years.

Manufacturing is now entering a new stage of robotics, with the deployment of collaborative robots known as cobots. Cobots are designed to collaborate with humans as well as with each other. Already operational in several manufacturing plants and in logistics, they have demonstrated a decrease in the number of accidents since it is no longer just the worker that needs to pay attention and be situationally aware but also the cobots. Logistics is expected to drive innovation and growth of cobots.

This market was valued at close to $650 million globally in 2018 and is expected grow at a 44% CAGR[86] in the period 2019-2025 to reach 10 billion $ in 2025[87].

Cobots are classified in three categories, depending on their payload, i.e., below 5kg, between 5 and 10kg, and over 10kg. These latter are the ones with the highest expected CAGR of 46%.
The fastest growth is foreseen in the automotive, electronics, packaging/assembling and logistics fields.
The uptake of Industry 4.0 with its integration of the various phases in the value chain may further push the adoption of collaborative robots, and MarketsandMarkets estimate[88] the cobot 2025 market value to reach 12.3 billion due to the rapid adoption of Industry 4.0 paradigms. The term "paradigm" is used since the effective use of cobots requires a rethinking of the operations on the manufacturing plan, with a re-organization of the work flow and a re-training of workers that have to become "symbiotic" with their robotic colleagues.

This is possibly one of the biggest challenges for industry. Additionally, Industry 4.0 goes hand in hand with the Digital Transformation process, affecting both workers and robots/cobots. They all need to interface and collaborate with cyberspace. Digital twins are becoming part of this process and should be considered when evaluating the market. The figures provided here reflect the physical world market value. The Digital Transformation will shift and add value in cyberspace.

The exoskeleton market is a further, important area of autonomous/symbiotic systems in manufacturing with a market value expected to exceed $1 billion in 2022 and reaching $5.8 billion in 2028[89].

[86] https://www.grandviewresearch.com/industry-analysis/collaborative-robots-market
[87] https://www.grandviewresearch.com/press-release/global-collaborative-robots-market
[88] https://www.marketsandmarkets.com/PressReleases/collaborative-robot.asp
[89] https://www.roboticsbusinessreview.com/research/exoskeleton-market-projected-to-reach-5-8b-by-2028/

The market value in warehouse (logistics) management[90] represented more than $1.2 billion and it is expected to grow to $6 billion in 2025.

2.3 Health care (including hospital management)

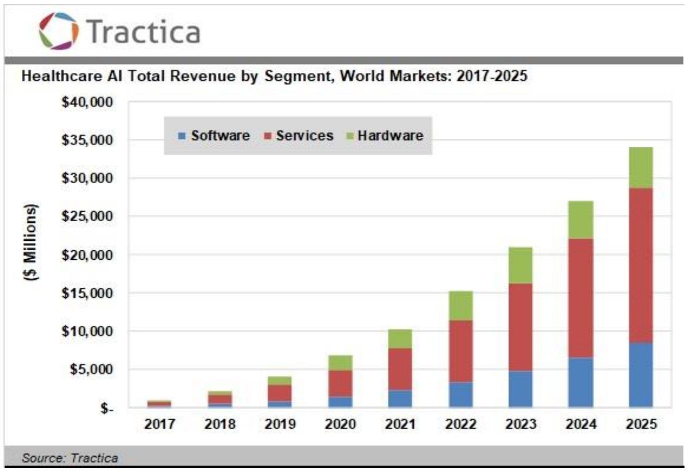

Figure 27 Rising market value of Artificial Intelligence in health care, segmented in software, services and hardware, with services showing the highest growth. Source: Tractica

Autonomous systems in healthcare are primarily robots (including autonomous implanted devices operating with sophisticated algorithms fed by local sensors data, like insulin delivery reservoirs), however there is a growing interest in soft robots (software systems) that can provide health care assistance.

AI is a growing component in autonomous systems for the health care domain expected to lead to a global market value of $34 billion by 2025[91] ($2 billion in 2018) – see Figure 27. The medical app market, presently mostly unrelated to (soft) autonomous systems will progressively become more entangled with soft autonomous systems for proactive healthcare due to sensors, cloud processing and AI. The application market (overall, including all types of medical apps) is expected to reach $11.22 billion in 2025[92].

Autonomous robots in healthcare can be segmented into assistive, rehabilitation, humanoid, delivery, implanted, surveillance and security (these latter obviously apply to other sectors as well). The global assistive robot market value was $359 million in 2018 and is expected to reach $1.2 billion in 2024[93]. A further expansion of the assistive robot market may come from humanoid robots, so far an area of research with several demonstrations, raising significant interest in Far East Asia. There is an expectation of reaching a market value exceeding $5 billion in 2024[94]. It is clearly a market dominated by AI, affective computing and autonomous systems whose uptake is rooted in specific culture and if successful will expand to other cultures.

The global rehabilitation robot markets, $641 million in 2018 (with cognitive and motor skill rehabilitation having a $87.1 million market value in 2017[95]), is expected to grow significantly reaching $6.4 billion in 2025[96] as autonomous robots are expected to replace part of the human therapist. A further push in this direction might result from the emergence of digital twins, mimicking the patient functionality "before" the pathology/trauma and then using that starting point to automatically through software develop the customized rehabilitation protocol to be assisted by the robot.

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[90] https://www.prnewswire.com/news-releases/mobile-logistics-robot-market-to-reach-11-26-bn-globally-by-2025-at-21-2-cagr-allied-market-research-300806631.html
[91] https://www.tractica.com/newsroom/press-releases/healthcare-artificial-intelligence-software-hardware-and-services-market-to-surpass-34-billion-worldwide-by-2025/
[92] https://www.prnewswire.com/news-releases/global-mobile-medical-apps-market-to-reach-1122-billion-by-2025-reports-bis-research-674813873.html
[93] https://roboticsandautomationnews.com/2019/01/21/healthcare-assistive-robot-market-to-surpass-1-2-billion-by-2024/20618/
[94] https://www.marketwatch.com/press-release/humanoid-robot-market-will-generate-sizeable-revenue-from-healthcare-sector-by-2024-2019-05-23
[95] https://www.globenewswire.com/news-release/2019/01/09/1682603/0/en/Healthcare-Assistive-Robot-Market-will-expand-at-19-CAGR-to-hit-1-2-Bn-by-2024-Global-Market-Insights-Inc.html
[96] https://www.prnewswire.com/news-releases/global-rehabilitation-robots-market-shares-strategy-and-forecasts-report-2019-market-size-at-641-million-in-2018-and-is-expected-to-grow-dramatically-to-reach-6-4-billion-by-2025--300813189.html

These figures do not include exoskeleton based rehabilitation ($130 million in 2018[97] including exoskeleton acting as prosthetics, with several –mostly US- companies on the market[98]) that may also gain traction in the next decade. Most of exoskeleton market is primarily focusing in augmentation (fatigue relief) in industry, manufacturing and maintenance (see Section 2.2).

The market of non-surgery robots in operation in the healthcare sector is expected to reach 60,000 units by 2025, from 15,000 in 2018[99].

The implantable device market in healthcare is huge, expected to reach $49.8 billion in 2024[100] (from $34.7 billion in 2018). Clearly, many of these devices are not smart autonomous systems, but the general trend is to equip them with sensors and processing capability to support more sophisticated protocols.

2.4 Retail

Autonomous robots and more generally autonomous systems (including softbots) are making progress in the retail space, from robots able to spot misplaced or low stock items[101] on shelves and incorrect pricing[102], to robots selling product lines, like Nestlé's Pepper[103], robots assisting customers and robots manning the shop 24-hours a day[104]. Delivery robots have been covered as part of delivery in Section 2.2.

The global market is already huge, estimated at $20 billion in 2018 and is expected to have a 12.7% CAGR in the 2018-2028 period, see Figure 28.

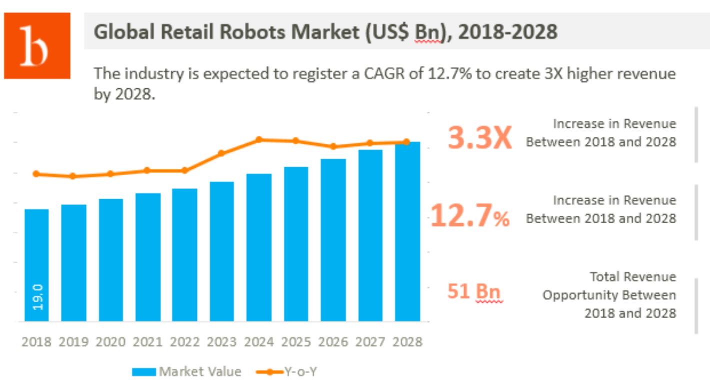

Figure 28 The global robot market in the retail space. Most of the drive is related to decreasing cost in retail operation. Source: Bekryl

Notice that growth is expected both in those countries that already have widespread deployment, like Japan, South Korea and the US, and by adoption in other countries. The cost of these systems is expected to decrease in the next decade, and more integration with the value chain will become possible, fueling adoption. Also, it is expected that evolution in functionalities will make part of these systems interact with customers, becoming sales agents. This is an area where evolution of product digital twins and personal digital twins may drive adoption and will benefit both sellers and consumers.

Interactions may take place in cyberspace, mediated by digital twins and on the shop floor, where digital twins serve as customizer agent, often making use of augmented reality[105]. According to

[97] https://www.prnewswire.com/news-releases/global-wearable-robots-exoskeletons-market-2019-2025-industrial-exoskeleton-devices-positioned-to-serve-commercial-wearable-as-purposes-military-exoskeleton-markets-shift-300796553.html
[98] https://aabme.asme.org/posts/robotic-exoskeletons-for-physical-rehabilitation
[99] https://www.roboticstomorrow.com/story/2019/07/abb-robotics-to-develop-solutions-for-the-hospital-of-the-future/13865/
[100] https://www.medgadget.com/2019/01/implantable-medical-devices-market-innovation-could-make-medical-devices-even-more-amazing-whats-behind-the-increased-market-demand.html
[101] http://fortune.com/2016/04/28/target-testing-robot-inventory-simbe/
[102] http://www.businessinsider.com/walmart-robots-in-50-stores-2018-3
[103] https://www.roboticsbusinessreview.com/health-medical/softbanks-robot-pepper-rolls-despite-doubts/
[104] https://www.twice.com/retailing/meet-chloe-best-buy-s-one-armed-checkout-gal-58761
[105] https://www.alliedmarketresearch.com/augmented-reality-in-retail-market

Global Market Insight, retail will be the third market[106] by value for AR, after industry and automotive.

2.5 Finance

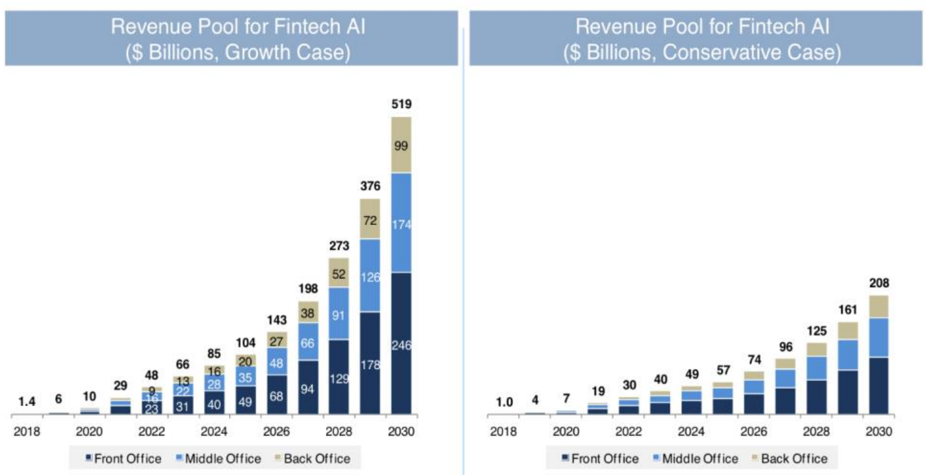

Figure 29 Aggressive and conservative market estimates for autonomous systems and artificial intelligence in the Fintech market. Revenue pool for AI start-ups is to reach 500 billion $ by 2030, exceeding 100 billion $ by 2025 in the aggressive growth estimate – US market. Source: Autonomous Next

Historically, the financial and insurance services sectors have been quite resistant to technology disruption. However, this is no longer the case as the waves of digitization, financial technology (FinTech) and insurance technology (InsuranceTech) are rapidly transforming the financial and insurance services industry[107]. This is evident in the momentum and tangible growth of FinTech/InsuranceTech enterprises and in the volume of relevant investments: Over $23 billion of venture capital and growth equity has been allocated to FinTech innovations during 2011-2014, while $12.2 billion was deployed in 2014 alone. Moreover, a recent McKinsey & Co study revealed that the number of FinTech startups in 2016 exceeded 2.000, from approx. 800 in 2015[108]. Furthermore, the vast majority of global banks and investment firms have already planned to increase their FinTech/InsuranceTech investments with a view to yielding a 20% average return on their investments. Beyond FinTech/InsuranceTech, financial institutions and insurance organizations are heavily investing in their digital transformation, as a means of improving the efficiency of their business processes and optimizing their decision making.

Today, finance is a business in cyberspace. Autonomous Agents (AA) and AI have already changed the landscape and will further change it in the next decade. Kensho's Artificial Intelligence Investment Analyses platform has been acquired[109] by S&P for $550 million, the largest price tag on an AI engine. Both AA and AI are utilized in Augmented Finance where software based reasoning is taking the lead. Although unnoticed by the general public, the digital transformation in the financial arena is changing the landscape.

As of 2018 in the US, there are some 2.5 million people working in financial institutions (including banking, investment, and insurance) ,and AA/AI is expected to have an impact in the range of a $1 trillion[110], $490 billion of which in the front office, $350 billion in the middle office and $200 billion

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[106] https://www.gminsights.com/industry-analysis/augmented-reality-ar-market

[107] Miklos Dietz et. Al., "Cutting through the noise around financial technology", McKinsey & Co, February 2016 and PwC, "Redrawing the lines: FinTech's growing influence on Financial Services", Global FinTech Report 2017, available at https://www.pwc.com/jg/en/publications/pwc-global-fintech-report-17.3.17-final.pdf

[108] https://www.mckinsey.com/~/media/mckinsey/industries/financial%20services/our%20insights/bracing%20for%20seven%20critical%20changes%20as%20fintech%20matures/fintechnicolor-the-new-picture-in-finance.ashx

[109] https://next.autonomous.com/augmented-finance-machine-intelligence

[110] https://autonomous.app.box.com/v/augmentedfinance

in the back office. Personal consulting agents, that can take the shape of Alexa, are now starting to revolutionize the front office.

As shown in Figure 29, the foreseen revenue out of AA/AI (in the US) may be reaching an aggressive estimate of $500 billion signaling a shift from the money saved using AA/AI to companies providing fintech services through AA/AI (most of these companies are newly created companies). Notice that in the finance industry, the digital transformation is not acting on a product, rather on services and the processes used in the "manufacturing" of these services. The shift in value also corresponds to a loss of jobs (see Section 4.5).

Although both AA and AI are the technology building blocks of Augmented Finance, AI takes the lion's share since it is the one that is analyzing data, evaluating risk and perspectives, and enabling more intelligent and automated processes, along with personalized services that are tailored to customers' needs.

This holds true for applications in different areas such as retail banking, corporate banking, payments, investment banking, capital markets, insurance services, financial services security and more. All of these applications leverage very large datasets from legacy banking systems (e.g., customer accounts, customer transactions, investment portfolio data), which they combine with other data sources such as financial markets data, regulatory datasets, real-time retail transactions and more.

AA are more executors, both locally and across a network. These characteristics of AA to exist locally and roam networks makes them applicable to a variety of contexts, becoming more a sort of commodity, hence limiting their market value. Besides, since they can be applied to a variety of contexts and they are network entities, it is foreseen that the major market value is found in telecommunications applications, particularly in the management of distributed resources. The global market value is estimated in $345 million in 2019 to grow to almost $3 billion in 2024[111].
A further segment of interest is the one of Neobanks, banks that exist only in the cyberspace. They are quite widespread in Europe and are on the rise in other geo-markets. This is a rapidly growing market, with funding growth from 750 million $ in 2017 to 2.2. billion $ in 2019[112] – see Figure 29. Furthermore, chatbots are widely used. The old style brick and mortar banks are upgrading their services and streamlining their processes by embracing the digital transformation. Digital banks (not owning any brick and mortar location but backed by large financial institutions) have been around for a while and are leveraging autonomous systems. The Neobanks[113] are based on a new model, completely relying on mobile access. They have not been born through a digital transformation of an existing company, but are newly created digital companies. As of 2018 the number of clients was in the order of a few million in Europe, with Revolut topping the list with 1.5 million customers[114] and 3.5 million in the US[115]

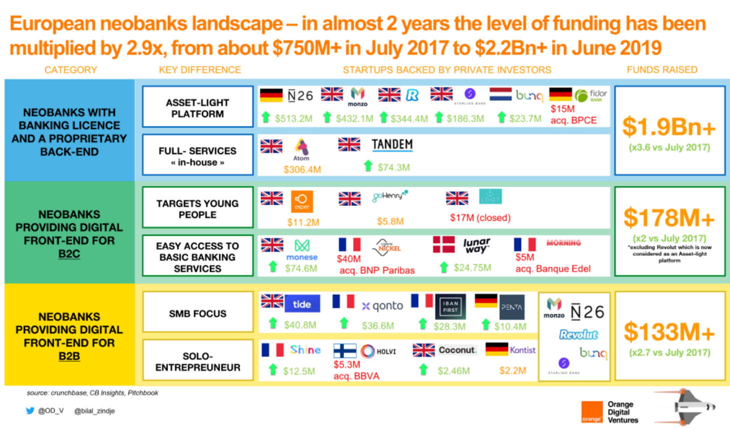

Figure 30 European Neobanks landscape. Source: CB Insights

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[111] https://www.marketsandmarkets.com/Market-Reports/autonomous-agents-market-201425821.html
[112] https://medium.com/@bilal.djelassi/full-stack-neobanks-are-taking-the-retail-banking-market-to-the-next-level-cc0f3d2692dd
[113] https://www.nielsen.com/au/en/insights/article/2019/market-ripe-for-neobank-success/
[114] https://www.businessinsider.com/uk-neobank-market-reached-critical-juncture-2018-3
[115] https://www.forbes.com/sites/ronshevlin/2019/02/07/consumers-saved-5billion-with-acorns-and-stash/#7236be232def

with a $1.58 billion in deposit (which is very small representing only 0.014% of all deposits in US banks).

The Fintech transformation, as in several other areas hit by the Digital Transformation is not, per sé, creating new value, rather it is decreasing the overall market value. By disintermediating the front office fintech apps have saved $5 billion to US consumers which translates to a $5 billion decrease in the Fintech market.

2.6 Transport

Autonomous systems in transportation can be segmented into public transportation systems, car rental and sharing systems, industrial (goods) transportation and private transportation. They can be further segmented in ground, air and water transport.

Overall the autonomous systems market in transportation is expected to reach a global value of $172.3 billion in 2024[116]. This estimate includes the autonomy level from 3 to 5, with 5 being full autonomy (this is not expected to be in place for private vehicles in the observation time frame). In addition to technologies listed in Section 2.1.1 (Machine Augmentation), autonomous systems in transportation will leverage and give a market boost to GIS/mapping, geo-fencing, and edge computing.

The global self-driving (level 5) cars and trucks market is expected to reach 6.7 thousand units in 2020[117] growing at 63.1% CAGR in the following 10 years to hit 700,000 vehicles sold in 2030. Notice that these figures relate to fully autonomous vehicles (level 5). Much higher numbers apply to lower autonomy levels.
There are several factors that may significantly modify these estimates, from regulatory framework to technology evolution, particularly LIDAR, image recognition, ambient infrastructures and battery cost/performance. The expected reduction in insurance costs to one-fifth of traditional insure costs is driving rapid adoption[118]. In the long term, 20 years, once the ratio of fully autonomous vs other vehicles swaps, the insurance cost of non-autonomous vehicles may surge to take into account the lower volumes which can further push the adoption of fully autonomous cars. However, for the coming years the market will remain negligible.

Autonomous vehicles will be electrical powered. The merging of the autonomous with electrical will change the whole value chain[119] and even more importantly, is bound to change the perception of mobility, from ownership to service, but this is going to happen beyond the horizon of this White Paper.

The segment of self-driving taxis will see a fast growth worldwide with over 100,000 fully autonomous taxis by 2022[120] with 42% located in the US.

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[116] https://www.prnewswire.com/news-releases/global-172-3-bn-autonomous-vehicle-markets-2019-2024-long-haul-trucking-market-will-grow-at-a-cagr-of-over-60-300818667.html
[117] https://www.grandviewresearch.com/industry-analysis/driverless-cars-market
[118] https://medium.com/the-ferenstein-wire/how-much-the-self-driving-version-of-your-car-will-save-on-insurance-in-1-graph-16ebcc27f26e
[119] https://transportationops.org/sites/transops/files/SOA%20FINAL%20market-framework-automated-vehicle.pdf
[120] https://www.businesswire.com/news/home/20180912005626/en/Global-Self-Driving-Taxi-Market-2018-2022-Key-Facts

On water, the autonomous ship market is estimated at $6.1 billion in 2018 growing to $13.8 billion in 2030[121]. The main driver is increased safety in operation. The slow growth is due to the long life span of ships; such that existing ships are not decommissioned for a long time.

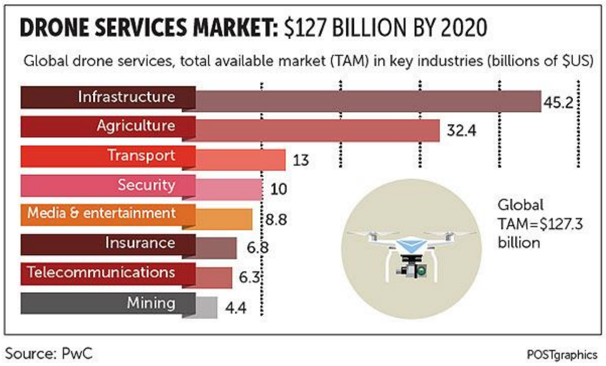

Figure 31 Segmentation of the drone service market at year 2020. Source PwC

Transportation based on autonomous drones is just beginning. It is expected to reach $11.2 billion in 2022 and $29.06 billion in 2027[122]. The segment of under 5kg payload has the highest expected growth with the market leaders in the Asia/Pacific area followed by North America.

Notice, however, that the service market for drones is much bigger, expected to reach $120 billion in 2020 from $2 billion in 2016 (see Figure 31). As noted in Section 2.1.1.8 the largest share of the market is in infrastructure surveillance followed by agriculture.

The transportation market follows with an estimated value at $13 billion Total Available Market (TAM).

2.7 Education

The education sector will continue to increase use of AR and VR and later, of cognitive digital twins. These three technologies/services area make use of both AA, AI and learning experience platforms.

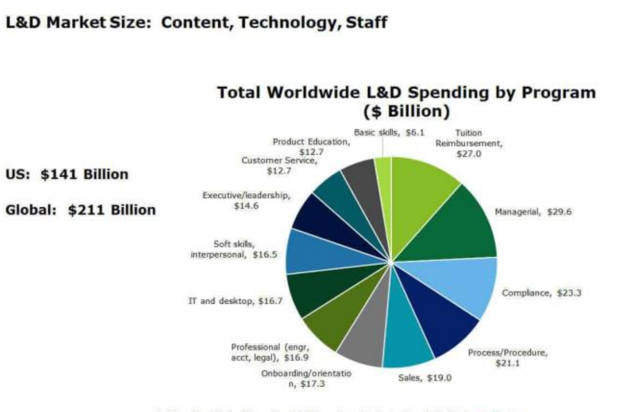

Figure 32 Worldwide learning spending. Source: Josh Bersin

One of the most rapidly growing markets is professional education and knowledge gap management for companies, with corporate learning tools having reached a $19 billion market value worldwide[123]. In 2018 the market value for Learning and Delivery (L&D) reached $211 billion worldwide (see figure 32 for the market spending segmentation).

Knowledge as a service (KaaS) will start to become a significant market in the next decade, beyond the horizon of this White Paper. It is mentioned here since it was specifically addressed in the second White Paper.

Organizations are not helpless when facing unintended biases. Alibaba founder Jack Ma demanded at the World Economic Forum: “Everything we teach should be different from machines.” Explicitly he mentioned values, beliefs, independent thinking, teamwork and care for others. This would be ensured by a holistic educational approach such as STREAM (Science, Technology, Reading, Engineering, Arts and Mathematics). Information leads to empathy, as it may push individuals outside their information bubbles and show the consequences of the planned behavior. As for all

[121] https://www.marketsandmarkets.com/PressReleases/autonomous-ships.asp
[122] https://www.researchandmarkets.com/reports/4542228/drone-logistics-and-transportation-market-by
[123] https://joshbersin.com/2018/06/degreed-pathgather/

aspects of corporate culture, it is imperative to instill a "tone from the top" by the CEO and other top management, which not only requires employees to do the right thing, but also adequately encourages and empowers them. The more tasks that become automated, the more important the knowledge and behavior of the existing employees. Due to this, many companies foster responsibility and accountability inside their interactive training sessions. The employee's authority is documented in the organizational approval matrix, an important document to define where the employee is positioned inside the company's hierarchy.
Applied education fosters confidence. Companies can support knowledge by requesting employees to participate in continuous learning. IBM and Mitsubishi Heavy Industries predict that blue and white collar employees will jointly evolve into "new collar". A holistic concept where employees use both their hands and mind.[124] In this concept the boundaries between white and blue collars are vanishing and Industry 4.0 grows in offices, factories and workshops. The employee's knowledge needs to be continually updated to keep up with the requirements.

Continuous education in times of changing job profiles not only requires new content, but also new ways of learning and teaching. Similar to manufacturing devices, the company's human resources department could manage digital twins for each employee. Such twins may include proven skills, observed behavior (for example from a used Exoskeleton or AR glasses) and even health information provided by wearables. AI can combine this data to predict the employee's career path and identify gaps on the way. The algorithm can autonomously identify adequate in-person or Massive Open Online Courses (MOOCs)[125] and set them up as mandatory tasks inside the employee's tasks manager application. Similar to micro-learnings, the AI may customize individual training plans to be tailor-made for each employee. For the case that the AI discovers that actual skills and behavior are necessary for the employee's further career inside the organization, the algorithm can execute intelligent nudging to inform the employee about the situation, or even autonomously (if this complies with local labor laws) terminate the contract with the individual.[126]

Training has two tasks, to transport information that is required to build up skills and to motivate employees. The first task, information, can be provided by online-training.

If new skills or knowledge is required, employees may practice either inside a virtual reality or in a physical environment. The best alternative may be a combination of the two, as the first steps can be trained in a simulation that employees then use to further build the skills in a physical training center. Since individuals appreciate the contact with other humans, in-person training is still required, especially for change-management and motivation. AI may reduce the number of teachers but will not completely replace them. Nevertheless, this is not a binary decision between algorithms and humans. Standardized online-training may include at some point a human teacher to foster the interaction and motivation of the student. Alternatively, human teachers will be connected to online knowledge and may utilize single modules organized by a virtual teacher, for example, or let the students do their homework inside an online portal. Human teachers can have an online chat-bot to answer questions, or the other way around, an autonomous global training program can include local workshops moderated by a human.

[124] https://spectra.mhi.com/meet-manufacturings-new-collar-workers
[125] http://mooc.org/
[126] https://www.theverge.com/2019/4/25/18516004/amazon-warehouse-fulfillment-centers-productivity-firing-terminations

3 INDUSTRY ADOPTION

3.1 Manufacturing

Manufacturing[127] is the area where automation has made big strides since the last century. Autonomous lathes and autonomous robots have become common and are prominent flagships of a rapid development. In the last few years, a new generation of robots can manage complex manufacturing processes building/assembling components and whole products in complete autonomy with no human supervision. FANUC[128], a Japanese company focusing on manufacturing automation delivers robots that need supervision just once a month, and an entire manufacturing plant may run autonomously.

To illustrate how digital transformation is changing manufacturing, it is important to understand the traditional manufacturing components:

1. Equipment on the floor that vary in the degrees of sophistication, automation, footprint on the factory floor, and role in the end-to-end manufacturing process.
2. The plant's physical building including electric power, air-conditioning systems, water systems, closed-caption TV, etc.
3. Computing resources required for all types of control, computation, data manipulation and dashboarding – includes servers, desktops, storage, network, tablets and more.
4. Processes and workflows designed to control the flow of operations inside and outside the plant.
5. Crossing of the value chain (Product Lifecycle Management and Production System Lifecycle Management) creates challenges in speeding up the manufacturing of new products and ensuring flexible and high-quality production.
6. Human resources required to run/manage/maintain the equipment, the supply chain, logistics as well as the plant as a whole.
7. The ecosystem to enable the plant to function including suppliers, partners, distribution and logistics, and consumers.

In a smart manufacturing plant, the digital transformation will impact all of the above, as follows:

1. Equipment will become more intelligent, able to make autonomous decisions, to continuously generate data reflecting their health, to call for help before one (or more) of their parts breaks or is about to fail, to communicate with their upstream and downstream neighbors in the manufacturing chain and to adjust their speed to deliver and guarantee a smooth flow, and more. As such, Cyber Physical Systems (CPS) possess a great deal of autonomy; they will require minimal or no human interaction at all. In other words, the synergetic and symbiotic behavior of equipment will be a pivotal factor in the smart manufacturing.
2. The plant's physical building infrastructure, similar to the equipment above, will also be able to make autonomous decisions, continuously generate data reflecting its health and call for help before they fail. They also need to cooperate to reduce energy consumption, reduce pollution and impact on the climate, inform about risks in the plant, but also reduce cost of operations and Total Cost of Ownership (TCO).
3. Computing resources, collectively, will have the task of establishing full visibility to everything inside the plant, own the intelligence to analyze the data generated from the plants' extensive infrastructure, deliver actionable decisions affecting the whole plant or one of its components (e.g., equipment), inform about all safety, hazardous and security aspects of the plant and make appropriate decisions, provide reporting and dashboarding to the businesses and more. To accomplish the above, the hardware and software stacks of such computing resources need to be augmented to be able to process very large amounts of data on whatever the

[127] Rosen, R., Fischer, J., Boschert, S. (2019). Next Generation Digital Twin: An Ecosystem for Mechatronic Systems? In: 8th IFAC Symposium on Mechatronic Systems MECHATRONICS 2019: Vienna, Austria, 4—6 September 2019.

[128] https://www.fanuc.eu/it/en/industrial-applications

required timescale is (e.g., real-time, semi-real-time or best effort). Intelligence including Machine Learning (ML) or Deep Learning (DL) need to be present and tailored to the specifics of the plant including business, production, vision and safety.

4. Processes will be redefined to better support the plant and the services it delivers or at least will be augmented; others may be replaced by agile processes, usually with intelligence. There will also be extensive use of Extended Reality (XR) - Augmented Reality (AR), Virtual Reality (VR) or Mixed Reality (MR) – for improved collaboration among workers, partners and remote experts, establishing more accurate visibility to inventory as a function of demand and more.
5. New software services will connect product development, production system planning and production execution in an online networked way. Based on digital twin approaches - an open, over the lifecycle evolving and well defined, semantically linked set of data, information and models for the product and productions system – will allow reconfiguration of manufacturing systems in de-facto real-time.
6. Human resources will be governing and orchestrating all operations of the plant. Although there will be demand for less workforce in the plant due to the higher degree of automation and autonomy, the workers' skills will need to be elevated to better manage the complexities introduced through the above digital transformation.
7. The ecosystem will evolve to become a more cohesive element in the end-to-end manufacturing chain. For example, suppliers & partners will further leverage technologies such as 3D Printing, advanced material and AR/VR/MR to more efficiently satisfy the plant's needs.

Given the above, smart manufacturing refers to digitizing every physical aspect of a manufacturing plant and integrating it into the plant's ecology including logistics, supply chain and partners. Digitization extensively bloats the amount of generated data, from within and outside the plant, and exacerbates the complexity of the plant. Hence the need to rely on AI/ML/DL, agent-based modelling simulations and digital twins to effectively operate the plant and predict how it will behave under all types of scenarios, whether in failure, production disruption, increased demand, altered business directions, or safety issues.

In current manufacturing plants in all industry verticals, there has been a separation between Operational Technology (OT) and Information Technology (IT). OT deals directly with the items on the factory floor in terms of managing equipment and all related infrastructure such as Programmable Logic Controllers (PLCs), valves, switches, and actuators. OT operates through a separate network that uses very well-entrenched protocols. IT, on the other hand, deals with higher levels of the stack and is closer to the business. Currently, OT and IT are separate, however, it is expected that IT/OT convergence is starting to become a reality and will be fully achieved in any smart manufacturing plant. The outcome will be lower cost, higher productivity and more agility to business needs. It will also be easier to analyze the OT data and provide decision makers a more comprehensive view on all manufacturing aspects such as material cost increase, valve failure or cybersecurity attack.

IoT will be the foundation to manage and assist future manufacturing plants to achieve the goals set by the plants' decision makers. For example, solutions such as predictive maintenance, asset management, end-to-end operational visibility and more will be essential in any future plant. One of the challenges that may delay adoption of IoT in existing manufacturing plants is the potential aversion to installing sensors on equipment for various reasons such as disrupting operations and the number of sensors needed for accurate predictions. This refers to, for example, making sure that a specific motor brush fails and not another component of an equipment.

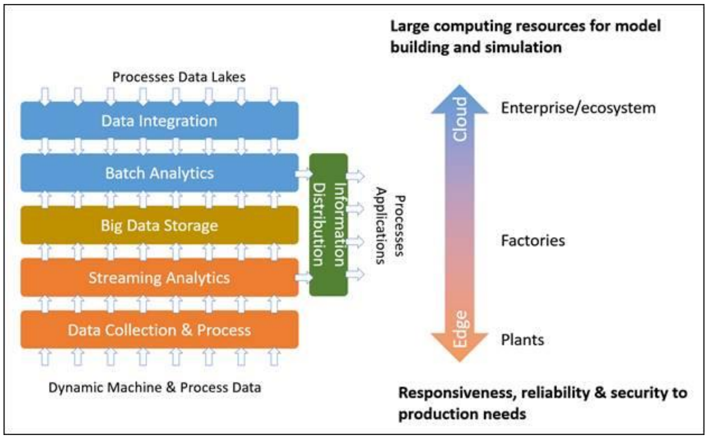

Figure 33 Data are pervasive in manufacturing processes, generated in the plant through IoT or from the supply chain and integrated into all processes. Source:Shi-Wah Lin, IIoT for Smart Manufacturing part 3 – A New Digitalization Architecture, October 16, 2017

The amount of data in a future manufacturing plant will be immense and will be come mainly from the sensors deployed in all equipment on the floor, the robots and cobots deployed performing various tasks, machine-to-machine (M2M) communication, and, of course, humans. Although data continuously grows, it is invaluable in establishing current and future profiles of a manufacturing plant, and future profile, but also helps decision makers predict how the plant can operate under all types of scenarios and conditions such as failures and demand or supply change.

Analytics will play a big role here, especially descriptive, predictive and prescriptive analytics. Descriptive analytics helps plant operators interpret the collected data to better understand current operations of the plant. Predictive analytics analyzes the data and helps predict plant behavior such as occurrence of failures. Prescriptive analytics helps decision makers find the best course of action under any situation such as supply chain disruption.

Robots and cobots are entering almost every stage in the manufacturing process. Cobots[129] are designed to collaborate with humans as well as among themselves and are already operational in several manufacturing plants and logistics with the main goal to increase efficiencies and improve safety. In fact, plants with cobots have seen a decrease in number of accidents as both humans and cobots jointly provide better situational awareness inside the plant.

While logistics may likely drive innovations and growth of cobots, it is expected that cobots will penetrate all elements of the manufacturing chain. Further, as more robots and cobots get deployed, the plant overall operation will need to be reassessed and optimized to better use them in collaboration with humans. This includes retooling the workflows and reskilling workers as they need to establish a symbiotic relationship with their robotic colleagues.

Digital twins are also becoming essential in any smart manufacturing, whether developed for a single piece of equipment, process or the whole plant. See section 3.1.2.2 for details on the role of digital twins in manufacturing.

A special mention should be given to additive manufacturing, see 3.1.3, where the interplay between data and manufacturing is particularly strong. The whole manufacturing process is “created” in software. The 3D digital model of the product is sliced by software into layers and each layer is then used to steer the deposition of the required material. The superposition of layers results in the final product (or component).

The following subsections outline the present status of automation and its near-term evolution in various industries.

3.1.1 Vision & Goals

[129] Cobots are currently classified into three categories depending on their payload: (i) Small, below 5kg; (ii) Medium, between 5kg and 10kg; and (iii) Large, over 10kg.

The statement "Digitalization changes everything" is well known. When it comes to the question of how and a step-by-step realization, it becomes more difficult. This chapter will address these ideas.

The general objective on an European level is given in the ManuFUTURE Vision 2030[130]. European Manufacturing in 2030 will be a globally competitive interconnected and adaptive sociotechnical value creation system that ensures sustainable growth and social welfare, in a resource-constrained world. Similar visions are formulated in national activities. It also considers that a digital ecosystem does not end at the national borders but rather is globally effective.

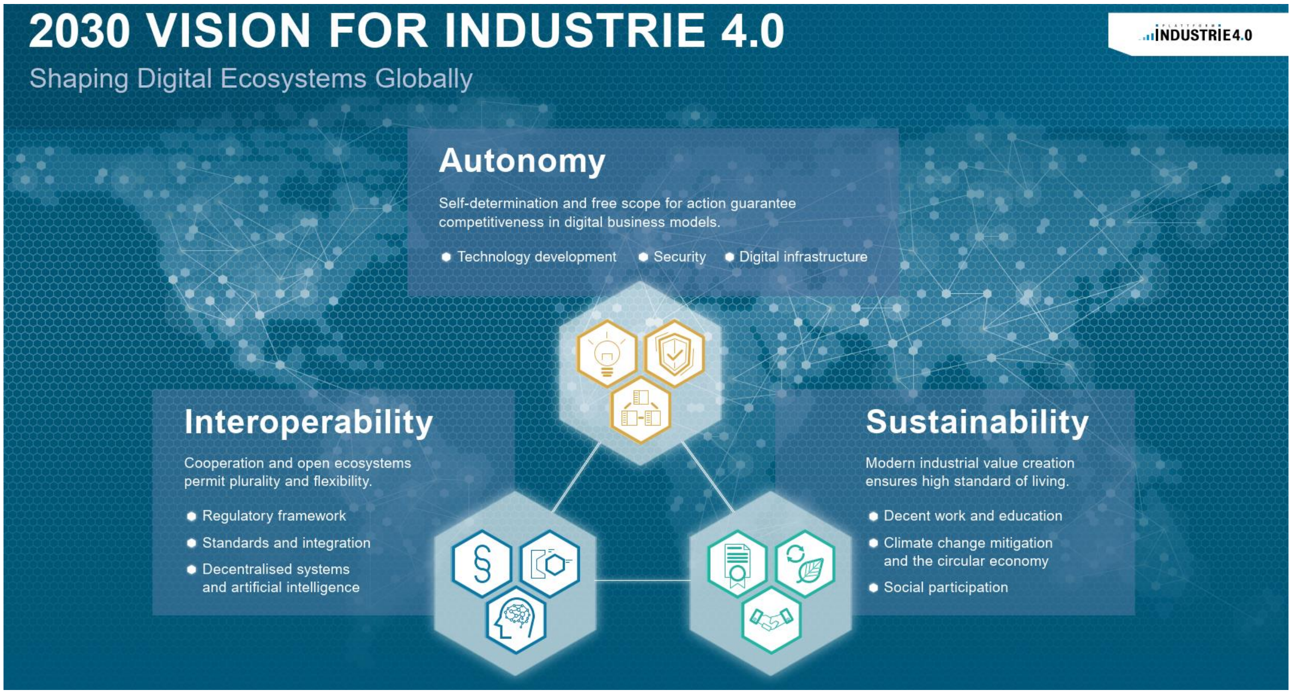

Figure 34 Industry 4.0 – Shaping Digital Ecosystems Globally

Figure 34 shows the vision of the German Platform Industry 4.0[131] which consists out of three interlinked strategic fields of action: autonomy, interoperability and sustainability. As already mentioned in market evolution (see chapter 2.2) the success of the digital transformation in manufacturing is based on two connected pillars. The technological research and development and the adaptation of existing business models as well as the creation of new business models. Technical triggers were the growing software share in the systems, the increasing availability of data in large quantities (Big Data), and the increasing connectivity of devices, machines and systems (Internet-of-Things). This creates a starting point that allows a closer cooperation between all elements in manufacturing. These elements are of different nature. On the production side, for example, there are machines that now act autonomously and coordinate with each other. Production execution and planning are interlinked and can also consider short-term order situations. The connection between production and product development becomes closer. Here, data and models about the producibility of the product are available. In product development, restrictions or opportunities (e.g., through additive manufacturing) from the production side are known to product developers. Similarly, product requirements are available in production planning and can allow for faster reactions to changes in orders. This is a step forward to realize visionary goals such as mass customization and 'lot size one'. New upcoming technologies like AI and digital twins will complement the technological pillar and will enable autonomous system behavior in a symbiotic way. The combination of data and technology opens up new business opportunities, especially in operations and service. Measurement

[130] http://www.manufuture.org/strategic-research-agenda/vision-2030/
[131] https://www.plattform-i40.de/PI40/Navigation/EN/Industrie40/Vision/vision.html

data and other information from the production machines can be used for optimized processes and predictive maintenance services.

The digital transformation will allow modern enterprise to take a holistic approach, to improve complete value chains, and to connect several value chains like product development, production planning and execution. Enhanced flexibility and increased efficiency are the technical and economic goals.

3.1.2 Technological enablers

There are many technologies that are instrumental in manufacturing automation. Some of these, considered to be most relevant, are addressed in the following sections.

3.1.2.1 Autonomy and Manufacturing

Autonomy is usually associated with robots, cobots and automated guided vehicles (AGV), but autonomy and cooperative behavior is important in a broader sense in future manufacturing. In order to be able to react in specific, mostly unexpected situations, future manufacturing systems will need to become more autonomous. Autonomous systems are intelligent machines that execute high-level tasks without human control. They know their capabilities, their internal state and recognize their environment and context, e.g., information from other hardware or software systems. They are able to make decisions. For this decision making, the autonomous systems will need access to very realistic models of the current state of the process and their own behavior in interaction with the real world. So the autonomous systems will include a digital twin in combination with AI technologies for intelligent decisions. Besides autonomy and digital twin technology, modularity and connectivity are important aspects to drive the future of manufacturing.

Increased flexibility in manufacturing begins with modularity in the design of products and production modules, leading to greater effectiveness in engineering of the production system. Autonomy provides the production system the ability to respond to unexpected events in an intelligent and efficient manner without the need for re-configuration at the supervisory level. Lastly, ubiquitous connectivity such as IoT facilitates closing the digitalization loop, allowing the next cycle of product design and production execution to be optimized for higher performance[132]. Figure 35 shows the Digital Twin as an enabler in all lifecycle phases.

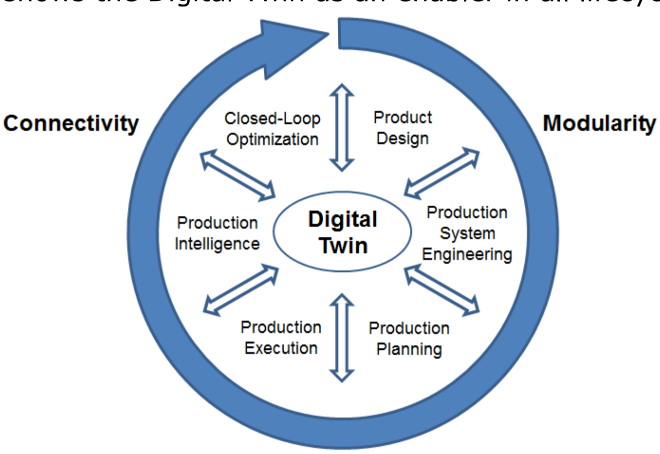

Figure 35 Notion of the digital twin in the lifecycle of a product. Source: Rosen et al, INCOM2015

Modularity is prerequisite for autonomy in manufacturing. Modular production units will allow:

- Distributed planning, shared between production units and production system. Production units can offer more detailed information than a generic planning system.
- Large numbers of offers and orders can be planned based on statistical assumptions and engaged by AI. Dynamic reaction will be possible.
- Improved decision support by means of detailed diagnosis and semantic context by using digital twins.
- Production units plan and execute offers/orders autonomously

[132] Rosen, R., von Wichert, G., Lo, G., Bettenhausen, K. D. (2015). About the Importance of Autonomy and Digital Twins for the Future of Manufacturing, INCOM 2015.

This optimistic description of the implementation of autonomy in manufacturing will take even more time to complete. This is similar to the realization of autonomous cars. A step-by-step realization, which offers added value in every step, is important for the economic implementation. The 5C architecture (see Figure 36), originally presented by Lee[133], gives a hint to the stepwise implementation of new services towards autonomy.

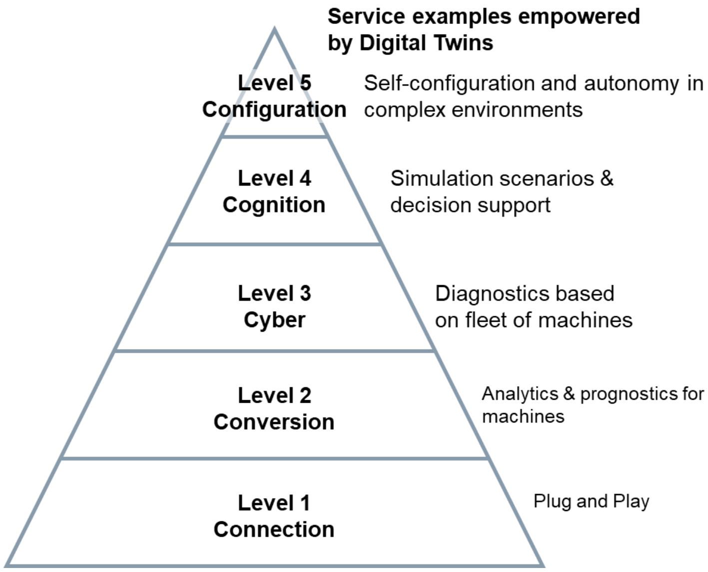

Figure 36 Notion of the digital twin in the lifecycle of a product. Source: Rosen et al, INCOM2015

On each level new solutions and services are possible. Each of these solutions will be available in several industrial domains and will benefit and provide economic value which in the end will accelerate the development of new services on a higher level:

- Extended use of soft sensors, which use digital twins to calculate values that cannot be directly measured.
- Predictive maintenance
- Execution of analysis and calculation of scenarios by using online digital twins, e.g., alternative operational strategies.
- AI based automated decision-making for optimal operation.
- Digital twin and digital companions which support different stakeholders in their different tasks

3.1.2.2 Digital twin in the lifecycle and ecosystem

As the complexity of manufacturing systems increases, the possibility of acquiring information on the system is rising as well. This makes it necessary to think about ways to handle all this information in a suitable way. Recently, the Digital Twin has become very popular, appearing as one of Gartner top 10 technical trends for 2017 and 2018[134] . Here it is looked at in an IoT context as a digital representation of a real-world entity. The digital twin collects all information on the state and usage of physical entities and links it to information on the state of counterparts and provides support in reaction to changes, thus adding value to the usage of the entity.

Digital Twin Prototype
vs
Digital Twin Instances

The exclusive focus on the data-mining aspect of the digital twin neglects an essential aspect of the original idea of having a digital companion throughout the lifecycle of all entities. The terms digital twin prototypes (DTP) and digital twin instances (DTI) were introduced to distinguish the different character and purpose of the Digital Twin[135]. In the early lifecycle phases, the digital twin consists mainly of artefacts used to optimize the product functionality. The digital models are used to check design alternatives and to test product functionalities against its requirements using virtual prototypes (the digital twin prototype). This approach greatly contributes to reduce time and costs during product development. On the other hand, the DTI emphasizes the aspect that with each individual physical entity, (digital)

[133] Lee, J., Bagheri, B., and Kao, H.-A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, Manufacturing Letters, vol. 3, pp. 18–23, 2015, DOI: 10.1016/j.mfglet.2014.12.001.
[134] "Gartner top 10 Strategic Technology Trends for 2017", received from https://www.gartner.com/smarterwithgartner/gartners-top-10-technology-trends-2017/
[135] M. Grieves, J. Vickers: "Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems"

information is also collected through the whole lifecycle. This need not be limited to sensor and operation data but may also include information from its production (e.g., supplier, production line). With the rise of sensors everywhere, a vast amount of data is available to be linked to the DTI. Also, as the DTP focuses on the general behavior of the entity, it can be seen as a common part of each DTI and can be exploited to create solutions.
The models included in the DTP are usually created for very specific design questions. Therefore, many different models tend to be available for the same component, each representing a different design question on an appropriate model granularity.

For a manufacturing system this will inevitably lead to a network of digital twins as every production machine will be able to exchange information with their neighbors and the whole system. Further, on a superior level, each manufacturing site is embedded in a network of suppliers and customers, thus establishing another level of interaction.

3.1.2.3 Symbiotic mechatronics

A typical manufacturing system has become more and more complex. The ultimate goal of the development is to optimize the design in such a way that the performance (e.g., throughput, costs) of the system is maximized. However, due to the high complexity of the overall system it becomes more and more difficult or even impossible to oversee all relationships and dependencies in the system. The usual approach in mechatronic product development is to identify synergies between functional groups and thus increase the overall efficiency by making common use of existing components. Knowing and being able to describe the whole system completely is a necessary requirement to find the optimal system, therefore alternative approaches need to be pursued to come at least closer to the theoretically possible optimum.

While conventional mechatronics is mainly focusing on synergy, designing interactions to create added value for a superordinate system, symbiosis refers to the individual benefits of cooperating partners.

The approach is to find a new principle in systems engineering to design subsystems and their interaction symbiotically (mutually beneficial) in order to promote the objectives of the overall system, or at least, not to impede them. Symbiotic Mechatronics[136] aims at a systemic view on mechatronic systems along their whole product lifecycle, in order to make the external and internal goals and objectives of the related subsystems and stakeholders transparent and to be able to find potential symbiotic relationships allowing for an improved support of the overall systems' goals. For this purpose, typical questions like the following ones need to be answered: What are the needs of the superordinate system and of the system elements, what is the potential for their disposal, and how can the subsystems be connected to benefit from symbiotic interactions?

Internal objectives of the subsystems need to be considered as well in order to include them in the design of the overall system, which is heavily influenced by a suitable choice of the subsystems' structure. The design of the overall system and its subsystems determines their potential for disposal, their goals and needs as well as the action-scope. Using this opportunity and guiding subsystems' and super-systems' objectives in the same direction, evolution of technical systems due to symbiotic interaction between subsystems could be supported.

Searching and creating symbioses between subsystems can be an alternative to optimization of complex systems that are hardly accessible to rigorous optimization. It is therefore a very promising approach to handle the complexity of future manufacturing systems, where more and more aspects are no longer controllable from a single point.

[136] https://www.lcm.at/en/company/comet-k2-symbiotic-mechatronics/about-the-comet-k2-competence-center/

3.1.2.4 AI and Data-analytics and Simulation

The combination of simulation and data-analytics, while at first glance seems antithetic, offers a further chance to handle the complexity of future manufacturing ecosystems. The main advantage of simulation-based methods is the strong focus on physical laws that describe the behavior of the system under consideration. However, this requires a deep understanding of the system and a high effort to create the model, but can give very precise predictions on the future, as long as sufficient information on the history is available. On the other hand, data based methods rely on a vast amount of high-quality data, from which they "learn" the system behavior. This method is therefore very suitable to analyze unknown systems as long as enough qualified data is available.

The chances are very high that for technical systems the benefits of both approaches can be combined to result in a more powerful prediction system, which can even evolve into an assistance system for operational support. For example, the physics-based models that were used to design the internal logistics for the manufacturing system can be used during the operation of the manufacturing system to plan short notice changes in the schedule. The required accuracy for this application can be achieved by a continuous learning and re-calibration of the simulation model from operational data.

3.1.3 Additive Manufacturing

The digital transformation of manufacturing is changing the whole value chain. In this section some of the technologies reshaping manufacturing and the implications on the whole value chain are considered

The overall landscape is characterized by a growing digitalization of each and every phase, starting, obviously, with the design phase. The development of a digital model through CAD makes it possible to start from existing models and to change them to fit new ideas or requirements. The visualization of the model using VR makes the interaction of designers and involvement of clients very effective. Single components can be designed by several competing suppliers (for example, some companies[137] are even setting up hackathons to get fresh ideas on the design of specific components).

From bits to atoms:
Additive Manufacturing

However, the crucial point of manufacturing is the actual manufacturing that is dealing with physical objects with atoms, not with bits. The digital transformation of manufacturing eventually needs to work on atoms. The correlation of the digital model of the object with the manufacturing tools is key. In the digital space we have all the flexibility we want, we can design the most complex shapes and provide each micro area with the desired characteristics. The point is: can we translate those fantastic shapes and characteristics into an object using a viable manufacturing process? If we plan to use the classic tools of manufacturing, like forging and casting of metals, the answer, in general, is no.

Figure 37 On the left is the usual piston rod manufactured using forging technologies. On the right is a much lighter piston rod providing even greater strength created with additive manufacturing technologies. Image credit: Streparava

While in classic manufacturing there are several constraints in the shape of component parts because of the limitation imposed by forging and casting, additive manufacturing that can be directly executed from the digital model increases the design flexibility (see Figure 37). There

[137] https://www.olcf.ornl.gov/2019/09/12/gpus-power-ge-code-at-olcf-hackathons/

are several additive manufacturing technologies available, and more are in the research pipeline. A few are considered below since they are an important component in the digitalization of manufacturing.

3.1.3.1 Power Bed Fusion

Power bed fusion is a set of technologies based on the fusion of the material(s) deposited by an ink-jet like nozzle. The fusion can take place using a chemical agent activated by thermal energy, laser or electron beam. At the moment, these are the technologies that have the biggest market share.

Jet fusion technology[138] is based on layering small particles of a material along with millions of droplets of a chemical agent. By using a highly sophisticated heating and cooling process the chemical reacts with the material particles "gluing" them together. The fusion process can make use of multiple jets thus increasing the speed of manufacturing the object. Most interestingly, the creation of an object occurs through the micro manufacturing of "voxels" (a pixel in a 3D space), and each of this voxels can be manufactured according to a design specification. Hence, a single component can consist of different voxels each with different properties, including strength, elasticity, color, transparency and texture. This means that jet fusion makes the manufacturing of components with a very complex functional structure possible.

In certain applications, this gives a tremendous advantage (like in the avionics where weight is a costly factor or in prosthetics where micro-characteristic differences can match the micro differences in living tissues).

3.1.3.2 Powder Bed Fusion - Laser fusion

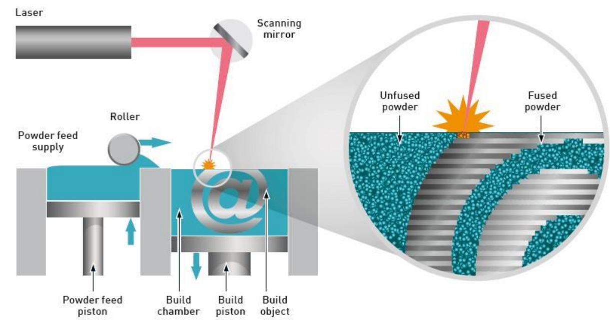

Figure 38 Schematics for powder bed fusion based on a laser beam that melts, fuses, the powder. Image credit: Malvern Panalytical

Power Bed Fusion based on Laser, SLS Selective Laser Sintering and SLM Selective Laser Melting was invented over 20 years ago by EOS[139], a German company still on the leading edge in additive manufacturing tools. It is based on the use of a laser beam, controlled by a computer, to meld or fuse, the metal powder. The laser beam fuses a thin layer of metal beads, some 20 to 120 μm thick, that are deposited by a moving nozzle, like the one on ink-jet printers, hitting the surface areas that need to become part of the object being produced. The first layer is deposited on a metal plate. Once the laser has completed the fusion, a second layer is deposited and the whole process is repeated over and over until the object is complete.

Each layer can use different kind of metal beads, like an ink-jet printer uses different color inks, thus creating objects with the desired composition with a precision in the μm range. The range of materials[140] that can be used is growing, now including aluminum, nickel, steel, and cobalt chrome alloys. Research is studying the application of nanotechnology to the creation of the micro beads to allow new alloys. Indeed, the next decade will be characterized by the increased capability, through computer simulation, of identifying alloys with desired characteristics. There is a potentially unlimited number of alloys, each with its own physical characteristics, and the use of computer simulation supported by artificial intelligence can enable designers to identify the one best fitting

138 https://www.stratasysdirect.com/technologies/multi-jet-fusion
139 https://www.eos.info/systems_solutions/metal
140 https://www.eos.info/material-m

the needs. Material science and nanotech can then turn this hypothetical alloy into a reality of microbeads that will be used through additive manufacturing in the creation of the object.

3.1.3.3 Powder Bed Fusion - Electron Beam Melting

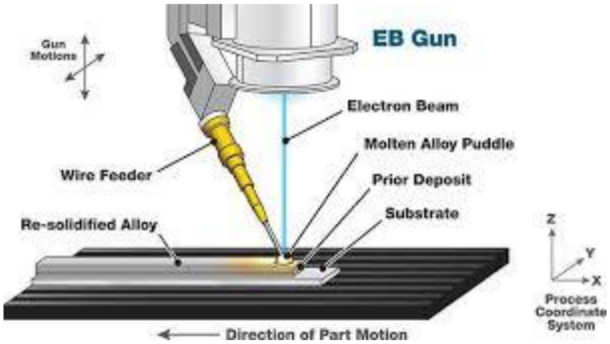

Figure 39 Electron Beam Melting schematics. The electron beam heats up the powder deposited leading to its melting. Image credit: Fraunhofer

An alternative way to consolidate microbeads into a single material is using Electron Beam Melting (EBM)[141]. Here the "heat" is produced by an electron beam. The system required for EBM is more complex and costly than the one used for SLS and SLM. Its advantage over those methods is the higher precision provided by the electron beam and the fact that the melting occurs in vacuum, hence no contamination can occur.

It is being used in the additive manufacturing of high value components, like some avionics parts. GE is manufacturing[142] Titanium Aluminide blades for airplane engines using this technology.

Lima has recently announced[143] the installation of EBM 3D printers in hospitals in the US to allow for on-site printing of orthopedic implants. The prosthetics are 3D printed in titanium and have a trabecular structure that is both highly resistant and light.

Avionics and medical prosthetics are indeed leading the way to the deployment of these technologies since they have very stringent requirements and require custom made products that cannot benefit from scale cost reduction.

3.1.3.4 Material Jetting

The material jetting additive manufacturing technology is very similar to the ones already discussed, however, the difference is in the material used. Here the material has to be photosensitive to UV light while in the previous technology the material was either glued by a special chemical or fused/melted by heat.

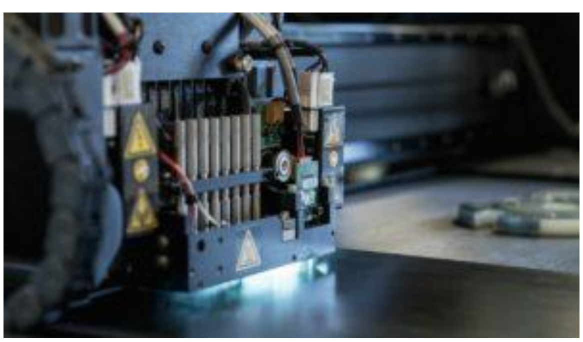

Figure 40 Material jetting printing head. Image credit: All3DP

The process[144] starts by printing a liquid resin, warmed up to 40 to 60 degrees Celsius, on a surface in the form of tiny droplets using ink-jet like nozzles. These are disposed on a line that moves over the surface. Each nozzle prints a specific material, part of which can be dissolved and used to create empty spaces in the object being printed. The droplets are fused with the nearby droplets, with both the one on the side and the one on the layer previously printed, using UV light. This layering is repeated as many times as needed to create the final object. The object is then immersed into a

[141] https://3dprintingindustry.com/news/new-facility-selective-electron-beam-melting-84074/
[142] https://3dprintingindustry.com/news/ge-additive-champions-lean-manufacturing-in-new-arcam-ebm-center-of-excellence-160550/
[143] https://limacorporate.com/repo/press/524e05dc77239f3a15dab766aaa59a9e432efde7/LIMACORPORATE_HEADS_FIRST_3D_PRINTING_SITE_ON_HOSPITAL_CAMPUS_TO_ADDRESS_COMPLEX_CUSTOM_ORTHOPEDIC_IMPLANTS.pdf
[144] https://www.3dhubs.com/knowledge-base/introduction-material-jetting-3d-printing

solvent that will remove the filling materials deposited to create empty space.

The use of liquid material allows for very high precision with a layer thickness as low as 0.013mm and a resolution better than 0.1mm. More evolution[145] is expected through the use of nanoparticles in the liquid ink. This has already been used to manufacture printed electronics[146] (printed circuits).

Additionally, this technology is being used in healthcare to print organs[147]. In this case the "material" is an ink made of living cells, infrastructure material like calcium for printing bones, and collagen.

The evolution in material jetting will lower the cost and increase speed of additive manufacturing.

3.1.3.5 Material extrusion

Material extrusion[148] is probably the most known 3D printing technology by the mass market because it is the one used by small 3D printers that have reached an affordable price point for residential users. However, there is not, generally, a captivating use case for keeping one of these 3D printer at home.

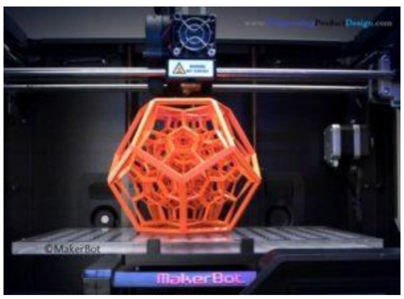

Figure 41 A plastic 3D printed object based on Material Extrusion and in particular with the Fused Filament Fabrication (FFF) technology. Image credit: MakerBot

The printer uses a (thermo)plastic wire, a filament, that goes through a nozzle, gets heated and is extruded on a surface in subsequent layers, building the desired object.

The advantage of material extrusion is in its low cost and ease of use. On the other hand, it is not as accurate as other additive manufacturing technologies, so it is rarely used in industrial applications. Also, the extruding nozzle should keep going, it cannot stop, otherwise the extruded material will create a bump.

3.1.3.6 Sheet lamination

Figure 42 Sheet lamination at work. Sheets are fused together using ultrasounds. Image credit: Loughborough University

Sheet lamination[149] is a technology that operates by overlaying layers of materials (metal) in foils. Once the first foil is placed, a laser cuts it to the desired shape, the unwanted material is removed, and a new layer is positioned. This is again shaped by a laser cutting out the unwanted parts and the layer is welded to the previous layer, using ultrasound (UAM - Ultrasound Additive Manufacturing). Depending on the type of 3D printer used the new layer can be welded before or after being cut by the laser.

Research is ongoing to make sheet lamination more flexible, able to include a variety of materials and embed pre-fabricated components, like sensors, in the sheet layering. Robots can be used[150] to increase the flexibility in additive manufacturing.

One of the problems in using different materials in the layering is the need for different bonding or welding procedures depending on the materials. As an example, paper layers

[145] https://blog.grabcad.com/blog/2017/12/04/evolution-material-jetting-3d-printing/
[146] https://www.pannam.com/blog/what-is-printed-electronics/
[147] https://techcrunch.com/2019/08/11/3d-printing-organs-moves-a-few-more-steps-closer-to-commercialization/
[148] https://engineeringproductdesign.com/knowledge-base/material-extrusion/
[149] https://www.sciencedirect.com/topics/engineering/sheet-lamination
[150] https://www.sciencedirect.com/science/article/pii/S2214860418305207

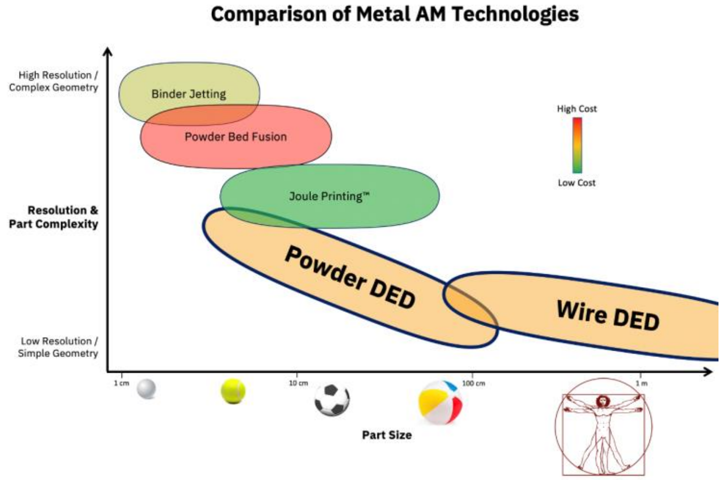

Figure 43 Schematic overview of various DED technologies. Image credit: Digital Alloys

are pre-coated with glue that is activated through heath and pressure, metal foils are welded using ultrasounds, and polymer foils by using pressure.

This 3D technology is usually used[151] to print prototypes since the resulting object is often too coarse to be a product.

3.1.3.7 Directed Energy Deposition (DED)

Directed Energy Deposition (DED) technology[152] can be considered a variation of the Electron Beam Deposition, or other deposition technologies involving laser beams, discussed in previous subsections. It is often used as a way to repair metal cracks by adding metal that becomes fused with the existing one, keeping the strength of the original part. An example is to fix cracks in fan's turbine. It can also be used to add ceramic materials and a mixture of metal and ceramics. Depending on the heating technology adopted (laser or electron beam), it must operate in a specific environment (inert gas to avoid oxygen contamination when using laser heating, vacuum when using electron beams).

The interest in DED is the possibility of creating alloys[153] spontaneously, at the time an object is being 3D printed. A further strength of DED is the lower cost of the whole process with respect to normal Laser Powder Bed and E-beam Powder Bed (see Figure 44).

The word "Energy" in DED emphasizes the significant amount of energy (heat) involved which creates stress in the underlining metal structure. Thus, continuous monitoring of the process is required, and when needed, the printing must be stopped to let the substrata recover from the stress.

3.1.4 Application examples

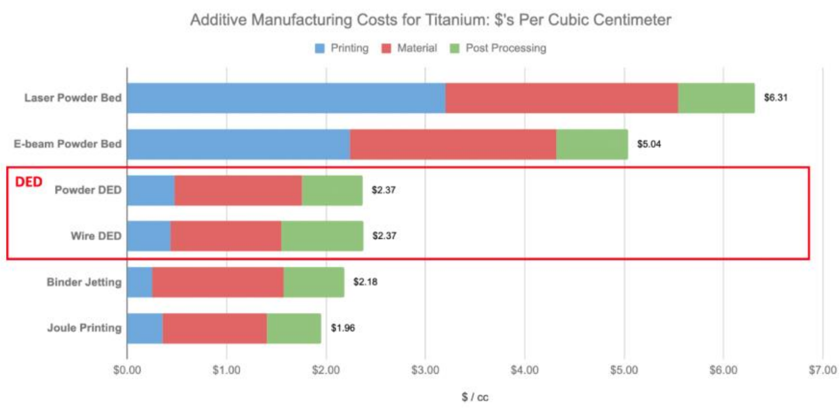

Figure 44 DED cost compared to other similar technologies. Image credit: Digital Alloys

For the success of future manufacturing and symbiotic autonomous systems, a stepwise realization with economic benefit on each stage of development is essential. One example of a service on level 3 of the 5C

[151] https://www.plm.automation.siemens.com/global/ja/our-story/glossary/sheet-lamination/55512
[152] https://www.3dnatives.com/en/directed-energy-deposition-ded-3d-printing-guide-100920194/
[153] https://www.digitalalloys.com/blog/directed-energy-deposition/

architecture is shown in Figure 45.[154]

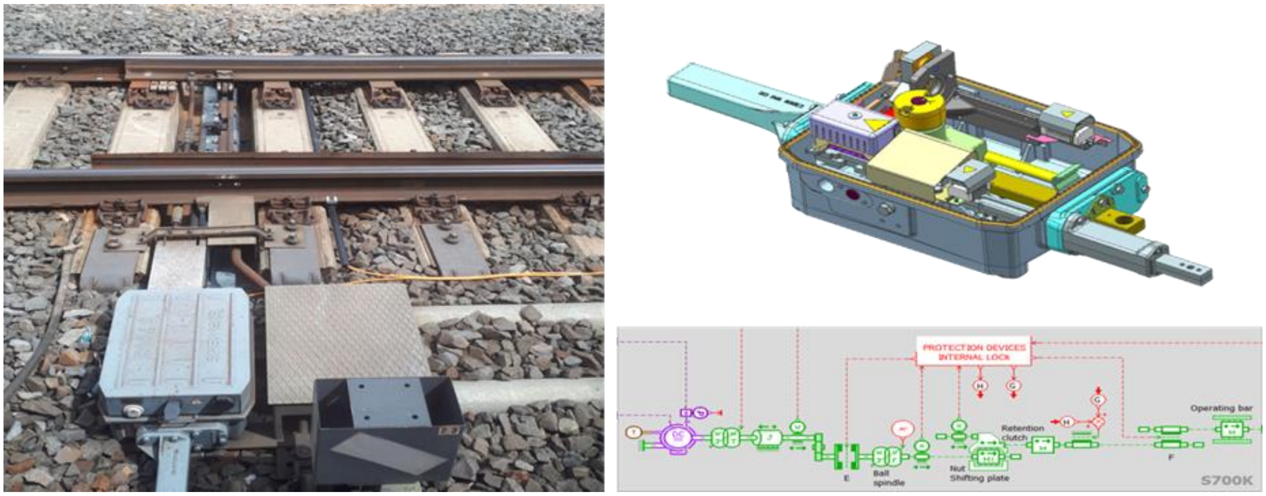

Figure 45 Multi-body model (top right) and derived 1D model (bottom right) of point machine S700K to validate system behavior and use for diagnosis services. Image credit: Siemens

Railroad switches, also called turnouts or points, are a key element of the rail network infrastructure. They are distributed all over the network, and their maintenance is crucial to guarantee safety and undisturbed operation. Within a railway network the turnouts are responsible for a high amount of the operational costs as monitoring and maintenance is mainly manual. Point diagnostics systems like the Sidis W compact from Siemens[155] are used to monitor the current condition of the point machine by analyzing the electrical power demand of the drive and point machine operation module. However, a prediction of the future behavior remains difficult. The interaction of a railway switch and its drive (point machine) is complex. On both subsystems many different parameters act in a way that it will be difficult to predict behavior. The use of physics-based models promises an efficient and cost-effective extension of such systems as not only real data, but also the immanent physics is used to identify potential vulnerabilities in the dependence of the current load, maintenance condition or operating hours. It can be further used to explain anomalies and identify potential causes of failure causes, thus, improve the maintenance process.

A further example is the development of a so-called Digital Plant Companion (DPC), which exists as a research result of a virtual lemonade production.[156] The idea of the DPC provides a vision of the next generation of operation assist systems for complex cyber-physical systems, such as discrete manufacturing factories or continuous process plants. The DPC provides decision support to different stakeholders that are involved in the operation of a plant or a factory, such as the factory manager, the plant operator, process engineers, or maintenance technicians. Such a DPC is an example for a solution on level 5 of the 5C architecture.

In order to provide these digital services, the DPC relies heavily on the semantically linked executable models and information of the actual plant, i.e., the digital twin. Based on these linked digital artefacts, the DPC adds different layers of services to execute different simulation, optimization and reasoning solutions. Examples are mechatronic models of the bottling line, biochemical simulation of the mixing of lemonade substances, virtual commissioning models to validate the automation and material flow simulation to calculate order and production times. To provide situational and context dependent information to the respective stakeholder, the DPC can

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[154] Boschert, S., Rosen R., Heinrich, Ch. (2018). Next generation digital twin. In: Horvath, I., Suarez Riviero, J.P., Hernandez Castellano, P.M. (Hrsg.) Proceedings of the 12th International Symposium on Tools and Methods of Competitive Engineering TMCE 2018, S.209-218. Delft University of Technology.

[155] https://new.siemens.com/us/en/products/mobility.html

[156] https://www.ifac-control.org/events/mechatronic-systems-8th-mechatronics-2019

be accessed via different types of user interfaces which include different forms of user interaction such as natural language understanding but also new forms of result presentation that allow an intuitive understanding of the currently most relevant information.

3.2 Healthcare

Healthcare costs[157] are on the rise, and this may be one of the main reasons why there is so much interest in automation. It should however be noticed that in a few health care areas automation is sought to deliver better quality, like in pharmaceuticals. Assistive automation in surgery is also an area to enable procedures that go beyond human possibility (for example, micro surgeries among others). In surgery, there is a growing digital transformation, with diagnostic procedures generating data that are analyzed automatically, creating a model that is used for simulating procedures and eventually by autonomous or semi-autonomous systems in surgery.

Clearly, health care is also an area where symbiotic autonomous systems are making the first steps, mostly in terms of smart prosthetics.

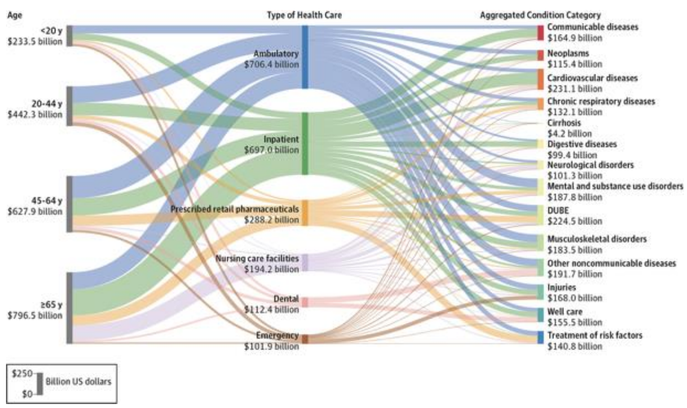

Figure 46 Splitting of health care cost based on age range, type of resources and pathology. Image credit: HealthPopuli.com

In the following, several examples of autonomous systems applications are presented clustered under the three main areas of disruptive transformation affecting health care:

- Delocalization: health care can be delivered everywhere to serve patients in remote locations as well as to decrease cost and increase efficiency and convenience;
- Personalization: health care is shifting from the application of statistically certified paradigms (like drugs approved after extensive trials) to personalized protocols taking into account the patient (genomic) specificity;
- Digitalization: health care is exploiting data generated by a variety of monitoring systems (including wearables) and using data analytics on big data in community, country, and transnational ensembles.

3.2.1 Delocalization

Autonomous systems are starting to play a role in the delocalization of care by providing on site assistance. Not surprisingly this has started in controlled environments, hospitals and care facilities, but it is now extending to home care.

Two examples of autonomous robots providing delocalization include ones preparing and bringing medicines to patients on a hospital ward, or robots used to disinfect rooms in hospitals, long-term care settings, or at home where there are debilitated persons that are not protected from infections (Xenex[158] developed ones that are used in hospitals).

In October 2019, ABB opened a research center[159] on the premises of the Texas Medical Center Innovation campus in Houston focusing on development of autonomous robots to be applied to

[157] https://www.healthpopuli.com/2017/01/01/consumers-health-economics-will-drive-health-tech-spending-lens-digital-health-ces-2017/
[158] https://www.xenex.com
[159] https://www.roboticstomorrow.com/story/2019/07/abb-robotics-to-develop-solutions-for-the-hospital-of-the-future/13865/

health care in a hospital environment. These robots are designed to be collaborative (cobots) and to work autonomously as a team.

ABB already provides robots[160] in the health care sector for preparing and delivering food. Non-surgical robots used in health care are expected to grow to 60,000 by 2025 (there were 18,000 in 2018).
A new wave of companion robots[161] are now on the market for elderly care and significant progress is expected in the next few years.

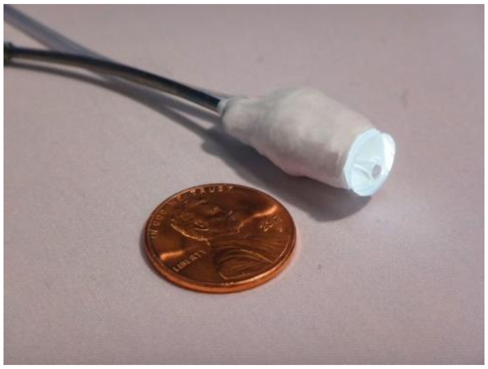
Figure 47 The tip of the robotic catheter developed at Boston Children's Hospital. Margherita Mencattelli. Boston Children's Hospital

Fully autonomous robots able to perform surgery in remote locations are not operational yet although they are being studied in several research labs. Currently there are robots that have a limited range of autonomy and can be operated remotely. 5G has often been linked to supporting remote surgery[162] using an onsite robot by taking advantage of its low latency that can support (to a limited extent) the use of haptic feedback.

A few trials have been performed, like the one at Boston Children Hospital where doctors have used an autonomous micro-robot[163] to navigate inside the body to reach a cardiac valve and repair it.

Suturing automation[164] is another area being explored and others are likely to be developed in the next decade. In the last year there has been a growing use of artificial intelligence, in its various forms, to provide surgical robots with advanced awareness and decision making capability.

Clearly this is an area where legal issues are crucial, i.e., who takes responsibility for the autonomous decisions of a robot and of the outcome of its operation?

3.2.2 Personalization

The sequencing of the genome is now a mass market reality. It cost had been decreasing[165] but has remained stable at around $1,000 USD since 2016. The cost is expected to start decreasing again in the next decade with more effective mapping technologies, leveraging machine learning, something that is becoming more effective as more genomes are sequenced and mapped. Companies like Illumina (a market leader in sequencing) and Nebula Genomics, Zenome, and DNAtix that are applying blockchain to the mapping and are making the genomic data accessible will likely dominate in the coming decade decreasing the cost for top of the line services. On the

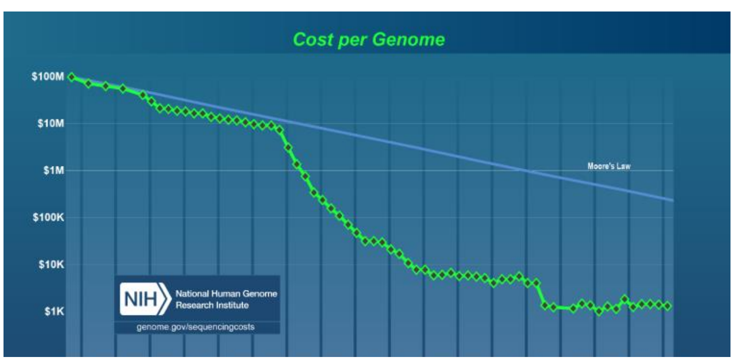

Figure 48 The decreasing cost for a full human genome sequencing. Source: NIH - National Human Genome Research Institute

[160] https://www.karolinska.se/en/karolinska-university-hospital/Innovation/Robotics-and-automation/
[161] https://www.digitaltrends.com/home/cutest-companion-robots-ces-2019/
[162] https://www.independent.co.uk/life-style/gadgets-and-tech/news/5g-surgery-china-robotic-operation-a8732861.html
[163] https://www.sciencedaily.com/releases/2019/04/190424153600.htm
[164] https://emerj.com/ai-sector-overviews/machine-learning-in-surgical-robotics-4-applications/
[165] https://www.genome.gov/about-genomics/fact-sheets/DNA-Sequencing-Costs-Data

other hand, other companies are addressing the mass market today, like Ancestry and 23AndMe, and are providing limited sequencing under $100 but are expanding their capability in sequencing and mapping rapidly as the number of genomes sequenced grows. We can expect in the coming decade that these two forces, one from the top, the other from the bottom will dramatically change the use of genomics in healthcare.

One of the problems today is the confusion, not only in the general public, but also in those that are not specialists in the field. This confusion can be seen in the different numbers that are associate to genome sequencing, like:

- Storage required for a human genome: the requirements go from 3GB (basically using one byte to represent each base pair) to up to 200 TB (that is the gigantic data set coming out from the parallel sequencing of the millions of fragments of the DNA), with some intermediate figure in the order of hundreds of GB to keep the unmapped strings of DNA;
- Cost to interpret the genome: as low as $850 for the sequencing, $3,000 for the mapping of the genome (moving from the strings of bases A-C-G-T to genes) to much more to understand the expression of genes;
- Cost to identify, or look for a specific gene (something becoming a standard protocol to define the way to cure a specific cancer): this cost can vary significantly (both in time and in money) depending on the gene or mix of genes.

The combined forces of lower cost and increased data availability (fueling predictive analytics and enabling more sophisticated AI) are resulting in a growing interest on precision medicine[166] otherwise known as personalization.

The Obama administration launched[167] the Precision Medicine Initiative (now known as the All of Us[168] initiative) aimed at creating a genetic biobank. France is actively working on the "France Medecine Genomique 2025" creating a genome bank growing by 235,000 whole genome sequences (WGS) per year.

At the same time there are companies[169] like GE and Philips that are investing in the creation of person's digital twins as a way to support personalized medicine. Notice that digital twins are already used to model processes, equipment and even hospitals[170] but these companies are looking at their use in the context of patients (more generally of people in a proactive medicine perspective).

Digital Twins for personalized Healthcare

Digital twins in personal healthcare are seen by classic healthcare industry players (GE, Philips, Siemens, Nokia) as a way to capitalize on data that are accrued through their equipment fostering improved quality in healthcare and decreasing cost. They are also seen, although never explicitly mentioned, as a way to defend themselves from the attack that is and will be coming from companies that thrive on data and that see digital twins as a way to capitalize on their data and enter into the healthcare space. Google and Apple are at the forefront of this new breed of companies, with others already mentioned, like 23andMe, also trying to capitalize on their availability of data.

It is most likely that for the first part of the coming decade there will not be a clear winner (in the fight between the "incumbents" and the "data companies") but that the players will cause an acceleration of the adoption of digital twins.

[166] https://www.labiotech.eu/features/genome-sequencing-review-projects/
[167] https://obamawhitehouse.archives.gov/precision-medicine
[168] https://allofus.nih.gov/about/all-us-research-program-overview
[169] https://www.reuters.com/article/us-healthcare-medical-technology-ai-insi/medtech-firms-get-personal-with-digital-twins-idUSKCN1LG0S0
[170] https://www.challenge.org/knowledgeitems/digital-twins-virtualizing-hospitals/

An important aspect is the expected evolution of digital twins to stage 4, a point where a digital twin may act as an autonomous system and start to roam cyberspace leveraging both data and services to provide a customized health guide to its physical twin. This is not far in the future; a few signs of this evolution are already visible (the Apple Watch 5 is a step along this path although in a very tiny segment in healthcare). By the middle of the next decade it is forecasted that health care digital twins will become autonomous systems supporting advanced personalized care[171].

3.2.3 Digitalization

The whole healthcare process, in many countries, is now digital or it is being digitalized. However, in many cases, if not most, the digitalization is fragmented in digital siloes; radiography and CT results are digital but are not open, and it is often impossible to relate these two results. This is the biggest challenge facing healthcare digitalization: not to digitalize the various parts but to make all of them coalesce into a single whole. The second challenge (in digitalization) is to make the analysis of data of different patients possible. Privacy and legislation are blocking the way, while the first challenge is more of a technical and organizational nature, yet, both are needed if we are to exploit the digitalization of healthcare.

The scheme in leveraging data is the same here as it is in any other areas:

1. ***What is happening?***
   The data gathered from the patient as a person, like the genome, metabolome, the environment, the occupation, the activities and habits (including travel, frequentation), the habits (smoker, drinker, vegan, suntan lover), as well as the data gathered as a patient like medical exams, use of drugs, data harvested from wearable devices, if correlated can help pinpoint what is happening and explain the symptoms. All of this person's data can be structured into the person's digital twin and can be the intermediary used by the doctor and by the healthcare system.
2. ***Why it is happening?***
   Similarly, the same data described in 1) can be used to work out what is the problem: is it a virus infection that is actually propagating among a community or something that has been acquired during a trip abroad, could it be pollution in the air affecting the airways and stimulating an allergic reaction, is it the outcome of an ongoing cure that is creating undesired side effect, etc.
3. ***What might happen?***
   Usually in healthcare there is no single outcome, rather a slate of possible outcomes that need to be evaluated. The probability of one vs the others are depending on the person/patient and on the context. Control of possible epidemics is also a question to be evaluated under this "what might happen" and involves stepping back from the patient to consider a broader picture. For example: Given the current ailment, or situation, and the patient history/specificity what would be the possible evolution if no action is taken? What could also be the effect on people in contact with that person?
4. ***What can be done to change the outcome?***
   Here the point is find the best cure or the best preventive measures to avoid spreading. As previously noted healthcare is moving towards increased personalization and this obviously includes finding specific drugs that fit that particular person.

   Rather than going for "one size fits them all", which has been the approach to cure in the last century based on many years of drug testing on animals and then selected patients through trials, healthcare is moving towards the design of specific protocols that are focusing on the specificity of the patient. Curing cancer is already being shaped in this way and will become even more so in the coming years. This is likely to create a disruption among

[171] https://www.technologynetworks.com/informatics/news/digital-twins-could-be-a-route-to-personalized-medicine-322311

the big pharmaceuticals, since a cure will no longer be tied to lengthy trials, rather to the specificity of a patient. This is turn generates the need for continuous, or almost continuous, monitoring. The former opens the door to many companies that can leverage on the specificity of an area and whose excellence lies in data processing (machine learning, and artificial intelligence in general), the latter to technology companies creating wearables, implants and ambient monitoring systems.

Clearly data, harvesting, processing and applying the intelligence derived from data are going to be the foundation of healthcare in the coming decades.

The Electronic Health Record, EHR[172], keeping track of the patient data, is now a reality in several countries. The European Community has adopted a recommendation[173] for the exchange of EHR across Europe. Notice, however, that this recommendation is to allow a citizen of a European country to make the EHR available to any doctor, hospital in the EU in case of need. It is not for making the data available for research nor for intelligence.

In the US the situation is even more complex[174] with some 700 different "standards" of EHR, since there is no unified accepted standards and EHR are tied to the specific vendor providing the software. In many cases there is not even an EHR but just an electronic medical record (EMR) used by doctors in their practice to keep track of a specific aspect (for example, a cardiologist, a pulmonologist, an ophthalmologist, and a gynecologist each have an EMR of a patient, and none of them has access to the EMR created by the other doctors).

A research project in Europe was funded by the EU to determine a viable way of using health data for research, Electronic Health Record for Clinical Research (her4CR)[175], to set the basis for leveraging all health data. It will be complex given the privacy concerns. At the same time there are bottom up approaches occurring, like the one of recently announced[176] by Apple that may put a pressure on governments to create and implement a top down solution for sharing data.

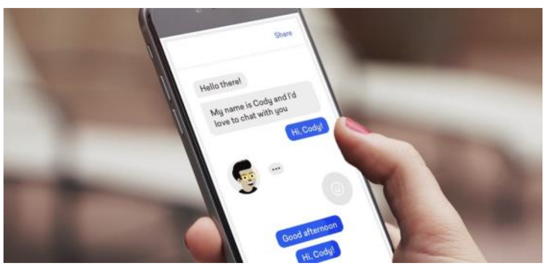

Figure 49 Chatbots are becoming widespread and are going to play a major role in healthcare, providing personalised doctor on demand services. Image credit: ISDDesign

There is no doubt in the scientific community that a full digital transformation making health data of hundreds of millions of people available would tremendously increase scientific knowledge and result in amazing advances in cures and wellbeing of citizens.

The availability of people's health data can be exploited by autonomous "bot" to:

- Discover patterns, like the emergence of epidemics, noxious factors in an environment, long term effect of various ambient conditions, and others
- Provide personalized consultancy services, such as "doctor on demand", through chatbots[177]. Hospitals and insurance companies have started developing chatbots as interfaces for patients to access medical expertise, for better understanding of symptoms (like YourMD[178] chatbot, already installed in a few million smartphones), helping in formulating a diagnosis

[172] https://www.healthit.gov/faq/what-information-does-electronic-health-record-ehr-contain
[173] https://ec.europa.eu/digital-single-market/en/exchange-electronic-health-records-across-eu
[174] https://www.himss.eu/himss-taxonomy-topics/electronic-medical-records
[175] http://www.ehr4cr.eu
[176] https://www.fastcompany.com/90402714/doctors-cant-wait-to-get-their-hands-on-apple-watch-data
[177] https://medium.com/@ISDDesign/5-advantages-of-chatbots-in-the-healthcare-industry-622dd9253384
[178] https://www.your.md

(like Sensely[179] chatbot designed as a service provided by insurance and pharmaceutical companies), helping in remembering to take a pill (like the Florence[180] chatbot) and more.

- Assist doctors in diagnoses and setting up a cure, like the services provided by Unanimous AI[181] where bots are roaming the health knowledge space on the web providing up-to-date information to medical doctors.

3.3 Retail

Autonomous robots are a reality in the distribution chain; Amazon has over 45,000 robots in its warehouses receiving orders and picking the desired product from shelves to take to the packaging and shipping point. AI makes these robots more flexible, and they have become part of the warehouse automation. Notice, however, that Amazon estimates that a fully automated warehouse where no human intervention is required at any time is at least 10 years away[182].

The newest robot generation[183] can replace 24 human jobs per warehouse; their deployment in all 55 Amazon warehouses in the US would replace 1300 jobs. Packaging robots can prepare 600-700 packages per hour which is four times as many as a human worker. Notice that these advanced robots are not cheap; each one costs in the range of $1 million. Nevertheless, Amazon expects to recover the upfront cost in under two years.

For the sake of this White Paper, however, we consider only those robots "manning" the point of sale, either a store or a department store, a mall, providing concierge service at a hotel, providing services to office customers and so on as part of the retail space. Robots confined to warehouses are considered as part of manufacturing (2.1 and 3.2) because manufacturing is evolving along the Industry 4.0 paradigm, thus including the supply and delivery chain.

Upfront cost limits adoption of robots in retail

An obvious issue is the cost of these robots. While a company like Amazon can exploit the robots' capability and each robot can replace several human workers, thus providing higher cost savings, a small retailer has only a limited use for a robot (shorter working hours, a discontinued flow of clients requiring the services of the robot and so on). It is also true that a robot designed to operate in a store has a price tag significantly lower than one operating in a warehouse but this is just to make it more affordable. As a matter of fact, it is easier to design a robot to operate in a controlled environment like a warehouse than one that has to interact with customers. This results in a limited set of functionality that further reduce the possibility to exploit the robot in a store environment.

The situation, however, is bound to change[184], and the effects are already visible. The increment of functionality making robots appealing in a shop environment are more dependent on software. It is through image recognition and artificial intelligence that the robot can adapt to a variety of situations and to the dynamics of interacting with customer. This supports the growth of functionality without an increase in price.

179 https://www.sensely.com
180 https://www.florence.chat
181 https://unanimous.ai
182 https://www.theverge.com/2019/5/1/18526092/amazon-warehouse-robotics-automation-ai-10-years-away
183 https://www.businessinsider.com/amazon-introduces-new-warehouse-robots-2019-5?IR=T
184 https://www.entrepreneur.com/article/333237

Figure 50 A Bossanova robot checking the inventory in a Walmart store

So far robots in stores have been adopted for inventory purposes (in large department stores, like Walmart trials with the Bossanova[185] robot) and as a way to generate the "Wow" factor, to attract clients that are sensitive to innovation. This also explains why the major areas of adoption are in Far East Asia, with South Korea leading the pack and Japan following. In the last year China has become a market leader, both in terms of production and adoption, however the numbers are low. Also from a perception point of view fewer robots deployed in South Korea lead to a higher penetration index given the much smaller size of the Country.

AT&T is working with Badger Technologies to leverage[186] in-store 5G networks to enable autonomous robots to roam the store for inventory and shelf replenishment. The 5G architecture supports a multi-access edge computing environment and is therefore suitable for supporting many autonomous robots. In-store 5G networks may ensure better security in the operation of robots with respect to the use of a WiFi network that is potentially easier to hack.

Dal.com Coffee[187], a South Korean company with franchises in many Far East Countries including Singapore, has deployed, as of June 2019, 45 robots in some of their coffee bars (mostly in Seoul). Each one is able to prepare up to 14 drinks[188] in parallel, package them in a box, and send a message to the customer app that the order (that was made through the app) is ready for pick up. Clearly these kinds of robots are autonomous, but they work in a well-defined environment with limited interaction with customers. It is more an advanced coffee dispenser machine than what would be characterized as an autonomous robot that is aware of its context and moves around.

In this area there is quite a lot of hype, but as pointed out, the main purpose of store managers in adopting robots on their premises is to generate the wow factor and attract customers. The situation is not that much different in the adoption of robots in a number of hotel chains[189]. The expenditure capability here is higher than the one of a small store owner but there is not the compelling economics sustaining the deployment of robots. Hotel chains are experimenting both to create the wow factor and to deliver service around the clock, both concierge service (providing information, however, can be done through information points and apps) and by using robots for room service, decreasing personnel demand. There are several examples of autonomous robots in hotels (Hilton, Crowne Plaza, Henn na, Alofts), but all of them are run as trials.

Chatbots may be expected to become more common in the next decade to serve as concierge in hotels and are also expected to be adopted by retail stores, possibly in conjunction with personal digital twins. In a way, a digital twin can be seen by a retailer as an advanced profiling tool however this is not the case. There is a fundamental difference between a client's profile and a client's digital twin: the former is "owned" by the retailer, the latter by the client. Additionally, a client's profile exists in multiple instances, each one linked to the store creating the profile, and each one independent of the other and unknown to the others. A client's digital twin exists in a single copy, mirroring the physical client and on its own it will expose and interact with the various stores, one at a time, to get information and services for its physical twin. Hence, stores will not be able to embrace the digital twin evolution on their own; they will have to wait for the uptake of personal digital twins, something that is likely to happen through smartphones apps in the next decade when the Alexa, Siri, and Toby are replaced by the person digital twin.

Profiling tools vs Digital Twins

[185] https://www.bossanova.com
[186] https://www.telecomstechnews.com/news/2019/aug/02/t-looks-bring-5g-enabled-autonomous-robots-retail/
[187] http://www.dalkomm.com
[188] https://www.csmonitor.com/Business/2019/0606/Robot-baristas-in-South-Korea-push-automation-forward
[189] https://www.socialtables.com/blog/hospitality-technology/hotel-brands-robot/

3.4 Finance

The vast majority of digital transformation applications for the finance and insurance sectors are data-intensive. This holds for applications in different areas such as retail banking, corporate banking, payments, investment banking, capital markets, insurance services, financial services security and more. All of these applications leverage very large datasets from legacy banking systems (e.g., customer accounts, customer transactions, investment portfolio data), which they combine with other data sources such as financial markets data, regulatory datasets, real-time retail transactions and more. With the advent of Internet-of-Things (IoT) devices and applications (e.g., fitbits, smart phones, smart home devices), several FinTech/InsuranceTech applications can take advantage of contextual data in order to offer better quality of service at a more competitive cost (e.g., personalized healthcare insurance based on medical devices and improved car insurance based on connected car sensors). Furthermore, alternative data sources (e.g., social media and online news) provide opportunities for new more automated, personalized and accurate services. Moreover, recent advances in data storage and processing technologies including advances in AI and blockchain provide new opportunities for exploiting the above-listed massive datasets and are expected to stimulate more investment in digital finance/insurance services.

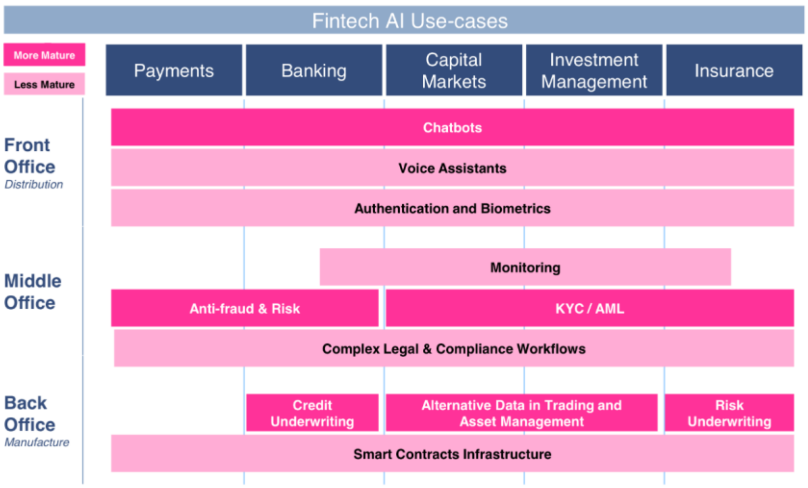

Figure 51 Various segments of Autonomous Agents and Artificial Intelligence use in Fintech. Credit: Autonomous Next

3.4.1 The Challenge of Digital Transformation

Financial and insurance digital transformation takes advantage of Big Data and IoT technologies in order to improve the accuracy and cost-effectiveness of their services, as well as the overall value that they provide to their customers. Nevertheless, despite early deployment instances, there are still many challenges that need to be overcome prior to leveraging the full potential of Big Data/IoT/AI in the finance and insurance sectors, which could also act a catalyst for attracting more investments and for significantly improving the competitiveness of enterprises in these sectors. In particular, financial institutions and insurance organizations are currently faced with the following challenges:

- Data Fragmentation and Interoperability Barriers: Currently, most of the data collected and possessed by financial organizations reside in a wide array of fragmented systems and databases, including operational systems and OLTP (On-Line Transactional Processing) databases, OLAP (On-line Analytical Processing) databases and data warehouses, data lakes (e.g., Hadoop-based systems) and others. In this fragmented landscape, heavy analytical queries are usually performed over OLAP systems, which lead financial organizations to transfer data from OLTP, data lakes and other systems to OLAP systems based on intrusive and expensive Extract-Transform-Load (ETL) processes. In several cases, ETLs consume 75%-80% of the budget allocated to data analytics while being a setup to seamless interoperability across different data systems using up-to-date data.

- Regulatory Barriers: Big Data and IoT deployments must respect a complex and volatile regulatory environment. In particular, they must adhere to a range of complex regulations, e.g., PSD2 (Second Payment Services Directive), MiFIDII/MiFIDR (Markets in Financial Instruments Directive), 4AMLD/4MLD (4th EU (Anti) Money Laundering Directive) for financial/insurance, while at the same time complying with general regulations such as the GDPR (General Data Protection Regulation) and the ePrivacy directive. To this end, there are a number of initiatives that aim at establishing regulatory sandboxes[190] i.e., specialized environments that facilitate experimentation through ensuring processing of data in-line with applicable regulations. Nevertheless, such sandboxes are in their infancy, demand the engagement of regulators and are not tailored to leading edge Big Data/IoT applications.
- Data Availability Barriers: In order to innovate with IoT and Big Data, financial and insurance organizations (including FinTech/InsuranceTech innovators) need access to realistic datasets (e.g., customer account and payments' datasets) that would allow them to test, validate and benchmark data analytics algorithms. Such data are hardly available, as their creation requires complex anonymization processes or even tedious processes for simulating/synthesizing them. Therefore, innovators have no easy way to access data for experimentation and testing of novel ideas. Moreover, the fragmentation of Europe's FinTech/InsuranceTech ecosystem is a challenge for sharing such resources across financial/insurance organizations and innovators;
- No Validated Business Models: Big Data/IoT deployments in finance/insurance have in several cases demonstrated their merits on the accuracy, performance and quality of the resulting services (e.g., increased automation, improved risk assessment, faster transaction completion, better user experience). However, there is a still a lack of validated business models that could drive monetization and deliver tangible business benefits.

3.4.2 SAS and Digital Finance State of Art Solutions

Big Data, AI and IoT enable a shift of the financial/insurance sector towards products and services, which will significantly improve the competitiveness of the sector and will stimulate more investment in Big Data and IoT driven innovation. Disruptive solutions based on SAS and related technologies are arising in different contexts of financial services; the following section presents an overview of innovative solutions that will impact the digital finance sector in the near future.

3.4.2.1 Credible Risk Assessment

- Credit Risk Assessment for small and medium enterprises (SMEs): most banks consider SMEs high-risk customers, which limits their ability to lend even to the bigger and wealthier SMEs. This is largely a result of Basel III and IFRS9 requirements but also a consequence of the fact that SMEs: (i) Have very limited coverage by credit reporting service providers; (ii) Are subject to weak contract or bankruptcy laws and judiciaries; and (iii) Are characterized by high informality in developing markets. This limitation has an adverse socio-economic, as SMEs contribute to more than 50% of EU economies. Banks are in need of a novel approach for accessing SMEs' credit risk, such as the sharing of large volumes of data across financial organizations and their processing based on AI techniques. Innovative solutions will integrate AI and blockchain-based systems for credit risk scoring of SMEs, enabling the collection and sharing of both traditional data (i.e., banking, accounting, transactional, and sales data) and various forms of alternative data (i.e., online ranking, news and blog feeds and social media, mobile, and individual data)
- Investment Banking: In today's lower return / higher risk business environment, one of the main challenges in asset management is to provide detailed risk information in a timely manner, i.e., in real time. Financial organizations and asset managers are therefore seeking

[190] Financial Conduct Authority, "Regulatory sandbox", White Paper, November 2015 and http://industrysandbox.org/regulatory-sandboxes/

novel ways for overcoming the current practice of risk applications relying on batch processing to produce aggregated reports. Alternatively, traders, risk managers, and sales negotiators should be supported on the fly, which requires real-time analytics technologies to process live operational data. Innovative real-time risk assessment and monitoring solutions will leverage SAS technologies for measuring various types of risk, and above all, market risk of portfolios of assets.

3.4.2.2 Personalized Retail and Investment Banking Services

Financial institutions currently have access to very large amounts of customer-related data from many different data sources, including both banking systems and alternative data sources (such as open data and social media). SAS technologies give the opportunity to aggregate, consolidate and share such data across institutions/organizations. Financial organizations are offering opportunities that are increasing the automation, accuracy and credibility of customer-centric processes, including KYC/KYB, services personalization, credit risk scoring and more.

3.4.2.3 Financial Crime and Fraud Detection

Financial crime costs the EU economy billions and facilitates drug trafficking, slavery and prostitution. An estimated £57 billion is laundered through London per year. In 2016, at any given time, an estimated 40.3 million people worldwide were in modern slavery, including 24.9 million in forced labor and 15.4 million people in forced marriage. The UK Government's organized crime strategy indicates that drug trafficking costs the UK an estimated £10.7 billion per year. In addition to the extreme cost to society, financial crime costs the business in terms of reputation and fines. Over the last few years, financial institutions have been fined billions. Using advanced computing techniques could start to change this environment by creating a more up-to-date, accurate, versatile and complete view of the customer's profile and behavior. This level of information could reveal abnormal behavior earlier and more accurately and enable the business to intercept criminal behavior more effectively. In the financial crime intelligence scene, ML has the ground-breaking potential to reveal much more realistic financial crime typologies, compared with traditional rule-based systems.

3.4.2.4 Insurtech: Personalized Usage Based Products

The convergence of vehicle-derived IoT and Big Data stemming from a massive number of drivers from all around the world is already revolutionizing transport services and holds the promise to disrupt the ways relevant insurance products are personalized and delivered to customers. However, most attempts towards offering pay as you drive programs rely typically on the installation of relatively simple OBD2 dongles, which are only able to collect data from a very limited number of vehicle signals. They assess the driver behavior analyzing acceleration, steering drive, speed and brake patterns, resulting in a coarse-grained classification. A large-scale system relying on high-quality vehicle batch and streaming data could allow for consideration of many more factors that suppose a fundamental factor at the time of establishing the risk of a drivers, e.g., quality of the roads in his geographical area (road roughness), identification of geographically aggregated driving patterns or the status and maintenance of the car. There may also be benefits for other models like usage-based insurance or even to increase the capacity for fraud detection. Moreover, the collection of additional data from connected vehicles (e.g., city pollution data from air-quality sensors of the cooling systems) can provide even more opportunities for added value insurance products and services.

3.5 Transport

The history of the transportation is closely linked to the evolution of the technology and has been key to some of the most important teleological and sociological growth throughout history. From simple things like foot protectors to the most actual and innovative inventions, like the drone-taxi, humans have always dreamed to go farther and, not less important, faster. This includes transporting goods.

From local to global, technology is making things happen

Thanks to the adoption of new technologies, it is possible to transport heavier and larger loads around the world in much less time than only a decade ago; and, of course, for only a fraction of the price. Quite a few important transportation modes in the past are now extinct, but many other managed to evolve and survive. Efficiency is key for success, and that is why transportation companies are and will be spending a lot of time and money in finding new inventions and discoveries to improve the service they are providing to their customers.

3.5.1. Brief Outlook of the Impact in the European Economy and Society

As stated in the publication 'Transport in the European Union – Current Trends and Issues,' "Transport services embrace a complex network of around 1.2 million private and public companies in the EU, employing around 11 million people[191] and providing goods and services to citizens and businesses in the EU and its trading partners" which gives us an idea of why transport is a key sector, in terms of business and employment, for the EU.

Since transport is a fundamental pillar of our economy and society, the European Commission has been trying to create a single European transport area, guaranteeing mobility while minimizing the environmental impact. That is why in 2011 a white paper was published titled "Roadmap to a single European transport area — towards a competitive and resource efficient transport system", that includes 40 well defined initiatives to build a competitive transport system focused on increasing mobility, removing barriers in key areas, including employment. One on the main targets is reducing Europe's dependence on imported oil, as well as reducing carbon emissions in transport by 60% by 2050.

The European Commission didn´t stop there but is also defining proposals for the modernization of mobility and transport in Europe to help the sector stay competitive and embrace the transition towards digitalization and a clean energy model. That is why 'Europe on the Move[192]' was launched in 2017. It is a set of initiatives that aims to maximize the security in traffic, reduce CO2 emissions and air pollution, minimize congestion; but also fight against illicit employment and ensure proper conditions and rest times for workers; and reduce red-tape for businesses.

[191] 'EU transport in figures' – DG MOVE statistical pocketbook 2017.
[192] https://ec.europa.eu/commission/news/europe-move-2018-may-17_en

Figure 52 Some of the Key Actions proposed by the Junker Commission since May 2017. Source: EU

It is also true that some challenges have been found like[193] creating a well-functioning Single European Transport Area, connecting Europe with modern, multi-modal and safe transport infrastructure networks, and shifting towards low-emission mobility, which also involves reducing other negative externalities of transport. 2018 was the 'Multimodal' year that put together very important initiatives to evolve transport in the EU, including the 'European Maritime Single Window'[194], that aims to "simplify and harmonize administrative procedures in maritime transport by introducing a single window for reporting formalities for ships".

The EU is putting a lot of effort in transport services, due to their critical importance for Europe, and that is why The CEF (Connecting Europe Facility) Regulation[195] of 2013 allocated a budget of 30.4 billion € from 2014 to 2020, of which EUR 24 billion are allocated for the transport sector. The Commission, on 2 May 2018, allocated a new budget covering 2021 to 2027 (post 2020). It is focused on developing the Trans-European Network (TEN-T)[196], with priority on some aspects of the TEN-T, like the cross-border sections and missing links. In terms of the climate economy, the Commission adopted on 28 November 2018 a long-term vision with 2050[197] as target date. The transport sector, as one of the main emitting sources of greenhouse gas, will play a key role in achieving the defined goals.

Looking at the future: Green Economy

All of the targeted goals require important investment in fields like research and development, mobility, and energy, which demonstrates the opportunities provided by the transport sector in Europe, but never forgetting the challenges associated to them.

3.5.2. Digitalization Levels in Transport, Breaking Silos

Not long ago the European transport sector comprised different silos (transport markets and countries) that acted in their own benefit. The goal of each one of the silos was to become bigger

[193] https://ec.europa.eu/transport/sites/transport/files/2019-transport-in-the-eu-current-trends-and-issues.pdf
[194] http://www.europarl.europa.eu/RegData/etudes/BRIE/2018/615681/EPRS_BRI(2018)615681_EN.pdf
[195] Regulation (EU) No 1316/2013 of the European Parliament and of the Council of 11 December 2013 establishing the Connecting Europe Facility, OJ L 348, 20.12.2013, amended by Regulation 2015/1017 on the European Fund for Strategic Investments, the European Investment Advisory Hub and the European Investment project Portal, OJ L169, 25.6.2015
[196] https://ec.europa.eu/transport/themes/infrastructure_en
[197] COM(2018) 773 final

and stronger, without taking into consideration the others. With the appearance of the communitarian policies depicted in the previous chapter, it is not an option any more.

From Silos to Links of a Single Chain across

The different silos are now becoming links of a single chain that works across Europe, although it is true that there is still too much work to do, and digital technologies are playing a key role.

According to the European Commission of Transport, we can consider different type of transport: rail, road, aviation and maritime, and all of them with two different markets: freight and passengers. Even though every single one of them has its own characteristics, all of them can be modelled using the Four Levels of Digitalization schema of the article "Smart Ports: A deep transformational moment[198]":

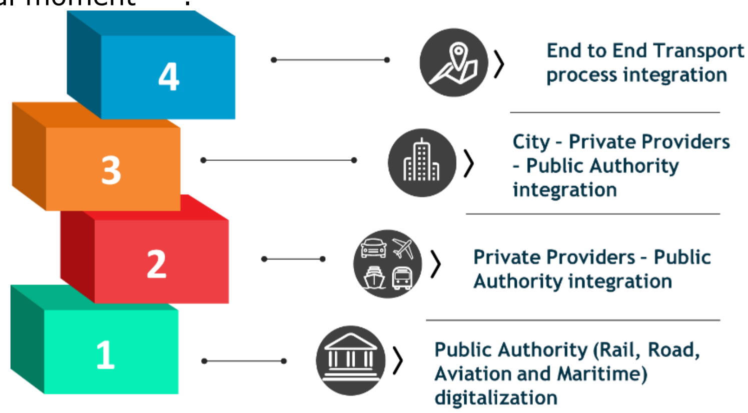

Figure 53 Four levels of digitalization model. Source: EU

1. Public Authority digitalization. Even though public authorities, regardless if they are related with rail, road, aviation or maritime transport, are composed of a very diverse set of stakeholders, all of them have a final common goal: maximize efficiency, security and environmental impact for the end-to-end transport process. This first level includes the implementation and deployment of digital tools that enhance the performance of the actual activities of the public authorities, or even facilitate the creation of new processes and procedures to improve the management of the Public Authority itself.

2. Private Providers – Public Authority integration. Agility is becoming a must for any type of business, even more if a public authority is participating. It means that intermodal and organizational integration between public authorities and their clients (public providers) should be one of the priorities in order to increase the level of competitiveness and improve the performance. This second level of digitalization includes mechanisms and technologies oriented to integrate public authority´s systems with public providers´ ones; and, even more important, includes the consolidation of the information exchanged via integrations created via evolved operation models. The implementation of this second level of digitalization is different depending on each specific transport market, but all of them have started the process to have this private providers – public authority integration in place.

3. City – Private Providers – Public Authority integration. Public authorities, private providers and cities are generating huge amounts of information so, why are not they sharing the information with the other parties? The answer is obvious: so far each one of them have been too busy trying to implement the first and second levels of digitalization already commented. Furthermore, the third level involves not only sharing information but, even more importantly, deployment of specific use

198 https://www.porttechnology.org/technical-papers/smart_ports_a_deep_transformational_moment/

cases oriented to manage freight and people transportation, and there are quite a few stakeholders that needs to be aligned to implement this third level of digitalization.

4. End-to-end Transport process integration. In this scenario all of the stakeholders participating in the transport process are aligned, the systems are integrated, and the procedures are shared by all the participants. This last level of digital adoption implies very high level of information exchange across all parties.

It is important to point out that the model depicted above describes the different levels of vertical digitalization but, in order of have the complete view of the digital status of the transport process, it is necessary to bring Horizontal Digitalization integration into the picture too. Horizontal Digitalization Integration can also be explained based on the Four Level Digitalization model (Figure 54), and it is referred to how the different stakeholders of each one of the levels are integrated with the rest of the players of the same level. In this case, five different levels of digitalization have been defined:

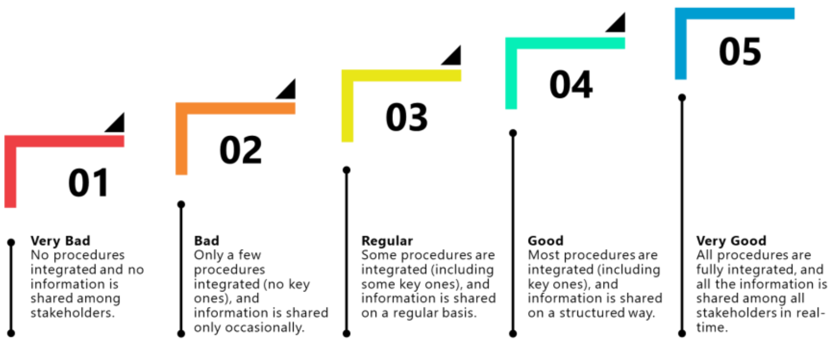

Figure 54 Horizontal digitalization model. Source: EU

Companies have realized that horizontal digitalization is key for their survival in this very competitive world, even though it means becoming partners with natural competitors. A very important example of companies that are embracing this horizontal digitalization model are the members of the Digital Container Shipping Association[199]. Giants like MSC, Maersk, Hapag-Lloyd, CMA-CGM, and more are collaborating to, in their own words: "Pave the way for interoperability in the container shipping industry through digitalization and standardization".

Considering both vertical and horizontal digitalization levels, it is possible to define the level of digitalization of the transport process for what can be called "The Polyhedron of Digitalization":

[199] https://www.dcsa.org/

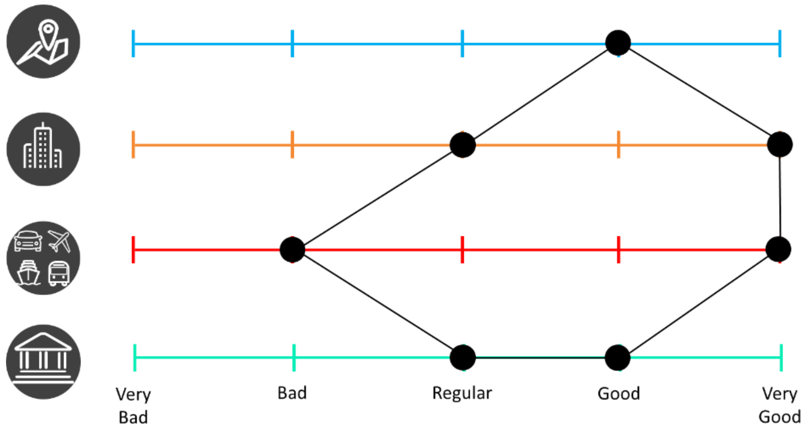

Figure 55 Polyhedron of Digitalization. Source: EU

The shape of the Polyhedron of Digitalization varies depending on the "digital status" in both vertical and horizontal directions. The best case scenario is a straight vertical line in the right part of the figure, which can be considered as a 360º Digital Integration of the Transport Process.

3.5.3. 360º Global Digital Twin of the Transport Process

It is more than proven that new technologies are changing the way business used to be. Companies like Amazon, Airbnb, Uber, and more are changing the rules of the game, forcing traditional companies to move from scaling up to horizontal and vertical digital development in order to survive. Furthermore, new autonomous transportation services are pushing the transport process to become a supply chain process, where people are treated as goods to be moved from one point to another.

All those changes and new technologies are forcing the beginning of this new era, where digital twins will play a very important role: "Digital twins are digital replications of living as well as non-living entities that enable data to be seamlessly transmitted between the physical and virtual worlds[200]". For that, a digital twin can be considered a digital representation of a physical asset, composed of a set of variables that, after being processed and aggregated, describes and predicts the behavior of the particular asset. One of the main advantages that a digital twin provides is the possibility of anticipating the behavior, potential failures or problems and abnormal behaviors of the asset, using a mathematical model in order to describe how the asset works. Even though this concept was inherited from the industrial manufacturing world, where is applied to assets like engines or robots, it can also be applied to other fields like transport, where complex systems´ behavior can be modelled and predicted, thanks to the real time data information provided by IoT systems, for example, and by applying AI, big data, ML, software analytics, and other technologies. However, in the transportation domain, the digital twin approach is different. It is not replicating the behavior of a single physical asset, but a complete complex system. In order to get a fully functional model, but also a feasible one from a computational perspective, some level of abstraction of individual entities is required, and the focus is on the complete end-to-end behavior.

From Stand-alone to 360º Digital Twins

Companies of different natures are already implementing digital twins, but those are covering only a portion of a complete process in a stand-alone model. Following the same model explained in the previous chapter, in order to have a full functional digital twin that represents a real end-to-end transport process, it is key to apply vertical and horizontal digitalization integration across all the stakeholders that participate in the process: *360º Global Digital Twin of the Transport Process*.

The 360º digital twin includes all the variables that impact the transport process, which allows the creation of a real virtual counterpart that replicates all possible scenarios of the real world. This way

[200] Saddik, A. El (April 2018). "Digital Twins: The Convergence of Multimedia Technologies". IEEE MultiMedia. 25 (2): 87–92.

it is possible to manipulate the different variables in the digital world until the desired outcome is reached, and afterwards this model can be applied in the real world with no risk. Furthermore, as digital twins learn and update themselves from all the sources providing information to represent their counterparts in the real world in almost real-time, the 360º Global Digital Twin of the Transport Process, once it is properly configured and deployed, can be used to automatically optimize the different procedures and means of transportation that are in place nowadays, and even to propose new ones taking into consideration all possible alternatives. Just imagine the positive impact it can bring in terms of energy consumption, traffic congestion, resources availability, travel-time, or pollution that in the end results in an improvement of the quality of people´s life.

3.5.4. Symbiotic Autonomous Systems in Transport

So far, we have talked about how new digital technologies are and will be positively impacting the transport process. Even more, it has been explained how the appearance of the 360º Global Digital Twin will be a real breakthrough that, combined with technologies like IoT and ML, will open the door for the implementation of SAS in Global End to End processes.
"loT will become part of our body and artificial organs will become normal in the third decade of this century[201]". This clarifying statement is stating that in the near future it won´t be necessary to have external artefacts to have information like position, pulse, blood pressure, and other metrics, but this information will be provided directly by embedded devices that will live in a symbiotic relation with us.

360º Global Digital Twin & SAS, the perfect couple

Just imagine that the system of a hospital could know beforehand that a certain person will suffer a stroke. That person could be not only alerted, but the system could also make all the arrangements to send an ambulance where that person is, after analyzing all information related with traffic, weather, optimal hospital to treat the disease, etc. Consider that a 360º Digital Twin of the Transport Process could manage all transportation procedures in a given country, controlling and optimizing all movements of freight and people inside the border in real time. This process could be extended to make it global across all countries that are members of the European Union creating a high level of optimization in terms of costs, resources consumption, citizen's satisfaction, etc. The tools are available to have a functional 360º Global Digital Twin of the Transport Process using SAS before 2050; but it is also true that there are a lot of stakeholders that need to work together before it becomes a reality.

3.6 Telecommunications

In telecommunications networks "autonomous system" means a collection of networks within a single administration domain, used mainly for connected internet protocols routing. The concept was originally structured by Cisco to take care of packet routing and security management within an administration domain. As of 2018 the number of unique autonomous systems (networks) in internet routing exceeds 60,000[202]. However, this White Paper looks at autonomous robots and software systems, including softbots and chatbots, applied in telecommunications.

In the past, there have been a number of trials to use autonomous robots in the monitoring and repair of telecommunications switches. That was seen as a potential cost savings for electromechanical switch maintenance but these switches have faded away, completely replaced by electronic switches. An area that is still labor intensive is the main distribution frame where hundreds of thousands of copper-pairs are connected and whose maintenance is labor intensive. However, here as well there is a progressive substitution of pairs with optical fibers, dramatically reducing the number of wires and simplifying the maintenance.

[201] https://www.eitdigital.eu/newsroom/blog/article/looking-ahead-to-2050-symbiotic-autonomous-systems-i/
[202] https://www.cidr-report.org/as2.0/

Todays and in the near future, the only telecom area where autonomous systems can play a role is in decentralized infrastructure maintenance and in particular in radio towers and submarine cables.

3.6.1 Radio tower maintenance

Several telecommunications companies, particularly wireless telecom providers (but also wireline telecom providers have a significant amount of wireless infrastructure), have started to consider drones as a potential technology to improve radio tower inspection and maintenance[203]. Verizon has acquired a drone company, Skyward, to own the drone technology and apply it to radio tower maintenance.

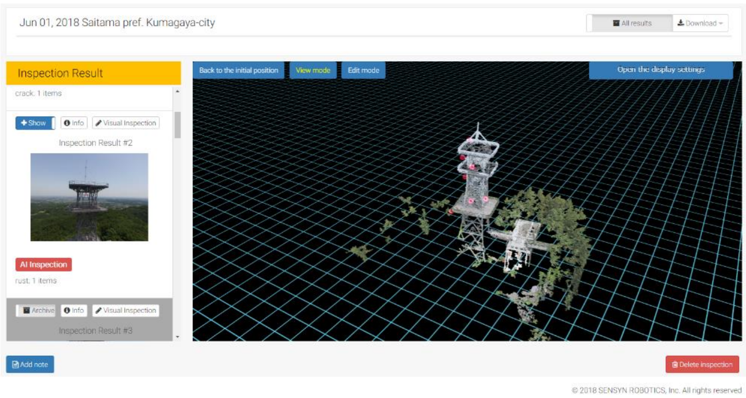

Figure 56 Report generated by an autonomous drone after a tower inspection. Dots on the tower indicate areas of potential problems. Image credit: Sensyn Robotics

Drones can significantly reduce the time needed for inspection, and most of the time they can make human intervention unnecessary. Even in those cases where human intervention is needed, e.g., to replace a component that cannot be replaced by a drone, it is useful to have the drone checking for potential hazards ahead, like the presence of wasp hives or structural damages.

There is a growing offer from several companies targeting the telecommunications tower monitoring market providing fully autonomous systems, like the one[204] from Sensyn Robotics able to photograph, analyze and report in full autonomy.

It can be expected that the next decade will see a significant growth in the adoption of autonomous drones in radio tower infrastructure inspection under:

- the converging steering of a regulation that is evolving to adapt to these new technologies. Today in several countries drones inspection cannot be autonomous; it must be supervised, on site, with the presence of a human remote-pilot thus significantly decreasing the cost saving advantages;
- the growing application of drones to the monitoring of power and utility infrastructures, that is going to increase the flexibility of the solutions and decrease the price. The overall market[205] is getting close to $10 billion in 2019 and is expected to grow significantly in the next decade.

3.6.2 Software Systems

3.6.2.1 Software Network Architecture

Telecommunications networks are by far software controlled and can be seen as autonomous systems. Routing and resource allocation is the result of autonomous decisions, often resulting through the interaction of distributed systems. There is a general framework for making decisions, but more and more equipment and control systems are endowed with some sort of AI.

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[203] https://www.eyeintheskytechnologies.net/2019/01/05/drones-telecommunications/
[204] https://www.sensyn-robotics.com/en/news/tower-check
[205] https://www.pwc.co.za/en/press-room/pwc-sees-us-9-46-billion-drone-solutions-market-for-power---util.html

The evolution expected in the coming years is towards more decentralized control, actually towards massively distributed systems, each one able to take autonomous decisions. Smartphones will become network nodes and will negotiate the access and use of resources through a variety of access gateways. 5G architecture, enabling the session control at the device level, is opening the door to a network resulting from the interaction of autonomous systems. The evolution of the infrastructure is towards a mesh of networks providing basic connectivity resources to service execution and delivery. Data centers on one side and user devices (smartphones, intelligent appliances, vehicles, robots) on the other will determine their needs for resources based on the services and context.

3.6.2.2 Softbots

Intelligent networks started the shift of network infrastructure towards softwarization. The transformation is now advancing rapidly with architectures supporting software defined networking (SDN)[206] and network function virtualization (NFV)[207]. Data centers are also becoming part of the network, and if on the one hand the evolution has led to a progressive decoupling of the network layer from the service layer, on the other hand the service layer is becoming a true infrastructure of itself. Communications and management of service interaction is evolving to support at the same time service independence and service leverage/aggregation. Softbots, roaming the service layer, are becoming an important component of the service layer, as well as autonomous systems to access and leverage data.

3.6.2.3 Chatbots

Chatbots are becoming the usual way to interact with customers. Telecommunications operators have thus far used them to support interaction focused on the delivery of their own customer service. At the same time chatbots offered by Amazon, Apple, and Google take a much broader footprint offering the possibility to manage a growing slate of services. Chatbots are autonomous systems that can grow their capabilities over time, often through ML, as result of the interaction with their user. This would be an area where a telecommunications provider should consider investing to increase customer stickiness.

3.6.2.4 Digital Twins

Digital twins are seldom used in telecommunications. Although this is understandable when considering the equipment, it is more difficult to understand when looking at the service side. Telecommunications operators should be ideally positioned to grow a strong tie with their customer and to raise their business from intermediating communications (by linking a to b) to intermediating demands versus offers. They could, in principle, offer tools to their customer to develop their own personal digital twin and the services to manage it. The digital twin, that should remain property of the related physical person, could then be hosted by a telecommunications operator supporting its many interactions with service providers. The risk is that telecommunications operators will not be able to step up, providing the opportunity of this business to big global service providers.

3.7 Security

Technology is amoral, it can be used for both good or bad purposes. The information age has made the world more connected, but it has also enabled billions of robocalls, email spams, mass surveillance using Closed-Circuit Television (CCTV), accelerated diffusion of fake news through social

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[206] https://sdn.ieee.org

[207] https://ieeexplore.ieee.org/abstract/document/8247541

media, malwares, and advance military drones. To defend and protect SAS systems against malicious use, security and fail-safe mechanisms must be designed in the system foundations.

SAS will be increasingly based on interconnected IoT devices including cyber-physical systems manufactured by diverse vendors. The IoT devices will enable digitization of all societal sectors including manufacturing, healthcare, retail, finance, transport and telecommunications as discussed in previous sections. A Symantec report[208] on IoT devices predicts that there will be up to 21 billion connected devices by 2020 (See Figure 57). The security impact on these systems will be far reaching with considerable physical environment destruction.

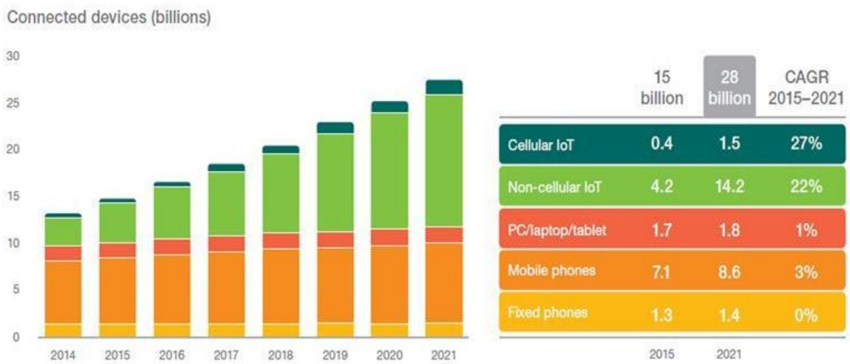

Figure 57 Growth forecast of connected devices (source: Symantec)

Most of the current IoT devices contain vulnerable software, insecure default configuration, and no security management functions. They increase the attack surface, rendering a SAS vulnerable to cyberattacks. A compromised IoT system can be used for Denial-of-Service (DoS) attacks, digital crime proxies, ransomware, data theft, and more recently, cryptocurrency mining cartels. For example, the recent Mirai worm targeted vulnerable connected consumer IoT devices such as cameras, baby monitors and switches; these devices became part of massive DoS attack campaigns[209]. With AI, the complexity of security attacks has increased enormously with more attacks being autonomous. Once an attacker assigns an objective, the autonomous offensive software bots continuously scan for vulnerable machines and humans on online sites. When a vulnerable target is identified, automated attack plans are dynamically realized without any human intervention. Management of SAS by humans will not be feasible due to the massive scale, speed, heterogeneity, and software complexity. For secure operations, SAS will need autonomous defense systems that can learn, adapt and defend against emerging threats. The foundation of SAS security will depend upon the trust stack of cyber-physical systems, including, the physical environment, the device hardware and software layers, and the AI model layer as shown in Figure 58. The threat actors can compromise any one or multiple layers rendering the whole system vulnerable.

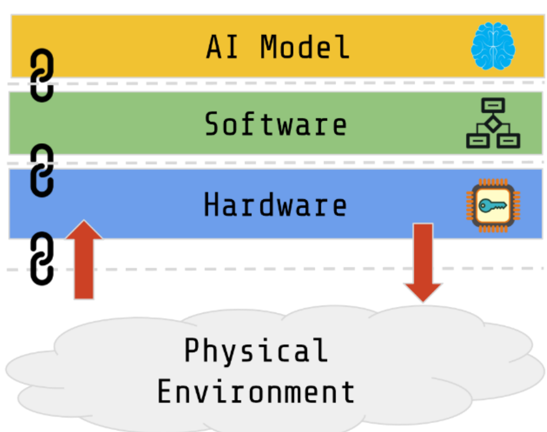

Figure 58 Cyber-Physical Trust Stack

3.7.1 SAS Threat Actors and Cyberattack Life-Cycle

The SAS threat actors can be broadly classified into four major categories: criminals, hacktivists, nation states, and insiders. The first three actors reside outside a network system operational perimeter. The cyber criminals are mostly interested in monetary incentives. The cyber hacktivists

[208] 208 https://k2partnering.com/cyber-security/how-iot-has-escalated-the-cybersecurity-issue/

[209] Antonakakis, Manos, et al. "Understanding the Mirai Botnet." USENIX Security Symposium. 2017

target specific entities with a goal of data theft or simply vandalism to tarnish an organization's reputation. The nation-state actors also target specific entities especially foreign governments and corporations with a goal of espionage, intellectual property theft, information manipulation, and destruction. The insider actors can cause the most damage to a system. The major risk is due to access policies, as these actors can turn rogue anytime. They are mostly employees or third-party contractors that are looking for revenge, profit gains or are under external pressure. For targeted entities, nation-states can also introduce persistent hardware or software implants via supply chain vulnerabilities that allow zero-day access.

A cyberattack life-cycle follows a standard set of steps, defined as intrusion-kill-chains[210], for gaining full access to remote systems. The life-cycle steps are reconnaissance, weaponization, delivery, exploitation, installation, command and control, and objective actions. The reconnaissance step involves research and selection of targets using digital footprints such as emails, social profiles, mailing lists, and conference proceedings. Weaponization involves remote access malware packaged with vulnerability exploits as payload files such as Flash video, PDF document, Office documents, audio or image files. The delivery step involves the transmission of the weaponized payload via different channels such as email attachments, physical USB drives, website URL access or open wireless networks. The exploitation step involves triggering the application code vulnerability for successful exploits. This step infects most systems that are not patched or the exploit is a zero-day threat. The installation step hides the backdoor in the system and makes it persistent. The command and control step involves communication with external malicious servers that provides further mission actions to compromised network hosts. Finally, the objective actions are achieved that can include data theft, destruction, extortion, or intrusion of another network. Figure 59 illustrates the cyber kill chain attack steps.

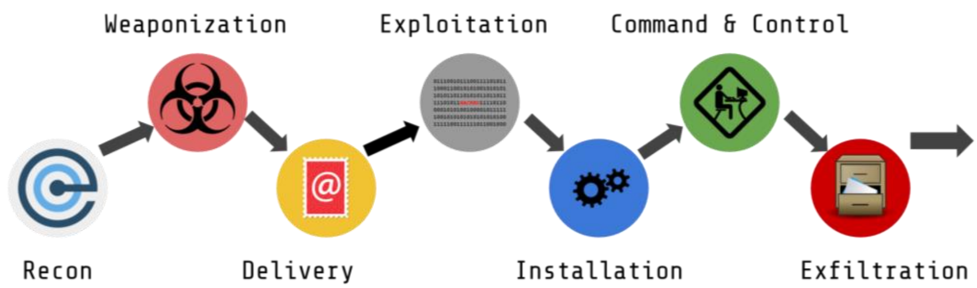

Figure 59 Cyber Intrusion Kill Chain

The malicious use of AI report[211] highlights increasing threats of using AI in cyber-physical systems. At first, the digital-space will experience an increase in social engineering attacks with human-level interactions and phishing attack campaigns; automated code vulnerability discovery and exploit generation; human-like service access for DoS; and finally, bot versus bot warfare will be seen. Second, the physical-space, commercial high-skill weapons with low skill humans; fully autonomous weapons; and finally, robot versus robot warfare will be seen. Lastly, in society, mass surveillance of citizens; massive fake news generation and diffusion channels, for example, deepfakes; personalized disinformation campaigns; denial-of-information attacks; mind-control attacks; and finally, political unrests with human versus human conflicts will be seen. These threats raise critical safety and security questions of AI in SAS environments. Furthermore, with digital evolution[212], the

[210] Intelligence-Driven Computer Network Defense Informed by Analysis of Adversary Campaigns and Intrusion Kill Chains, E. Hutchins et. al., Lockheed Martin Corp., 2011

[211] Brundage, Miles, et al. "The malicious use of artificial intelligence: Forecasting, prevention, and mitigation." *arXiv preprint arXiv:1802.07228* (2018).

[212] Lehman, Joel, et al. "The surprising creativity of digital evolution: A collection of anecdotes from the evolutionary computation and artificial life research communities." *arXiv preprint arXiv:1803.03453* (2018).

behavior of AI models in complex environments can be nondeterministic resulting in reduced trust in the system operations.

3.7.2 SAS Defense

Establishing cyber defense requires complete monitoring and management of hardware and software supply chains. All phases of supply chain management, including hardware manufacturing, secure code design and development, vendor and code delivery management, AI model learning, and operational best practices, are critical. We cannot defend what we cannot observe. Similar to offensive bots, defensive bots using self-healing (or self-repair) approaches, including threat identification, diagnostics and autonomous restoration are essential for SAS security. In fact, if we look at the 2018 Hype Cycle for Emerging Technologies[213] (see Figure 60), the field of “Self-Healing System Technology” is positioned at the Innovation Trigger stage and planned to reach the Plateau of Productivity in 5 to 10 years.

[213] https://www.gartner.com/smarterwithgartner/5-trends-emerge-in-gartner-hype-cycle-for-emerging-technologies-2018/

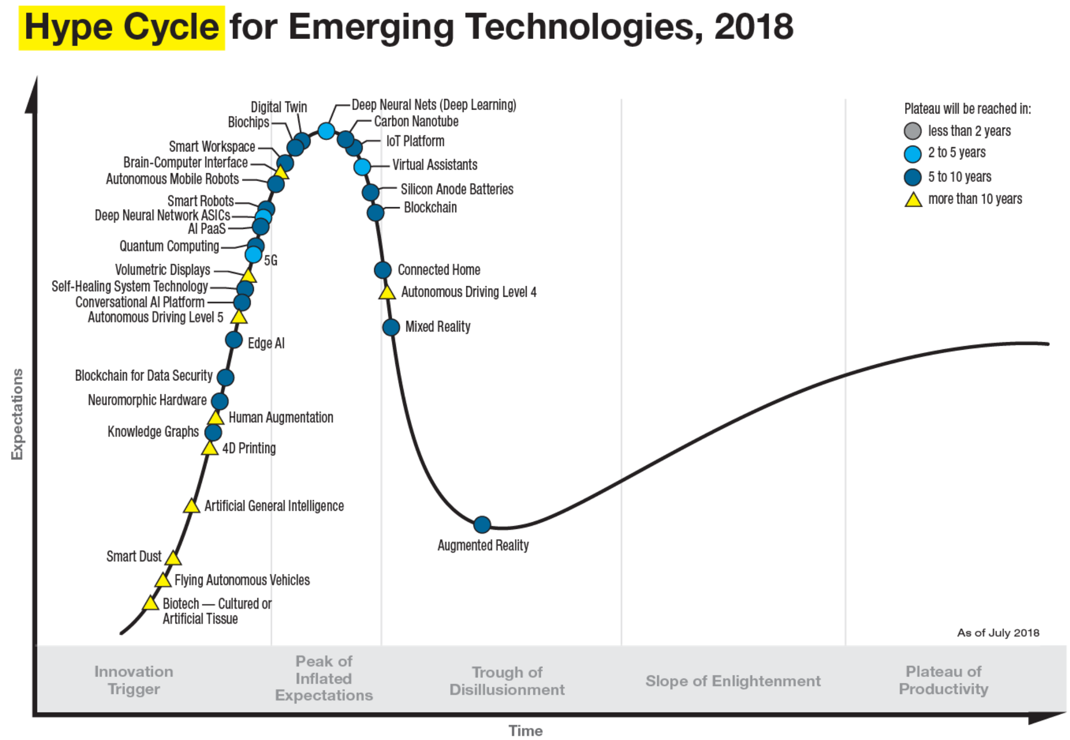

Figure 60 Hype Cycle for Emerging Technologies (source: Gartner)

Having a network-first approach is essential to scalable security operations. Each device in the network can be tracked through the registration, configuration, operation, maintenance, and quarantine life-cycle steps. The device operational state can be divided into configuration, static and dynamic behavior layers. The configuration layer can provide secure operational system defaults such as sanitizing default passwords, selecting secure protocol suites, best practices, software hardening rules, and whitelisting to limit unwanted communications. The static layer can provide protection from known malware file signatures, malicious network traffic such as phishing emails and domains. The behavior layer can provide runtime knowledge using learning-based methods to model both, normal and abnormal behavior of machine hosts. Figure 61 illustrates these layers with the bottom configuration layer reducing the most attack surface followed by static and dynamic behavior layers.

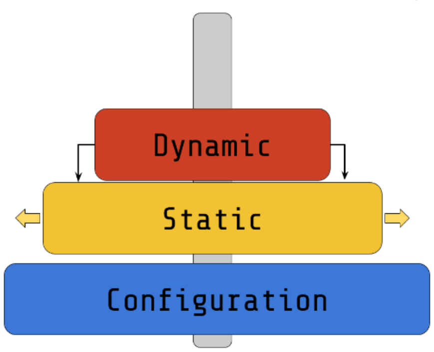

Figure 61 Operational Security Layers

3.7.3 Software Code and Self-Awareness

Software code is the foundation of all digital life. The hardware and software vulnerabilities can be reduced by using secure design, AI-assisted development, testing, and deployment methods[214]. Trusting a computing stack involves verifying code at each infrastructure layer starting with hardware, bootloader, operating system, device drivers and application software. Automated hardware Trojan implant detection methods[215] can help secure the network hardware layer. Secure-

[214] Allamanis, Miltiadis, et. al. "Learning to represent programs with graphs." *arXiv:1711.00740* (2017)

[215] Xiao, Kan, et. al. "Hardware Trojans: Lessons learned after one decade of research." *ACM Transactions on Design Automation of Electronic Systems (TODAES)* 22, no. 1 (2016)

boot chain forms a trust chain by verifying code signature starting from hardware chips, mitigating many attacks like bootkits, rootkits, and persistent malware.

Using formal mathematical methods to prove software security states establishes trust in the computing base. For example, the seL4[216] provides a formally verified kernel that can stop attackers from full node compromise. The DARPA deepspec[217] project goal is to create interface specifications and verification of full functional correctness of a software and hardware stack. This can be extended further to create self-aware host machines. A self-aware system can automatically repair runtime state or repair behavior by writing a patch and updating system code without any downtimes. In 2016, DARPA conducted the Cyber Grand Challenge (CGC) [218] competition to explore similar ideas in automatic defensive systems that are capable of reasoning about flaws, formulating patches and deploying them on a network in real time. Furthermore, monitoring systems that explain the logical reasoning of AI model decision making process are critical to the success of SAS. The explainable AI (XAI)[219] DARPA program tries to address the logical decision-making problem of AI models. Establishing trust in the AI models by formally certifying the models and their corresponding behavior should be a requirement that standards and policy makers need to understand and collaborate on effectively. Finally, proper cybersecurity awareness education for consumers, industries and government actors is critical to create a safe and healthy cyber-physical space.

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[216] Klein, Gerwin, et al. "seL4: Formal verification of an OS kernel." In *Proceedings of the ACM SIGOPS 22nd symposium on Operating systems principles*, pp. 207-220. ACM, 2009.
[217] High-Assurance Cyber Military Systems, Defense Advanced Research Projects Agency (DARPA), 2015, www.deepspec.org
[218] Fraze, Dustin, Defense Advanced Research Projects Agency (DARPA), 2016, https://www.darpa.mil/program/cyber-grand-challenge
[219] Turek, Matt, Defense Advanced Research Projects Agency (DARPA), 2016; https://www.darpa.mil/program/explainable-artificial-intelligence

4 SOCIETAL IMPACT

4.1 Digital Reality Versus Reality

We feel appropriate to start this section of societal impact with a discussion resulting from the evolution of the concept/perception of reality as we are growing into a space that is progressively more and more "digital".

It is now over 25 centuries that philosophers have been discussing the meaning of reality, stating that there is not such a thing as reality, since what is now was not what it was a moment ago and it will no longer be a blink of an eye from now. Others claim that reality is something that we can only perceive through our senses, and our senses introduce a distortion, hence what we perceive is just a shadow of reality.

For the lay man, and each of us is a lay man, reality is clear: it is the fact that when we wake up in the morning, we expect to see what we saw as we went to sleep. If not, we are surprised. Reality is the space in which we live and which makes sense to us; we will leave the obscure debates to the philosophers.

This sense of real "reality" is so intertwined in our perception of the world that it is our perception that is creating our reality. In the last 100 years physicists came up with a scientific, measurable, view of the world, of a reality that doesn't match with our perception: the fact that there is an absolute limit to speed, so that once you get close to that limit 1+1 equals 1, not 2, or that something can be in several places at the same time, that its existence is not an absolute but it depends on whether we are observing it or not,

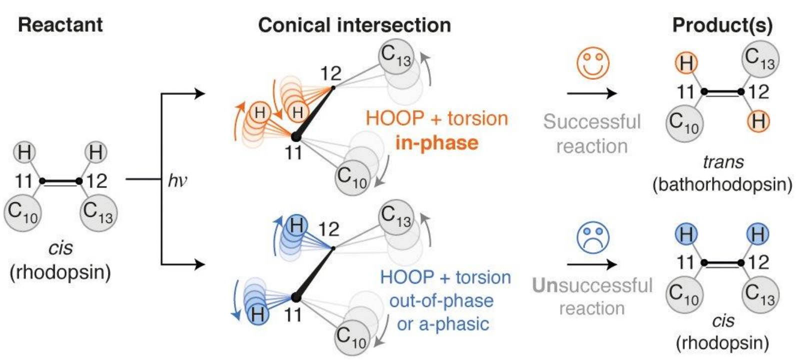

Figure 62 The quantum effect on rhodopsin. Image credit:

Curiously, these esoteric characteristics of reality have a real effect on our life. GPS can only work because engineers take into account the dilation of time, as a consequence of different speeds in a given reference frame. Our eyes can see because quantum effects make the rhodopsin in our retina able to intercept photons and convert them into electrical signals for our brain. A gyroscope works based on optical fiber that exploits the Sagnac effect: the fact that a beam of light will always travel at the same speed "c" independently of its direction (which is very counter-intuitive by the way) and what changes is the phase, so by having a difference in phase there is interference among two light beams and this interference can tell us the relative position in space of those two beams. There are many such examples.

However, as we disregard the obscure discussion of ancient time philosophers we similarly disregard the physical reality behind our everyday life, sticking to "what I perceive is what it is". Perception leads.

In these last few years, technology has become more and more able to trick our senses and this creates a new problem. If what we perceive is what we feel as real, what happens when this perception is distorted by technology?

A few years ago, IEEE Future Directions created an initiative to study the technologies that in a way or another create and distort our perception of reality called IEEE Digital Reality. The IEEE SAS Initiative has merged into the IEEE Digital Reality Initiative, and as mentioned previously, this third White Paper reflects and leverages this merging.

The name Digital Reality suggests a different "reality"; it is a digital creation, using bits and a variety of ways to render those bits so that they can be perceived, seamlessly, by our senses. Sometimes it is a full digital reality, or VR, with no ties to the "real" reality; some other times it is a digital reality that is overlaid on the real reality, what we call AR, augmented because bits are now adding onto atoms, like showing information (text, images) on an object; and yet, some other times digital objects are created (like in virtual reality) and are placed in the real reality –calling this mixed reality.

In all views the point was recognizing that technology can create a reality that is different from the one we are used to, a digital reality - digital because it is leveraging bits, and this digital reality has an existence of its own. The initiative was looking at the fostering the progress of technology and its application to make this digital reality more and more sophisticated; in other words, to make it more and more perceivable as reality by us, human beings (the measure of all things, as the philosophers of the old, more specifically, Protagoras used to say).

The parallel FDC IEEE Initiative, SAS, started at about the same time as IEEE Digital Reality, put the focus on the augmentation of machines that is happening at the same time as augmentation of humans. Here the key is the word "symbiotic". The initiative wanted to explore the feasibility of symbioses among humans and machines, and indeed its conclusions (see the second SAS White Paper) were that the parallel augmentations were not just influencing one another, they were also creating a new "reality" based on the symbioses of humans and machines.

Crucial parts of this symbioses are:

- the expansion (not just growth) or artificial intelligence making machines more aware of their environment and context (the environment is what is around or where the machine operates, the context is the understanding of what and why things are occurring);
- the growth of prosthetics (worn and embedded) augmenting humans that are becoming, not just functionally but also perceptually, part of humans (my brain over time will consider a prosthetic hand, if I have one, as an integral part of my body);
- the presence of digital twins, bridging the world of atoms (reality) to the world of bits (digital reality).

One of the main messages coming out of that initiative, in relation to the topics being discussed here, is that a digital reality may not necessarily exists as a separate, different world to which we associate the word "digital" (this word becomes a separator from the actual reality to the one being created), rather through symbioses where digital reality may become part of the reality. The knowledge I can seamlessly access on the web becomes an integral part of my knowledge, part of my reality. Symbioses merges the digital with the atoms, and of course humans with machines, changing our perception, what we feel as real.

Hence it shouldn't come as a surprise that the two initiatives, IEEE Digital Reality and IEEE Symbiotic Autonomous Systems are now being merged into a single initiative. But what is the connection between the two? It boils down to the ongoing digital transformation. The digital transformation transforms the reality of atoms (and processes and organizations based on atoms) into a digital reality, but this transformation is not annihilating the world of atoms (by the end of the day you still want to eat spaghetti), rather it binds the digital world to the real world, the digital reality to the "reality".

The new Initiative launched by IEEE Future Directions capitalizes on the results achieved by the afore mentioned IEEE Digital Reality and IEEE Symbiotic Autonomous Systems Initiatives, and it is called *IEEE Digital Reality: Fostering and leveraging the ongoing Digital Transformation*.

The Digital Transformation is affecting most businesses and many paths of life and is transforming our perception of the world. Consider the changes in the way of life and in our perception of the world: it makes sense to consider these two together because they influence one another. The way we live shapes our perception of the world and likewise our culture and societal blueprint steer our way of life in what we feel the desirable direction.

In this respect, the Keidanren report[220] is very interesting. The report, "*Toward realisation of the new economy and society*" has been published by the Japan Business Federation in April 2016, was subjected to several discussion and refinement and presented at CEBIT 2019 as the vision of Japan for the Society produced by the Digital Transformation.

An intriguing point is the concept of walls, barriers that need to be addressed and overcome to make the shift to what they call Society 5.0. The report identifies 5 "walls":

- The wall of ministries and agencies, basically pointing to the need to reform the government to integrate with the new environment brought forward by the digital transformation (and of course leveraging the possibilities opened up, in particular leveraging the data created by pervasive IoT and using those data by "think tank" functions);
- The wall of the legal system, recognizing that the new meshed bit-atoms reality requires a new legal framework (and this also connects to new fiscal framework, something being heavily debated today, as geographical barriers are no longer clearly defined in business);
- The wall of technologies, recognizing the exponential growth in a bottom up fashion requiring an overall planning effort to make investment at the country and transnational level consistent and effective;
- The wall of human resources, pointing to the need of rethinking the education system; the report clearly focusses on the Japanese situation but several aspects apply in general;
- The wall of societal acceptance that goes beyond seeking a consensus, pointing to the need of serious consideration of new ethical issues and societal implications.

It is, actually, on this last "wall" that we focus here.

The IEEE Symbiotic Autonomous Systems Initiative foresees a seamless "absorption" of cyberspace and smart machines in our perceived reality space. Actually, the Initiative foresees a convergence that results in a symbiosis of humans and machines, but if we look at this from our human standpoints it is no longer a symbiosis but an absorption. The reason is that we continue to be and feel as our unique self; we will never perceive that our self has abdicated in favor of a super-self.

So, we can imagine ourselves in a not too distant future being seamlessly connected to cyberspace (much more seamlessly than we are today, when we use our smartphone). Prosthetics of different forms will enable this connectivity. We will still be using our eyes and ears for the coming two decades but these senses will be extended in various ways to let cyberspace become part of our "knowledge space" and "experience space" (in the future embedded prosthetics and eventually a mixture of prosthetics and genomic engineering will upgrade sensorial capabilities).

We will potentially know everything we may want to know and even everything that we will need to know, as if we had that knowledge in our brain. Notice that this requires much more than a seamless, proactive, Google Search. If today, we search for Maxwell equations we can obtain them but we will

[220] The Keidanren Report: https://www.keidanren.or.jp/en/policy/2016/029_outline.pdf

not “understand them” unless one has the needed background. How can a seamless connection transform a physical connectivity into a semantic connectivity?

One way would be to use an intermediary that can fill the gap between raw data (information we do not understand are equivalent to raw data) and something that is meaningful to us. This intermediary has a name: a personal digital twin. A person’s digital twin is much more than a replica of a person, including experiences and knowledge. It is a platform to rise communications to a semantic level.

For sure today we consider our smartphone, our digital social space, as a part of us, probably to the extent we consider a “limb” as part of our physical body. Losing data of our digital life is impactful. So, we might say that “my digital twin will become an integral part of me”. Perhaps it does not become part of my “self” in the sense that one would consider it not as an “external” object rather one will not perceive it at all. Eventually it will be part of me in the sense that I will be seeing through it, as I am seeing today through my eyes, but also through my glasses and through a microscope. Reality is the same; it is not created by the device one is using (eye, glasses, microscope).

Notice that today we perceive long distant stars as real objects, yet they are a rendering of electromagnetic waves made by computers, as an example, the wonderful image of the crab nebula, something that has been created by a computer, and yet we interpret it as “real”. Our ancestors saw constellations in the sky by supplementing virtual lines created by their brain to what they were seeing as points of light.

The point made here is that the digital twin will be providing us with a perception of reality that will be created out of bits and atoms that generated part of those bits.

This creates some challenges:

- Different personal digital twins are likely to create different “realities”. This might contrary to our expectations: different brains exposed to the same “facts” can drive quite different perceptions of reality. Digital twins may make this even more frequent and more difficult to intercept.
- The digital twin extraction of semantics and its delivery to our brain will be based on some third-party services, and it is not clear what kind of control a person will have in that regard and what level of transparency on the processes creating the semantics will be available. Again, this is not completely new; today. data is accessible through a search engine, and search engines have become able to hide information, facts and reality. Think about it: a Google search provides list of pointers plus the indication that there are an additional large list of pointers. Only the first few results are generally accessed. However, two different people running the same search are provided with different results based on the search engine’s knowledge about the person’s preferences. Hence the results, upon which we perceive reality, will be different from person to person.

The reasoning followed so far has pointed to the evolution from a reality “out there” to a digital reality that is being created and that we can perceive in various ways using technology. Furthermore, as technology becomes more advanced, both in the creation and in the fruition of digital reality, the boundary separating reality from digital reality fades away and the two create a new symbiotic reality that is ultimately the one we perceive. However, while reality as we have known it for centuries was an objective one, it was the same for every person getting exposed to it. Alternatively, the symbiosis of digital reality and physical reality, mediated by technology, will tailor the perception to the specific need of that specific person. The personal digital twin will play this role of intermediation and personalization. What it is searched on the web may produce different results depending on who is searching. Two persons looking at the same “thing” will get different facts. Reality is becoming subjective. Notice that from as far as we can tell reality has always been interpreted in a subjective way, leading to different perceptions and understanding in different brains: what was seen as an act of god a thousand years ago is now seen as a natural phenomenon; what an engineer sees in a car may be different from what another person sees because of different education and interest; and so on. However, now there is a subjective reality not in terms of different interpretations of the same objective reality but rather in terms of accessing different realities via different data sets.

The digital transformation is doing much more than shifting some atoms into bits. It is creating the possibility of an unlimited slate of features in cyberspace that become intimately connected with atoms, a product, to the point that they are actually defining the product itself and of course its perception by a user.

Take the example of Mevea[221]. They are using digital twins as starting point in the specification of a product and using them to interact with their customer making them perceivable as a real product through VR. Once there is an agreement with the customer they will further develop the digital twin to the point that it can become an executable manufacturing specification. Part of this specification will result in actual metal being forged into the product for example and another part will be used to create the software giving life to the product. The digital twin remains associated to the soft and hard parts of the product and can be used for simulation and training, and over time feedback from the field will lead to changes. The customer does not see a dividing line between soft and hard; to his experience both are present at the same time.

Take the example of a personal digital twin of a backhoe operator. This personal digital twin might engage in an interaction with the backhoe digital twin resulting in a different experience to different operators using the very same backhoe. This can be generalized to any product: to the car, that will become aware of that particular driver and interact seamlessly with her, to a kitchen robot that being aware of that particular cook will interact in a very specific way.

In contrast, a particular backhoe operator, a driver, or a cook, will perceive a very specific reality that will differ depending on who is exposed to it, although the object they are interacting with is (at atom level) exactly the same. The digital reality, now no longer perceived as an independent one, being part of the "reality", is changing the subjective experience.

In summary, digital reality, made possible by technology evolution and its adoption, is creating a new world in cyberspace, something that was clearly "artificial". Two forces have started to blur this separation:

1. The ease of accessing cyberspace is making it an integral part of our everyday life.
2. The intertwining of features delivered through cyberspace with the one embedded in a product continues to make the boundary blur.

Technologies like digital twins may change our visibility of cyberspace (profiling is already a step in that direction) resulting in the perception of different digital realities. Since digital reality is becoming more indistinguishable from physical reality the result is that the distinction between objective and subjective reality becomes more difficult.

The digital transformation is accelerating and in some areas is the cause of this blurring of boundaries. It is happening because there is a very strong economic incentive to shift the business as much as possible to cyberspace, since transaction cost is much lower and the potential market reach is the whole planet.

[221] https://mevea.com/solutions/digital-twin/

This transformation is creating some challenges:

- Who is controlling and influencing our perception of reality? It is nothing new, of course; the impact of media on society as a whole and on the single individual is a well-studied area. What is new is the loss of transparency and the highly increased effectiveness of the influence.
- In the past we had an objective reality, we could disagree on its interpretation/meaning but the starting point was the same for everybody. It made sense for Leibniz saying: "*quando orientur controversiae, non magis disputatione opus erit inter duos philosophos, quam inter duos computistas. Sufficiet enim calamos in manus sumere sedereque ad abacos, et sibi mutuo (accito si placet amico) dicere*:*calculemus.*[222] Now we are seeing that the starting point for two persons may be different; reality is subjective once it gets mediated by technology. The problem is that cyberspace has become so huge and complex, and semantic cyberspace, the one derived from the analysis of data correlation, is beyond the human understanding.
- In a framework of digital twins mediating the access to digital reality and creating a personal (perceived) reality, who will be responsible for the outcome? Will we have to abdicate negotiation to digital twins, asking them to sort out differences among them first and then come back to us with a modified, but accepted, reality? This is an area where there may be bigger issues than the ones that are now under the spotlight when considering AI.
- Controlling personal digital twins means controlling a person's perception of the world. Do you think this is so far away in the future that it is not a real issue? Consider Siri, Alexa, Cortana, Google Assistant. They are a first step in the direction of a personal digital twin. They are getting more effective every day (in performance, seamlessness, and knowledge). They are not necessarily in any way malicious, nor do their proponents have any bad intention, however, it is the very nature of these digital intermediators to skew the objective reality into a subjective one.
- Technologies like VR and AR (plus Mixed Reality) are clearly tools to bridge cyberspace with the world of atoms. They are getting more seamless, and it will become more difficult to distinguish what is physical reality from what is artificial. This is not just a consequence of the improving the supporting technologies, rather it is because the artificial world is becoming an integral part of the real world, we are reaching the point that the real world cannot exists without the artificial one.
- Products and services are becoming a mélange of physical and digital realities, and it will become impossible to have one without the other. Additionally, there has always been a goal for the market of one, customization to the individual client/user; there has always been a goal towards the creation of seamless interfaces, making use of products features as straightforward and natural as possible. What better way to achieve this than by "embedding" the user in the product? Digital twins make this real, and Industry 4.0 is pursuing this goal as well (and it is not by chance that digital twins are becoming a pillar in Industry 4.0). Since we are "individual" when we become part of a product we are also creating an individual reality of that product that is different from the one of likewise products "embedding" different individuals. We will be more and more in a symbiotic relation with (several) products and likewise (several) successful products will be in symbioses with us.
- Finally, all of the above is not happening all of a sudden, but in tiny steps that defy our perception. Think about the smartphone: in some 20 years it has changed from a curiosity for some top echelon business people to an integral part of every person's life, and we cannot pinpoint a date when this transition took place.

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[222] If controversies were to arise, there would be no more need of disputation between two philosophers than between two calculators. For it would suffice for them to take their pencils in their hands and to sit down at the abacus, and say to each other (and if they so wish also to a friend called to help): Let us calculate

4.2 Personal level

The following three sections address the consequences of the digital transformation perceived not merely as identifying technological innovation and its impact on business, government and society at large, but more specifically as getting under our skin, so to speak and changing human nature itself. The new actors that are rapidly emerging from the sea change are, at the personal level, the concept of digital twin, and, at the community level, that of the Social Credit System in China (culturally matched by the theme of "surveillance capitalism" in the West). Considerations about digitally twinning cities and even a whole country can help to recognize that the digital transformation is becoming the foundation of culture. In very broad terms, the digital transformation is tending to eliminate privacy –but not private identity– and, by increasing controls, to suppress or reduce autonomy. Digital twins may or may not be developed as instruments to resist or to condone such trends. With symbiosis, to be or not to be is still the question, but on what conditions under the digital transformation?

At the personal level, the concept of the digital twin, previously amply exposed and detailed, is the Trojan Horse pushed through the door of human selfhood by the digital transformation. It is also a model that allows for examination of an epistemological revolution in the making. The concept is growing as much in our thought processes as it is in industry. It helps us understand and visualize what the digital transformation is also doing to our human presence in the world. The twin is really us "being digital" and affects and modifies how we occupy space and time. Once properly applied to the human person, the digital twin, symbiotically intertwined with that person's body and mind, will define what it is to be human (if humanhood still remains the principal criterion to define us). While the digital twin may not have a "mind" of its own, whatever amount of ML, AI, or even AGI technology can supply the mind of its user, the physical twin cannot remain unaffected by the association.

The first thing to observe is that people's tendency to trust and delegate cognitive operations to machines, notably in their smartphone, ends up inviting them to make less use of their own, and thus risking leaving them fallow. Indeed, our smartphone remembers for us, and AI tells doctors, lawyers, and financial advisers what to focus on and decide when not automatically deciding for them. But perhaps, the most striking aspect of this general exodus of our faculties to networks and data, is the more perplexing but possible emigration of that very center of decision and implementation that we call the self for lack of a more precise word. Indeed, in anthropology, to have a self is neither a given nor a necessity for humans any more than for other lifeforms. An important epistemological question is raised in section 4.1:

Would my Digital Twin be part of me? Would it become part of my "self"?

The answer proposed in the section is that whether we see with or through our digital twin, it will amount to little more than using a tool or a pair of glasses. This is true if we can ignore the retroactive effect of using our tools. As McLuhan famously said: "We shape our tools and thereafter our tools shape us".

Italian artists and self-made psychologists Salvatore Iaconesi and Orianna Persico make a pertinent observation:

> "For sure, we know that the self acts simultaneously as the separation and meeting point (between the subject and the outside world), and as such it allows us to establish relationships (between the I, the others, the world)" (Salvatore Iaconesi and Orianna Persico). [223]

[223] S. Iaconesi & O. Persico, Sreaming Egos, Digital Identities, published on line: https://blog.goethe.de/streamingegos/archives/163-A-model-for-Autobiographical-Memory-Track-6.html#r

This simple and intuitive observation can be verified by rapid introspection, but that boundary is now fading precisely because people tend to delegate their basic cognitive faculties to efficient digital services. Our memory goes into our smartphone, our judgment and reasoning abilities are trusted to AI, and even our imagination and creativity are supported by automated designing, drawing, painting, writing (for poetry and standard letters, news, etc.). Even as we outsource our mental operations and allow our memory to be distributed in different databases, we are emptying ourselves of the contents and cognitive strategies that centuries of patient accumulation and refinement had included within the privacy of our psyche.

The externalization of selfhood is looming on the horizon. Our 'self' is the origin of our choices and decisions and thus, commands their execution. But even as we must now refer back to external contents for stored facts and algorithmic decisions, our cognitive life is engaged more and more in the digital realm. It may soon happen that ever more sophisticated digital assistants, our technological twins, will make our decisions for us and negotiate our free will with the benefit of high performance data analytics that will interpret our needs for us. The effective result of all these changes is that virtual life is uprooting us from our biological ground to which we devote less and less attention. More than a mere twin, the digital kind will be a second self, one that, instead of being restricted to running one's body in the physical world, will be empowered to access, record and analyze not only our own behavior but correlate it with everything that is available online.

If the majority of our decisions are henceforth taken by SAS systems, our center of decision will also emigrate to the digital twin. An intriguing suggestion was made recently by César Hidalgo, Director of the Collective Learning Group at M.I.T., proposing that our digital twin would eventually vote on our behalf.[224] This exteriorization of the operating self would be a radical reversal of the effect of literacy that encourages the reader to internalize the human experience. In particular, using alphabetic literacy internalizes and silences language itself. The inner self in the West is a product of the alphabet[225]. Privacy in the West has long been taken for granted, and now, of course, not anymore. The loss of privacy is the strongest signal that we are also losing our mind, so to speak, or, to be precise, losing the individual control of our mind.

Thus, while the industrial and commercial development of the personal digital twin will bring unquestionable benefits, as well as being a mainstay of a teleological drive that has long past the point of no-return, among the most urgent question is how SAS needs to take this epistemological change into account. People are being emptied of their psychological content and strategies without most noticing because they labor under the illusion that, apart from additions to our technical capabilities, human nature, their own in particular, is the same as it always was. "Human nature" has changed before, and it is changing again. Western cultures are going through a transition that is poorly acknowledged and even rarely recognized at the individual level: people who have been used to developing and growing, to feeling, imagining and thinking as internal and private experiences, are maybe not fully realizing that such psychological faculties are henceforth AI-assisted. Westerners still consider mental activities as the exclusive property of internal memory, intelligence and judgment. But instead of developing from within, they are projecting (or rather letting go of) their identity online. For example, is it not conceivable that the evolution of our digital twins will eventually become the modality whereby people negotiate their relationships with the Internet and all its contents and processes, benefitting from search and access tools of the first order, and play the dominant role in handling SAS and the total environment? Assuming symbiosis is completed within the next thirty years, will humans still benefit from any capacity to resist intellectually, let alone politically or even emotionally?

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[224] C. Hidalgo, from an interview with Silvia Lazzaris, Corriere Innovazione, 27 – 09 – 2019, p. 5

[225] Learning to read and write, people take a large measure of control over language, internalizing it in the silence of their minds and thus grow and enlarge that mind.

The following graph was devised by students at the School of design of the Polytechnic University of Milan[226] to sort out categories and relationships between any human and a digital twin. The association is much too complex to be exhibited in a single graphic; nevertheless, what is interesting about this first attempt is to examine the links between various aspects of having a twin, keeping in mind that a record and analysis-on-demand of all these relationships will be available to the digital twin in ways and with consequences unimaginable for the physical twin.

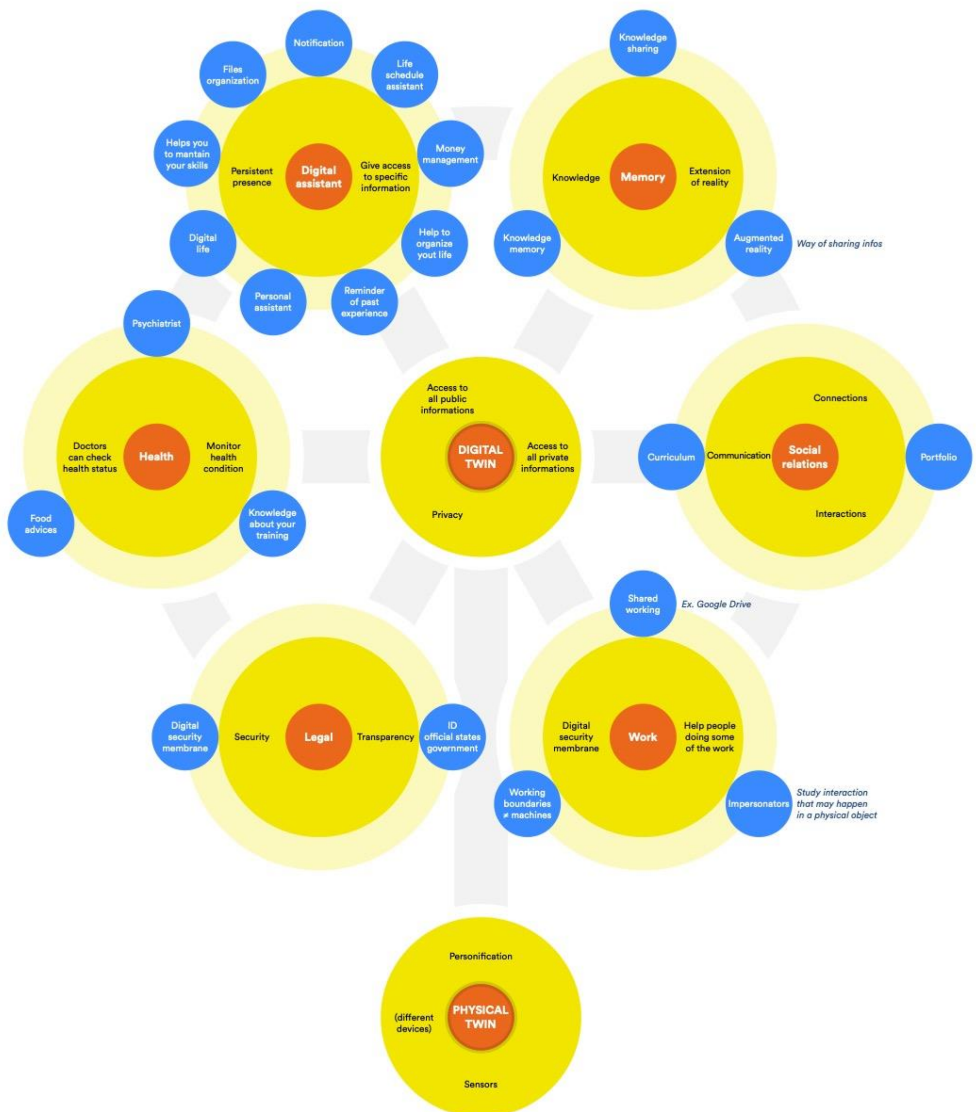

Figure 63 Graphical representation of possible relationships among a human and a digital twin
Image credit: Andrej Cattaneo and Arthur van der Wer

[226] Milan Polytechnic, School of Design - http://www.indaco.polimi.it/en/interview-with-derrick-de-kerckhove

There are various ethical and technological questions regarding this personal digital twin. The ethical questions concern the privacy of the user being accessed maliciously every time the AI is trained; the fact that the company is able to control an exact clone of the user, with related possible malicious uses; and especially the possibility of people to interact with someone that actually does not exist anymore in real life, something that fosters creepy sensations inside the users' minds.

On the technological side, instead, the first question is if the company is actually able to deliver a similar feature, but it's believable that sometime in the future, some company will be able to exploit the progress of AI to create something similar; the other question is if the digital replica of the user will continue copying the user for the rest of his "life" or if sooner or later it will start evolving in an independent way. We humans learn and evolve during our years, changing our characters, our beliefs, and our behavior, and it is unknown if a digital human can do that as well. And if humans can do that, it is also unknown in what way they evolve their behavior and at what pace.

If this proves to be true, the digital humans will reach the final stage where they will have a completely independent virtual life, completely detached from the one that we know here. They can start having their own identity.

4.3 Community level

The concurrent evolution of machine augmentation and human augmentation is converging towards symbiosis, that is, an intimate interpenetration between humans and machines or programs, a physical and mental co-existence in cyberspace. The arrival of 5G technologies almost guarantees (potentially and to the extent that 5G will keep up to its promises of pervasiveness, low latency and practically unlimited bandwidth) the effective realization of this intimate symbiosis. It is even possible that in a fully symbiotic environment, people will not need passwords anymore because the instant and systematic analysis of a person's presence in whatever context will be the unique and incontrovertible assessment of that person's identity. These engineering innovations will affect our bodies, our minds and the whole environment. Intelligent prosthetics, sophisticated robotics, decision-making algorithms, affective and sensitive digital assistants, and intelligent environments, well beyond today's idea of smart city, all point to the formation of that entirely new way to occupy space and time.
Most people haven't quite realized yet that, by spending more than half their waking hours in front of one screen or another, they are spending a substantial part of their lifetime in a parallel universe, a second space, just as immersive as the physical one, but responding to different dynamics. Social life in cyberspace may be just as intense as it is in the physical one, but it is experienced differently. It is crowded by 'friends', an exponentially growing number of individuals to whom we are indeed 'connected' but whom we hardly know and may never meet in person. In spite of the very loose acquaintance we have with most online contacts, we and they form an emotional continuity that seems to function like a social, electronic extension of our limbic system. Tweeting and retweeting messages good and bad generate 'likes' and fuel echo chambers that feed each other in an unending spiral of mutual reinforcement.

Digital transformation does not merely delocalize, but de-territorialize community, which is both a blessing and a curse because the same ensemble of technologies allows distant community formation or distributed maleficence such as terrorism. Social media, at first hailed as 'relational', intimating a new beginning in community formation and social harmony, instead has turned into harbingers of division, strife and hate mongering. One explanation for this phenomenon is that the digital transformation is responding and contributing – although not exclusively – to a deep crisis of identity provoked by instant communications, surveillance capitalism and an accelerating mutation from one social order based on bureaucracy to another based on real-time electronic and algorithmic data management.

Digitally driven social disruption has already happened and continues to transform society and governments in a dramatic way. There is, however, a big difference between what occurred before and after social media. The incipient digital transformation creeped in with promises of liberation of consumers and citizens from the constraints of established business and administration practices and dicta. Disruption then only threatened established commodity and entertainment markets and services, such as music, cinema or transportation, gradually removing intermediaries and allowing users to access production tools, distribution and branding strategies on their own terms. What even the occasional nay-sayer had not predicted was the tidal wave promoted by the same social media that would drown the aspiration of renewed democracy and grassroots community dreams in brutal extremism. What emerged instead of harmony was the discordance of fake news and populist tweets. An emotion-driven connective and collective social limbic system operating at viral speeds has turned local gossip into global clamor allowing dangerous private agendas such as terrorism and electoral manipulation to disrupt virally and globally an already fragile social order.

Where we are now: democracy, in many nations, is in tatters and, where the rule of law still governs the others, it is threatened by mounting angry trends that erupt in violence to make their point. The instauration of social credits in China points to the fact that the solution may arise from different features of the source of the problem, that is, digital transformation. If among the surging drives of this metamorphosis the trend to the digital twin highlights its psychological impact, social credits extend its logic to the social and political control of society, a solution, of course, that comes at great cost to western notions of civil liberties. Note, however, that the emphasis here is on liberties, not on civic values. In China, where the community trumps the individual, it is not customary for people to hold secrets. Yasheng Huang explains what makes Chinese people susceptible to not only tolerate but even welcome the principle of social credits:

> One reason Chinese attitudes are different is that as recently as the 1980s, the word "privacy" had negative connotations in China. Chinese norms are anchored in 2,000 years of a Confucian culture that values the intensity of interpersonal relationships. One way to solidify those relationships is through transparency and full disclosure. A circumstance that triggers secrecy is typically an unsavory one. If something is good, why not tell us? Privacy in this context was equated with preserving a dirty secret. To be private was to be antisocial.[227]

Social credits are really "individual" credits, meaning they are attributed to individual persons in the name of social benefits. But individual credits are not new in the west, far from it. Shoshana Zuboff gave it a name, "Surveillance Capitalism"[228]. Bankers, lending institutions, businesses, human resources departments, insurance companies and other administrations have openly attributed "credit ratings" to private customers, potential hires and charges. At the other end of the surreptitious rating, whistle-blowers including Wikileaks and Edward Snowden have revealed that western governments have also been spying and judging their citizens in the name of security. Both surveillance capitalism and social credits show the way to the future, each according to their respective cultural ground, not primarily because of political maneuvering, but essentially because of the technological penetration of the social body.

Our IEEE research team identified many legal and security, as well as ethical issues (see 4.6) emerging from the rapid development of new generation expert systems that are already replacing human skills in labor and professional competence in law, medicine, business and arbitration. For example, IBM has already introduced Watson into the legal field, to cope with the complex structure of legal knowledge contained in the federal statutes, regulations, treaties, contracts and jurisprudence. Some algorithms are already being used to determine prison sentences. If we start

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[227] Yasheng Huang, "China's Use of Big Data Might Actually Make It Less Big Brother-ish", *MIT Technology Review*, August 22, 2018: https://www.technologyreview.com/s/611814/chinas-use-of-big-data-might-actually-make-it-less-big-brother-ish/
[228] S. Zuboff, *The Age of Surveillance Capitalism*: The Fight for a Human Future at the New Frontier of Power, PublicAffairs, 2019.

trusting algorithms to make decisions, who will have the final word on important decisions? Will it be humans or algorithms? What are the potential victims of algorithms?

- Autonomy: more decisions are made by machines, less freedom of decision and movement for people;
- Individual property and control of thought: we are no longer exclusive owners of our thinking because AI is perfectly capable of retracing it, even in real time;
- Psychological interiority: First, thoughts and feelings are being projected onto social media, and machines are acquiring internal cognitive functions, including memory, intelligence and imagination;
- Reputation: the era of transparency exposes ourselves.

The real question is how humans behave under such conditions of vulnerability.

Not only does the adoption of new technologies raise ethical questions, some of them, such as the appearance of the printing press or now the digitization of human culture, demand a radically new ethical order. The Renaissance witnessed a brutal redefinition of what it meant to be human during the painful transition between a predominantly oral and communal religious authority to an individualistic humanist social and political order. While transiting from "shame" to "guilt", the object of personal responsibility in western society shifted from "the other" to the "self". Today, as people are ever more exposed to continuous monitoring by automated electronic systems, and while, in some countries, behavior itself is controlled by algorithms, responsibility shifts away from the self to the now almost self-organizing whole social order, including, and perhaps eventually prioritizing the care of the environment. Shouldn't symbiotic autonomous systems always be developed with their aftereffects on people and the environment in mind? Shouldn't large scale predictive analytics be applied to each innovation before implementation? Even as algorithms and AI take the lead in introducing a generalized symbiosis between individuals and the environment itself, shouldn't an ethical dimension be consciously included in their programming?

4.4 City level

Few entities better demonstrate the penetrating – not to say invasive – effect of the digital transformation on cities (smart or not) than the promised arrival of 5G technologies. By corralling every single data collection and transmission (humans, sensors, actuators) into itself, 5G deployment will make the city akin to a single interconnected body such as our physical flesh and body is connected continuously to itself. The application of the digital twin concept to the urban environment certainly leads cities in that direction. Starting with Singapore, several cities are implementing a full control digital double of the city, with all its services, resources, identification of people's locations and behaviors, integrated and operated semi-automatically.

4.4.1 Application of the Digital Twin Concept to Smart Cities

The basic design of a digital city platform consists of three layers. First, there are data sources, such as city maps, blueprints of buildings, transport network information, and real-time sensors, that together create the digital twin. The second layer is a generic platform which offers the basic digital twin functionality, that can be accessed by authorized stakeholders, commercial, residential, or governmental. Finally, applications can be developed that harness the power of the digital twin to create solutions for both the social and physical worlds[229]. A central platform where all the disparate modelling done by different government agencies provides an integrated home with a common look and feel. In order to feed the digital twin, a city needs pervasive IoT. The main stumbling block with IoT is that there is no common protocol, and each supplier has their own approach[230].

[229] https://eu-smartcities.eu/news/rotterdams-digital-twin-redefines-our-physical-digital-social-worlds
[230] https://openlm.com/blog/creating-digital-twins-for-smart-cities-the-race-is-on/

In 2016, the UK initiated a long-term project to create an operating twin for the whole country, beginning with London[231]. The Centre for Digital Built Britain's Digital Framework Task Group (DFTG) was launched by HM Treasury in July 2018 following recommendations by the National Infrastructure Commission in the report Data for the Public Good. The report recommends:

1. A National Digital Twin – enabling digital twins to come together to help plan, predict and understand UK's assets;
2. A Digital Framework – for effective information management; secure sharing of data;
3. A Digital Framework Task Group – set up by the Centre for Digital Built Britain to provide coordination.

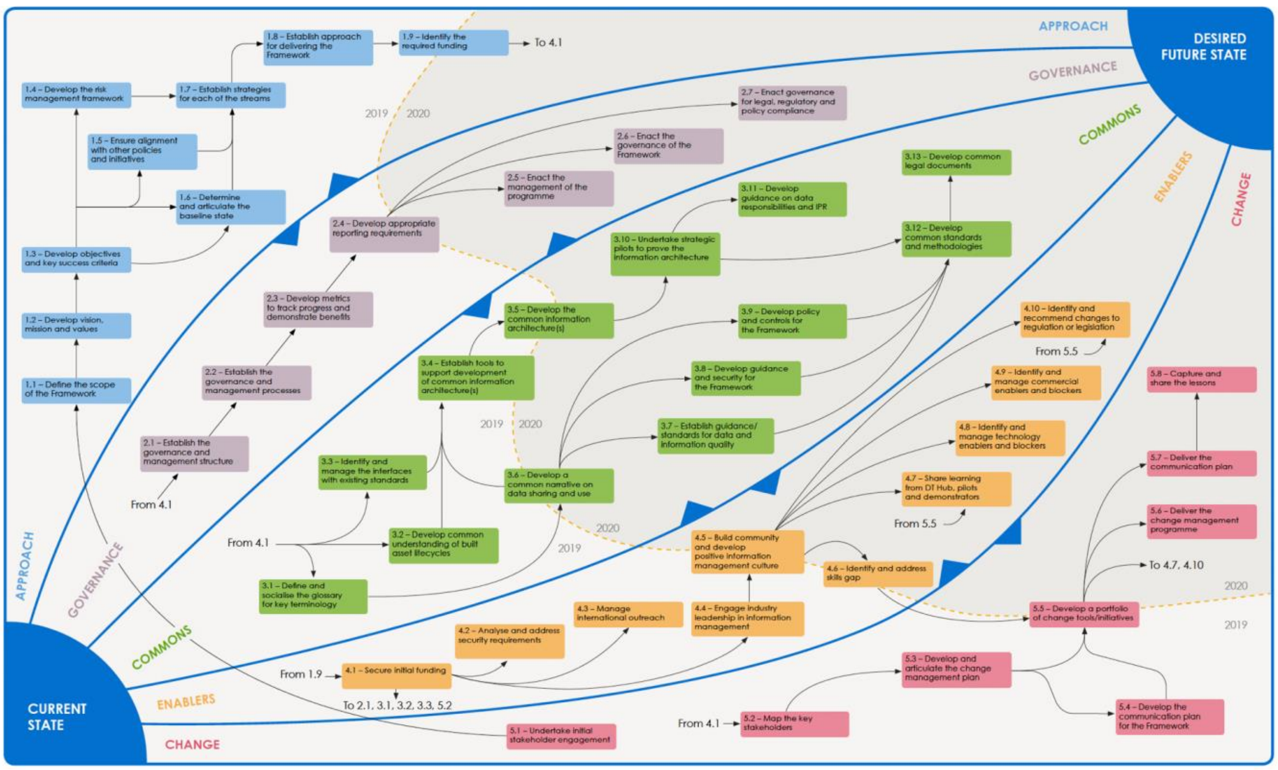

Figure 64 Digital Twin Hub (DT Hub) is a Web-enabled collaborative community for those who own or are developing digital twins within the built environment[232]

The graph above is interactive and itemizes all the steps that are associated with the task of twinning digitally not only a city but a whole country. According to the working group the definition of the *National* digital twin is "an ecosystem of digital twins connected via securely shared data". Their home site declares:

"The purpose of this long-term initiative is manifold: at the most basic level it is to provide a focus for learning and sharing experiences on digital twins;
To drive innovation, develop skills and advance the "state of the art" for digital twins in the built environment;
To identify good practices, develop a guide and produce standards on data sharing and digital twins;
To show the advantages of digital twins; creation of use cases that will provide evidence for the development of business cases and municipalities;

[231] A rich and fascinating discussion group on the matter can be found at https://www.cdbb.cam.ac.uk/blog
See also https://www.cdbb.cam.ac.uk/CDBBResearchBridgehead
[232] https://www.cdbb.cam.ac.uk/news/2019April8RoadmapPressRelease

Provide a record of work on digital twins within the built environment; showing who is doing what where;
Identify the main digital twins, pilots and demonstrators
Identify the gaps that need to be addressed in the transition to a national digital twin and define the additional work / drivers that will fill them;
Promote the adoption of the information management framework and create the foundation of the national digital twin".

4.4.2 The Feeling City

The purpose of the theme "The Feeling City" is to interface three important concepts that have emerged from the looming combination of IoT, Big Data, Data Analytics and 5G, that is, Digital Twinning, Smart City and Sentiment Analysis. While the literature on digital twins as applied to smart city initiatives is still growing, not enough attention so far has been given to citizen well-being over and above the efficiency of urban functioning. The idea is to design a model of urban happiness that is based on both monitoring citizen mood and engaging the city dwellers to share their concerns and levels of satisfaction with the city fathers and planners.

The idea is gaining ground, notably in India. Dr Sreedhar Cherukuri, commissioner, Andhra Pradesh Capital Regional Development Authority (APCRDA), observed that Amaravati is a greenfield city built with "the happiness" of its citizens at the core of its vision. "While digital twins have the potential to be immensely valuable for planners and city authorities, extending access to other stakeholders can increase engagement in smart city projects". Amaravati is implementing a digital twin user ID scheme for every citizen that will serve as a single portal for all government information, notifications, forms and applications. Therefore, he said, having a digital platform that enables all the city's stakeholders to contribute to this common goal is vital "from Day 0". [233]

4.5 Jobs impact

Technology has impacted jobs for thousands of years. As new, or more effective technology became available, jobs changed and, more recently, some jobs no longer require humans. The Industrial revolution is a clear example; the digital lathe at the end of the last century and assembly lines "robotization" is another; the ongoing computerization of many activities (and support to many activities) yet another example. So, in a way, the present period is nothing new.

What is new, at least in perception terms, is that technology is now providing alternatives to what typically consider human characteristics: intelligence and decision making. In reality, there is a whole spectrum of intelligence (in degrees and quality) as well as a whole spectrum in decision making. Machines have been equipped with mechanical decision making for centuries now (when at the end of the path stop, when the strength in screwing the bolt exceeds XYZ then stop). Technology evolution is extending the range of machine intelligence and decision making capabilities.

Symbiotic Autonomous Systems are becoming an artificial enhancement for humans. The keyword is "symbiotic", the capability on both sides, human and machine, to take advantage, seamlessly, of the other to perform a task or reach a goal. AI devices can support with physical tasks, but also liberate us from (some) decision making. Notwithstanding these advanced possibilities, it is imperative that employees keep up their abilities for creative and critical thinking.

Industry 4.0 (less a revolution, but part of a continuous evolution of automation that goes beyond the factory boundary to cover the whole value chain) and AI (including machine and deep learning) can be leveraged for a positive vision of the future, leading to job enlargement, including functions with a higher grade of human dignity. Technology has no soul; by its design it is neither good nor

[233] https://www.smartcitiesworld.net/special-reports/special-reports/the-rise-of-digital-twins-in-smart-cities

bad. Humans can use it to create a better world or at least a better workspace, but this is not automatic development.

There has been a series of defeats by humans challenging AI in gaming. It started back in 1997 when Chess grand-master Garry Kasparov lost against IBM's "Deep Blue". It continued and even accelerated: Go (2016), Poker (2017) and StarCraft II (2018). To be fair, we should also acknowledge that because of AI many more people have had the opportunity of becoming better at playing chess, with the possibility of training their skill against a computer. The possibility of leveraging AI, in all its application for training, is becoming more important as is discussed in this paper in section 2.7 (market) and 4.6 (societal impact)

Nevertheless, these defeats have been against specialized AIs. So far the combination of human brain and body is not beatable by any robot in a general context. Erik Brynjofsson, Director at the Massachusetts Institute of Technology for Digital Economy defined: "AI won't be able to replace most jobs anytime soon. But in almost every industry, people using AI are starting to replace people who don't use AI, and that trend will only accelerate."[234] A protection against a complete replacement, nevertheless if there is also a benefit to the human employees depends on the answer to the question of who is in the lead of the human AI-team, the employee or the algorithm? It should also be acknowledged that the flanking of AI with an employee to carry out a task is usually creating a different working environment requiring different working skills that sometimes may not be easily acquired by the person that was performing that activity before it evolved as result of the AI flanking. This is a big issue and it has been an issue for the last few decades. As jobs became automated new jobs were created but in many cases those new jobs required different skills not available to the people who lost their jobs because of automation.

Human enhancement has existed for centuries, as we added glasses, artificial teeth or hearing aids to our bodies. Machines, starting with levers and pulleys, provided humans with prosthetics to increase their strength. SAS go one step further as here they can not only add sensors and mechanical abilities, but intelligence. For example, smaller exoskeletons are not designed to provide general additional force, but to redistribute "the load over your shoulders and into your core muscles, so you're using the right muscles to perform the lifts, thus reducing risk", as stated by StrongArm Technologies chief marketing officer Matt Norcia[235]. Instead of only muscle, exoskeletons add additional brain power to the employee. One of the device's goal is to avoid costly accidents inside the workshop. Even if the equipment does not provide general additional strength, it may lock if it predicts a potential accident due to an incorrect lifting approach, overstepping security barriers or not wearing of safety glasses. With the exoskeleton locked, the individual is unable to lift and / or an alarm signal may be triggered. The AI overrides the decision by its human user. The device is connected to the cloud so that the employer can monitor processes and activities, raising privacy concerns as could be expected. Due to this, processes can be adapted to reduce risks and are a benefit for the individuals and the organization, as the lower number of work accidents in most countries means lower insurance fees and taxes.

Exoskeletons are designed to support the body. To support the mind, SAP and EMOTIV developed the headset "Focus UX"[236]. Its aim is to reduce employees' stress level triggered by information overload. The device analyzes the user's interests by the way he is looking at the screen. The system learns and allows the employee to interact with the information without a mouse or keyboard. This way the individual perceives the processing of information as natural. Furthermore, the AI leverages real-time analysis of the employee's cognitive state of mind and can assess the cognitive load, stress

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[234] https://sloanreview.mit.edu/projects/reshaping-business-with-artificial-intelligence/?utm_medium=social&utm_source=linkedin&utm_campaign=airpt17
[235] https://www.instagram.com/p/BrnhZawHLwz/?hl=en
[236] https://news.sap.com/2018/10/sap-emotiv-adaptive-assistance-well-being-productivity-work/

and attention levels.[237] As the manufacturers are aware of the ethical concerns, they implemented in parallel an "Ethics Advisory Panel for Artificial Intelligence."[238]

Paul Ryan, IBM Watson's UK Director of Artificial Intelligence said: "Every major decision, business and personal, will be made with the assistance of cognitive technologies.[239]" The collaboration of humans and machines include light exoskeletons, AR glasses, autonomous vehicles and AI managers. These examples of potential usage for intelligent algorithms show that AI may not only replace blue collar labor, but also white collar-tasks. These artificial employees would not be hired by a HR-manager, but directly approved by high level management. They not only get perceived as competent, but also as supported by the company's leadership. The result could lead to anticipatory obedience by the human colleagues. Depending on the particular task and the employee's character (success-seekers vs. failure avoiders), this gets perceived as frustrating or comfortable.

The term "cyborg" was first defined in 1960 by the scientists Manfred Clynes and Nathan Kline. It describes a human individual with artificial parts to replace missing ones or to achieve enhanced abilities. Taking a fresh approach means that many more cyborgs exist today than we thought of. In a study from 2016, researchers from the universities of California, Santa Cruz and Illinois determined that more and more people depend on the internet as resource of information. Today's schools and kindergarten bring children in contact with computers and the internet early. Instead of pure fact learning, today's students learn where to find information and how to access it.[240] With this, today's students have access to more information than any other generation before them. Due to the amount of data it is clear that pure fact learning cannot work anymore. Other factors such as accessing the information and adequate processing become more relevant. The internet developed into an external extension of our brain. Even if individuals do not have any physical updates on their body, information storage became outsourced, as we perceive to be in a continuous connection to "our knowledge" on the net. According to the lead investor of the study, Dr. Benjamin Storm, memory is changing. If we need to answer a question, we use less time to remember the required learned information but easily access the internet to let Google or Wikipedia find "our" information.

This requirement of the modern age is on the other hand a risk factor. The individual perceives the internet, especially his or her preferred pages, as source for objective information, but in reality it may be flawed based on the author's opinion. Even worse, employees may be led to pages, including Twitter and other social media, which communicate fake news and flawed information. More than information inside a book, articles on the internet, including encyclopedias as Wikipedia, can be changed from one moment to another making previous ones irrelevant or wrong. Such changes are not easily detectable by the reader.

Cognitive Offloading describes the effect where individuals outsource parts of their knowledge and decision making processes to the internet and intelligent algorithms. Humans delegate decisions to AI especially if the personal involvement is low and the outcome perceived as precise. The higher the perceived safety of the outcome, the less the individual's own intelligence is needed.

Employees process information from the open internet, but maybe also from a protected cloud (intranet). In opposite to its name, the information does not fly through the air, but is stored on one or several physical servers. With this, it is subject to cyber-attack and data privacy risks. Mostly discussed are the risks that non-authorized (or even authorized) users steal the stored information. But hackers may work in less conspicuous ways. Similar to a Trojan virus that stays non-active for a period of time inside the system, a hacker can provide unrecognized alternate information and

[237] https://news.sap.com/2018/10/sap-emotiv-adaptive-assistance-well-being-productivity-work/
[238] https://news.sap.com/2018/09/sap-first-european-tech-company-ai-ethics-advisory-panel/
[239] https://currnt.com/q185/is-ai-applicable-to-all-business-problems
[240] https://neurosciencenews.com/memory-internet-cognition-4854/

databases, so that the company uses this wrong information for their decision making process. With this, virtual information can lead to physical consequences, including damages.

The next generations of personal assistants and other AI-applications observe the employees' decisions to predict their behavior in future scenarios. When a sufficient learning level is reached, empathic AI can precisely predict how the individual would behave in different situations. This is for the employee's convenience, as in unknown scenarios the individual would not need to start an extended decision making process which requires time and the acquisition of information, instead the AI could execute the work, or at least give suggestions what to do and why. Such an app would be connected to the world's databases combining this information with the individual knowledge of the person. It would decide for the human, based on his / her personal preferences.
Algorithms are always biased. Ivana Bartoletti, founder of the "Women Leading in AI"-network stated: "An algorithm is an opinion expressed in code."[241] The effect gets fostered by the biased decision where to install the sensors to gain information to use, including the selection of external databases to connect with the internal AI.

AI can be divided into two parts: the original model,[242] including theoretical models (assumptions), and the flow of information. If only few data are available, the individual may critically challenge the decisions by the AI, as the employee is able to interpret the information. If more data and factors are involved, the sophisticated algorithm processes the information so that a human decision maker can understand it. Furthermore, the more factors get compiled via a statistical analysis, the more non-relevant information gets lost. The answer what is, and is not, relevant depends on the original model. The more complex the algorithm, the more difficult to challenge its results.

Transparency demystifies the AI (including SAS) and enables the human to develop design-thinking skills to understand the machine's behavior. Actual and coming IEEE P7000TM standards want to ensure the well-being of employees when working together with autonomous and intelligent technologies. Their application supports a strong position of the human inside the system, a sign of respect from the employer towards the employee.[243] Transparency and standards, together with audits and certifications, enable not only that empathic AIs can predict human behavior, but also humans can comprehend the algorithm's decisions. Working jointly with machines and intelligent algorithms can be perceived as a dehumanization of the workplace. To build up a successful symbiosis, the employee should be in the lead and concentrate on strengths like creativity and ingenuity. Even more, the AI device may eliminate undesired routine tasks, so that the employee can concentrate on the more challenging tasks.

If the human does not stay in the lead of the Human-AI Team, the combination leads to a devaluation of the job-profile, the human will be the "beta" and the algorithm the "alpha". An example is presented here for autonomous trucks. Even if luxury cars like Tesla are an important communication channel for the self-driving technology, a faster growth in the beginning could come from commercial vehicles, where the "pleasure of driving" is not a relevant factor. Intelligent software can replace the human driver and take away the risk that because of cost pressure drivers often are fatigued and cause accidents. Furthermore, the self-driving vehicle will be included in the company's "just in time production"-process, so that speed and route could be adapted and with this the vehicle will arrive exactly at the time it is required to. This, of course, occurs keeping in mind actual weather conditions and traffic situation. It is no surprise that McKinsey & Company forecasts that by 2025 already one third of the trucks will use advanced self-driving technology.[244]

[241] https://www.theguardian.com/pwc-partner-zone/2019/mar/26/why-are-virtual-assistants-always-female-gender-bias-in-ai-must-be-remedied
[242] https://www.ge.com/digital/applications/digital-twin
[243] https://transmitter.ieee.org/new-ieee-standards-artificial-intelligence-affecting-human-well/
[244] https://www.trucks.com/2016/09/12/one-third-trucks-autonomous-2025/

The Stanford Encyclopedia of Philosophy defines utilitarianism: "Though there are many varieties of the view discussed, utilitarianism is generally held to be the view that the morally right action is the action that produces the most good."[245] Utilitarianism can be used to define values for the numerous trucks, this depending the value of their loading, urgencies and expiration dates. Such valorization could be part of a supply-chain blockchain. A potential governmental system of transportation could centrally manage the speed and routes of the numerous autonomous trucks to not only maximize the individual travel-time, but the overall traffic for all participants, including trucks, but also keeping safety for individual cars and pedestrians in mind. Such a system may include the possibility that local police may alter the routes to lead single trucks into a control station, or just stop them on the way for individual controls.

Today's job profile of a truck driver is not limited to driving but includes also being mechanic and supporting the loading and unloading of the trailer. The first is not only the main purpose, but also the function which requires the highest qualification, confirmed by the mandatory license. Self-driving vehicles can substitute this part of the overall job function. It is up to the government to decide if a self-driving truck still requires a licensed driver inside the cabin or not. If not mandatory by law, companies may decide to keep a human inside the truck as a mechanic and support for the loading process. The job of a truck driver gets limited to being mechanic and helper. Qualifications such as a license are not required anymore, so that the original salary decreases. Former truck drivers have can look for different jobs, seek new qualifications or continue working on the truck, but then with lower responsibility and salary.

4.6 Ethics in Symbiotic Autonomous Systems

Ethics are the moral principles that govern a person's behavior or action. Technology (Tech) ethics is a field of study that seeks to understand and resolve moral issues that surround the development and practical application of technology. Tech ethics focuses on subjects such as the relationship between technology and human values and well-being[246]. This section explores some aspects of ethics and particularly technology ethics applied to autonomous systems as well as mixed reality (VR, AR, etc.). This piece is meant to indicate current thinking on these topics as well as depict areas for further development.

4.6.1 Ethics of Autonomous Systems

The ethics of autonomous systems rests on three pillars[247]. The first of these pillars is universal human values: AI can be force for good in society provided that it are designed to respect human rights, align with human values and holistically increase well-being while empowering as many people as possible.

The second pillar is political self-determination and data agency: if designed and implemented properly AI has a great potential to nurture political freedom and democracy, in accordance with the cultural percepts of individual societies, when people have access to and control over the data constituting and representing their identity.

The third pillar is technical dependability: AI should deliver services that can be trusted. This trust means that AI will reliably, safely and actively accomplish the objectives for which it was designed while advancing the human-driven values they were intended to reflect. These ideas are closely aligned to the Asilomar AI Principles[248].

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[245] https://plato.stanford.edu/entries/utilitarianism-history/
[246] Technology Ethics, TechTarget, https://searchcio.techtarget.com/definition/Technology-Ethics
[247] IEEE Ethically Aligned Design, First Edition (EAS1e), https://ethicsinaction.ieee.org
[248] Future of Life Institute, https://futureoflife.org/ai-principles/?cn-reloaded=1

For a topical discussion of the ethics of autonomous systems consider the case of truly autonomous vehicles. Autonomous connected vehicles will probably be much safer than those operated by humans, but they won't be perfect. They will also be sharing the roads with human driven vehicles, at least in the near term. Current laws codify our ethical standards as humans. They include standards for vehicle safety and liability. How must these laws change with autonomous vehicles? Ethical standards need to be created and used to guide laws concerning liability and fair decisions.

In human liability law there is a reasonable/prudent person standard[249]. Simply stated a person is negligent if they didn't do what a reasonably prudent person would have done under similar circumstances. There are many factors used in deciding whether someone acted like a reasonable person such as the person's experience, knowledge, ability to perceive and the particular activities and circumstances. Extended to autonomous machines we might say that a reasonable/prudent robot should meet or exceed the expectations for a reasonable person. This is simple to say, but complex in operations since it involves ethical choices in technology and actions.

Automated vehicles access a lot of sensory information for every decision they make. Should there be a collision this data should be available for analysis of the decisions and perceived alternatives that the vehicle considered. In fact, California requires that test autonomous vehicles save the last 30 seconds of sensor data before a collision for such an analysis. Autonomous vehicles (AVs) will be held to incredibly high safety standards. The following presents some scenarios to get an understanding of the sort of decisions a reasonable prudent robot would have to make[250].

AVs will need to know when laws should be broken for the safety reasons. For instance, if a child runs into a street a reasonable person would swerve over a double yellow line to avoid hitting the child. An AV should be able to make a similar decision. For another example, if an AV can minimize its liability by driving slightly off center away from a larger vehicle but closer to smaller vehicles to minimize its risk but possibly increasing the risk for the smaller vehicles, should it do that?

In the US legal system lives are often valued in wrongful death lawsuits by how much a person might have been worth in the future based upon their education, job prospects and other factors. Should AVs make decisions on risk avoidance based upon such information—e.g., adjusted pedestrian buffer spaces based upon its assessment of the worth of the pedestrians? Most of us would be very bothered by such a decision.

In a no-win scenario when a crash is inevitable and an AV has to optimize the outcome based upon some goal, what should that goal be? This situation is fraught with moral issues. A hierarchy of protecting the most vulnerable first (e.g., pedestrians), followed by cyclists and then cars with human passengers may seem the natural answer, but what if the AV has to choose between crashing into a wall, killing all its human passengers or swerving to miss the wall and killing several pedestrians—what choice should it make?

In terms of economic damage, how should an inanimate object be ranked. For instance, if an AV has to choose between a slight fender bender between itself and a car driven by a human or totaling itself to avoid the fender bender, what should it choose? Should an AV damage less expensive vehicles before doing so to more expensive ones? Is it ethical to program an AV to avoid collisions with other vehicles from the same manufacturer?

There is likely no single guiding principle of ethics that can guide every scenario an AV must be programmed for. Instead it may be better to identify a variety of ethical solutions to various types of situations. Ethics then becomes an important part of the engineering design process.

[249] https://definitions.uslegal.com/r/reasonable-prudent-man/
[250] https://futurism.com/images/laws-and-ethics-for-autonomous-cars

Towards creating standards for creating ethical autonomous systems, the IEEE Standards Association has created a series of standards, P7000 that are meant to address specific issues at the intersection of technological and ethical/societal considerations[251].

4.6.2 Ethics and Mixed Reality

Immersive media technology can be useful but it could also be used to provide false information. Likewise, AR can help us understand more of the world around us or possibly mislead us. It depends upon the motives and technologies of the source and distribution entities. False news and misleading but viral information has caused problems with important political and other institutions and is a factor in the creation of closed special interest groups formed around false conspiracy theories and perhaps even terrorist recruitment. As the technologies for representing false realities gets more real the messages it tries to deliver can become more compelling.

Deepfake is a technology for human image synthesis based upon artificial intelligence. It combines and superimposes existing image and videos onto source images or videos using a ML technique known as generative adversarial networks[252]. These images and videos have been used to create fake celebrity pornographic videos and revenge porn. They can be used to create fake news and malicious hoaxes. With the improvement in AI technology and computer rendering these images can look as good as real videos.

For these reasons, ethical standards for mixed reality systems are extremely important. These standards should include technologies (for instance with distributed ledgers) that allow for authentication of images and videos and the people, places and times when they were captured so content can be verified to be real or fake.

[251] For more information: https://ethicsinaction.ieee.org/#set-the-standard
[252] https://en.wikipedia.org/wiki/Deepfake

ANNEX 1 – Digital Transformation

From Scarcity to Abundance

The Digital Transformation everyone is talking about today is fueled by advances in technology, mostly transducers, i.e., sensors and actuators, and semantics extraction tools, i.e., artificial intelligence supporting data analytics.

The reason why industries and institutions alike are interested in the Digital Transformation, however, is based on economics. The Digital Transformation is shifting the economy of atoms to the economy of bits. The economy of atoms is an economy of scarcity: atoms are limited; if you give an atom away you no longer have it. On the contrary, the economy of bits is an economy of abundance; if you give bits away you still have them (a copy actually, but in the world of bits copies are indistinguishable from the original).

There is more than that, however. The economy of atoms has high transaction cost, i.e., it costs money (and resources) to move atoms along a value chain, while the cost of moving bits is basically zero. This decreases both the capital expenses (CAPEX) required to enter the business of bits and the operating expenses (OPEX), although for support infrastructures (such as communications networks and data centers), CAPEX and OPEX are still huge (hence the small number of companies operating in that space).

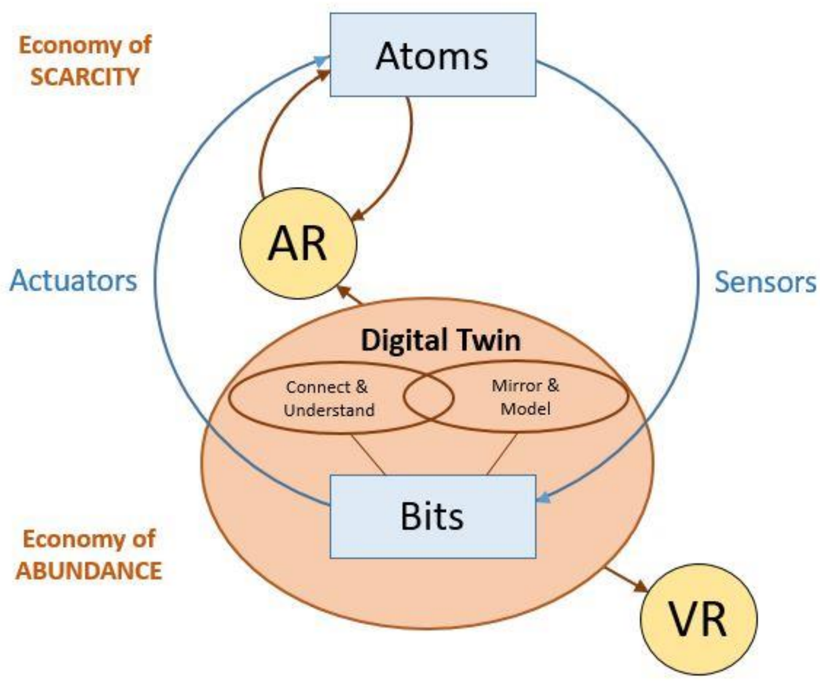

Figure 65. By moving from the economy of atoms to the economy of bits, we are also shifting from the economy of scarcity to the economy of abundance

The diagram shows the loop connecting bits and atoms: bits are created using sensors, forming data. The value of bits is very low, approaching zero, but the value of data can be high if they are meaningful. Hence there is a drive to make sense out of data through mirroring and modeling, and connecting and understanding. Digital Twins, data based entities, are an example of meaningful and actionable data. Through artificial intelligence and data analytics, semantics emerges. Semantics is crucial in the economy of bits because it is delivering value (and the perception thereof): we don’t pay for the data but for getting their meaning and for the convenience of getting them.
For example, I am not paying for a song’s bits, I can get those bits for free through YouTube, as an example, but I prefer to buy them from an online store for the convenience of getting them securely and quickly. Another example: I am not paying for a blood exam to get numbers but to know the meaning of the numbers.

Given the advantages of the economy of bits over the economy of atoms, industries are scrambling to move their atoms operation as much as possible to the bits domain. The two, bits and atoms, get connected by technologies like augmented reality and virtual reality. These two provide an access to the world of bits and more and more through Digital Twins they ensure the connection to the physical twins.

Two currently running IEEE-FDC initiatives have been working on some crucial components of the Digital Transformation, the Digital Reality Initiative (Augmented Reality- AR and Virtual Reality - VR) and the Symbiotic Autonomous Systems (SAS - Digital Twins). The results they have reached so far and the communities they have aggregated are a perfect starting point for a new initiative that aims at leveraging on the growing interest of industry to exploit the economy of bits. Several industries have already voiced support to a strong initiative in this area, and the most effective way to move ahead quickly is to leverage the results achieved by these initiatives. The new initiative will have the name "*Digital Reality: fostering and leveraging on the ongoing Digital Transformation*".

Digital Twins are at the same time a digital model of some physical entity (object, aggregated objects, processes, etc.) and a digital shadow of the physical entity, mirroring its present situation (hence supporting monitoring and simulation) as well as its history – Digital Threads - (supporting root cause analyses). The Digital Twin can, in some situations, also be used as a proxy of the physical twin, something that is leveraged in Industry 4.0 as well as in other areas.

In a way, AR connects the world of bits to the one of atoms by overlaying bits on atoms. VR, on the other hand, leverages the world of bits.

Flanking bits to atoms

The economy of atoms has existed from the time an "economy" existed. The economy of bits is much more recent, although the immaterial economy has roots that go far back in the past, like the economy of knowledge or the Knowledge Society that was hyped in the last decade.

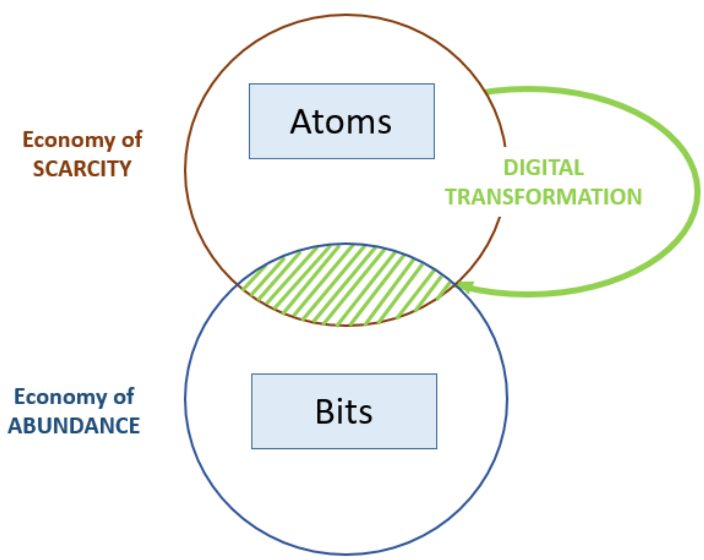

Figure 66. The two worlds of atoms and bits are coexisting and leveraging each other.

Like bits, one can transfer knowledge without losing that knowledge. The problem with the "economy of knowledge", however, is that it takes a long time to transfer knowledge, and the "duplicated" knowledge is seldom like the original one (it can be better or worse, but it is unlikely to be equal). Because of this, an economy of knowledge is not an economy of abundance. Actually, companies often complain of the scarcity of knowledge, notably of the difficulty of finding the skilled people sorely needed to develop the business. In the coming decades we might be seeing the economy of knowledge shifting to the economy of abundance, but that knowledge will not be from humans, rather it will be owned and managed by machines (through artificial intelligence and data analytics).

Today, bits are the only entities in the economy of abundance with:

- an unlimited possibility of duplication (at zero cost)
- absolute fidelity (copies are equivalent to the original)
- very low cost of manipulation (e.g., to create bits out of bits)

- ubiquity (zero cost to move from one place to another)

Some futurists foresee in the coming decades other entities that will become part of the economy of abundance, like energy (such as unlimited energy through fusion and photosynthesis in smart materials) and intelligence, such as Artificial General Intelligence (AGI) and Artificial Superintelligence (ASI). Artificial Intelligence will also bring knowledge into the economy of abundance which will surely lead to a dramatic change in economy and society.

The Digital Transformation is driven by the willingness to reap the benefit of the economy of abundance, hence it focuses on using bits as much as possible. As noted previously, this transformation requires the creation of digital models, transforming atoms into bits by using sensors. It is clearly relevant, as shown in Figure 66, for those businesses that today are operating in the economy of scarcity (most companies today). It is not relevant to those business (a few) that are already operating in the economy of abundance, those that have been born in that economy. Notice that atoms will remain in the digital transformation, and along with them a part of scarcity, but the transformation will leverage bits more and more (denoted by the striped area in the figure).

Also notice that those few businesses that grew in the economy of abundance space need to use a few atoms as well, but these are seen as backstage resources made generally available, like saying that a restaurant needs to use water: this is normally taken for granted, provided by commoditized infrastructures. Likewise, for companies that operate in the economy of abundance: they leverage the existence of digital platforms.

The Digital Transformation allows companies that are operating today in the economy of scarcity to shift part of their business to the economy of abundance. This shift is usually quite complex and the transformation will lead to, and requires, new business models, since the economy of abundance has different rules of the game.

How many bits are needed?

The Digital Transformation eliminates the need to work with some atoms, replacing them by bits. These bits are used along with the remaining atoms, flanking them. Atoms will still be needed, and the question is how many atoms and how many bits? The general recipe is to reduce the atoms in favor of bits as much as possible. The percentage of one over the other depends first on the kind of business and second on the availability of technologies. The increased capability of technologies can increase the bits percentage correspondently decreasing the atoms percentage. As one is planning for a Digital Transformation one should aim at the greatest possible shift from atoms to bits.

Now, let’s clarify what is meant by percentage and number of atoms vs bits. Clearly, we are not counting the atoms, like estimating the number of atoms making up a product, nor we are counting the bytes representing a product during its life cycle. Rather, we are estimating the overall value of the value chain as it is today when operating on atoms, through the product life cycle, from design to use. We then look at the value remaining in the atoms as we move as much as possible to the realm of bits.

One point to notice is that while the overall functionality is kept by the Digital Transition the overall economic value of the parts involving atoms plus the parts involving bits is *lower* than the original value. This is the reason why there is a drive to move from the former to the latter. The lower value results from the increased efficiency of the value chain(s) involved in that product life cycle. Since the increased efficiency translates first into higher competitive advantage and potential higher margins, the players in the value chain are eager to pursue it. Eventually, this increased efficiency translates into lower prices to the end consumer increasing market interest, pulling along the value chain and steering the transformation.

There are businesses where this shift in value can be very high, and others where it is lower, depending on the specific product or sector.

Consider the music industry: atoms are still needed for recording and listening. Everything else, however, can be done using bits. Given this, it is not surprising that the price of music to the consumer has approached zero.

Consider the car industry: there are a lot of atoms that need to be managed through the value chain. Some parts have been converted into bits, namely the design phases, part of retailing and customization (largely using the web) and a small part of the maintenance (where remote maintenance, using sensing and data analytics, can take place). However, most of the value chain is still tied to atoms. In the future, new technology will allow for different manufacturing processes, for example, using 3D printing. Industry 4.0 is addressing these changes, using bits to replace atoms in manufacturing of cars and in other industries.

Taking a broader view

The Digital Transformation affects much more than a single product or industry. It affects the value perception at societal level. Consider the car industry. Cars are part of the larger market sector of transportation. In the transportation sector cars have been a solution to the need for convenience in moving from A to B. If the Digital Transformation is applied not to the car or the car industry but to the need of getting from A to B, a completely different picture emerges.

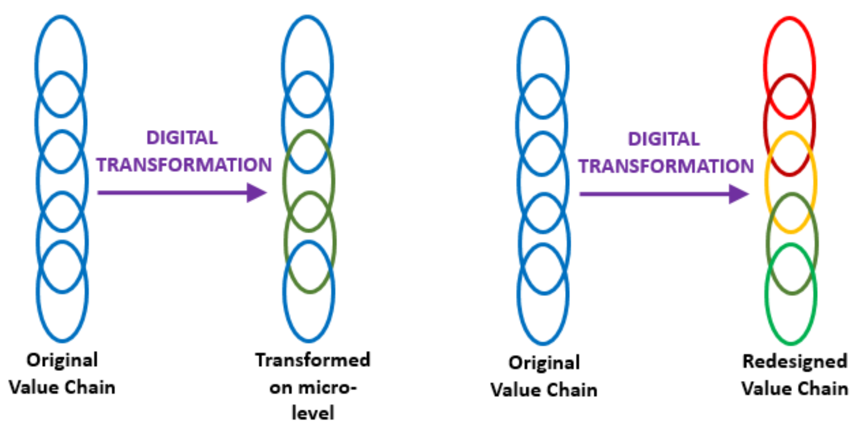

Figure 67. The Digital Transformation may take place at micro level, in a single stop of the value chain, or it may completely redesign the value chain. In this latter case some players may simply disappear while in the former they may be replaced by others more fit to the modified value chain. Using robot to perform certain activities may lead to a reduction in jobs, however a digital transformation that makes irrelevant certain activities is both decreasing jobs and erase the value of those activities, hence making previous business no longer viable.

Cars are clearly a very inefficient way of responding to the transportation need. Our cars remain parked up to 90% of the time, and we spend money "just in case" we need them. Up to know, this model was the only way to meet our needs. However, today we have started to see that companies like Uber and BlaBlaCar are leveraging that inefficient use of cars. By changing part of the value chain to bits they can increase the efficiency and provide the means for people who own a car to share it with other users.

Think about companies that are providing car-sharing services: using bits alone through your phone, a car in your vicinity is displayed, you reserve it and you even open and start its engine. Using bits, the company renting the car knows where it goes, where it is left at the end of the drive and also if it needs maintenance. This is increasing the overall efficiency of those cars, with a usage percentage that can grow to 30%. That is 20% more than the usual car efficiency and is resulting both in a business opportunity for the car sharing services and a decrease in transportation cost thus stimulating the market to drop ownership and move to car sharing.

Fast forward twenty years: self-driving cars will be common, and the societal perception of a car will be dramatically different from today. A car may look much more like public transportation, although it will still offer the convenience of today's cars. Car sharing efficiency with self-driving cars may well exceed 50%. That will further reduce the cost of transportation and attract even more people.

Notice the important role being played by societal and cultural aspects. Self-driving cars will remove all the "pleasure" of being a "reckless driver", since you no longer get the opportunity of being reckless. They will be perceived, as mentioned, as public transportation on demand.
There will be no more advertisements showing amazing acceleration or breath-taking top speed. From the point of view of driving, all cars will be alike. The value perception will shift to the comfort of the interior, to services (in bits) that can be enjoyed during the trip, and so on. The industry will be profoundly redefined since customers will look at a different set of values, and delivering those values will require different skills.

These are some examples to show that the Digital Transformation can affect those sectors that today seem rooted in the atom economy. By taking a broader view, atoms may be flanked more and more by bits changing the value chains and the entire economic landscape.

The loss of value

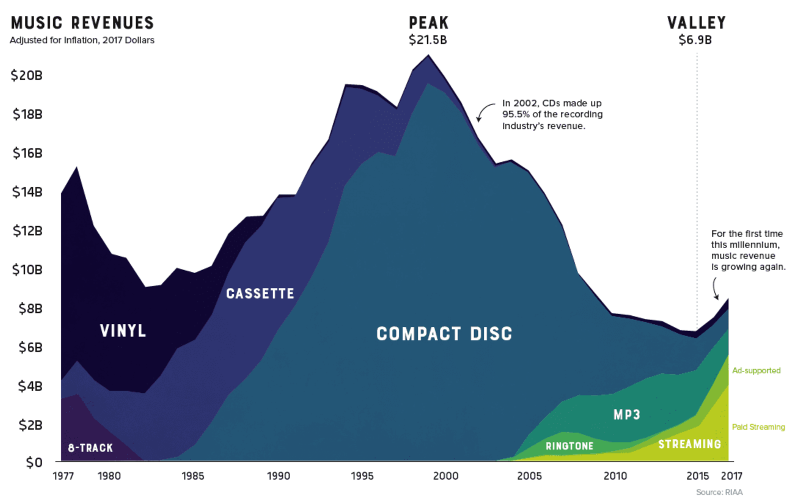

Figure 68. In the music industry, revenue rose as the industry improved the value chain by managing atoms, reaching a broader market, then as the Digital Transformation took over the value chain, the revenues collapsed quite rapidly killing most players in the process and opening the door to new players.

As previously mentioned, the Digital Transformation is decreasing the overall value of a value chain, by increasing its efficiency and eventually moving the benefits to the end consumer that will be paying a lower price. Obviously, if the price is lower the total revenue will also be lower as will the value generated by that value chain.

One might think that a lower price will lead to an increased market and that may offset the decrease in price per unit, but it is not true, particularly when the Digital Transformation is applied to a mature market. Take the example of the music industry or the one of the newspaper industry, two areas where the Digital Transformation has occurred (although it is not over yet). Their overall value today is lower than the one they had 20 years ago. Back in 1995 the music market had a value of $21.5B; in 2015 it was down to $6.9B. In these last few years it is slightly increasing but we are well below $10B; over 50% of the value chain value has disappeared. Additionally, by 2017 the old value chain, the one based on atoms (CD, vinyl, cassette), generates less than $1B in revenues, while the rest is generated by the digital representations of music which is basically controlled by new players. Back in 2002 Napster fueled the Digital Transformation. It was fought by the incumbents that eventually won the battle against Napster but lost the war to the Digital Transformation.

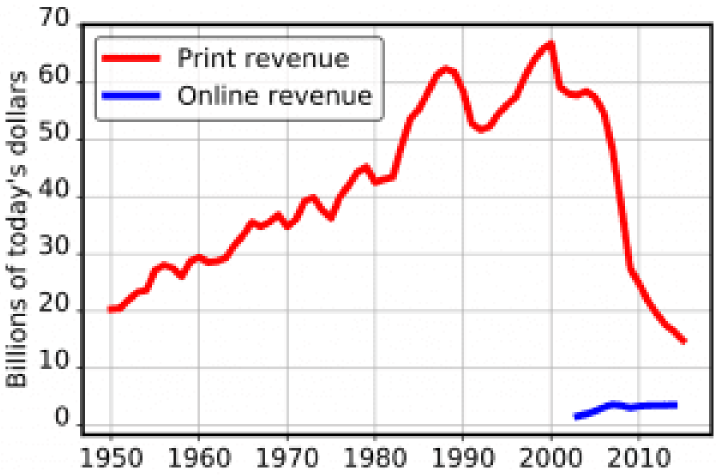

Figure 69. The growth and fall of advertisement value for newspapers in the US. Notice that in the last few years we have seen a growth in the value they generate from their online (bit) services but it is nowhere near enough to make up for the loss of value on the atom based value chain. Source: US Department of Labor

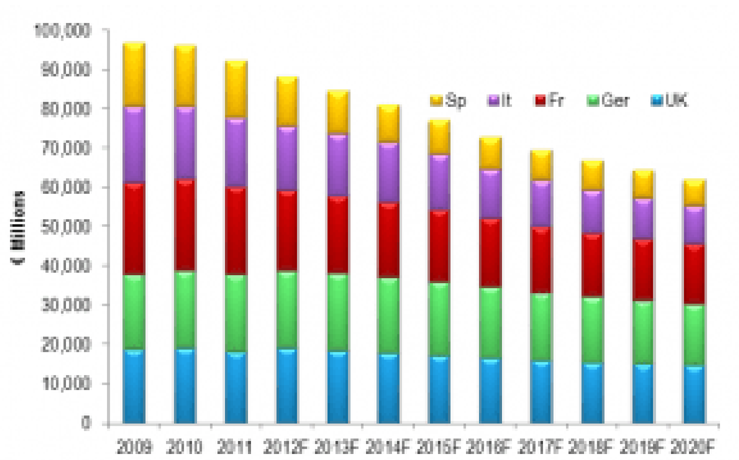

Figure 70. Telecom Incumbent Operators are seeing their revenues shrinking, and it has just begun. Source: IP Carrier

The world of newspapers has been hit hard by the Digital Transformation, with revenues generated by ads in their printed copies falling from over $65B (in the US) to less than $15B (in the US). The uptake of digital advertisement is a drop of water in the ocean of losses generating less than $5B in revenues. Hence the total value of the advertisement on the newspaper value chain went down from the $65B to less than $20B of today.

This is happening fast in many areas, and it usually follows a pattern of growth followed by a plunge that is the result of the Digital Transformation disruption.

Even areas that in theory should benefit from the Digital Transformation are feeling the decreasing value of the atoms-related value chains. For example, the Telecom Operators, even though their networks are carrying more and more bits because of the ongoing shift from atoms to bits, are still tied up with costly infrastructures and heavy labor costs. As the Digital Transformation progresses in their area (with flatter infrastructures based more on software than hardware, as will happen with 5G), we will see a sharper decline of atoms based revenues.

Digital Transformation – Disruptions

The Digital Transformation with its resulting loss of value disrupts businesses, affecting incumbent players and opening the doors to new ones. Disruptions can have different roots that may be difficult to pinpoint. Sometimes it may be clear that a disruption is on the making, and yet established companies may find it difficult to take countermeasures to save their business.

Usually, the problem is that their business is very profitable and moving to a new one would endanger their existing one. As shown, it is typical to see a business increasing revenues and then all of a sudden losing most of them. Predicting where that turning point will be reached is difficult, since it relates to several intertwined aspects, a bit like seeing the stock market rising, and although you know very well that sometime in the future there will be a downward spiral you don't know when to sell your shares. Even by looking back it is sometimes difficult to see why the market changed trends at that particular time although it is easy to explain why.

Figure 71. The drop in Kodak stock value as Digital Transformation took over making film cameras obsolete. Source: CNN

Sometimes, however, the disruption is brought forward by one single cause and is easier to analyze, like in the case of the Digital Transformation sweeping over the photography industry where disruption was a consequence of tech evolution and happened in three phases of transformation:

- Analog to Digital Cameras
- Digital Cameras to Smartphones
- Digital Photography to Computational Photography (ongoing)

Analog to Digital Cameras

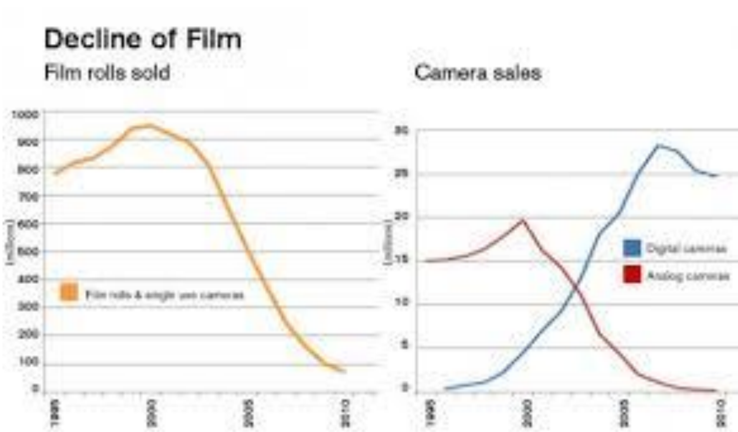

Figure 72. The decline of film based cameras was relatively quick, less than 10 years from the peak to bottom up. Image credit: Technology Review

As shown in Figure 71, the film market increased (surpassing 86B$) until the turn of the century, then all of a sudden it took a plunge leading to its (basic) disappearance in a decade (the marginal market for film photography was sustained by some industrial applications, like medical radiography that is now also disappearing by shifting to digital).

The disruption brought to the companies that produced film, such as Kodak, was the consequence of the uptake of digital photography (see the right side of the figure). Notice how the downslope of film market matches the downslope of the analog camera market and is a mirror image of the uptake of digital cameras.

The uptake of digital photography was fueled by tech evolution in three areas:

1. The improved resolution of digital sensors to capture the image (from 30,000 pixels to over 10 million pixels in the mass market. My current camera has 56 million pixels.)
2. The improved processing capacity that supports the conversion of the data produced by the digital sensor into an image
3. The improved storage memory capacity that has been matching the increased resolution, with the size of a photo moving from some 100kB in the year 2000 to the up to 50 MB currently available (a 500-fold increase).

On the consumer side, the shift to digital meant less expensive photos (no need to buy film nor to print them out. The consumer could decide later what to print or could opt to keep them in a digital form viewable on a screen) and the possibility to look at your photo immediately. It also meant the possibility to duplicate the photos at zero cost and send them to friends immediately.

Some side effects were generated by this analog to digital transformation:

- The possibility to look at your photo immediately made it easier to learn how to take better pictures. You can experiment, change the settings, and immediately see the result.
- The zero cost of taking a photo has multiplied the number of pictures we take and has also helped in making us better photographers.
- The immediateness of taking a photo and looking at it has developed a new culture for images and new habits. Now we take a photo as we would have taken a note in the past. We are moving more and more to a visual world (and we are "visual animals").

The impact on the business was dramatic. On the one hand it displaced those companies that were basing their business on film production (Kodak went bankrupt, Fuji survived because its business was not based on film only). It is particularly interesting to notice the analysis on the survival of Fuji where it was pointed out that shifting the company to only the digital world would not have covered for the loss in the film roll market: the latter generated much more revenues (and margin) than the digital roll (remember: the Digital Transformation *lowers* the value of the market) hence they undertook a business re-engineering that changed the fundamentals of the company, something that is very difficult to do in general. They started this re-engineering when their business in the analog photography was still very strong.

On the other hand, it created the market of digital cameras that went way further than replacing the analog camera market, it actually expanded the market as digital cameras became cheaper (and the cost of developing went down to zero).

Digital Cameras to Smartphones

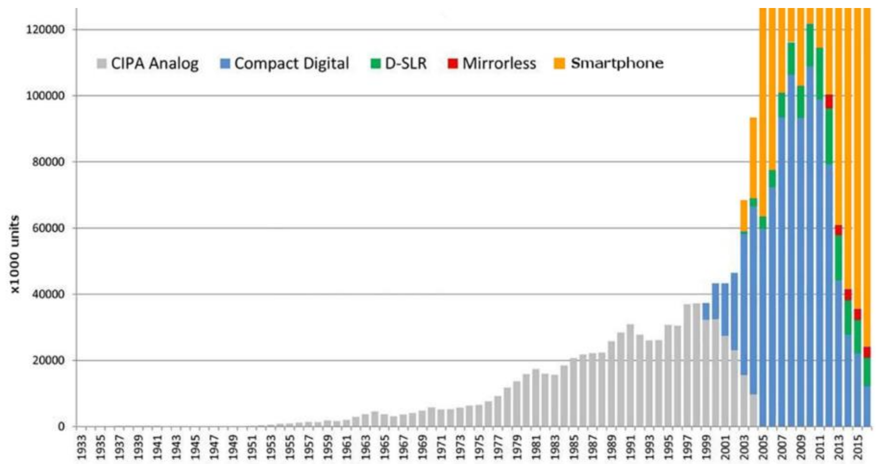

Figure 73. The growth of digital cameras and their downfall as result of the shift to the smartphones. Source: CITA

The second disruption that swept the photographic world was again the result of technology evolution although it was sprinkled with cultural aspects, fueled by flanking value chains, making this an interesting disruption to analyze.

As shown in the graphic produced by the Camera and Imaging Product Association, the market of digital cameras (both compact and reflex, with the compact ones taking the lion's share) took over analog cameras in just 5 years (1999 to 2004) with a market in 2005 that was double (in terms of number of units) the peak reached by analog (film roll) cameras in 1998.

The quickness in the change is amazing and is a direct consequence of the Digital Transformation: the lowering of cost as result of the shift from atoms to bits. In this case the zero cost was the operation of a digital camera, with an unlimited film roll and the disappearance of the need to develop the film. The printing of a digital image was a decision of the end user; most were and are happy keeping their picture in digital form and viewing them on a screen at zero cost.

The success of digital cameras was such that it pushed smartphones companies to embed them in their product (actually cell phones started to embed a low performance digital camera before the appearance of the smartphone, but it was the latter that eventually disrupted the market).

The problem with embedding a camera in a phone is that it does not fit; a compact camera is too bulky to fit into a phone. To compromise, the size of the image sensor is decreased which lowers the resolution, and the size of the lens is reduced which results in lower luminosity and higher noise. Of course, as technology evolves, some of these constraints are overcome although some of them cannot be overcome because of physical limitations.

In just 5 more years, by 2009, the number of smartphones with an embedded digital camera sold was level with the number of compact cameras sold. Their image quality was not equivalent with the one delivered by a compact camera, but people always had their smartphone with them became used to taking pictures with their smartphone everywhere.

Consider image quality: in 2010 a compact digital camera would deliver better quality than a smartphone but was that a deciding factor for people to buy a compact camera? Actually, less and less because most of the people couldn't tell the difference (which is the case if the image was not printed but viewed on a screen, like a television or the smartphone screen). Another factor kicked in: the rise of social networks and the sharing of photos. At that point the image quality was limited (in general) by the screen resolution (very few would take a picture from a social network and print it out, they were intended for fruition on the screen). Smartphones are much more convenient than a compact camera to post photos on a social network since they are always connected to the web. The embedding of connectivity in compact camera was too little and came too late.

However, the deciding factor was volume: look at the second graph showing the volume in units of smartphones (orange) vs compact cameras (blue) and digital reflex (green). The difference is not just huge, it is rapidly growing (last year considered in the graph is 2016, now the gap is even bigger). People with a smartphone had no need for a compact camera, and as more and more people got a smartphone less and less people bought a compact camera. By 2015 the game was clearly over. The market for compact cameras is now basically zero and companies that benefitted from the first wave of the Digital Transformation in photography saw their business dying out. From the point of view of the consumer, the Digital Transformation has delivered the same services (better actually) at a lower cost (basically for free). Of course it was not just the increased capability of smartphones that make the difference, it was the concurrent decrease of price in mobile internet access that make the sharing of photos basically free. The Telecom Operators were cut out from the benefit of the digital transformation in this area, and actually they had to pay (in terms of network investment) for it.

The volume of digital reflex has remained roughly stable since those cameras attracted a different market, and until 2017 reflex digital cameras were no match for smartphone cameras.

Another deciding factor, as previously mentioned, was the uptake of social media that started to make large use of digital photos. Instagram (as one example, the same growth is experienced by Snapchat, Twitter, Pinterest, Tumblr, etc.) started in 2010 and by 2015 has grown to 400M users. In June 2018 it exceeded 1 billion users active in a month worldwide. Every day some 100 million photos are uploaded and over 40 billion are shared. These numbers are mindboggling and there, in a nutshell, is what Digital Transformation is all about: killing cost and making possible to do (new) things because they become affordable.

And it is not over yet.

Digital Photography to Computational Photography

Figure 74. The L16 has 16 lenses, each time you take a photo you are using several of them, and software takes care of fusing the individual lens output into a single photo. Image credit: Macfilos

The next disruption coming up in photography is going to be computational photography, again the result of technology evolution.

To make better quality photography you needed better equipment: a good camera, a good film roll. This did not change with the shift to digital photography where you still need a good digital camera (with a good sensor and electronics) and a good lens.

By using post processing software (bits) you can improve on your photo, and post processing software has become more and more powerful. Now part of this post processing can take place in the camera making taking high quality photos easier.

We are already starting to see more advanced features that can be performed inside the camera using software (and a lot of processing power) that would not be possible outside of the camera.

Take the L16 camera. After a few years in the making (more than they expected), it hit the market in 2018 as a completely new type of camera, based on computational photography. It leverages bits much more than atoms (although making the atoms comply was really tricky). As shown in Figure 73, the L16 has 16 lenses that come in 3 focal lengths: five 28m wide-angle modules, five midrange 70mm, and six 150mm telephoto ones (equivalent). Yet when you see the image on its screen, you can swipe your finger and decide the focal length you actually want, anything between 28 and 150! Now, notice that the result will be an image taken at the focal length you select, even though there is no optical lens delivering that focal length (unless, of course you select 28 or 70 or 150). Do not confuse this with the electronic zoom you have in your digital camera which is just clipping the area to be used on the sensor making objects appear closer as you zoom further and further. However, in a camera with a real optical zoom, the depth of field and bokeh will change as you change the focal length. Not so if you use the electronic zoom. Also, using an optical zoom (or changing your lens to a longer focal one) causes objects to become compressed, not so with an electronic zoom.

The difference is that an electronic zoom relies on atoms (your camera optical lens and its sensor) while computational photography relies on bits.

Modern smartphones have started to use computational photography providing enhanced capabilities. As an example (see the waterfall photo I took), they can use several snapshots (automatically taken when you push the shutter) and combine them to create the same result you would get by using a long exposure time. Notice that in most cases, with your digital camera, you won't be able to use a long exposure time because there is too much light around and you would end up with an over-exposed photo. You could use filters, but again this is not a solution that could work in many situations.

Figure 75 Photo of the Doi Inthanon Waterfalls, taken with my iPhone.

Figure 76. Photo of the Doi Inthanon Waterfalls, taken with my iPhone simulating a long exposure time.

Take the picture my iPhone generated simulating a long exposure time. Nice effect, isn't it? Well I could have used dark filters (not really practical on an iPhone) to get the same effect exposing for 2 seconds. The problem would have been, however, a sharp increase in noise (because of the long exposure time); I would have needed a tripod to keep the phone absolutely still, and moreover if there was a person in the frame that person would have to remain completely still for those two seconds.

With computational photography the solution is all in the bits (and in the application managing them). There are many things that computational photography can do today, like decreasing noise and increasing sharpness. However, there are even more things that it will be able to do in the coming decade and that will disrupt photography and the related value chains.

First, the requirement of having good atoms to get good photos will no longer be present. This will disrupt the companies whose selling point has been delivering good lenses and always better and better sensors. Of course they will remain a factor (like having the sensor embedding on the processing chip will make computation faster) but it will no longer be a competitive edge. The competitive edge will shift to companies developing software (signal processing) which requires a different set of skills and will no longer require massive capital expenditure. A small company in India may become a leader in some computational photography features, while today it would be impossible for a small company to become a leader in digital imaging chips.

Second, by using computational photography the requirements for atoms decrease, hence the price of the cameras will also decrease (a very interesting proposition to win the consumer market) and likely their bulkiness will decrease letting any object/product, become a potential camera. Any product will be able to "see" how you use it, how you like it and report back. Progress in this image processing may be primarily driven by self driving cars that in the next decade will be relying on it to become aware of their environment.

Third, bits can be analyzed to detect objects, deriving semantics. This is likely to open up a new market for companies like Amazon that might be willing to provide the very best computational photography features completely free aiming to make money from understanding consumer preferences (usually you photograph what you like) and offering related goods.

We are seeing the first steps being taken today with the increased number of cameras on smartphones: there used to be two cameras on a smartphone - one in the front and one in the back. Now there are several phones with three cameras and a few with four. Also, it won't be long before companies will start to use both the front and back camera, with the one facing you helping in determining your mood as you take a picture (or the other way round detecting what is the environment in which you are taking a selfie).

It is likely that the next decade will see the complete shift to computational photography which will become an opportunity for several new businesses (or a reinforcement for several existing businesses). As the focus shifts from atoms to bits, the value lies on what is leveraged from the bits, and several companies will need to reinvent themselves as their business will fade away.

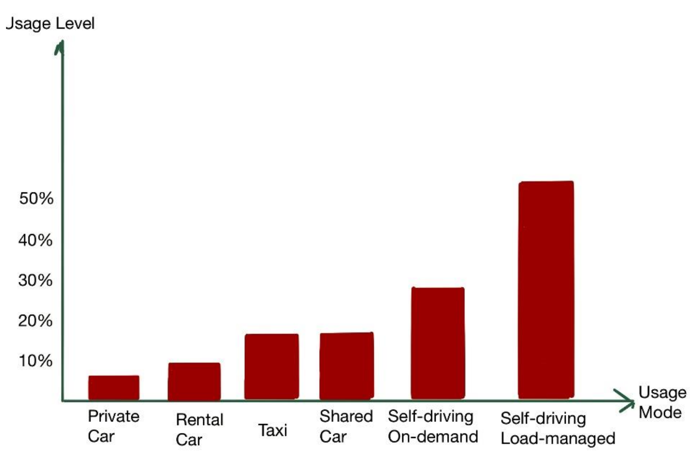

Figure 77. Cars have a very low usage time, being parked most of the time. In the future as they become "services" their usage will increase significantly. Here the Digital Transformation is both the result of a value perception change and enabler for the change.

Digital Transformation – Towards the disruption

Consider what may happen, in terms of Digital Transformation, in the area of private transportation (cars). It helps to look back at how the car market evolved. At the very start, cars were an artisanal product; there was no standardization and no rules of operation (the roads were not paved, driving licenses were not required, there were no speeding tickets). That all changed with the birth of assembly lines (Ford in 1913) designed to produce affordable cars that even a blue collar worker could dream of buying. Cars started to become available in the thousands and then hundreds of thousands, and by 1918 most US States enforced a registration plate, started to test the driving abilities (a driving license like the one we have today came later, in the 1930s) and put regulations in place. In other parts of the world the timeline might have been different but the sequence of steps from artisanal car to mass market was the same.

However, affordable is a relative term: because of cost very few people could afford buying a car (until the 1950s) and public cars, or cabs, started to appear in response to the business opportunity (1908 in New York and at the turn of the last century in Europe). Car rental was soon to follow (in 1916 in Omaha later bought by a certain John Hertz, in Germany Sixt started in 1906).

While cabs were the response to the huge cost of owning a car, car rentals leveraged the increased effectiveness of having a car shared by multiple customers, by ensuring the splitting of cost across the customers and increased usage of the car. As computers increased the efficiency in managing rentals and smartphones improved the interface with web services, there has been a growth of car sharing services (such as Uber or BlaBlaCar). They leverage the fact that cars are seldom in use, and it makes sense to exploit their unused time, thus sharing cost.

As you can see from Figure 77, cars have a very low usage time, being parked most of the time. In the future, as they become "services," their usage will increase significantly. Here, the Digital Transformation is both of the result of a value perception change and an enabler for the change.

Even in the best situation a shared car is not actually used very much (although it may double the usage time of a private car that is estimated in the US to be around 5%[253], 4%[254] in the UK). While this is not a complete Digital Transformation, it has put a dent in the taxi business and is starting to affect public transportation.

Private transportation does not solely depend on technology; it is very much a cultural shaped landscape. People consider car ownership as part of their freedom; it enables them to go where they want when they want. It has been part of the young person's dream for the last 50 years. In these last few years, however, the mood has shifted. In several cities millennials consider the car an unnecessary cost[255], considering it much more effective to use a share-car service whenever you need one. This mood shifting is likely to be accelerated by the coming of self-driving cars. A self driving car will likely be perceived as a public transport, rather than a private one since you lose control of driving.

Some recent studies show that with less than half the number of cars urban dwellers could get the same level of transportation service they get today by owning a car. In addition, the cost will decrease by some 80% (in the long run) as cars are becoming a commodity and their usage time increases significantly, in the range of 30% (see graphic).

This will extend the Digital Transformation and disrupt the car manufacturing companies. They will no longer be able to sell cars by advertising their speed or acceleration. They will no longer be in a business to consumer market, rather in a business to business market. Selling cars as commodities and only selling half the volume is likely to depress the market, and consolidation among car manufacturers will accelerate.

At the same time, a new market may emerge for delivering personalized services, creating sort of personalized cocoons that people will be willing to pay for. There are already some ideas of cars splitting into a commodity moving platform upon which a personalized living shell can be created. This latter may remain in the private ownership domain (and be commercialized by the likes of Gucci and Armani) whilst the former will be a public or large corporation domain.

Still, growing the usage time to 30% is still rather inefficient. Consider the introduction of moving platforms that can reshape themselves to carry (mostly) people during daytime, and carrying goods in night time. That may boost the usage of these movable platforms beyond 50% and would be a disruption in the whole transport value chain. This may occur within the next 30 years, with earlier introduction in certain niches.

Digital Transformation will occur in the transportation sector not necessarily fueled by technology evolution but rather by societal changes. Clearly advanced technology will be needed, but it will not

253 http://fortune.com/2016/03/13/cars-parked-95-percent-of-time/
254 https://www.racfoundation.org/motoring-faqs/mobility#a5
255 https://www.fastcompany.com/3027876/millennials-dont-care-about-owning-cars-and-car-makers-cant-figure-out-why

be the deciding point. Regulation and cultural aspects will be the dominating factors. Additionally, the digital transformation in the transportation sector is likely to happen in niches and in phases. In the longer term niches will expand and phases will evolve. Along the way the whole industry and our perception of cars will be changed.

Digital Transformation – Distributed Digital Platforms

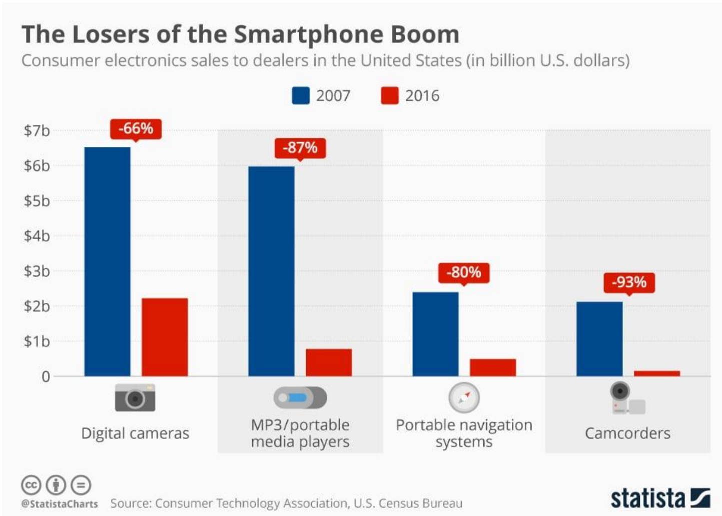

Figure 78. The smartphone has become a digital platform. This chart shows the decline in sales in the US of digital cameras, portable media players, portable navigation systems and digital camcorders as result of the availability of their functions on smartphones.

The Digital Transformation is made possible by technology advances and is steered by economic and societal factors. It is a whole system transformation that requires the availability of a tremendously complex infrastructure, similar to how the atoms economy has evolved over centuries by creating in parallel tremendously complex and intertwined infrastructures. Logistics value chains have become extremely effective and extremely complex. Computers have boosted their efficiencies and made possible the creation and management of even more complex infrastructures. These computers supporting infrastructures are slowly morphing into infrastructures of their own. The large data centers that are supporting shipping of parcels and containers are now managing the shipping of bits in a structured way (e.g. by adopting blockchain).

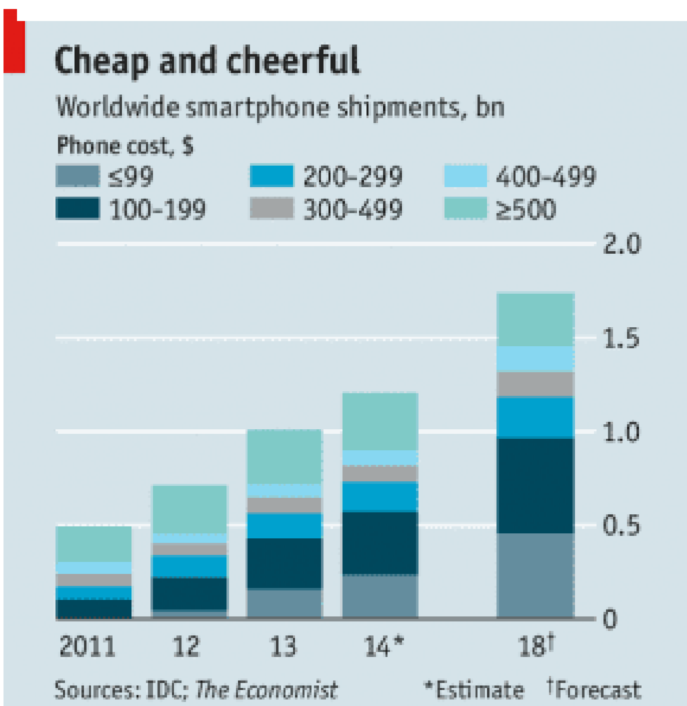

Figure 79. The number of smartphones is rapidly increasing, over 1.5 billion have been sold in 2018. Notice the rapid increase of low cost smartphones, a crucial factor in their global pervasiveness. Source: IDC data, The Economist

It is interesting to notice that in many cases we are seeing the transformation of what has been created as a self-standing support to a specific activity into a platform supporting the growth and integration of activities and becoming an infrastructure supporting the digital transformation of one or several sectors.

This is surely the case of the smartphones. As shown in Figure 79. The number of smartphones is rapidly increasing, over 1.5 billion have been sold in 2018. Notice the rapid increase of low cost smartphones, a crucial factor in their global pervasiveness. Source: IDC data, The Economist the number of smartphones sold increases every year, and now almost all new phones being sold are smartphones. In the next decade we can expect that normal cell-phones will fade away, replaced by smartphones. This is enabling a worldwide transformation of many sectors because smartphones are:

- storage and processing units that support a variety of applications

- connected to the web and can be orchestrated
- using just a handful of software platforms (basically just two: Android and IOS) and this stimulates the creation of applications and keeps the cost of porting an application to a different platform reasonably low
- acquired through a distributed investment, basically every end-user pays for the phone and even when they are subsidized the subsidizing companies see a short term return
- creating a digital culture seamlessly changing the behavior of people which is probably one of the most crucial factor in fostering the digital transformation.

Smartphones have become a de facto distributed digital platform that is being used in a variety of market segments. Take, just as an example, the bike renting business.

There are a few companies, some operating in many countries, offering bike rental by leveraging smartphones throughout the value chain. The entire process of renting a bike is managed through the smartphone:

- Location of nearest bike
- Reservation of rental
- Unlocking the bike which starts the 'metering'
- Charging of the rental fee
- Relaying of information of final destination of bike to update database for use in next rental process

Figure 80. Smartphones have created a de-facto Digital Platform that industry and institutions are leveraging. Image credit: Space Technologies

Mobike[256] is a Chinese company and the largest bike rental in the world, operating (as of end 2018) in over 200 cities, in 19 countries and rapidly expanding. Creating a bike rental in the atom world requires a significant investment in the operation of the business. In addition, the business doesn't scale in terms of operating cost. Every new rental location requires a dedicated operation staff. In the world of bits, the operation cost does not increase for a good portion of the value chain (reservation, payment, monitoring, advertisement).

Mobike does not need to train people how to use their smartphone, nor how to use digital payment methods on it. At the same time, users of Mobike get continuously trained in the use of their phone as the digital interface to the digital world.

The potential of smartphones seen as a distributed digital platform is huge and institutions, like cities' municipalities, need to learn how to leverage them to make cities smarter. Smartphones are an existing digital platform in an existing culture that can be leveraged with very limited investment. Obviously, as with all forms of Digital Transformation, there are a number business that are suffering, to the point of disappearing. As shown in Figure 78. The smartphone has become a digital platform. This chart shows the decline in sales in the US of digital cameras, portable media players, portable navigation systems and digital camcorders as result of the availability of their functions on smartphones., the smartphone has basically killed point and shoot digital cameras, camcorders, portable navigators and MP3 players by moving the functionalities that required atoms to the world of bits. Now software applications, using the smartphone as a digital platform, can deliver them, at lower cost (sometime even for free).

[256] https://mobike.com/

Digital Transformation – Digital Platform Characteristics

The discussion on digital platforms began by considering the one created by smartphones because it was easy to point out the basic characteristics of a digital platform:

- it needs to have storage capabilities
- it needs to have processing capabilities
- it needs to have embedded connectivity
- it needs to be open to let third parties develop on it
- it needs to affirm a standard to decrease the cost of interfacing
- it needs to support scaling to accommodate more users and features
- it needs to aggregate investment creating an attraction point

All of these features are present in the digital platform created by smartphones:

- Each smartphone has GB of storage capacity on board and this capacity keeps growing, thus fueling new applications. Samsung has recently announced 1TB Universal Flash Storage, [257] and its new Galaxy S10 might be offered in a configuration with 1TB. Notice that it took just 4 years to move from 128GB to 1TB which is a doubling of capacity every year, faster than the Moore's law prediction.
- Each smartphone has a processing capacity that far exceed the one of personal computers five years before and the one of supercomputers 20 years before[258]. This processing power keeps growing each year as new generation chips become available. Currently, processing power in a smartphone is no longer an issue, and comparing different smartphones based on processing power is basically meaningless.[259] Smartphones are a delicate engineering tradeoff between various characteristics, like processing capacity, graphic processing capacity, power consumption, screen resolution, thickness, heat dissipation, radio reception, and so on.
- Smartphones have increased their connection capability, actually anticipating 5G in the sense of being able to manage several radio channels and different communications protocols concurrently. A smartphone today can operate on a variety of spectrum frequencies, using GSM, 3G, LTE, Bluetooth, WiFi, NFC protocols. In this respect it is more sophisticated than a radio station of a telecom operator. In addition, it can create and manage local networks (tethering).
- Smartphones have a very limited number of operating systems (with Android and IOS taking the lion's share). This create a consistent and open environment for third parties to develop applications. Third parties see the advantage of developing their apps on this software environment since they are assured of a huge potential market. Additionally, the periodic updates to those OSs take care of backward compatibility (or ensures that an easy path to compatibility is provided) thus preserving the investment in developing applications (notice that the average life cycle of apps is pretty short, so repetitive changes in OS version that eventually lead to incompatibility are not seen as a problem, the investment in developing the apps having been recovered);
- Smartphones, as just pointed out, use a very limited set of OSs that create an aggregation point for third parties. Equally important, the companies behind these OSs have created and made available an application development environment (e.g. Android[260], IOS[261])

[257] https://mashable.com/article/samsung-1tb-smartphone/#xYjqYJFFoZq5
[258] https://pages.experts-exchange.com/processing-power-compared
[259] https://gizmodo.com/why-comparing-smartphone-specs-is-a-waste-of-time-1822794285
[260] https://developer.android.com/studio/
[261] https://developer.apple.com/library/archive/referencelibrary/GettingStarted/DevelopiOSAppsSwift/

that is both facilitating third parties development of applications and provides uniformity (as an example in the user interface), a most crucial aspect to ease users interactions.

- Smartphones' continuous development (and significant backward compatibility of applications) makes scaling possible in terms of delivering ever more complex apps and their intrinsic distribution that is managed collectively by the increased capabilities in network access makes scaling of their number a reality. Possibly no other infrastructure has proven so good at scaling: we have moved from few thousand to several billion phones worldwide, with no issues in service provisioning (occasional downtimes generate surprise in addition to anger, and this is proof of how good the service really is).
- The growth in smartphones is the result of a massively distributed investment, sustained (mostly) by individual users. This investment requires an investment from the network side (roughly in a 70 to 30% ratio, meaning the end users bear 70% of the overall cost and the operators 30%) but this investment is both much lower than the one required by a fixed network and most importantly it scales smoothly with revenues. Operators can invest at the same time as they get returns (this is not the case for a fixed network). Hence smartphones have created and continue to create a growing business opportunity that attracts more and more business which in turns steers the overall growth.

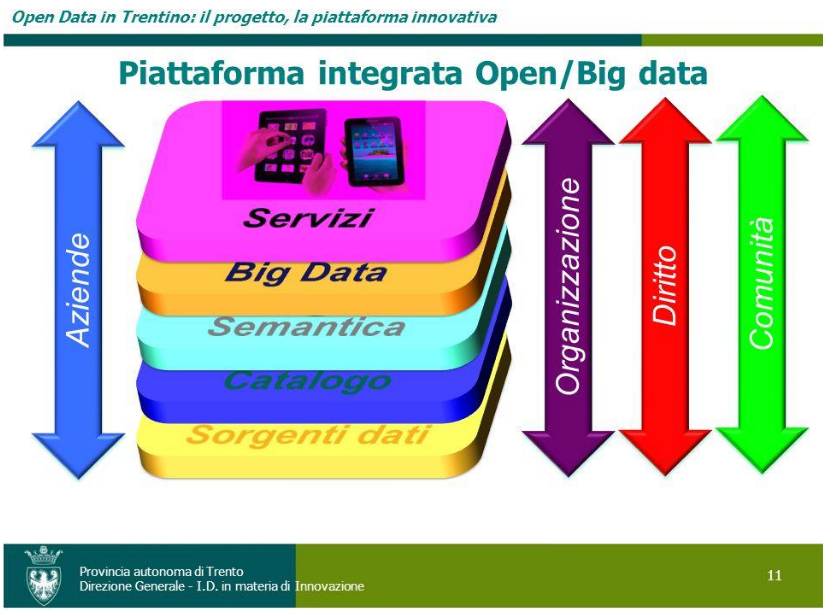

Figure 81. General architecture of the Open Data Trentino. Various data streams, at the bottom, are unified through a common ontology (catalogue) that in turns is interfaced by a semantic layer. This latter, using a variety of software algorithms produces data that are exposed to applications. These latter are both embedded in the platform and provided by industry (aziende). The platforms comply with a set of regulations (Diritto), is structured to support operation processes (Organizzazione) and is intended to serve the whole citizenship (Comunità). Source: Provincia Autonoma di Trento

These characteristics of smartphones, seen as a digital platform, need to be present in other digital platforms to succeed. These are required when both assessing the chances of a digital platform and when designing a digital platform.

Self-driving cars may become a digital platform; they have, at the core, all of the above characteristics, but of course work is needed to develop them and the whole ecosystem. This is a role of institutions, regulators, and industry. It is also a space where neutral organizations like EIT Digital and IEEE may play a significant leading role.

Digital Transformation – Creating an Institutional Digital Platform

The Open Data Initiative in Trentino stems from the recognition that data can be leveraged to create value. At the same time, this creation of value requires a structured approach; it needs to be part of a regulatory framework and needs to involve players and users alike.

What about starting from scratch to create a Digital Platform that could succeed? As stated it needs to have the following characteristics:

- it needs to have storage capabilities
- it needs to have processing capabilities
- it needs to have embedded connectivity

- it needs to be open to let third parties develop on it
- it needs to affirm a standard to decrease the cost of interfacing
- it needs to support scaling to accommodate more users and features
- it needs to aggregate investment creating an attraction point

Let’s take, as example, the Open Data Initiative[262] set up by the Provincia Autonoma di Trento back in 2013. Six years have now gone by, so we can also see its evolution from the point of view of results (disclaimer: this is a personal take on that initiative and does not necessarily reflect those of the Trento Province).

Over the last 30 years, the Trento Province has accumulated a significant number of databases, recording data on a variety of societal, economical and operational aspects in Trentino. Over 120 databases spanning from agriculture data (apple and strawberry), traffic data (vehicular flow on all Trentino roads, geo-located accident reports), health care, and so on.

Each of these databases had different characteristics required different access permission and was designed to meet specific objective. The first step was to recognize that all these data shall be made available. That required the publication of the ontology and the design of a framework of access rules.

This led to the Open Data Trentino: a platform was developed to integrate the access to all of the Province databases, ensuring that use can be tracked, proper ownership maintained and privacy assured. This latter is particularly tricky since individual data may be stripped of identification but by correlating several data, identification may emerge. The solution was to open the access to data not as access to the raw data but through date services where a data service function would return the desired (permissible) information emerging from a data set, yet hiding the raw data.

This was the starting step. The next one was to foster an open data mind-set on players, both providers and users. To pursue that the Province required that all service providers under a Province contract would be required to open the data, in accordance to the Trentino Open Data Framework, for the part that was involved in the contract execution. This was a crucial step since the Province is a main player and it is investing on citizens’ services. By enforcing their suppliers to adopt an open data framework they not just increased the data pool, they also created a culture.

Furthermore, the Province assured a regulatory framework that protected those commercial enterprises that would open their data on their own, based on the Trentino Open Data Framework. This was a crucial step since it allowed companies to create data ecosystems for their products and services, initiating a Digital Transformation in their sector (and basically forcing others to follow suit).

Notice how these steps fulfilled the set of characteristics I previously listed for a successful digital platform:

- it needs to have storage capabilities
- it needs to have processing capabilities
- it needs to have embedded connectivity

These first three were actually present in the IT infrastructure of the Province, pre-dating the initiative. There was some discussion on setting up a data center for Trentino but the scale was not large enough to make it economically sustainable; it was much better to rely to existing data centers.

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[262] http://www.innovazione.provincia.tn.it/opendata

- it needs to be open to let third parties develop on it – *achieved by providing the Open Data framework and the regulatory framework;*
- it needs to affirm a standard to decrease the cost of interfacing – *achieved by publishing the ontology and the application interface;*
- it needs to support scaling to accommodate more users and features – *the choice of a mixed architecture with a distributed set of interconnected databases and apps (services) that may be hosted on different servers plus local processing at the edges (smartphones) ensure graceful scalability;*
- it needs to aggregate investment creating an attraction point – *the feature of tracking usage thus protecting ownership is crucial to the establishment of a sustainable business for all parties involved and the development of the regulatory framework created the attraction point.*

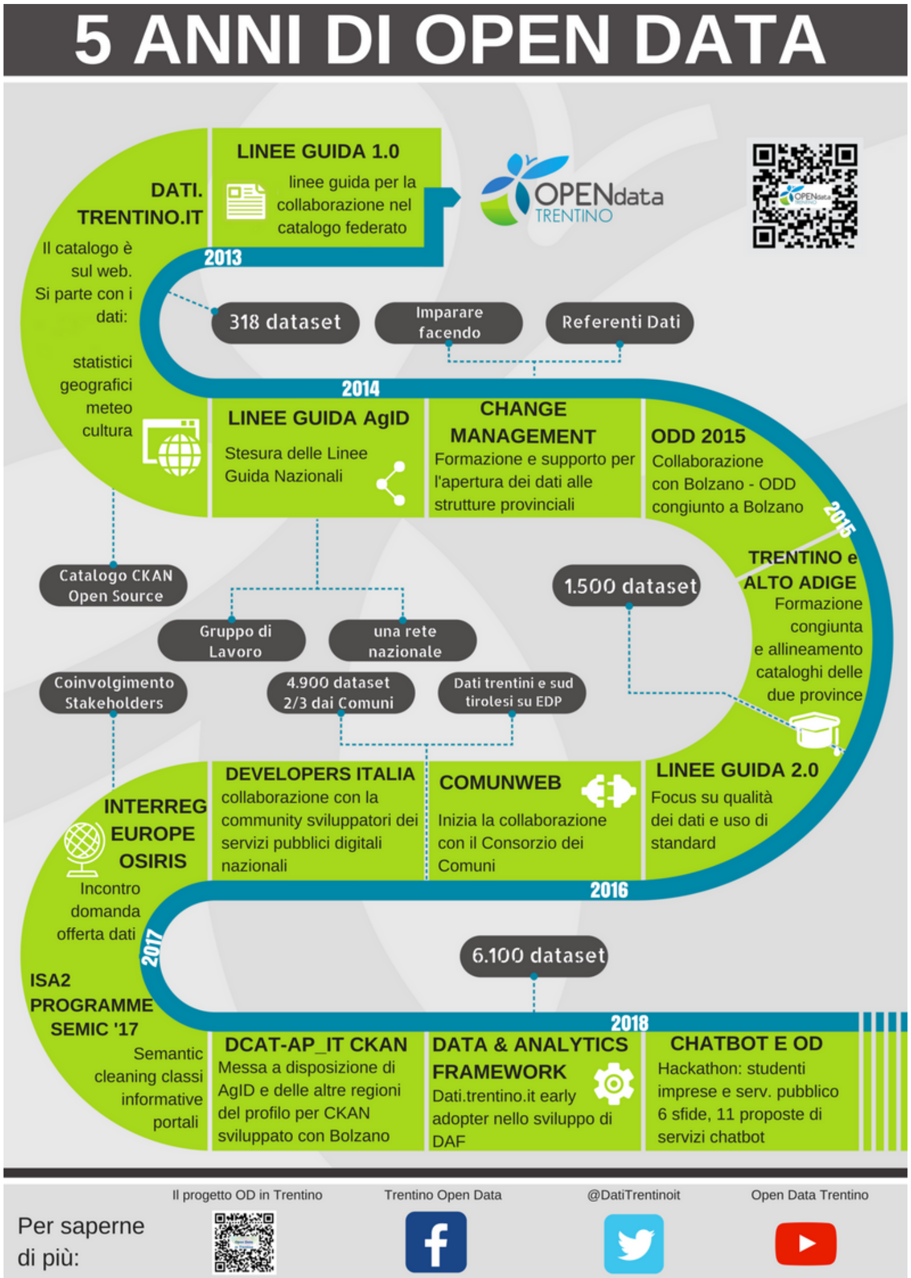

Figure 82. The roadmap followed by Trentino Region in the development of their Digital Platform, starting from the Open Data. Source: Trentino Region

It should be noted that the shift towards a Digital Platform is not a downhill path. It requires effort to overcome resistance from incumbent players who have carved their business space and that may see the shift as a loss of control and value (which it is).

Creating momentum is very important, and this requires involving players and creating a critical mass. It requires proving that the creation of services (hence value) on the new platform is possible and attractive to business, both existing and new. Several actions, including hackathons to stimulate service creation leveraging on the Open Data, have been put in place. Main players, like FBK, Engineering and TIM have provided commitment and support.

At EXPO 2015 in Milan, Italy, the Municipality of Milan had the objective of creating a digital ecosystem (E015) where all data related to the EXPO could be shared in an open way and leveraged by third parties, in addition to the EXPO 2015 organization. Several streams of data, including private and public transportation, events, restaurants and hotels were available, however each stream had different owner(s) and structure. The task of creating an ad hoc digital platform was given to CEFRIEL, an innovation company active in helping organizations master the Digital Transformation.

The first step was to create a solid and open data infrastructure with a well-defined set of application programming interfaces (API). Once complete, all data were opened to third parties. Training courses were prepared and various forms to attract business interest were put in place.

EIT Digital decided to participate in EXPO and to leverage the E015 data platform focusing on the creation of tourist services leveraging data provided by E015. The result was 3cixty[263], an advanced recommendation systems able to guide a multitude of tourists in personalized ways. Now has become a digital platform to support tourist-oriented service creation. At the same time E015 has evolved, and in 2018 it has been morphed into a digital platform serving as a smart "brain"[264] to aggregate and ease the access to data in the Lombardy Region and is now being managed by the Region IT department.

Some of the lessons learned were:

- Starting with a very focused objective works well but as soon as the platform is used, it is evident that there are other data streams that would be valuable that are not in the platform. 3cixty needed to integrate additional data streams that proved quite complex (for example, tourists going to the EXPO in Milan in 2015 were also interested in visiting nearby towns, like Bologna, Florence, Venice but data about those towns were not part of the E015). Therefore, there was a need to integrate the data streams, moving from a homogeneous to a heterogeneous system.
- The effort required in the buildup of a digital platform is not trivial; it was costly in resources of many kinds. Focus streamlines the effort but also reduces the revenues and the life time of the platform. EXPO 2015 was over after 6 months and clearly the cost of developing the platform was not recouped over that short period of time. Being able to re-use the platform by re-adaptation in a broader context was important. It clearly required some more investment but at the same time it leveraged the culture that was created by the original platform.
- The openness of the platform may backfire. What the end users really like is a consistent look and feel. Openness should not necessarily mean "do whatever you want". A framework that ensures and mandates uniformity in the end can win the users (as happens in the "closed garden" of the Apple development environment and to similar extent with Android).

Even thought to a lesser extent the E015 Digital Platform conforms to the requirements stated previously (the first three –storage, processing connectivity- being ensured by the Lombardy Province servers):

- it needs to be open to let third parties develop on it – *achieved by providing the Open Data framework;*
- it needs to affirm a standard to decrease the cost of interfacing – *achieved by publishing the ontology and the application interface;*

263 https://www.eitdigital.eu/newsroom/news/article/eit-digital-presents-3cixty-at-the-milan-expo-2015-a-city-and-event-exploration-platform/

264 https://milano.corriere.it/notizie/cronaca/18_giugno_16/e015-nasce-cervellone-digitale-scambiarsi-dati-informazioni-5e1da204-714b-11e8-8802-e09859fdb268.shtml

- it needs to support scaling to accommodate more users and features – *the choice of an architecture with apps (services) that may be hosted on different servers plus local processing at the edges (smartphones) ensure graceful scalability;*
- it needs to aggregate investment creating an attraction point – *the drive of the Lombardy Region to aggregate the digital asset and the commitment to the Digital Transformation with two main focus (Citizens' services and Industry 4.0) result in an attraction point for third party business.*

This is a good example of a Digital Platform that was designed to meet a very specific goal (supporting EXPO 2015 service creation) and that has been able to evolve to become a more general Digital Platform. As this evolution has been crucial in moving from a "cost" deemed necessary to support EXPO 2015 to a revenue generator, expanding its scope and its useful life time.

Digital Transformation - A Digital Platform for Smart Cities

Consider Digital Platforms designed for specific application areas, starting with Smart Cities. To determine the interest existing in this area, a search on Google (on February 11th 2019) returned over 200 million references. At the Smart City Expo World Conference[265] (Nov 2018 in Barcelona) the theme was *"Digital Transformation: When Bridging Digital and Physical Means Smarter Living"* a number of companies presented their own Digital Platform tailored to Smart City needs. Among these,

- Huawei presented[266] the result on traffic in Shenzhen (its headquarter city) when its platform was deployed to control city red lights: a decrease of 17% in traffic jams;
- The municipality of Singapore assigned[267] ST Engineering with the task of deploying its smart city digital platform to the new green area of Punggol Digital District in Singapore;
- SAP presented its vision of future cities[268], achievable through their flexible digital city platform;
- EIT Digital presented CEDUS[269], the pan-European digital platform for smart cities, developed and deployed by a consortium led by engineering.

There are a large multitude of initiatives, products and companies operating in the digital platform area for smart cities. This should not come as a surprise. There is a huge amount of money being spent for the smartification of cities, and that amount keeps growing year over year to reach some $158B in technology investment[270] in 2022 (according to IDC[271]). Notice that this is just about investment in technology, if you include investment in digging, pouring concrete and the like the investment will be close to $1 trillion.

These big numbers are the result of a multiplying factor, i.e., the number of cities around the world committing investment to their smartification. A major part of that investment is not "reusable". If you have to dig to lay optical fiber, the cost of digging (and for optical fiber) is localized and cannot be reused. That is part of the world of atoms and its economy.

265 http://www.smartcityexpo.com/en/topics/digital-transformation
266 https://dcnnmagazine.com/infrastructure/huawei-and-the-smart-city/
267 https://enterpriseiotinsights.com/20180711/channels/news/singapore-preps-open-digital-platform-tag40
268 https://www.sap.com/industries/smart-cities.html
269 https://www.eitdigital.eu/newsroom/news/article/eit-digital-innovation-city-enabler-winner-of-select-for-cities-award-2018/
270 https://www.idc.com/getdoc.jsp?containerId=prUS44159418
271 https://www.idc.com/tracker/showproductinfo.jsp?prod_id=1843

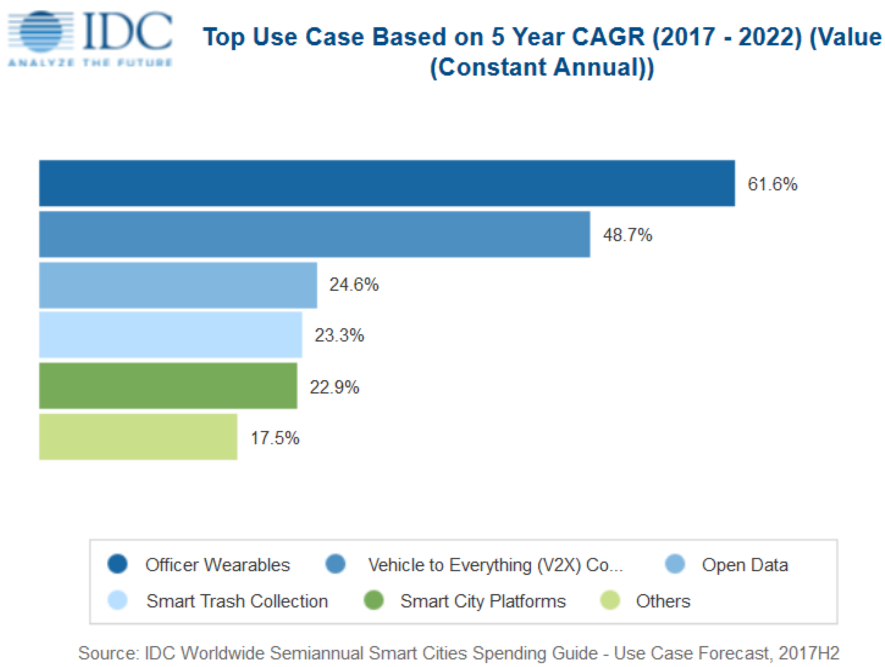

Figure 83. The technology investment in smart cities, globally will keep growing over the next 4 years (in the graphic the CAGR between 2017 and 2022). Although the most impressive CAGR is estimated in personal wearable (for city officers) one should note that the investment today in this areas is basically zero, so any growth will have a significant CAGR. Notable the CAGR expected in Smart City Platforms (22.9) and in Open Data (24.6). A digital platform is actually embedding both and we already have significant investment today, so such a CAGR means big bucks. Source: IDC Worldwide Semiannual Smart Cities Spending Guide

However, some 10% of the overall investment around the world is made using bits, in creating applications. This is part of the economy of bits, and it is to a great extent reusable in different contexts. This is where the Digital Platforms play a role: making reuse of applications possible in many cities. This is why there are so many players and initiatives in the Digital Platform space. These platforms are the enabler of the cities' Digital Transformation, and by shifting them into the economy of bits can dramatically decrease cost. The problem, of course, is that today we have too many platforms and they are usually incompatible with one another.

The fact is that while everybody agrees that having a Digital Platform is the way to go no one seems to agree on a single platform. It is as if in the smartphone domain rather than having 2-3 de facto platforms (Android and IOS having the lion's share) we had millions of platforms. Immediately the potential market for application developers would become fragmented and no longer appealing.

To avoid this fragmentation, the European Commission invested a significant amount of money, over 300 M€, to develop a common, open platform called FIWARE that could be used in several application areas, smart cities being the most obvious one. As in any cooperative project, the result was a set of compromises that although valuable in a scientific perspective required a focused approach to create an industry savvy product.

The FIWARE Foundation[272] consists of over 50 members[273] (at the end of 2018), and it is unclear at this point if in the end it will be attractive to cities around the world. The numbers are good: over 100 cities have expressed interest in using the platform, over 1,000 startups are now developing services for that platform, and there is a very intensive effort by the Foundation to keep growing and spreading the gospel through a variety of events.

The EIT Digital is supporting the effort in making the FIWARE Platform a reality throughout Europe through one of its innovation activities, CEDUS[274].

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[272] https://www.fiware.org
[273] https://www.fiware.org/about-us/
[274] http://www.cedus.eu

At the core of all digital platforms is an Open Data Framework, and for each application domain an ontology is required. This part is likely to be standardized, and the evolution of artificial intelligence holds promise to implement these standards at a semantic level.

Digital cities may be a crucial turning point for digital platforms. The application domain and the specific requirements are so broad that standards restricted to the syntax of the data ontology may not be sufficient. Standardization activities, like the ones carried out at ITU SG 20[275] are surely important (they also define a common metrics) but they may not be sufficient. Consideration of the semantic layer may lead to a solution that can aggregate most of the players.

Digital Transformation – A Digital Platform for Industry 4.0

After considering the abundance of Digital Platforms for Smart Cities (and the need to converge on a limited subset through the adoption of a semantic layer), this section considers the Digital Transformation of the whole production (including supply, distribution and operation chain), what is called –mostly in Europe- Industry 4.0.

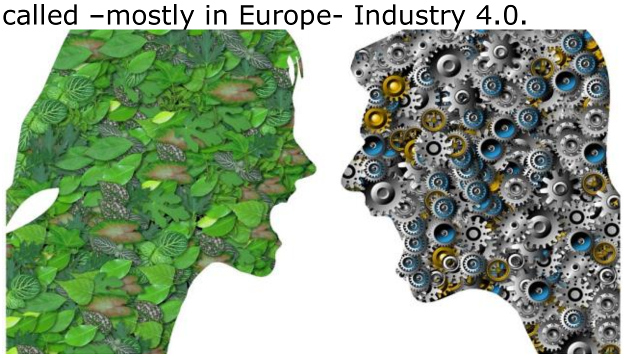

Figure 84. An image representing the clash between a green environment and the needs of industry and market leading to its exploitation. The Finnish view of integrating Industry 4.0 with the Circular Economy aims at transforming this clash into a synergistic endeavor made possible by rethinking the whole life cycle. Image credit: Tulevaisuuden tutkimuskeskuksen blog

The landscape is still fragmented, but it is different from the one of the digital transformation of cites because in Industry 4.0 the major players are industries, mostly private, operating with a different set of constraints, namely a strong quarterly results.

The landscape is fragmented but one can attempt a classification of approaches in terms of Digital Platforms in four trends:

- End-to-end platforms
- Cloud based platforms
- Connectivity platforms
- Data platforms

End-to-end platforms are looking at the whole set of processes, providing an integrated set of hardware, software, security functions, connectivity fabric and management tools to sustain a new value chain. Their strength is the potential effectiveness since everything is right sized and fits nicely with everything else. Their weakest point is … the same! An industry would require a complete repositioning that is difficult to manage in the transition phase. A government institution, designing a long term vision and plan may well adopt this approach but a single company is unlikely to buy it. Initiatives like the ones in Finland and Germany may be set in this category.

Finland has taken a holistic view considering Industry 4.0 and the circular economy[276] (the economy of embedded recycling) as a single goal that can be achieved only by reconsidering whole value chains and related processes. This requires significant investment in research and the Finnish Government is betting on it.

Germany is leveraging its strong position of industrial enabler, (it is usually said, with some simplification but it makes the point, that Germany creates the tools China uses in manufacturing products that the US market consumes) and its government has set the goal of transitioning its

[275] https://www.itu.int/en/ITU-T/ssc/Pages/default.aspx
[276] https://ffrc.wordpress.com/2018/09/12/bridging-industry-4-0-and-circular-economy/

industrial capability to leverage cyberspace. The plan is Industrie 4.0[277] and it is targeting 2020 (which may turn out to be an intermediate step towards a full Digital Transformation).

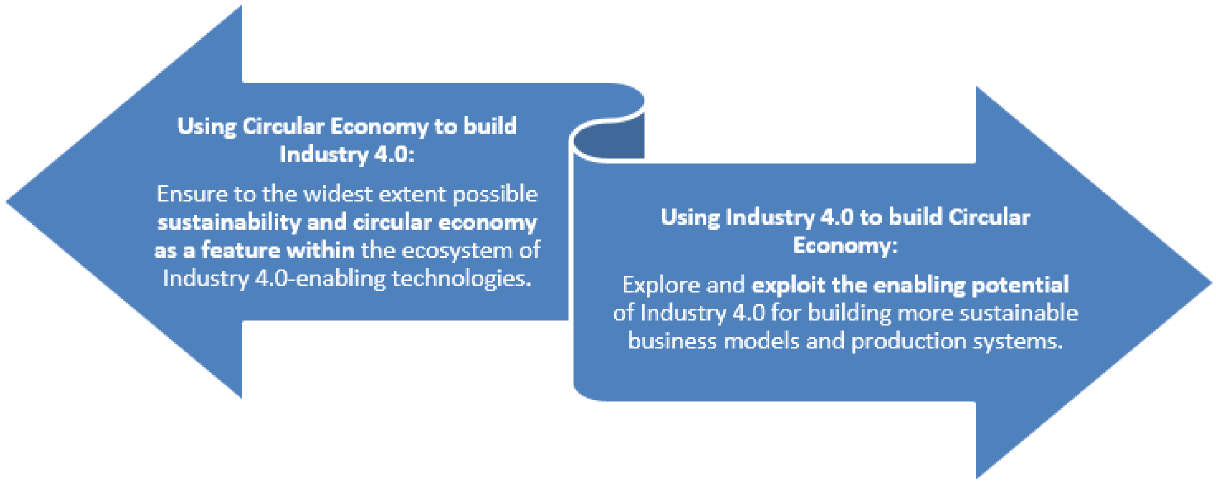

Figure 85. Finland National Initiative on Digital Industry stems from the vision of making the future manufacturing in synch with the Circular Economy. Image credit: Aalto University

Both cases, used as slightly different examples, are based on the same approach: a rethinking of the whole manufacturing value chain. They are Government Initiatives that use a variety of levers, from investment in innovation to research coordination at universities to fiscal support for industries buying into the transformation. They include the layout of advanced low latency communications infrastructures (under the 5G banner), the orchestrated deployment of IoT, the creation of a (walled) Open Data Framework and so on. The main issue is setting up an effective orchestration capability, attracting industry and creating a de facto standard.

277 https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Industrie%204.0.pdf

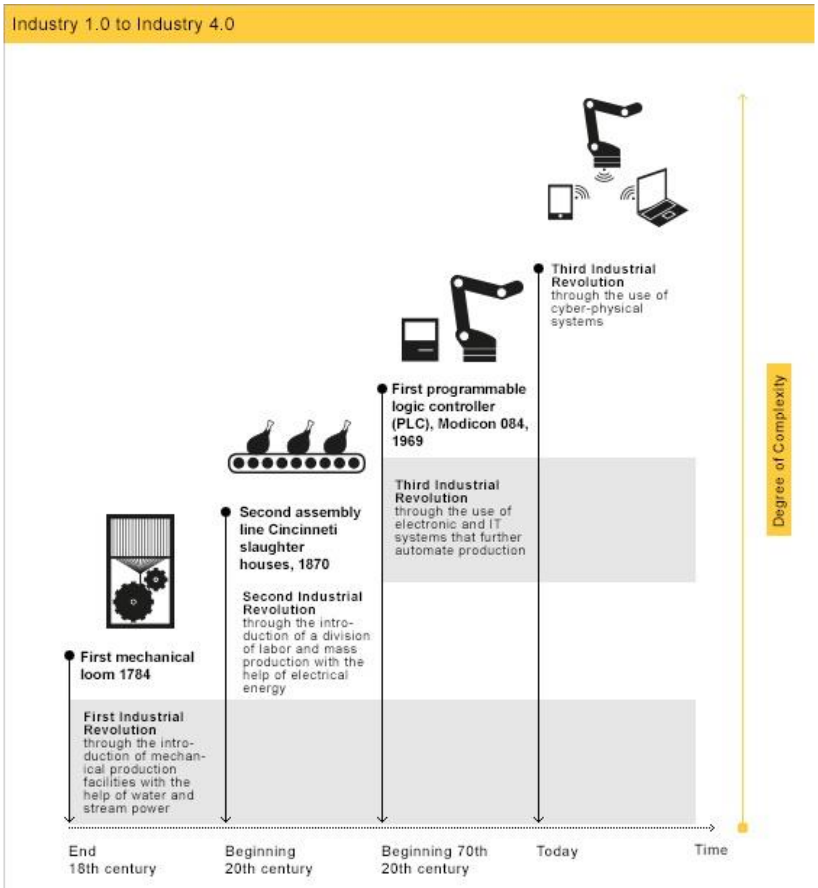

Figure 86. The German Government sees the transition to a Digital Industry has a further evolutionary step of manufacturing. Image credit: GTA

The new EIT Manufacturing[278] was set up exactly in this spirit. The activities of EIT Digital in the Digital Industry area[279], on the contrary, are much more focused and do not pursue this global approach.

Although an end-to-end approach is clearly a theoretically better approach to creating a Digital Industry, its practicality remains debatable and it can only be pursued in a top down approach with the government in the lead.

A much smoother transition to an Industry 4.0 can be pursued by leveraging the clouds that several industrial players are already using. There are clouds that have been and are used as a way to obtain flexible, on demand processing and storage capabilities (basically lowering the total ownership cost), and there are smaller private clouds that companies are using to share data along the supply, distribution chain and that are now progressively used to monitor the usage of their products.

By integrating the various existing clouds, already embedded in the manufacturing processes (extending northbound to the supply chains and southbound to the distribution chains and beyond), a major company may take the lead steering the Digital Transformation from the hub (the company) out (involving its suppliers and distributors). This has been happening in aeronautic manufacturing where Boeing and Airbus are very strong players that can pull their supply and distribution chain in their desired direction.

Other players, like General Electric, delivering high value products (like turbines in the case of General Electric. Notice that the cost of the engines for a 747 or A380 is about one fifth of the cost of the whole plane) can also have the power to steer the supply and delivery chain in their desired direction, and indeed General Electric has its own (private) cloud to keep track of its turbines.

Of course, some industries are already operating in cyberspace (i.e., they are dealing with services that are mostly bit based), and companies operating in this space are already using the cloud as their "manufacturing" infrastructure.

Amazon Web Services is now being offered a digital platform and there are specific guidelines[280] in place to enable the Digital Transformation to these Services.

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[278] https://eit.europa.eu/eit-community/eit-manufacturing
[279] https://www.eitdigital.eu/innovation-entrepreneurship/digital-industry/
[280] https://aws.amazon.com/government-education/digital-transformation/

Azure is also offering specific services to manufacturing[281] and support to the Digital Transformation (as well as, obviously, support to all industries already operating part of their business in cyberspace).

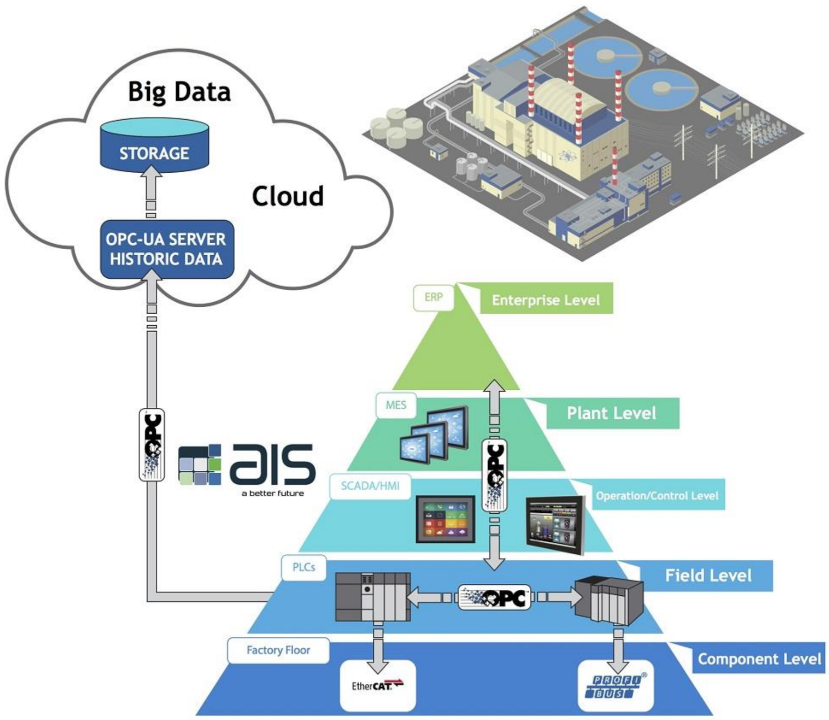

Figure 87. Cloud based solutions, including the major manufacturing protocol standards and integrating IoT and PC industry grade devices, are now becoming available. In the graphic the architecture proposed by the American Industrial SystemsInc. Image credit: AIC

System integrators make use of these large clouds and support companies in the Digital Transformation by integrating local clouds and streamlining all processes to operate in the new environment. The Digital Transformation will make significant use of these clouds at the edges and connection providers, like Ericsson, are scrambling to integrate distributed clouds (or fog or edge computing) into their connectivity offer.

Indeed, this view of cloud at the edges represents the transition point from the cloud approach to the connectivity approach. Companies like Cisco are pushing for this approach[282].

As a matter of fact, the Digital Transformation is flattening hierarchies: all components in a value chain are potentially interconnected with all the others (once industries rely on bits, accessing them in parallel and from any point of the globe is no longer an issue). Interconnection takes place among organizations, enterprises, suppliers, manufacturers, providers and users, among products and products components (IoT), and in the form of feature interoperability among services. Interconnectivity is the name of the game in Industry 4.0, and it is made possible, conceptually by the shift from atoms to bits and practically by the availability of pervasive connectivity infrastructures.

We have continually said that communications infrastructures are just killing distance, everything is here and now, but that is true only at macro level. At the level of robots there is still the perception of difference between local parties and distant ones: this is called latency. Some of this latency is connected to the speed of light (actually the propagation of the electromagnetic field) which cannot be overcome (although by moving manufacturing component in a cloud one could physically co-locate some activities): controlling a robot in London from Turin implies a delay of 2.7 milliseconds per direction so some 5 milliseconds if you need to make decisions based on a response. The only way around this would be to virtualize the robot and its controller and operate them together in close proximity in a cloud, but this can be made only if you can virtualize both, and that is seldom the case.

[281] https://azure.microsoft.com/en-us/industries/discrete-manufacturing/
[282] https://www.cisco.com/c/en/us/solutions/enterprise-networks/intelligent-edge.html

In practice, however, controlling a robot in London from Turin using a plain vanilla telecommunications network is likely to involve a delay (latency) of some hundreds of milliseconds. A radio system like LTE (4G) may on average add a latency between 50 to 100 ms. A properly designed 5G network may significantly cut this latency below 50ms. Because of this, and the expected penetration of 5G in the long run, many consider it as the ideal communication infrastructure for Industry 4.0.

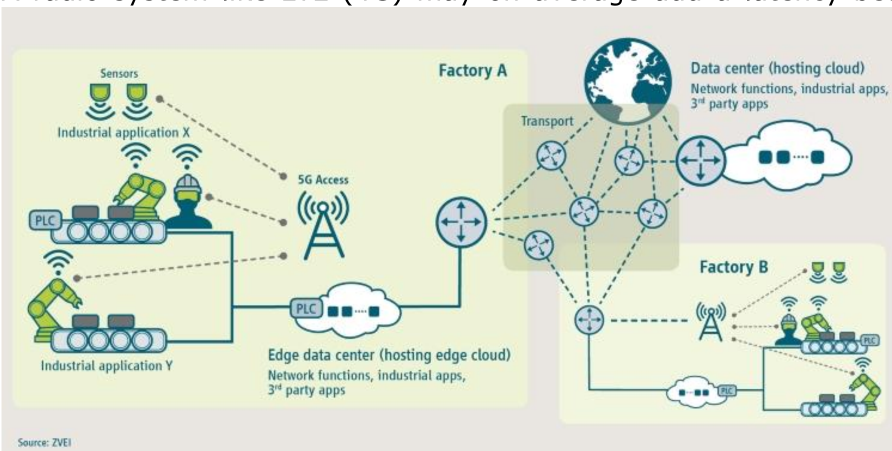

Figure 88. 5G supports communication with unprecedented reliability and very low latencies, as well as massive IoT connectivity. In the graphic the various types of 5G access points relevant to Industry 4.0. Image credit: 5G ACIA

Many CEOs and experts in the space believe 5G will be a welcome bonus to manufacturing, once it is deployed. In the meantime, industry is making the most out of 4G and even 3G.
Nevertheless, it makes sense for Telecom Operators to ride the (future) wave of 5G boasting of its low latency that indeed in some niches could make a difference.

5G is coming with a different network architecture where clouds at the edges become an integral component. In this sense a connectivity infrastructure based on an integration of edge computing, multi access capability and micro cells delivering high throughput (5G) will be a most interesting platform for Industry 4.0.

However, a pure communications infrastructure, although highly performant and pervasive is not sufficient to be a digital platform enabling Industry 4.0. As mentioned previously, it must include the cloud part, which in turns makes sense only if you are including data.

In a certain sense data come for free to Industry 4.0. Over the last decade computers aided tools have become the screwdrivers and pliers of the past in manufacturing. Bits are pervasive in product design, prototyping, digital lathe, robots. Additionally, bits are a crucial part of inventory, shipping, quality control, invoicing, payment collection, features delivery, feature updates through new releases, and more. Bits have become an integral part of the manufacturing value chain.

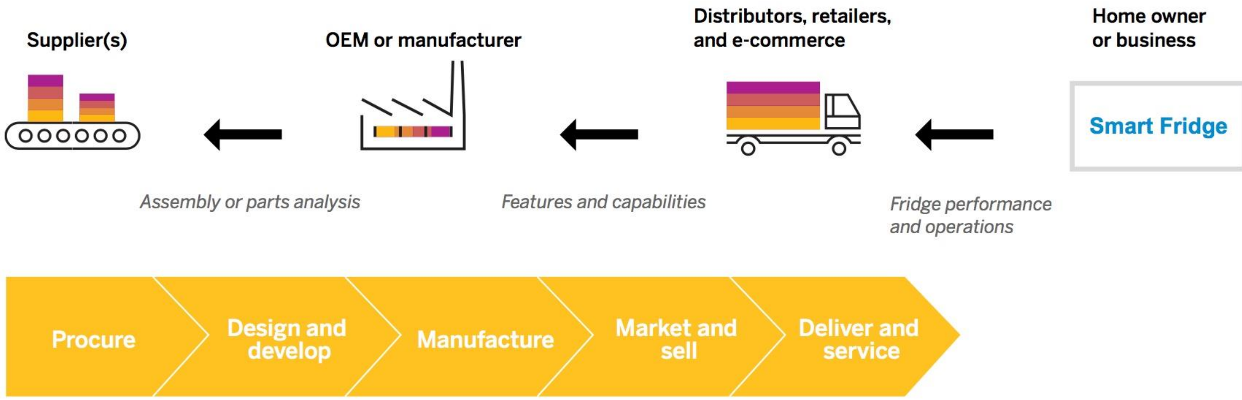

Figure 89. The basic concept of Industry 4.0 is a flattening out of the Value Chain with every player becoming able (potentially) to interact with all the others. This is achieved through the sharing of data and this is why many feel that the digital platform should be focusing on data. Image credit: SAP

In some cases, like when dealing with software creation, bits are almost 100% of the raw material needed. There are computers and clouds to run them on but you can take those for granted, and the packaging of bits is fading away, since by far applications are now downloaded directly from the company "cloud" or from some online store.

At the same time the pervasive use of bits over the last decades has happened through waves of digitization. This has resulted in landscape that is not homogeneous, where different tools are not talking to one another and where representations differ in different parts of the value chain and throughout the manufacturing processes. The number of data records and databases has ballooned to the point that one of the big issues facing companies today is achieving interoperability among the different components.

In Industry 4.0 the issue gets even more difficult to manage since the variety of systems that would need to interoperate are no longer within a single company but are owned and operated by different companies.

A further component that has become more and more relevant is the growth of sensors as data generators. IoT, with a continually increasing number of sensors, are amazing data generators but at the same time they cover a very broad spectrum with thousands of ways to generate data (in terms of frequency, volume, characteristics, etc.). People incorrectly talk of IoT as if they were a single "thing", an entity clustering with common characteristics. The variety of the IoT and the different manufacturing and operation landscape (including in this latter the communications paradigms involved) makes the term IoT basically useless if we want to leverage the data they generate (or the ones used in their operation). As a corollary, when someone claims that 5G is great for IoT one should be aware that there is not such a thing as generalized IoT that share common communications requirements such that a single communication paradigm can fit them all.

Companies like SAP are looking at providing integration frameworks[283] (and related tools) to manage this diversity. In case of SAP they are offering their B1iF, Business One Integration Framework, pointing out that Industry 4.0 is about meeting and leveraging four main challenges:

1. Data volume, processing and connectivity

[283] http://blog.asug.com/b1/industry-4.0-and-sap-business-one-how-your-business-can-prepare-for-the-next-industrial-revolution

2. Exploiting data beyond manufacturing, using those same data through analytics and AI for business
3. Exploiting data to improve human machine interaction (haptic, augmented reality, virtual reality)
4. Effectively linking bits to atoms

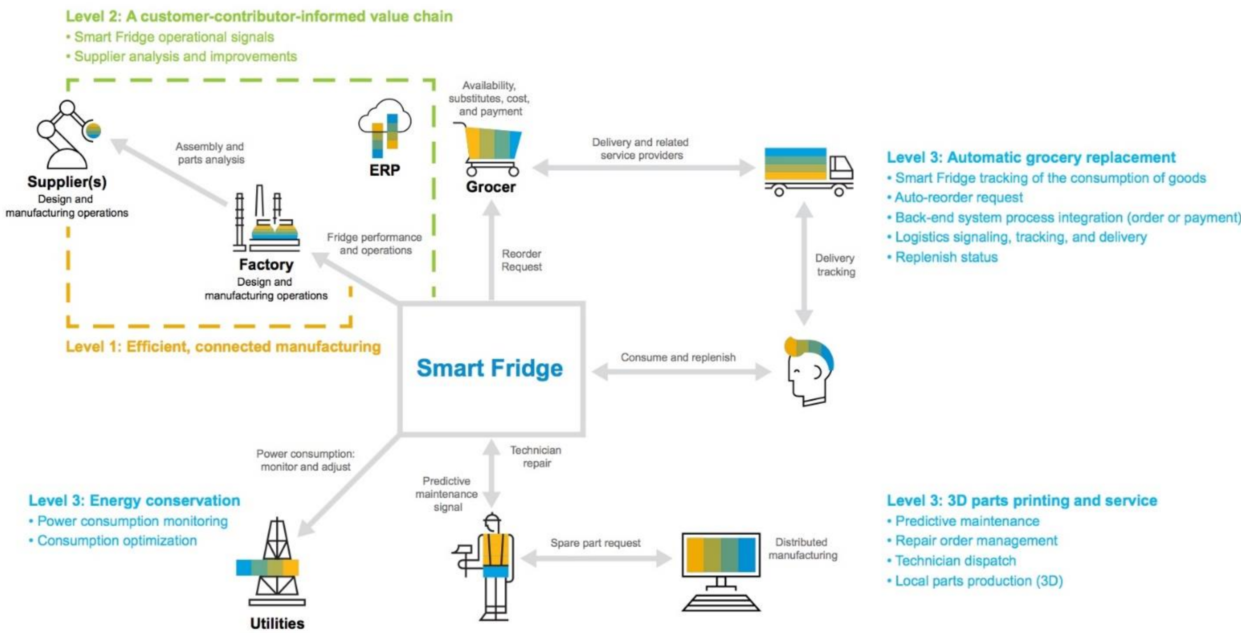

Figure 90. The flattening of the Value Chain in the case of Smart Fridge[28]. Notice the role of IoT that sensing at the customer premises the usage and providing data upstream for analyses. Data analytics, integrating data from thousands of fridges in operation, provide hints to operation problems, allows the provisioning of maintenance services and helps in design of future products. These data percolate throughout the Value Chain. Suppliers can be alerted of issues in the component they provide and continuous re-design is enabled. Image credit: SAP

As noted, any digital platform needs to acquire a strong footprint and SAP is leveraging their presence in the manufacturing industry with their ERP solutions. They are building on those and leveraging the effort they made on creating HANA[284], the platform designed to support IoT in industrial environments. They are actively socializing the value of B1iF[285] by creating an open environment allowing third parties to develop applications and using a common data ontology as the aggregation point. The approach is very similar to the one presented when discussing an institutional driven digital platform, particularly the Province of Trento. Both are using data as their starting point. In case of SAP there is a much stronger integration with the cloud and with several tools that SAP is providing (based on their existing portfolio on ERP applications, well known by the industry).

Digital Transformation – Semantic based Digital Platform

Of the four approaches to Digital Platform for the Digital Transformation of Manufacturing, Industry 4.0, the one based on data is the most convincing. The end-to-end approach is adequate but probably over ambitious and it does not take legacy into account. The communication based approach is just a component that would not help unless there is a parallel shift in a data based approach. The cloud solution, similarly to the communications, is sort of given, is the screwdriver

[284] https://www.sap.com/products/iot-platform-cloud.html
[285] https://blogs.sap.com/2018/08/14/integration-framework-for-sap-business-one-b1if-central-blog/

that you need but what is really important is understanding how to use the screwdriver, where are the screws and which one need to be turned (the screws, obviously are the data).

At the same time, there is the huge, overwhelming variety of data, of ontologies and of structure of existing data. Each of them has a purpose, and investment have been put in creating those structures and relative applications. Although this might be considered a "sunk" investment it creates a huge inertia making any change difficult.

This consideration applies beyond Digital Platform for Industry 4.0; it more generally applies to most verticals, from health care to smart cities, from logistics to construction. The reason for discussing Digital Cities and Industry 4.0 was to show how different verticals may have different requirements and constraints (i.e. Smart Cities are driven by public investment, Industry 4.0 by private investment) but also to show the similarities and the unifying point is surely "data". And, as mentioned, data are heterogeneous, tied to legacy systems, and have issues related to privacy, ownership, reliability.

How can we move forward keeping data at the core of evolution, yet taking into account their variety and the issues related to data?

It makes sense, when planning for the next step to look further down the lane, to understand the direction both in terms of where we would like to go as well as in terms of what directions are enabled by technology evolution (of course taking into account societal and economic implications). This is what the IEEE Future Directions Committee (FDC) is really doing, taking a longer view span, identifying the desirable horizons, and together with IEEE OUs taking the first steps in the desirable direction.

As an example: what is going to happen, or become possible, after Industry 4.0?

SAP have their own ideas and they are surely worth considering. According to SAP (refer to the following graphic), by leveraging the results of Industry 4.0 that make production more efficient from the market viewpoint by including the users in the value chain (getting direct feedback from product/service use through IoT and a flattened value chain), it will be possible to evolve the products/services much more rapidly (and perhaps charging the customer for the evolution). This can be done by dividing the atoms from the bits in the product. The product becomes a combination of hardware with a long life span and software having a much shorter life span. The hardware part may be sold using conventional business models, while the software part may be sold as a service (paying for each subsequent release, paying a subscription fee, paying an on-demand feature evolution, for examples). This will foster an "Incremental Innovation" with a direct customer involvement (empathy).

The subsequent phase fully blurs the boundary between customers and producers leading to an ecosystem driven by innovation (being hinted by the EIT Digital 2020-2022 Strategic Innovation Agenda[286]) which will cause a significant disruption in the market place since the ecosystem takes the lead, at the expense of today's incumbent players (remember the loss of value implied in the shift from atoms to bits). That is why SAP names this phase Disruptive Innovation.

[286] https://www.eitdigital.eu/enhancing-the-global-impact-of-european-innovation/

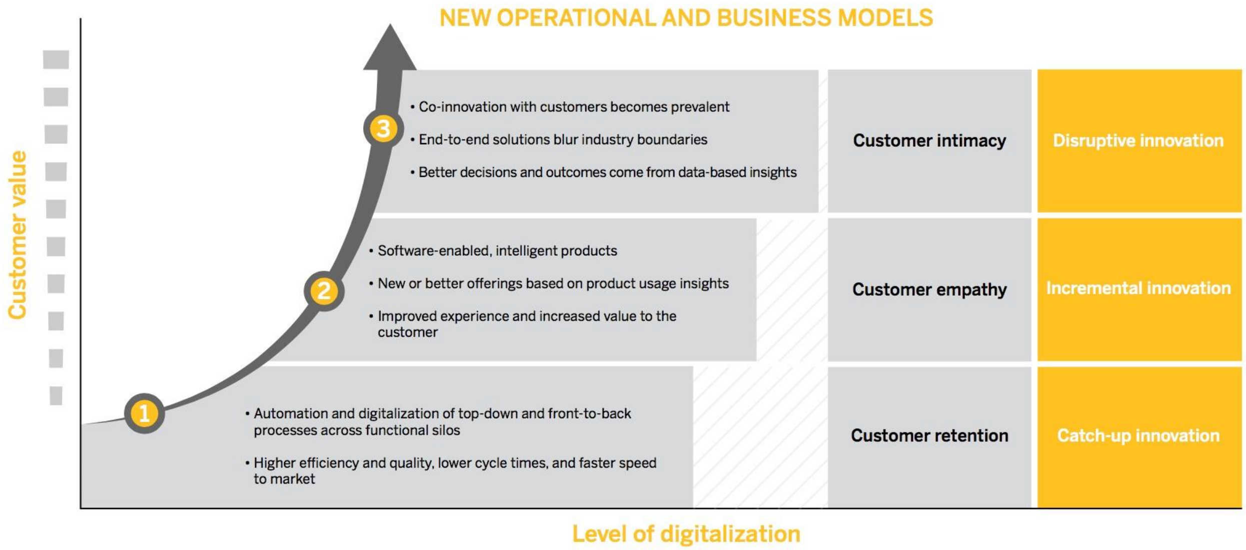

Figure 91. Two phases naturally following Industry 4.0. Industry 4.0 enables a more efficient production in terms of "market efficiency" (the previous industrial phases have basically improved the efficiency from the point of view of the manufacturing industry, increasing in the subsequent phases the efficiency of the supply and distribution chains). Image credit: SAP

How can we take into consideration the diversity in data we have today and move towards an ecosystem where every player can potentially interact, make use, and leverage the data? The answer lies in semantics. By using semantics, the issues related to syntax can be avoided (which does not mean you can get rid of syntax, however), and by operating on semantics alone, different players can interact with one another. Of course semantics need to be extracted from syntax, and this requires in the easiest case some ontology, but in most cases it requires intelligence to correlate data into a context (which means with other data, with a time line, with a purpose). For this we have artificial intelligence in its various forms, with deep learning and machine learning being the crucial ones.

What do you actually get when you start operating on data based on semantics (let me re-iterate: semantics depending on the data-context relation)? You get Digital Twins! Indeed, Digital Twins are semantic representations describing an object, its behavior, its history, and its possible relationships with the context in which it can operate.

Companies like General Electric have started to create and use Digital Twins[287] as a springboard for their Digital Transformation, and the Digital Platforms they have created are based on Digital Twin interactions.

Digital Twins are going to be the future of Digital Platforms, the strong enabler for the Digital Transformation, and their implementation will result in a successful Digital Transformation.

[287] https://www.ge.com/digital/applications/digital-twin

ACRONYMS

4AMLD/4MLD - 4th EU (Anti) Money Laundering Directive
5G – Fifth wireless generation
AA – Autonomous Agents
AGI – Artificial General Intelligence
AGV – Automated Guided Vehicles
AI – Artificial Intelligence
APCRDA - Andhra Pradesh Capital Regional Development Authority
AR – Augmented Reality
ASI - Artificial Superintelligence
AV – Autonomous Vehicle
BCI – Brain Computer Interface
CAD – Computer Aided Design
CAGR – Compound Annual Growth Rate
CAPEX - Capital Expenses
Cas9 – CRISPR associated protein 9
CCTV - Closed-Circuit Television
CD – Compact Disk
CEF - Connecting Europe Facility regulation
CEO – Chief Executive Officer
CGC - Cyber Grand Challenge
CO2 – Carbon Dioxide
CPS – Cyber Physical Systems
CRISPR - Clustered Regularly Interspaced Short Palindromic Repeats
CT – Computer Tomography
DBS – Deep Brain Stimulation
DED – Direct Energy Deposition
DFTG - Digital Framework Task Group
DoS - Denial-of-Service
DPC - Digital Plant Companion
DL – Deep Learning
DTI – Digital Twin Instance
DTP - Digital Twin Prototype
EBM - Electron Beam Melting
EHR - Electronic Health Record
EMR - Electronic Medical Record
ERP – Enterprise Resource Planning
ETL - Extract-Transform-Load
EU – European Union
FAA – Federal Aviation Administration
fMRI – functional Magnetic Resonance Imaging
GDPR - General Data Protection Regulation
GPS – Global Positioning System
HANA - High-performance ANalytic Appliance
her4CR - Electronic Health Record for Clinical Research
KaaS – Knowledge as a Service
KYC/KYB – Know Your Customer/Know Your Business
IFRS - International Financial Reporting Standard
IoT – Internet of Things
IR – Infrared
IT – Information Technology
LED – Light Emitting Diode

LIDAR – LIght Detection And Ranging
LoRaWAN – Long Range Wide Area Network
LPWAN – Low Power Wide Area Network
LTE – Long Term Evolution, i.e. 4G
M2M – Machine to Machine
MiFIDII/MiFIDR - Markets in Financial Instruments Directive
ML – Machine Learning
MMI – Mind Machine Interface
MOOCs - Massive Open Online Courses
MR – Mixed Reality
NB – Narrow Band
NFC – Near Field Communications
NFV - Network Function Virtualization
ODB – On Board Diagnostics
OLAP - On-line Analytical Processing
OLTP - On-Line Transactional Processing
OPEX - Operating Expenses
OS – Operating System
OT – Operational Technology
PDF – Portable Document Format
PLC – Programmable Logic Controllers
PSD2 - Second Payment Services Directive
ROCE – Return On Capital Employed
SAS – Symbiotic Autonomous Systems
SDN - Software Defined Network/Networking
SLM - Selective Laser Melting
SLS - Selective Laser Sintering
SME - Small and Medium Enterprises
STREAM - Science, Technology, Reading, Engineering, Arts and Mathematics
TAM – Total Available Market
TEN-T - Trans-European Network
TCO – Total Cost of Ownership
UAM - Ultrasound Additive Manufacturing
URL – Uniform Resource Locator
USB – Universal Serial Bus
USD – United States Dollar
UV – UltraViolet (light)
VR – Virtual Reality
WGS – Whole Genome Sequence
WiFi – Wireless Fidelity
XAI – Explainable Artificial Intelligence
XR – Extended Reality, includes Virtual, Augmented and Mixed Reality