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Post Pandemic Megatrends 2021

A Digital Reality Initiative eBook

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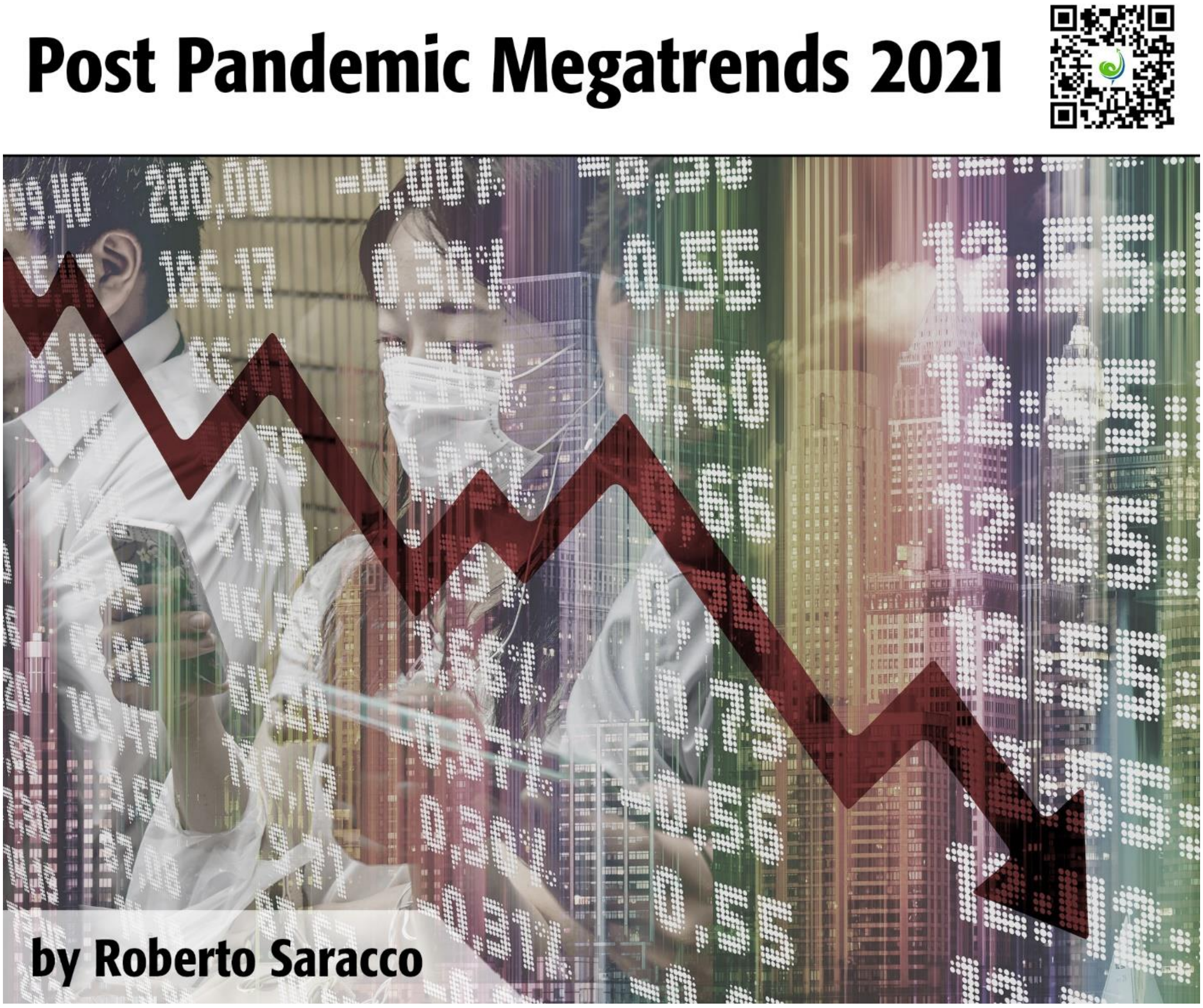

IEEE DigitalReality

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1. Introduction

One of the goals of the Digital Reality Initiative is to monitor and foster the Digital Transformation, a major factor in pushing several activities into the cyberspace maintaining a seamless continuum between the physical space and the cyberspace. This is affecting much more than the way we operate, do business and access services: it is changing our perception of reality, blurring the dividing line between physical and cyber.
The pandemic and the related countermeasures have accelerated the use of the cyberspace, most of the time as a way to survive the new landscape and constraints. The big question for companies is to understand what will happen once the pandemic will be over. Will our life go back to the pre-pandemic "normal" or will there be a new normal? Also, what will be the longer term effect of the changes induced by the pandemic?
This eBook is addressing these questions and it is using two main sources of information:

- the report[1] released by the Future Today Institute on post-pandemic megatrends
- the work carried out by the Industry Advisory Board of the Future Direction Committee through hundreds of interviews and interactions with hundreds of companies.

The Future Today Institute has just released its annual analyses of macro trends. This year it is a special release in that the pandemic has created a disruption in our lives and in business. So it is particularly interesting to take a look at their analyses and foresight.

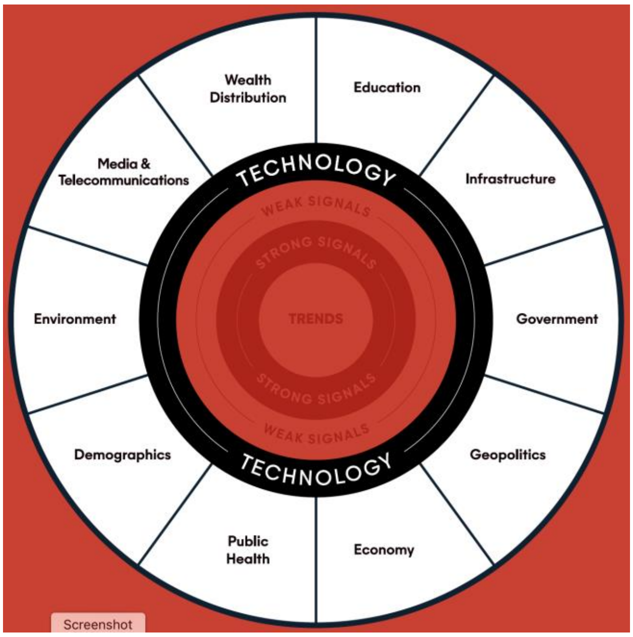

Fig. 1. The 11 macro-forces that are shaping our future, 10 on the outer ring, the 11th, technology, underpinning all of them. Image credit: Future Today Institute

As shown in figure 1 they are considering 11 "forces" that condition/steer the evolution. Also notice that no single entity has the control on these forces in today's world. In fact, each of them affects, and is affected by, the whole planet and even the big powers can only control/steer a small part of it. Take, as an example, telecommunications infrastructures. There is no single entity that controls (nor can control) the overall connectivity. This has several effects:

- upgrades to an infrastructure by a player steers (forces) other players operating in the market to respond;
- the delivery of a service that is tied to a specific infrastructure, like the offering of an edge cloud, can only benefit the small constituency of that Operator, whilst a cloud service provided "over" the telecom infrastructure can potentially benefit everybody. This is a big issue for Telecom

[1] https://futuretodayinstitute.com/trends/

Operators that are self limiting their market! In other words, in order to reach the whole market they should operate as “over the top”.

Besides, these forces are mutually influencing one another. This means that we have to deal with a complex system where it is not possible to segment one part and look at it independently of the others.

The common denominator that is affecting everything is technology and technology is affected by all the other forces in its evolution since they can steer investment and in turns this provides fuel to innovation and stimulates progress in specific areas.

The FTI report starts with an interesting presentation of the methodology they have adopted: this provides several insights on what is important in identifying scenarios and it is a value in itself, particularly interesting if you are involved in foresight.

I also found interesting their characterisation of scenarios in terms of time horizon:

- up to five years: look at what is ***probable***
- from five to ten years: look at what could be ***plausible***
- beyond ten years: consider what is ***possible***.

The near term horizon can be used for tactical decision, the medium term for creating a strategic vision and the long term to consider system wide changes and their impact on long term planning. If you are interested in learning more on foresight methods, specifically applied to the Digital Transformation you may want to look at the IEEE-EIT Digital DX course[2].

What is important to notice, and this is the specific value of this year FTI’s report, is that a disruption can change the landscape and make actual scenarios that were considered possible in a 10 year time frame. Of course, their actualisation cannot exploit conditions that would become available in the longer time frame but still they are becoming reality by “making-do” of what is available today. An obvious example is the scenario of a strong uptake of remote working that was seen as possible in the next decade and that all of a sudden has become real.

In the following I will consider expected Megatrends taking into account the impact of the pandemic.

2. Pervasive Artificial Intelligence

Artificial Intelligence is bound to be the underlying force that will shape this decade and will change the landscape in the next one:

- autonomous vehicles
- personalised and contextualised web-spaces, aka Spatial Web
- personalised healthcare
- collaborative/symbiotic human machine landscape
- shared knowledge

AI has been able to match, and in a few situations to exceed, human capabilities. The SuperGLUE[3] benchmark has been exceeded in January 2021 by MS AI[4] for Natural Language Understanding.

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[2] https://professionalschool.eitdigital.eu/professional-courses/

[3] https://super.gluebenchmark.com/

[4] https://www.microsoft.com/en-us/research/blog/microsoft-deberta-surpasses-human-performance-on-the-superglue-benchmark/

Overall the AI market is expected to keep growing at a 42% CAGR throughout most of this decade.
AI is already a widespread reality, thanks to the growing amount of data and data streams (correlation is a key enabler) and to the continuous increase in processing capacity and availability. Additionally, the growing availability of APIs for AI[5] and of low-code software designed to foster the creation and application of AI with minimal amount of coding needed is making AI affordable to a variety of business. In synch with the easier and more affordable trend in AI software development we are seeing an increasing effort to develop chips to support AI at hardware level and it is foreseen that more and more these chips will become available at the edges (in the last decade specialised chips to support AI, like Synapse, Cerebra and NVIDIA were targeting the servers in the Cloud and in the big data centres). This means that AI in this decade will move both as Machine Learning and as application much closer to the points where data are created (smart IoT clusters).
The Digital Twins are becoming smarter, by embedding AI that operates on their local data and correlates them to contextual data. A strong evolution is expected during this decade providing a further impulse to embedded AI exploiting local data. An interesting point made in the FTI report is the expectation of a growing use of “Deep Twins” in the Operating Room (for surgery). The Deep Twins are a variation of Digital Twins able to mirror a patient from the point of view of a surgeon. The surgeon is using, through simulation software, also AI based, the Deep Twin to perform a virtual surgery and once she has found a satisfactory procedure she will apply that procedure to the real patient. The Deep Twin is present throughout the surgery and is being used in case a complication arises to allow an on-the-flight simulation to evaluate alternative procedures.
AI has been applied in the healthcare space in the design of new drugs. The Covid-19 has both accelerated the effort to exploit AI for finding vaccines (and symptomatic cure) and the results proved that indeed AI can accelerate the design and testing of vaccine. Having been able to move from need to market in just one year is an unprecedented success that is largely based on AI. This is going to accelerate the application of AI to healthcare.
The report provides many more insight on the evolution of AI in various sectors, on the research trends and on the societal aspects. The overall message is that AI will both grow in performances and in application with a shift towards the edges (decentralised AI) and this is possibly the novelty expected in this decade.
What I see at the core of this AI percolation in any vertical and of its mass market penetration is the rise of ultra-smart phones. These phones will have:

- huge storage capacity – up to 128 TB
- huge processing capacity
- neuromorphic embedded processing (SoC)
- full network node capability (6G)

[5] https://www.programmableweb.com/news/14-top-artificial-intelligence-apis/brief/2019/09/29

- local AI contributing to federated AI

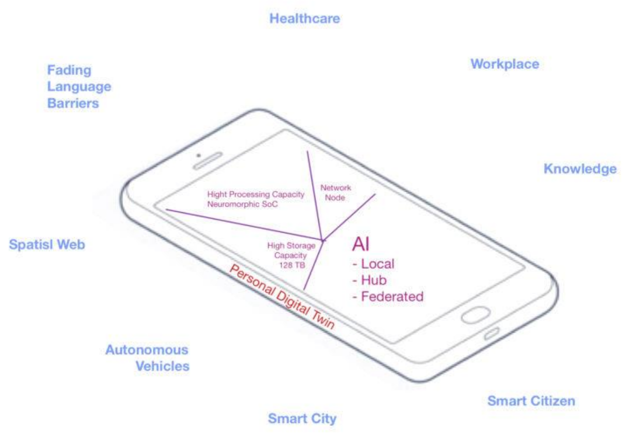

Figure 2. That Artificial Intelligence will become ubiquitous in this decade it is a given. The question mark is on the form that it will take, how it will transform the landscape and what might be the sources of AI, Personally, I bet the smartphone will be a key player.

These (expected) characteristics are the needed ingredients for supporting a mass market distribution of AI and at the same time are creating a gigantic platform for applications. As I indicated in the drawing in figure 2, I see the emergence of super smart phones that will encapsulate our personal digital twin. This PDT is the aggregator of data, both the ones created through the smartphone and the ones made available by other personal devices (like wearables, laptops, tablets…), and the processing point of data to create intelligence. This is made possible by the ever increasing processing and storage capabilities of the smartphone -including the use of SoC, System on Chip, embedding neuromorphic architectures to support AI- and the participation of these smartphones to a fabric of communications at the edges (look at this in terms of a “fog”, tiny local interconnected clouds). This fabric connects local points of intelligence, the ultra-smart phones, into a federated architecture that further creates an emerging intelligence that feeds back onto each ultra smartphone. Additionally, each of this ultra-smartphone becomes a local hub connecting other intelligence points, like smart vehicles, smart appliances, smart environment….

In short, my vision for AI in this decade foresees the smartphone as a major component that will accelerate the growth of AI through decentralisation and federation.

A lot of research is needed but I see some clear signs pointing in this direction.

AI is the engine enabling progress in a number of related technology areas, as discussed in the following.

2.1 Digital Signature

A technology area boosted by AI progress is the one of Scoring and Recognition. It is interesting to notice that the starting statement in the FTI’s report discussing this area states:

Anonymity is dead

Indeed, in spite of all the talks about privacy, the reality is that each one of us has, most of the time unwittingly, a digital identity in the cyberspace that can be matched in various ways to our physical persona. There may, actually, be several digital identities for each of us. The chip on my passport has biometric information that can be used to check my identity at an automated boarding gate at the airport or at an international border, my fingerprints are recognised by my smartphone and possibly by my car lock, my face is recognised to enter a protected area at the office, Alexa recognises my voice… Are these separate instances of identity, are the data used in each instance confined in the specific application domain? I, for one, can trust that the fingertips identity recognition on my car door keeps the data to itself, locally, and that it may be unlikely to be hacked, I have the same trust about my smartphone keeping my biometric data locally but I am a bit less confident that there won't be any hacking attempt on those data and I am definitely less sure about the way Alexa (and the likes) are managing my identity data. In the end I am trading my confidence versus my convenience of using those devices/apps/services.

As noted, there are several ways of creating, and then checking, the identity of a person and, once you have that, someone can start storing (tracking) information on your whereabouts, learn about your behaviour, make judgement and pick up judgment from others, in other words give you a "score". This is already happening (in on line commerce, in social networks, in social relations in China…) and it is going to become the norm by the end of this decade. Hence the reason why identity recognition is associated with the scoring part…. and they both may be convenient and frightening.

Recognition technology is bound to evolve rapidly, actually the evolution will be faster than the regulatory effort to provide safeguards (hence, I guess, the tagline "Anonymity is dead").

Figure 3. Facial recognition at the Hong Kong Airport. The image picked up by the videocamera at the gate is matched with the one stored in the passport chip to check the person's identity. Image credit: Hong Kong Airport Authority

Facial recognition, as an example, has already reached a very high sophistication and, most importantly, it has become affordable and practical (see figure 3). China has experimented[6] (is using?) a 500 Mpixel camera that is able to pick up thousands of faces (at a stadium, at a city crossing…) with sufficient clarity, even in low light condition, to allow a software to perform facial recognition for thousands of people at a time. If only a few years ago facial recognition had a bias for certain races (because of the images used to train the system) now it can recognise any face, even a partial face. It can even recognise cartoon characters in movies and pets' faces. We can only expect it to become even more effective in the coming years.

It is not just facial recognition. Voice recognition has made significant progress (and the Covid-19 further stimulated studies on identifying voice patterns that could be associated with infection) to the point of recognising an accent thus pinpointing the origin of a person, even if that person is speaking a foreign language, as well as to detect emotion. This very same applications able to detect subtle nuances in voices are also able to duplicate them, thus fuelling deep fake issues.

By coupling different sources of identity recognition, like voice, messages sent on social networks, web sites and the way that a person is looking at information on a

[6] https://nakedsecurity.sophos.com/2019/10/01/chinas-500mp-camera-will-identify-you-at-a-distance/

given site, AI software can reconstruct the “personality” of that person and predict what would be the reaction to certain stimuli (information, images…).
This multiple sourcing of data obtained through “recognition” technologies applied to a person is summed up in the FTI’s report by the tagline:

Your body is a dataland

This is seen as an enabler, and a driver towards tele-healthcare, an area that has taken up steam as consequence of the pandemic.
Recognition technology is further progressing through computational photography where there is a lot of work, and results, in recognising objects in an image.
All of the above can be summarised under the trend towards a diffuse, pervasive digital signature of people and objects that will create a mirroring of any entity in the cyberspace.
Signal processing, the technology underpinning all kinds of recognition, has progressed enormously. As an example it is now possible to detect what is going on behind a wall[7], in an apartment as an example, by analysing the subtle changes in the WiFi field generated by an access point inside the apartment and trickling out of it (a person moving inside the apartment creates small perturbations to the electromagnetic field and these perturbations can be detected and analysed). It is also possible to identify a person by analysing the distortion caused to sound waves as they pass through that person body (bio-acustic signature[8]). There are many more ways to pick up biometric parameters that can uniquely identify a person and, as you can see, many of these technologies are based on widely available signals so that identification can occur everywhere, undetected by the identified people.

2.2 Social Scoring

How could you possible think about a codified social monitoring leading to the appraisal of your individual behaviour AND the sharing of this appraisal to everybody in your social circles and furthermore having that influencing (positively or negatively) the relations you have with institutions? It looks at the opposite of a

[7] https://www.youtube.com/watch?v=2GD6deoBC60
[8] https://cacm.acm.org/news/240803-the-bioacoustic-signatures-of-our-bodies-can-reveal-our-identities/fulltext

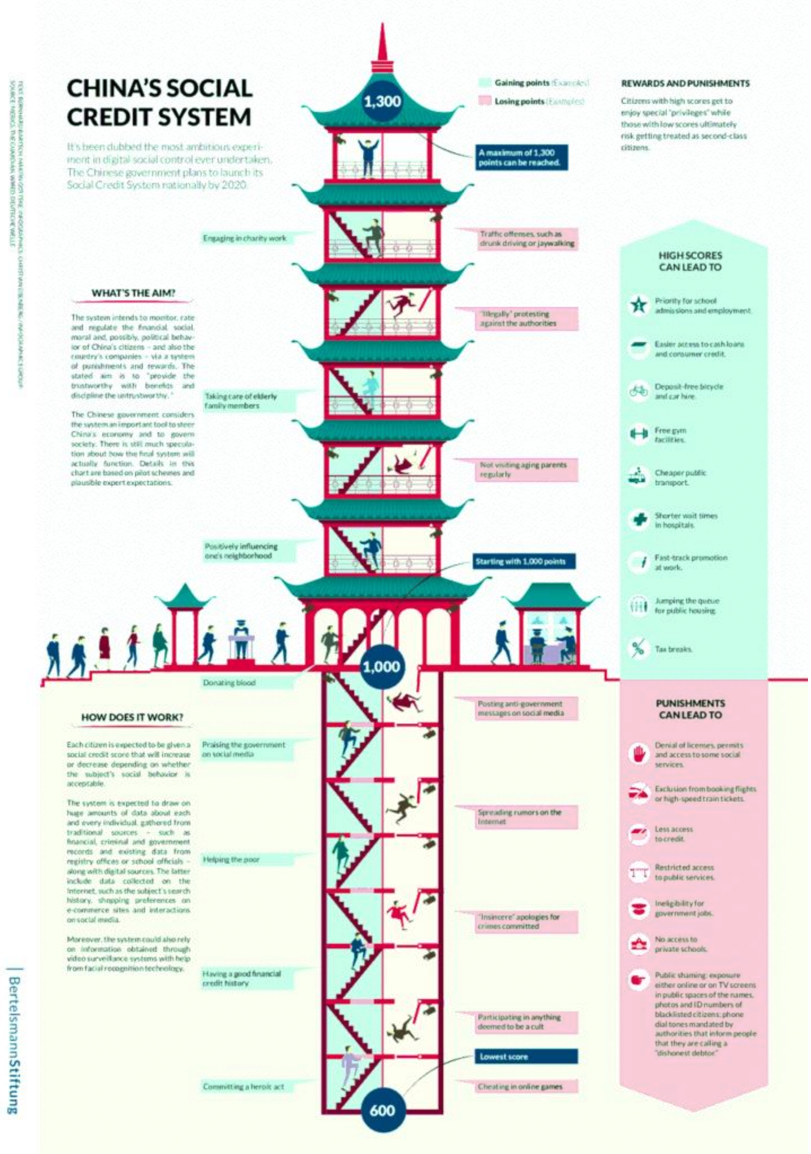

Figure 4. Representation of the Chinese social scoring system. The upper part is the reward, the recognition that your social behaviour provides value to the society and society should pay you back and leverage on you. The lower part, the underground portion, is highlighting the negative impact of your behaviour on the society that leads to social shame. Image credit: Merics, The Guardian, Wired Deutsche Welle

Western culture of privacy and a recent pronouncement of the EU explicitly forbids any form of social scoring (credit) by public institutions[9]. Yet this is what is happening in China (see figure 4), and it seems to be acceptable in that cultural context, read the article: Social scoring in China: Big Brother squared[10].

The overall trend, however, is towards a growth of the scoring, possibly in different forms depending on the context, during this decade, sustained by the increased access to personal data, that, as pointed out in the previous section on "digital signature", are becoming more and more accurate through their correlation to the point that the "network" knowledge on a person may exceed the self knowledge of the person (i.e. the network will know more, and be able to derive more accurate inferences about ourselves than we, the data generators!).

I mentioned in the previous section that biometric data interpreted via Artificial Intelligence (with specific learning on each single person) can detect emotional status and predict probable reactions to a variety of situations. There is a new technology area called biometric scoring that by making use of accurate monitoring of the way we are using our devices (like the way we type on the keyboard, the force used on a touch screen to click on something) over time is able to provide hints on our interests, our perceptions on what is shown on the screen: in other words how we feel and how we react. This information is used in scoring our personality. It is nothing really new,

[9] https://emerging-europe.com/news/eu-proposes-new-ai-rules-that-would-ban-china-style-social-scoring/

[10] https://www.smart-industry.net/social-scoring-in-china-big-brother-squared/

banks have been scoring our likelihood of repaying a loan, what is new is the accuracy on the one hand and the use of that scoring in a variety of activities we are engaging on line.
Amazon has applied to a patent to provide SSaaS, Surveillance Scoring as a Service, a service made possible by analysing the data gathered by delivery drones in an area and evaluating the type of people moving around in that area… This is just an example that is indicating a trend that will lead in this decade to a sort of data-based Big Brother. Interestingly, the report points out that the uptake of self driving cars will dramatically reduce the number of tickets for traffic violations that in turns will result in major underfunding of police. Hence the need to turn to scoring to intercept minor violations in several areas leading to additional tickets!
I feel that people, at least in Western Countries, will not allow this kind of slippery slope to take place. Nevertheless it is a given that some sort of "scoring" will become more and more applied in areas like retail, advertisement, social circles and most likely in workforce hiring. These are all areas where some sort of analytics is already applied. As more data are becoming available, the analytics can become more precise, hence more useful and will see a broader adoption.

3. Diminished Reality

The pandemic, and related countermeasures, have changed our everyday life and we can expect a changing landscape of reality:

- New Reality -augmented, diminished, mixed, virtual
- Synthetic Reality/Media
- News and Information Summary

Figure 5. Augmented reality, adding a vase with flowers on a table, is "easy". Diminished reality is difficult and partly magic, like removing the table and "creating" what the table presence was hiding. Image credit: Fayteq

Notice that none of these are "new" in the sense that they are not available today or were not present in some forms in the last decade. What this trend is saying is that we are shifting towards a new landscape whilst in the past the landscape contained, here and there, in some space and time niches some elements of what will become dominant in the future. The new landscape will be formed through exploitation of tech advances, that in turns have been fostered by the "new normal". A little bit like what was cellular communication in the early 90ies and what it is today: then it was the existence of some radio based communications, now is a landscape where cellular communications form an integral part of life (could you imagine living without a cellphone?) and in a way it has reshaped our lives.

3.1 Diminished Reality

In this new landscape the separating line between truth and false gets blurred. We have already seen that in photos where it is possible to add and remove parts. This second aspect is called diminished reality[11] (because you are removing something from the real -virtual- space).

Let's start from a simple photo, the one in figure 5. You have a table and chairs in a room. In the second one you see an example of "augmented reality", a vase with flowers has been placed on the table. The vase may be an artefact, it may only exist in the digital space. Using software it has been overlaid on the table and in doing so it is masking whatever happens to be in the background (like part of the frame and part of the shelf). Now consider the third photo. Here the table has been removed by software and the software has created a background that was previously hidden by the table. The problem here is that we don't know if what has been created is what was hidden by the table. It has to be credible, otherwise our eyes (brain) will spot something unusual and smell "fake", but as long as it is credible we have no way to spot that something has happened to change the reality.

This "removal" of parts of an image has become a standard feature of photo editing applications and is making use of artificial intelligence: the software has to guess what could be hidden and recreate it. The progress in this area is continuous, it is achieving impressive results but it is far from being perfect. The point is that in order to create a credible background the software would need to understand the overall photo, the same way our brain understands it. As an example, removing a person from a beach but leaving its shadow would ring a bell of fake in most viewers. Similarly not recreating a reflection, a sparkle would signal to our brain that something is wrong. It is expected that diminishing reality will become "real" by the end of this decade. This would be an amazing result since, as I articulated, that result can only be achieved once the software is able to get the same level of understanding that our brain has.

Diminished reality can also be seen as a way to decrease the complication in an interaction. Imagine you are working on an airplane engine to perform some periodic maintenance. With Augmented Reality your glasses can overlay some pointers to guide you to the exact place needing your intervention. With Diminished Reality all of the complicated wiring, bolts, pipes disappear and only the parts requiring your attention remain visible.

Now think about a webpage full of data and think about applying diminished reality to replace that page with one containing the minimal number of information that really matters to the task at hand. These are self explanatory examples of the power of diminished reality. They also highlight the complexity in delivering it: the software needs to understand what is relevant to you at that specific time, as well as what makes sense to hide. Diminished Reality can greatly simplify interactions, more than the simplification that can be achieved with Augmented Reality but it is way more difficult to deliver in a consistent and meaningful way.

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[11] https://medium.com/@Namenode5/augmented-reality-is-easy-diminished-reality-is-where-the-real-magic-happens-2282af38e73a

Notice that, as with any alteration of the physical reality the big question mark is on "who decides" what is relevant? And who is responsible for the outcome of an action based on an altered reality?

3.2 New Realities

Figure 6. Infrared glasses provide a different view of the world, converting temperature of objects into colours. Is this vision of the world any less real than the one we perceive with our eyes? Image credit: Pixel IR

As technology progresses the world of bits and the world of atoms fade into a single reality. However, this reality will be dependent on the mediation devices that will be used, both hardware and software devices. The rooting of reality into the devices used to capture it is nothing unusual, although we seldom think about it.
Every day we use devices to connect our brain, hence our perception, to the external world: our senses. What I see is slightly different from what you see because my eyes are not like yours (I am actually half blind so I get most information from just one eye and that limits my appreciation of depth, I am also getting different colour information from each of my eye and this is also affecting the overall perception). It is not just about me. Every one of us has slightly different eyesight resulting in a slightly different perception of the world.
What about the eyes of a bee? They are much better in the higher frequency of the spectrum (shorter wavelength), to the point that a bee can see ultraviolet colours that we cannot see. A snake, is on the opposite side, perceiving longer wavelengths -infrared- and again getting a different view of the world. A shark perceives the electromagnetic field (like it has an embedded cellphone in its head!) and thus gets another view of the world.
Is the perception of a bee, snake, shark any less real than ours? No, they are all equally real, and they all work pretty well in terms of interacting with the world "out there".
I am making this point to clarify that the role of devices (we call them senses in the animal kingdom) is crucial in connecting with the world and the perception of the world is tied to the capabilities of these devices.
The eyes, per sé, are just gathering data on certain light wavelength, the retina performs some processing of those data and much more processing takes place in various parts of the brain[12] (most of it, but not all, in the occipital part of the brain). You may call this the software processing part. Same is true for the sensors we can use to pick up data from the world out there. A good portion of the "meaning" of the data captured relies on signal processing and software. The evolution we are seeing is both in the hardware (sensors) and software.

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[12] https://www.brainfacts.org/thinking-sensing-and-behaving/vision/2012/vision-processing-information

Figure 7. The Vuzix M400 add on transforms normal glasses into smart glasses to support a variety of application fields, like telemedicine provided by a practitioner, nurse at home, guided by a doctor from remote. Image credit: Vuzix

If I wear glasses that can convert the longer wavelengths of the spectrum into shorter wavelengths I can perceive temperature in the ambient as red/yellow halos around objects. Is this view of the world less real or is it actually more real than the one provided by my unaided senses?
It is foreseen that in this decade we are going to experience a tremendous progress in hardware and software connecting us to the world, augmenting our senses and transforming our perception of the world.
I used the "eyes" as an example, but it is also about hearing, touching, "feeling", smelling… And it is not just about the world out there, it is also about the perception of the cyberspace, of bits. This indeed, is something completely new: we are creating bits, they do not exist in the world (although is some cases they may represent some physical world characteristics). This second aspect, the perception of bits, creates brand new problems.
If, I guess, we can agree that the world perceived by a bee, although perceived in different ways that lead to a different interpretation of the world, is as real as the one we perceive, it is much more debatable if a world perception resulting from the mixing of bits and atoms is real. Probably many of us would say that such a world would be a distortion of the real world, or to put it bluntly, it is not the real world. Yet, what the FTI's report claims, and this is indeed a big claim: this decade will see the rise of a New Reality where bits and atoms merge into a single entity.

3.3 Senses Augmentation

We already have a number of "tools" that let us explore the "reality" out there beyond the possibility offered by our senses. Think about the telescopes that have opened up the vision of other galaxies, and even better think about the radio telescope that has allowed us to look at the cosmos through electromagnetic radiation that is beyond our senses' detection capabilities.
Of course, these tools are not for every person, nor for everyday use. More recently cameras detecting infrared wavelengths, and glasses with infrared capabilities have augmented our vision (although they are designed, and used, in very specific applications -like firefighting).
A variety of augmented reality glasses is available, allowing the over-position of digital information on the ambient perceived by our eyes. They usually come associated with microphone and earplugs to extend our aural perception as well, or to feed information through sound.

In this decade we foresee the initiation of the transition from hands-on to heads-up mobile computing, in other words the fading away of the smartphone to be replaced by other devices that will seamlessly interact with our senses without requiring our "attention". Communications and awareness will be achieved through our senses augmentation. The transition will take several years and will continue through the following decade.
Interestingly, the report makes a point in suggesting that the transition has already begun in the form of smart glasses that provide augmented "sound", not vision. They are referring to the Amazon Echo Frames, released on the market at the end of 2020. These glasses are sold with non graduated plastic lenses that one can easily replace with graduated ones from any optometrist. They embed microphones and speakers keeping you, seamlessly, in touch with Alexa. It is just a tiny step towards augmentation but it is an interesting one because this is achieved seamlessly.
In this decade, according to the report, we will be seeing an increase in devices performance with smart eyeglasses becoming better and better in displaying artificial images overlapping them on the ambient (AI will play a crucial role in this area) whilst Head Mounted Display -HMD- will become lighter, easier to wear and easier to adapt (today they can create dizziness…). This might result in a convergence of the two by the end of this decade. There are several players chasing smart eyeglasses as the future replacement of smartphones, Apple has been rumoured to be one of them.
Again, let me stress that the keyword is "seamless": these devices need to be seamless in:

- wearing – you should not perceive them
- cost – the cost should be aligned with a cost of a (good) smartphone
- intrusiveness – other people should not see you as a cyborg

These devices are creating, or let the wearer enter into, a new reality. This is an issue per sé: our social life is based on the assumption that we are all living, and perceiving, the same reality, this is what makes social life possible. We are already seeing the impact to social interaction when we interact: our culture, roots, education -you name it- has a profound impact on our interpretation of reality. Now imagine interaction when the perceived reality is mediated by devices. There will be people using them and people who will not use them, among those using them the software will differ and more than that, it is most likely that the software (possibly mediated by each person's digital twin) can create different realities, better fitting that specific person but at the same time creating a different perception from the one created in another person.
This evolution is another example of a two edged sword: lot of good stuff along with lots of new issues. However, another interesting point raised in the report is the possibility to see (perceive) the world with the eyes of other species. Augmented glasses and software could be triggered to capture the same wavelength of a bee, or to see sound waves (like a bat) or an electromagnetic field in the radio waves range, (like a shark) or more simply a subset of our eyes capabilities to see with the eyes of our pet… This will bring a new form of empathy, according to the report,

letting us experience the world putting ourselves in "the shoes" of a different species.

Figure 8. A virtual robot goes to work inside a digital recreation of a suburb north of Seattle. Everything in this image is fake in the sense that it has been created artificially, yet it is also true, since it represents to a precision of 1 cm the surrounding of the virtual robot and the behaviour of the robot. Image credit: AMAZON

It is not just augmented glasses or augmented hearing: holograms have made significant progress with the possibility to see life-size person by using a phone booth like setting (watch this clip, it is impressive!). It will take few more years for hologram tech to become affordable and, here again, seamless.
"Spatial display" is another technology that is emerging. Sony is pioneering this technology: it can provide a really good 3D spatial perception. The drawback is that in order to deliver a stereoscopic image the system requires to track the eyes of the viewer: hence it can work for one viewer at a time.
We are already used to panorama videos, videos in which you can look around by moving your mouse, or just your phone (that picks up spatial information from the embedded gyroscope): 360° videos will become much more common as 360° video cameras become affordable and as easy to use as our smartphone camera. Actually, whilst today's a special optics is required, in the coming years normal wide angle lenses, placed on the four edges of the smartphone (we already got two of them) will be used and software will take care of stitching the four streams into a single 360° video streaming. In addition volumetric video will become affordable (also thanks to LIDAR and AI) and will be combined with 360° videos to deliver an immersive experience (in 360° video you can look around you, in a volumetric video you can move around an object present in the video to see it from different perspectives). Expect these high processing demanding technologies to become available in your hands by the end of this decade.
We can expect by the end of this decade to see a significant portion of the web content becoming available in AR and VR form. This will transform our web experience from a "looking at it" into "becoming part of it". Spatial audio, relating the sound to both its origin and your position will further improve the perception of "being there". This is what is starting to be known as "life in a metaverse", digital reality becoming reality.

3.4 Synthetic Media

It is now several decades that video games have acquainted us with synthetic reality. Imaginary landscapes and ambient are recreated by computer graphics along with sounds that match the objects and the ongoing actions providing a "credible" reality. Actually, the first synthetic environment screamed "fake" at all times and in spite of the amazing progress in computer graphics (partly due to

software and a lot to huge increase in processing power provided by GPUs) these synthetic media don't fool us into believing it is the real thing.
Something that has happened in these last years is the construction of the synthetic reality/media starting from real world data. As an example, the MS Flight Simulator 2020 (watch this clip) provides amazingly nice scenery (but they still don't look "real"). These are created in the Azure cloud by AI software making use of some 2 PetaBytes of photographies that have been taken from satellite, covering the whole planet. The AI software stitches the photos together and modifies the result based on the point of view (and the altitude of the aircraft). As I said, the result is impressive, at some points your brain may be fooled into believing it is real, but most of the time it will look somehow fake (it might be difficult to describe why it looks fake, but it does…). However, and this is the important piece of information, the rendering might look fake but the mirroring of the real world is accurate since it starts from real data.
Similarly, look at the image in figure 8: it is a snapshot of the rendering of a suburb of Seattle created by Amazon to test the behaviour of their autonomous robot to deliver groceries at home. The rendering has been made to deliver a 1 cm accuracy (so that all possible obstacles on the path of the robot can be simulated and tested). The robot itself, shown in the photo, is a digital replica of the real robot and engineers at Amazon study its behaviour to fine tune it. Actually, they are using the digital twin of the physical robot, the same one that will be used to monitor the actual robot as it delivers goods.
The FTI's report foresees an increase in synthetic media in this decade, with an increased use of real data for rendering. The evolution will continue in making the rendering more "real" (with attention given to shadows – a crucial hint used by our brain in decoding the world) but the most important part of the evolution will be in the use of real world data, sometimes harvested through entities digital twins.
The main technologies that will make possible the improvement of synthetic media are:

- speech syntheses, already well advanced, will make use of frequencies and intonation of a specific person to provide a perfect copy of that voice (further increasing the deep-fake issues);
- custom voice modulation based on the emotional content of the discourse, using AI
- deep behaviour and predictive machine vision (also fostered by advances in autonomous driving) where the software is capable to predict the next behaviour of the entities in an ambient, including how a person would react to a specific situation (notice that this can be used in the reverse, that is to generate a situation leading to a specific -desired- behaviour, a marketeers/advertisers dream)
- generative algorithms for voice and movement, allowing their transfer from one person in a video to another in a different video (deep-fake again!). The Israeli start up D-ID[13] applies this technology to deliver several impressive services (watch this clip visualising their living portraits)
- automatic generation of synthetic environment based on real world data (as in the afore mentioned MS Flight Simulator)

[13] https://www.d-id.com/

- simulation of human behaviour through a synthetic character. Samsung, as an example, is proposing the creation of artificial humans you can interact with (look at NEON[14]). This can be used as a companion, as a character in a synthetic media. It could also be used to simulate an interaction: first you "embed" the characteristics of a person into the artificial character (as they can be derived by AI software analysing the behaviour of that person through video clips, posts, messages…) and then you can simulate various interactions to understand how that person would be likely to react letting you practice and finely tuning the approach. It could also be used as a personal digital twin, automatically created by AI that you can insert in a synthetic ambient and study how it (you) would react to a variety of situations. It looks like science fiction and yet it is the bread and butter of this decade's research.

The whole area of synthetic media is fraught with social issues that go beyond the deep-fake problem.

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[14] https://neon.life/?utm_source=paid search&utm_medium=google&utm_campaign=artificialhuman0309&gclid=CjwKCAjwjbCDBhAwEiwAiudBy96KNudonNghFhSkMMH6MAIPZ9zE-ZbBCT31SnYaQtC8UI4g3ZRcNRoCLFwQAvD_BwE

4. Future of Work

The Digital Transformation is ongoing and it is a major force in reshaping the market, in terms of value perception -thus shifting demands- and in reshaping the way the offer is created. Both of these factors are clearly affecting the workforce in

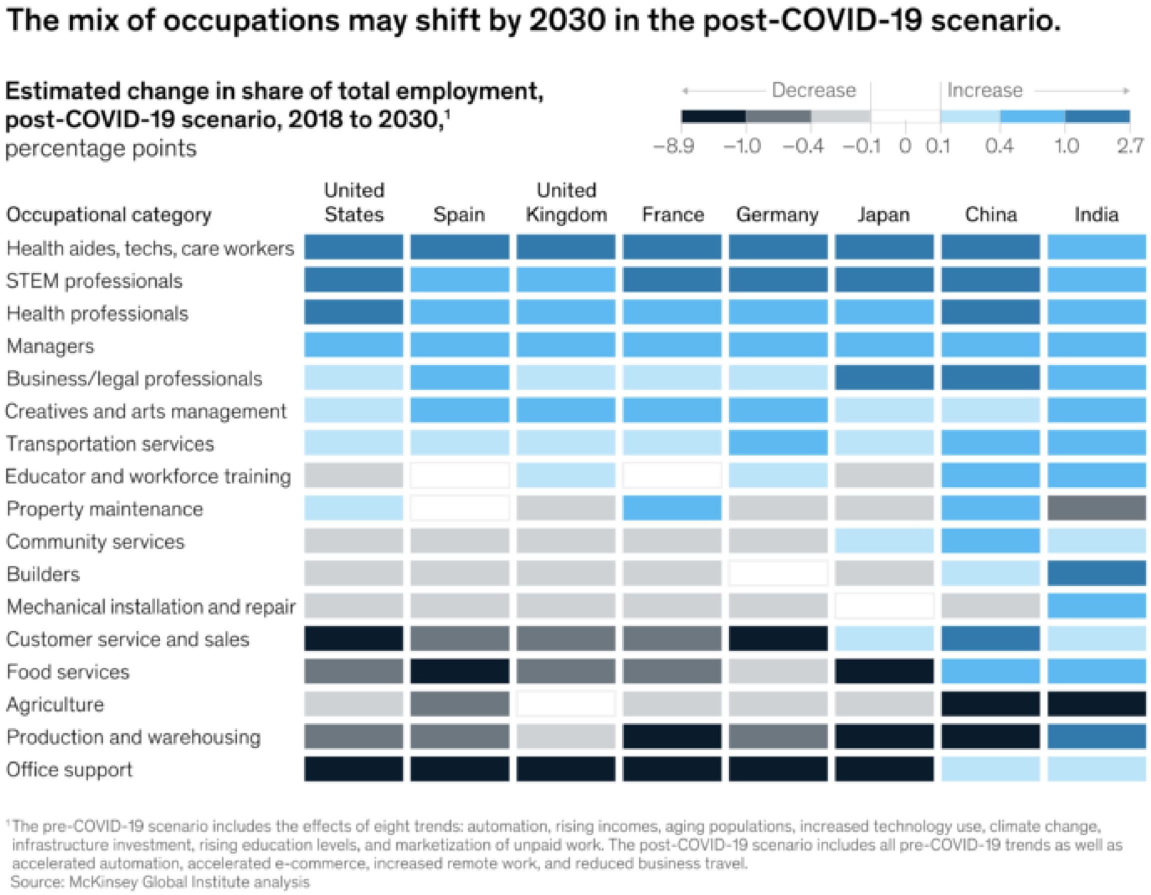

Figure 9. Overview of changes in workforce occupation by sector and by geography. Darker blue signals a strong increase, black signals a strong decrease. Image credit: McKinsey

volume, in quality (skills) and in the way of work.

a) Volume

- As shown in figure 9, graphic created by McKinsey, over the next ten years we will have a significant change in jobs demand, depending on the geography and even more by the sector.
- With the exception of China and India (that have a strong -emerging- internal market) and that are expecting a growth of jobs over the whole landscape, the other geographical areas, to different degrees, are expecting a growth of jobs in the areas of (in the expected ranking of growth):
  – Health aides, care workers
  – STEM professionals
  – Health professionals
  – Managers
  – Business/legal professionals
  – Creatives and arts management

– Transportation services

On the other hand, the expectation is in a decrease of jobs (in order of lower to greater decrease):

– Community services
– Builders
– Mechanical installation and repair
– Customer service and sales
– Food services
– Agriculture
– Production and warehousing
– Office support

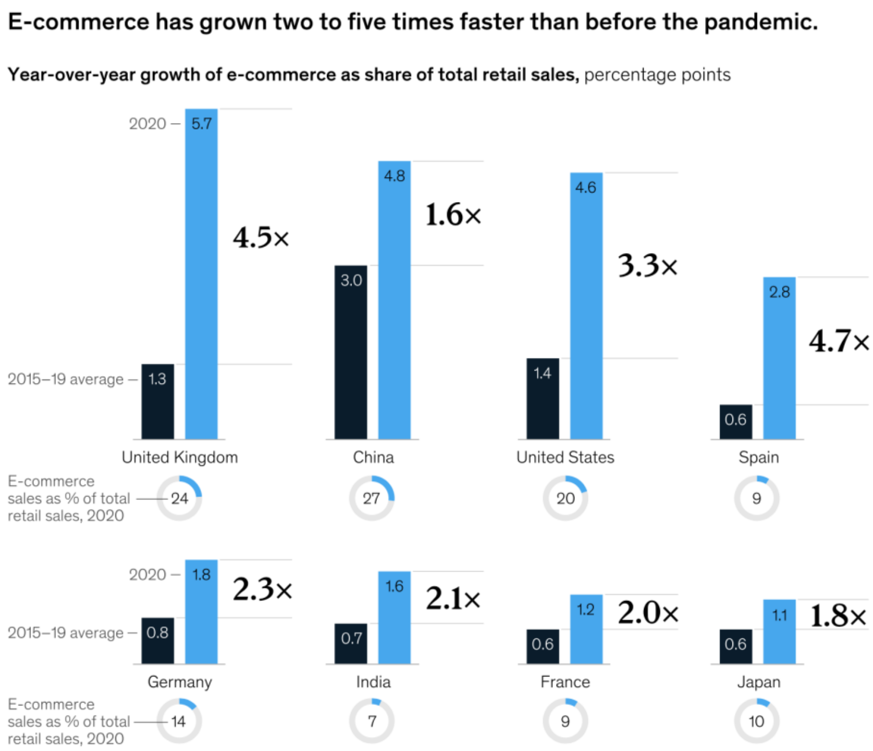

Figure 10. Sharp increase in e-commerce as result of Covid-19. It is important to notice not just the increase -year over year- but also the share of eCommerce vs brick and mortar. Image credit: McKinsey

If you remember previous forecasts on jobs demand you'll notice that with the possible exception of Healthcare the differences are not significant in the post-Covid scenario. This is not surprising in a 2030 horizon since the shift is driven by the DX, the Covid may just accelerate it in some sectors, like the sudden increase in on-line shopping that has increased the pressure on mom-and-pop stores and on malls (see figure 10).

b) Quality

- The expectation is for an ever increasing automation and support in working activities coming from the use of artificial intelligence. The shift of many activities to the cyberspace requires increased skills and knowledge to operate in that space and in turns these operations create data that are fuelling AI algorithms thus further increasing its role in work activities.
- STEM curricula are becoming even more essential in tomorrow's workforce and continuous education is becoming a must both for companies and for individuals that are seeing their competitive value on the work market shrinking at a time when the market itself is shrinking, thus requiring individual workers to look for new employment opportunities.

- The cooperation between workers and machines will keep increasing also in quality: it is no longer about "operating" a machine, rather about merging competences with cross learning.

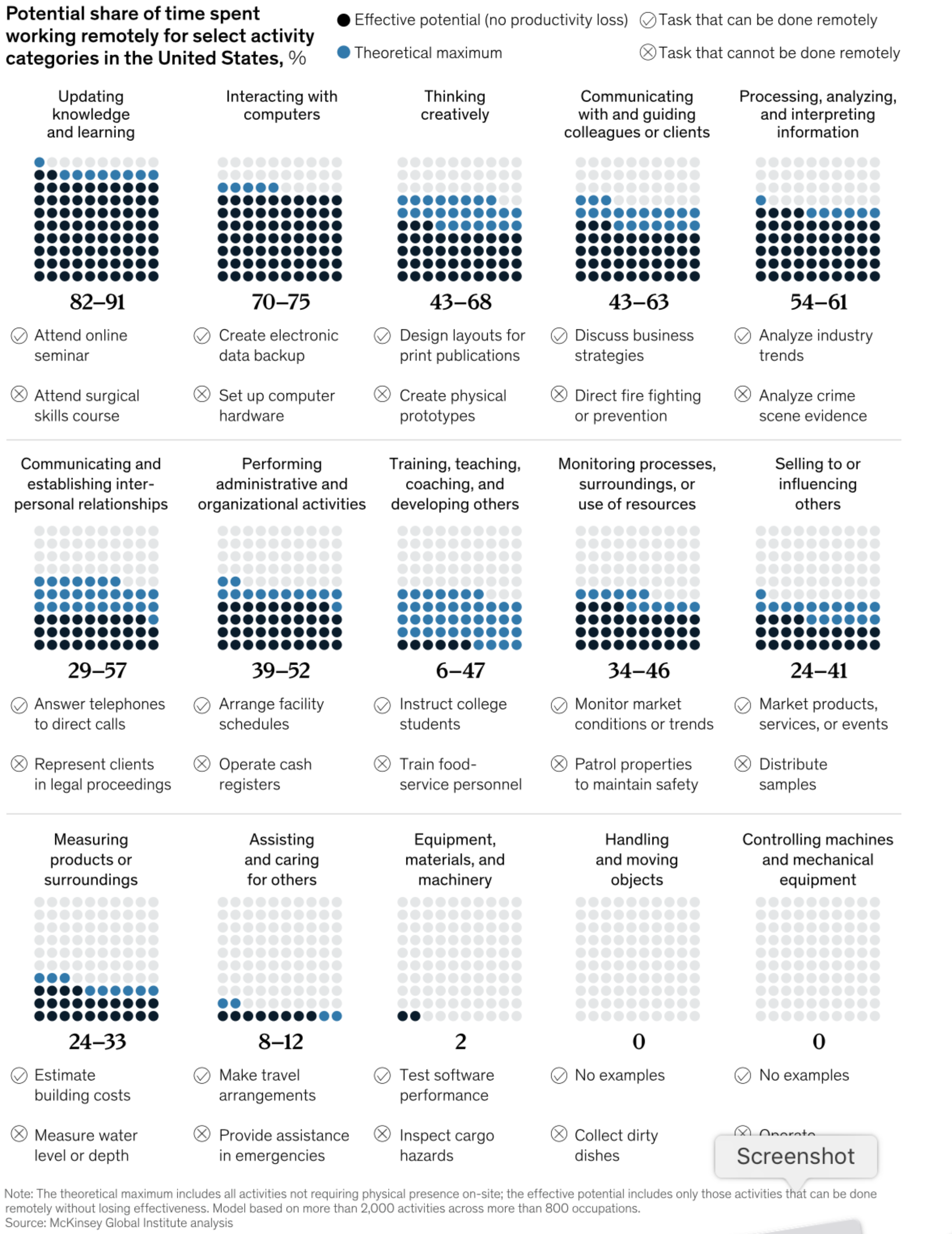

Figure 11. An interesting analyses evaluating the potential for remote working depending on the specific activity. Each square consists of 100 dots. The black ones represent the current use of remote working, the blue the untapped potential for remote working, the white ones the percentage of work that cannot be done from remote. The analyses focuses on US data. Image credit: McKinsey

c) Way of working: Hybrid, virtual and in-person workforce

Of the three elements previously mentioned, volume, quality and way of working, the FTI report focuses on the latter and I feel this is correct, since the long term impact of the pandemic will be mostly felt on the way of working.
Companies have been forced to have their workforce operating from remote, whenever possible. This has resulted in three discoveries:

- it can be done, with limited or no productivity impact
- it decreases cost
- a significant portion of the workforce actually liked the new dimension of work

As pandemic and social distances will fade away those three facts will remain and a number of companies will stick to a new normal. Google is considering requiring their workforce to be on site for just 2 days a week, the remaining 3 days can be WFH (Work From Home) or WFA (Work From Anywhere). My youngest son has been working from home (homes actually, sometime in Milan, sometime in Turin, and from time to time from our vacation home on the mountain). Now he is considering moving to Spain getting a flat by the sea and work from there. This is the WFA that several workers have come to appreciate.
Although the end of the pandemic will restore the "normal" way of working for many companies, the expectation is that the level of remote working in Asia will be 4 to 5 times what it used to be in the pre-pandemic area, according to Anu Madgavkar, McKinsey Global Institute partner, and we know that other geographical areas are even more inclined to adopt remote working than Asia.
Remote working changes the way of working: it requires a different organisation, a clear focus on objectives rather than on activity. Also, it requires in many cases different tools (the replication of the office environment at home is not straightforward, it takes more than a PC screen to get the same "feeling" and interaction level not to mention security aspects).
Sure, it is not possible for any type of work, as shown by the McKinsey analyses reported in figure 11. Remote working is clearly easier to support for white collars whilst blue collars usually need to be "on-site". However, we are seeing that technology supporting remote interaction with machines like robots is now becoming available. The possibility to control from remote a robot using VR and a low latency communications network is enabling blue collar remote working more and more (watch this clip).
On the one hand workers appreciate the increased flexibility of remote working and less commuting time (in some cases we have seen people moving away from cities where they have been living to be reasonably close to the office to the countryside enjoying better and cheaper living environment), on the other companies have realised that they can save office space, hence real estate cost (including cleaning and maintenance) and are therefore interested in continuing at least partially remote working, as pointed out in the FTI's report.
The report is also noting that so far data are not conclusive on the impact of massive remote working on productivity, nor on the actions that can be taken to increase remote working productivity. The forecast for this decade is leaning towards an increase of hybrid working, that is work that at a company level will

comprises both remote and on-site working and at individual level work being partly on company/client site and partly from remote (WFH/WFA).
The recreation of the office feeling when operating from remote is the focus of several companies, including start ups that have seen the pandemic effect as an opportunity to push their offer to the marketplace.:

- Teamflow: recreates the organic flow of proximity conversation by showing a virtual office floor plan populated with colleagues icons that a person can hear talking once they are sufficiently close. One can move around and get close to engage colleagues in conversation by moving her own icon around the virtual office floor;
- Gather: emulates the routine of office work, including a coffee with colleagues using a collaboration software that brings back to a "retro" interpretation of the office work;
- Reslash: provides a virtual space that is cluttered, not organised, to stimulate serendipity and creativity, quite the opposite of an office space designed for a structured activity. It is interesting since rather than trying to recreate a physical office space in the cyberspace it takes the opposite approach: leverage the unconstrained possibility of cyberspace to stimulate creativity;
- Sneek: recreates the possibility of dropping by at a colleague office, peek in to see if she is willing to chat

We can expect several companies coming up with tools to make remote working both engaging and productive and the availability of better/different interface technology is likely to boost this trend.

5. Digital Fashion

Figure 12. Nice dress, isn't it? It has been created by a top designer and sold for 9,500$. The only drawback is that you cannot wear it because it is a digital dress…. Image credit: The Fabricant

The FTI's report presents an interesting scenario on the evolution of fashion: the emergence of digital fashion, flanking the usual one. That this scenario is not a figment of the imagination can be seen considering that a number of companies, including the big brands, have started to invest in the area.
Gucci, as an example, has created Sneaker Garage where you can select digital sneakers as well as design your own digital sneakers. You won't be able to wear them but you can have them worn by your avatar on a number of platforms creating metaverses. A further possibility offered by some digital apparel is to use the digital version to create your desired apparel and then have it manufactured by some companies.
This is expected to become more and more feasible and enter into the mass market in the second part of this decade. At that point the value of digital fashion will grow tremendously.

The Fabricant, a Dutch company – see figure 12 and watch this clip-, is a point in case. Already two years ago they managed to sell one of their digital dresses for a staggering 9,500$. What can you do with a digital dress, given that you cannot wear it? Well, you can place yourself inside the dress and post the image on your social network. The software can customise the dress to get the best fit to your body and it can also animate, using artificial intelligence, a catwalk, or a plain walking to create a video clip of you. It can also start from a videoclip uploaded by you and change those plain sweater and jeans into a fashionable apparel to your taste.
We are already used to create a digital (fake) ambient on Zoom (and several other video conferencing platforms) to make our on-line meetings a bit better (whatever you mean with "better"). Wearing digital apparels is just a further step on the way towards a digital reality.
Additionally, consider that the availability of increasingly performant 3D printers should make possible to print your digital dress into a real fabric. At that point you will be able to wear it. I expect that by the end of this decade such printers will become more and more common in department stores. First they will serve the need to reduce stock and yet be able to serve customers on the spot, secondly, they will allow for customisation (in colours and trimmings), third they will be able to produce custom made apparels so that they will fit perfectly.

Figure 13. A 3D full body scanner can take precise measure of your body and create a digital replica that can be used in manufacturing custom apparels. Image credit: Fibre2Fashion

There are already several types of 3D full body scanners (see figure 13) used in some department stores to "measure" your body. The scanner creates a digital model of your body that is stored in your "fidelity card". When you look at an apparel in the store a simple scan of the bar code attached to the apparel will let you know what would be the right size fitting you and some apps will even provide you on the spot (on your smartphone screen) the image of you donning that apparel. Likewise when shopping on line, the availability of your digital model can be used by the on-line vendor to display on the screen the image of you donning that apparel and you can see yourself in 3D on the screen, move around and even see you walking to get a feeling of how you would look like. A further step is to custom order the apparel, after you have seen it on "you" in the virtual space. Notice that as technology progresses you will be able to see yourself in the cyberspace with better and better resolution to the point of believing you are actually looking at yourself in a mirror. As you move, the image on the screen moves along with you (see how AI can be used to animate portraits).
According to the FTI's report digital fashion will become "big" in the coming years. People will be able to shop for a digital apparel, try it on in the virtual space and use it in the virtual space at (virtual) social gatherings. Of course, it will also be possible to use that digital apparel as the blueprint for producing a real apparel, possible ordering it on line or having it downloaded, and printed, at the nearest mall.

In the next decade, with the growing possibility of manufacture at home, we might print our dresses every morning and recycle them in the evening (no more washing machine and full recycling!) just to print a new dress the next morning after having bought a model on the web as we sit on our couch in the living room. For the gifted ones the dress will be created/designed in house using apps to convert their creativity into a digital model that will be automatically customised to their body using its digital model.

5.1 Digital Make-up

I remember I saw the first tiny steps towards digital make-up at a mall in Singapore over 20 years ago. If I am not mistaken it was an Oreal booth showcasing cosmetics and giving clients the opportunity to try them on a screen where a face of a girl/lady was displayed (you had the possibility of selecting among a good number of faces to take into account age and ethnicity). A palette of colours corresponding to different Oreal products (lipsticks, powder, eyelids, …) could be used by the client to "paint" the face and get an idea of the result. An assistant was available to help (and, as I remember, it made quite a difference on the result!). Anyhow, it was something new and there was a line to access the three stations at the booth.

Figure 14. The main cosmetic brands are racing to provide a digital make-up as a way to improve customer experience and drive sales. Image credit: Guerlain

Twenty years is an aeon when we talk of digital stuff. Today, digital make up is arising at the intersection of facial recognition, 3D mapping, augmented reality and artificial intelligence (plus a huge amount of processing power). Pour all these ingredients in a high resolution -large- screen and you get a whole new slate of possibilities. Oh, don't forget the plus that may derive from smartphones, social media and personal digital twin!

The FTI's report points to digital make-up as an important revenue generator for this decade and notice how most cosmetic brands are scrambling to leverage on technology possibilities to increase customer experience (read "sales").

Notice that we are getting used to digital cosmetics, or digital enhancement: all photos published on fashion magazines have been retouched (guaranteed) and these photos have drilled into our subconscious the desire to look as nice as those people …

Hence the booming of retouching functionality for photo post-processing apps (Luminar AI is making heavy use of AI to change the skin tone, remove blemish and crow's feet, to slim your tummy and much more! -watch this clip) and we have

started to see some of these enhancement functions in video call software, like Zoom!
In this decade we can expect a booming business, and along with that a continuous improvement of retouching software for communications in the cyberspace. This evolution creates opportunities in the real space: you can digitally transform your look in the cyberspace and then a software will provide counsel to improve your look in the real space as well. Clearly, you have much more latitude of intervention in the cyberspace but the cosmetic industry is there to help you improve your looks in the real space.
Another interesting prediction made in the FTI's report is that cosmetic brands may generate revenues from digital make-ups. Whilst so far that has been used as a way to improve marketing effectiveness and support on-line shopping, the growing use of the cyberspace as supplement to in person meetings creates an opportunity for these brands to offer digital wares that can be used to improve the looks in the cyberspace. Clearly, companies like Zoom are also in that business space and for them the beautification may be a way to foster the use of their connection tools so they might be offering that for free. Cosmetic brands will have to top their offer with something that could be perceived as significantly better.
The competition is on!

6. Healthcare

6.1 Home based healthcare

At home healthcare is nothing new. As technology progresses there are more and more opportunity for continuous monitoring and remote diagnostics. I remember I started to be involved, from a Telco perspective, in telemedicine 40 years ago as we were looking for application of ISDN, an amazing technology that could provide 64kbps connectivity, and with some ingenious tricks push it to 128kbps. I know it seems ridiculous now, but at that time we worked with other companies to support EKG data transmission from a (bulky) equipment that could stay at home of the patient.
Compare that with the tiny pad shown in figure 15, the AliveCor Kardia, that detects electrical fluctuation through your fingertips and sends them to your smartphone

Figure 15. Easy to use devices for at home health monitoring and testing devices will become more and more common. In the picture a device for EKG, as easy as placing two fingers on a pad and reading the result on the smartphone screen. That result is shared with the doctor for analyses. Image credit: AliveCor Kardia Mobile

where an app will process them and create the EKG with possibility of raising a red flag and sharing the data with a doctor thousands of miles away.

As expected, the FTI's report foresee an acceleration of the transformation in the whole healthcare sector as consequence of Covid-19 pandemic. Actually, I found the part on healthcare the most interesting one of the whole report for the insights it provides on the profound disruption looming ahead.

The technology evolution is ubiquitous and in this sector we are seeing a convergence of technologies that produces a multiplying effect leading to a disruption in the rules of the game.

The technologies that have most impact in this transformation are:

- genomics (including rapid testing, gene manipulation – CRISPR-CasX- leading to rapid drugs/vaccine creation);
- Bio/physiological parameters detection (both through wearable, implants and external devices) through advanced, low cost sensors;
- Signal processing (SoC, artificial intelligence including machine learning for custom analyses);
- Cloud and Edge Cloud for low cost, high intensity processing, along with pervasive communications infrastructure – 5G is not a must but of course it is nice to have;
- Local detection, processing and storage provided by personal devices, like smartphones, that are easy to use and do not burden with additional cost the healthcare system;
- Blockchain and data protection / data frameworks -like GaiaX- providing a robust and shared architecture that both increases data sharing possibilities whilst preserving privacy.

Interestingly, most of the above technologies are not stemming out of the healthcare sector, they are not controlled by that sector big players and yet they are transformative of the healthcare processes and business. We know very well then whenever there are radical processes changes the established companies (incumbent) are facing a challenging time. We are seeing names like Amazon, Google, Microsoft and Apple, that are major forces in those technology evolution, starting to flank the big healthcare players with the aim of replacing them in the long run (or at the very least to put a significant dent in their business). If you click on those company names you see some articles discussing their growing role in healthcare. I'll come back onto this transformation in a later section, for now let's look at the evolution of healthcare devices that can change our home into a healthcare hub, actually into the first healthcare hub.

The smartphone is becoming the de-facto processing node for a variety of medical sensors that in an increasing number are getting a FDA approval (that is usually steering the approval of several other healthcare institutions in different Countries), in addition to already mentioned portable EKG we have:

- Apple Watch, Fitbands, SmartWatches are becoming more and more widespread and are sensing more and more parameters, from electrical signals (detecting irregular rhythm) to oxygen-blood saturation, blood pressure, temperature, sugar in sweat, …;
- VR headsets, like VROR Eye Dr., that can perform ophthalmic examination locally and send the data to an ophthalmologist;
- portable sensors, like Steth IO to capture breathing "rumours" that are pre-analysed in the smartphone (watch this clip) and then transferred to a pulmonologist;
- portable ultrasound devices, like Butterfly IQ, that connect to the smartphone for image display and first level analyses;
- salivar testing to detect a variety of mouth bacteria, like Paratus Diagnostics. The race is on to provide Covid-19 salivar testing at home;
- ear infection tele diagnoses, like CellScope, to check on your baby or kid ear canal and sending the images to the paediatrician,
- fertility tracking bracelet like Ava, worn as you sleep, provides data to a smartphone app to monitor fertility cycle.

Additionally, our homes will host a number of smart appliances/devices that can double up as healthcare monitoring by providing data to artificial intelligence based software (the AI relates to the capability of the software of learning over time the digital signature of that specific person and interpret any changes, raising an alert if needed):

- smart toilets will become labs for daily test of several physiological parameters,
- smart mirrors will look at changes in your face, detect spots on your skin …,
- smart showers will embed sensors and scanners to detect suspicious moles,
- safety cameras will provide continuous feed of your whereabouts at home and image recognition software will spot changes in gait that may signal a neurological condition,
- smart toothbrush can detect early gum diseases and cavities…
- microphones, like Alexa, will provide your voice digital signature to be compared and analysed, making it possible to spot some medical conditions (apps to detect the risk of being Covid-19 infected are already on the market and they analyse your voice pattern changes over time and the type of cough…).

The list goes on and on. Part of the devices and appliances mentioned are already a reality and will get better in the coming years, others are still on the drawing board but can be expected to soon changing the way healthcare is being monitored, making it proactive and customised.

6.2 Tele-Health

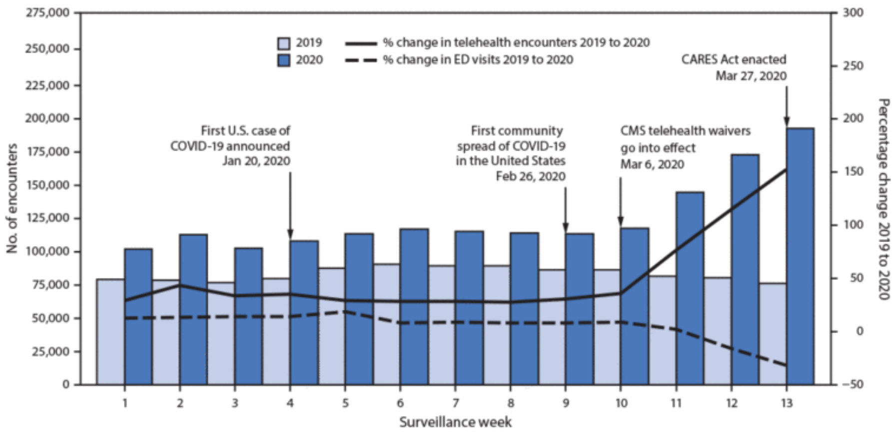

Figure 16. The usage of tele-health services in the US increased sharply, as shown in this graphic, as the Covid-19 started to affect US. The vertical bars represent the number of tele-consultancy per week in 2019 (pale blue) and 2020 (dark blue) in the first 3 months of the year. Notice the sharp increase in March 2021. The solid black line represents the increase in % of tele-consultation, the dashed line the decrease in % of on site consultation. Image credit: CDC

The pandemic has accelerated the adoption of tele-health in many Countries. In the US, according to Fair Health, the usage of tele-health has increased over 4,300% between March 2019 and March 2020. Medicare and Medicaid have added over 80 services in 2020 to be delivered remotely and have set the same price for on site and remote service delivery.

In Italy we have seen a surge of remote consultation and prescriptions and, interestingly, the expectation is that the pandemic has led to a point of no-return in several areas of healthcare provision. When the pandemic will be over many of the services (like prescriptions) will be delivered from remote. Figure 17 shows with the black bar the amount of tele-consultations in 2019 (in %) versus the amount of tele-consultations expected in the post pandemic phase. Notice that with the exception of use of tele-consultation for specialists the expectation is for a tripling in the volume. For specialists consultations the increase is more limited but still in the order of 30%. Interestingly, the uptake of tele-rehab and tele-examinations that was mentioned in the previous section will leverage on a variety of devices becoming available at home.

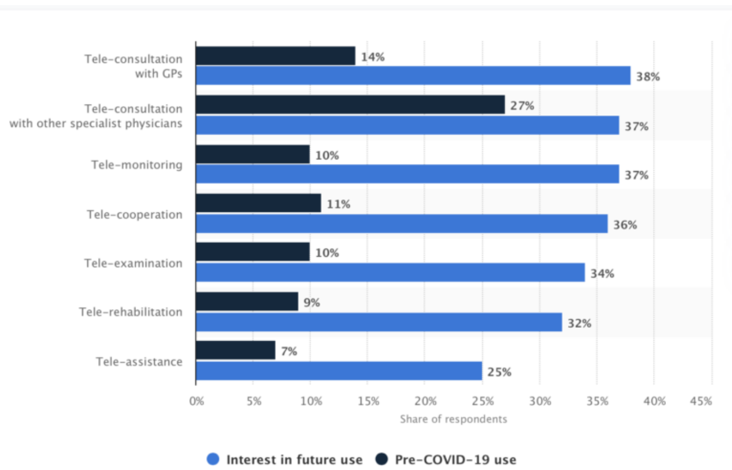

Figure 17. Graphic representing, for different health care services, the delivery through tele-health in 2019 and the expectation of delivery in the post pandemic phase. Use of tele-health is expected to triple, on average. Image credit: Statista

Tele-health is disrupting the geography of health care. In the coming years we may see the rise of points of excellence providing this service to people all over the world. A person in the Philippines may decide to subscribe to tele-health service delivered from a service provider located in Sweden. That service provider will take care, if need arises, to link the patient to a local doctor or health care centre / hospital for on site care.

This tele-service provisioning is bound to create hubs of delivery

and the management of the increasing demand will be met, most likely, with automatic response systems, software applications based on artificial intelligence, plus a systematic use of natural language interaction.
Each patient will have a corresponding healthcare record, recording his vitals (possibly automatically updated in quasi-real time depending on the level of service required), prescriptions taken, plus all the result of exams, consultations and the sequence of his genome. This record will be used by machine learning algorithms to create a model of that person and a variety of software applications will be monitoring both the patient and the potential risk of the environment on that patient. In other words, this shift towards tele-health will be supported, and mediated, by the creation and use of personal digital twins.
Also notice that the uptake of tele-health is shifting the value towards those "software companies" that can have access to the largest volume of data/patients since they would be able to leverage on both volume and diversity to derive better intelligence and more accurate services. In other words, in the health care area by shifting to AI, increased volumes means increased customisation potential (quite a different situation from manufacturing where increased volume leads to averaging the product features).
Additionally, the delivery of healthcare support, particularly monitoring, using software and personal digital twins can enable continuous consultation (one person may get in touch with her virtual doctor as many times as wished, every single day with a single subscription cost. The increased effort on the provider side is negligible, the perceived advantage on the receiving side is huge. As an additional benefit, the more a person uses the service the more data are being accrued, increasing the provider data space value.
The "softwarization" of tele-health services is going to change the landscape of healthcare by the end of this decade, as pointed out in the FTI's report. Do notice, however, that the previous considerations on personal digital twins are mine, derived from the work being done with the Digital Reality Initiative at IEEE FDC.

6.3 Tele-Health Delivery

Figure 18. Preparing a drone for Covid-19 tests delivery in Ghana, Africa. Image credit: Zipline

As I pointed out we have plenty of technology, and more to come, for remote monitoring of our health parameters and remote diagnoses. However, this can help only up to a certain point, beyond that you need "on-site" intervention. However, this on-site doesn't need to be the doctor site, it can still be your own! Luckily, technology can support that too and in the coming years it will become even more supportive. Implantable drug dispensers have become available in the last few years (first experiments go back ten years ago) and are becoming more and more powerful. Some of them can be controlled wirelessly, others can be programmed, others are connected with implanted sensors (like the most recent insulin pumps).

Military is studying the possibility to have battle field intervention by robots to provide first aid. It is still at research stage but out of these researches we can expect solutions applicable to our everyday life. For sure remote surgery is on the radar to provide support to people and communities living in remote areas. We cannot imagine complex surgery performed in remote location without a human surgeon support but minor assisted surgery is becoming viable. The use of AR on site and VR from remote should be able to offer trained nurses the capability to perform limited intervention under a remote supervision.
For sure, the delivery of medicines to remote areas, on demand, is already a possibility. I was on a call organised by IEEE on the future of work virtually clustering several people in Africa and one of them was working with Zipline. This is a US company that has specialised in packages delivery using autonomous drones. They are serving remote locations in Africa delivering drugs, including vaccines. According to their website their autonomous aircrafts/drones have already flown over 8 million miles delivering over 700,000 packages (watch this clip).

6.4 Biometric Screening

The pandemic and the need to check vital signs, mostly temperature, to assess a potential Covid risk, has provided steam to biometric sensors. This is nothing new, of course. Temperature screening at airports was introduced at the time of SARS, back in 2003. What is new is the widespread use of biometric screening that is now part of the procedure to enter offices, shops, theatres and more. In turns, we can expect biometric screening to become a fixture in homes and offices feeding data to personal healthcare data analytics.

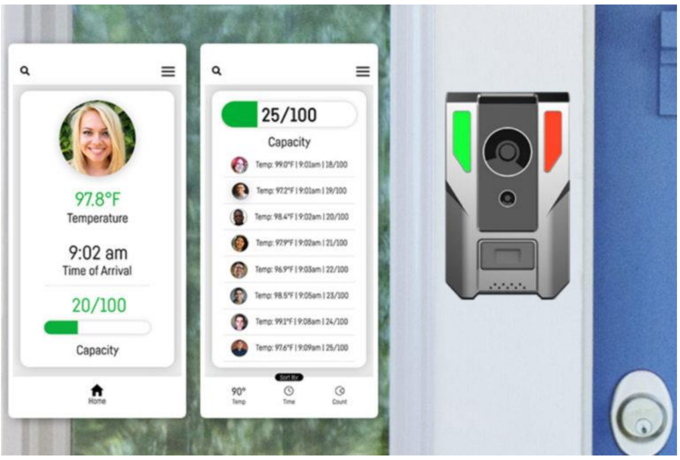

Figure 19. A video doorbell that takes the temperature of the visitor and displays it on the home dweller smartphone to let her know the potential risk of opening the door… Image credit: Ettie

Ettie has included a temperature scan into its doorbell, see figure 19. As you ring the bell the sensor picks up your temperature and report it to the people inside (sending a message on their smartphone in addition to lighting a green or red light by the door). The same information is reported to you, letting you know if you temperature is below the risk thresholds.
More than that, the Ettie doorbell keeps track of whoever rang the bell, the time and the face. If the face is known it associates a name. Facial recognition is becoming more and more effective, at least as an indication, and faces can even be searched on the web.
An example is PimEyes: you upload a photo with your face and PimEyes search for it returning a number of web sites that contain your face. I gave it a try and I should say I was impressed by the result.

Figure 20. The photo on the left is the one I uploaded, the one on the right is one of the hundreds that were found on the web by PimEyes

PimEyes returned photos of my “face” that were taken several years ago and that looked pretty different from the one I uploaded (see the figure). PimEyes is asking you to acknowledge that what you are uploading is your face to keep privacy, but of course there could be very little control that indeed what I uploaded was my face!
PimEyes is just an example. There are quite a number of web services that can search for a photo and apply biometric screening to find other occurrences on the web. I guess there is no need to highlight the privacy issues. Your face is getting screened by thousands of cameras, most of the time without you being aware. A recent study has found that a US citizen face is captured some 230 times per week (there is one camera every 4.6 people in the US, second only to China where there is one camera for every 4.1 people). If you like statistics, here is the list of most “surveilled” cities in the world.
However, security cameras make only for a tiny fraction of our presence -recorded- in the cyberspace. The number of photos we post on FB, Instagram… and more than that the ones that friends, acquaintances and just other people are posting on the web that by pure chance include us, is staggering and keeps growing. The increase of biometric screening provides a further push (yes, I know, it is not a given that a biometric screening would result in our image/identity stored somewhere, but it might and I am pretty sure in many cases it will…). There are laws to protect data gathered through biometric scanning, but they are different from area to area and they do not cover any person, nor any situation.
The FTI report suggests that the biometric scanning increased by the pandemic is not going away and it will contribute to the fading away of our privacy. Actually I am not really concerned about this, since my privacy faded away step by step as the web has expanded.

6.5 Digital Transformation of Healthcare

Until 2019, in the pre-Covid era, Healthcare was lagging behind several other sectors in terms of Digital Transformation. The music sector as well the travel sector were well ahead, and even the manufacturing sector was considered to be much more advanced than healthcare.
The pandemic did not change the situation at a snap of a finger but raised the awareness that healthcare cannot scale in the physical space and we need to move to the cyberspace whatever can be moved and the sooner the better. Indeed prescriptions, tele-consultation, tele-monitoring, as pointed out in the previous sections, have increased dramatically and have changed the perception of both doctors and people that:

- it can be done
- there is a value in doing it

• technologies can help a lot

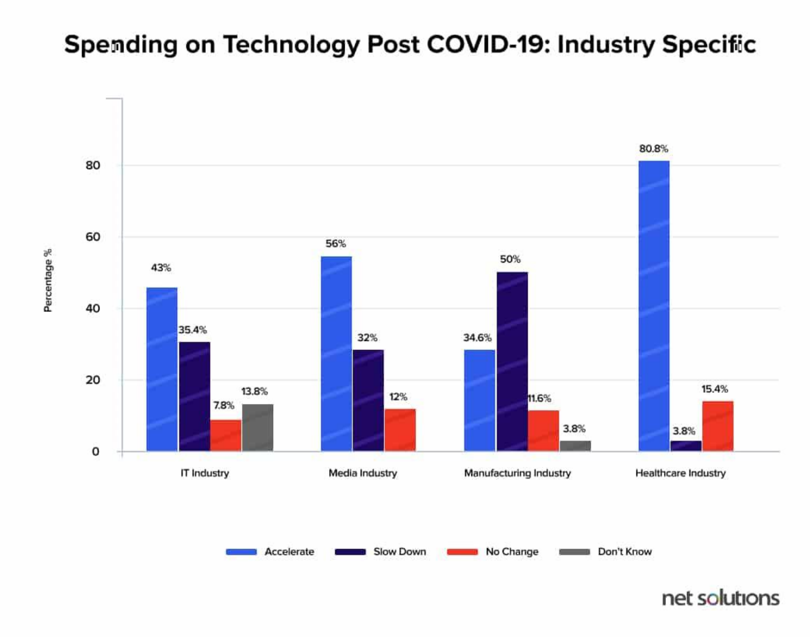

Figure 21. Post Covid-19 spending in technology, based on a poll of 100 top level executives in 10 Countries. Notice the overall consensus of a sharp increase in technology investment in the healthcare area. Image credit: Net Solutions

Hence, even when the pandemic will be over it is most likely that this type of "healthcare through the cyberspace" will remain. An indication is also in the expected growth of technology investment expected in the healthcare area, as shown in figure 21. This is just a tiny fragment of what DX should be, the massive leverage of data to deliver healthcare, a first step.

However small, this first step is important, I feel, because it has set the transformation in motion. This is clearly addressed in the FTI's report. According to the report in the third quarter of 2020 investors poured 8.4 B$ into US global health, a good portion of those aimed at accelerating the DX into the whole healthcare value chain, including insurers and Government Agencies. The goal is to leverage data to make home care possible, with remote assistance supported by software (AI).

We can expect data to take the lead in the coming years:

> personal data containing

- the genome sequence;
- the metabolome and proteome (these are further down the lane in terms of massive availability);
- the record of exams, diagnoses and prescription (these are already available, in most Countries, in digital form but are difficult to access and are often contained in different non-communicating silos);
- physiological data resulting from real time monitoring through wearable – contextualised in terms of stress, emotion, activity, ambient temperature, humidity;
- behavioural data resulting from ambient sensors, including food intake.

> community data containing

- presence of abnormal incidence of pathologies
- global environmental factors
- emergence of specific symptoms
- usage of medicines

- proximity and contacts
- comparison with other communities with similarities or differences

The intelligence derived from the data analytics applied to the above data (notice the importance of both personal and community data) will become important both in the identification of potential problems and in the monitoring of the impact of decisions taken at personal and community level.
We are going to have an immediate feedback from the personal level to the community level and the other way round. This is bound to lead to better curing protocols, better proactive healthcare and to a decrease in healthcare cost.
Most of the issues are not technological. We could say that the required technology is already available (in many Countries at least), although it is obvious that technology will progress significantly leading to the harvesting or more data with higher sensitivity. The real issues are of organisational and regulatory types.
Privacy is clearly a potential stumbling block, particularly in Western Countries.
In Europe, the interoperability among data spaces -preserving data sovereignty and privacy- is now being addressed by the Gaia-X initiative. The pandemic is also pushing towards transnational data sharing at community level (and in a much more limited way at personal level, as an example for health passport and at a more specific level for vaccine effectiveness and side effect). Notice that the shift towards federated Clouds and in perspectives towards “fog” to include data spaces located under people’s control (like in smartphones, in vehicles, in home’s hubs) requires both interoperability (and standards) as well as a regulatory framework.
The FTI’s report indicate as emerging players in the Healthcare Digital Transformation companies like General Catalyst, Geisinger, Epic, Accenture, Alibaba, Qualcomm and Nokia; none of them would have rung a bell just 2 years ago when discussing the healthcare sector.
The focus on data is clearly bringing the big data companies to the fore, from Amazon to Google (Google Health) to Apple (Apple’s Health Records) to Microsoft and Salesforce, particularly when considering personal data and enterprise community data (Salesforce).
In 2018 Amazon acquired PillPack, a mail-order pharmacy, and rebranded it into Amazon Pharmacy in 2019. Patients in the US can ask their doctor to send the prescription directly to Amazon for prompt home delivery. In parallel Amazon launched Health-lake, an AWS healthcare analytic platform that is HIPAA compliant (the Health Information Privacy Application Rules in the US), capable of converting unstructured healthcare data into structured ones, in practice simplifying third party access to data to enable new services. Part of these services are in the area of drugs creation (in partnership with Accenture and Merck). Additionally Amazon has created Amazon Care, a telemedicine program designed for its employees, but obviously expandable well beyond that.
Amazon Transcribe Medical provides doctors with an automatic speech recognition to support dictation of prescriptions and exams, Amazon Care Hub supports caregivers in senior homes and Alexa is now able to recognise changes in a person’s voice detecting emotional status and in perspective some tell-tale signs of an incipient health issue.
Last year Amazon launched Halo, a wristband harvesting several wellbeing parameters. These data can be automatically uploaded to the physician (most likely

to one of the physician software assistant) to facilitate consultations and proactive prescriptions.
At Amazon Go -shopping stores- shoppers select food and pay using biometric data that can be correlated to that shopper health record.
Put all of that together and the trend is clear. Amazon, as several other big data players, are looking at the healthcare arena as their new marketplace and this is bound to disrupt the whole healthcare system.

6.6 Digital Twins in Healthcare

The FTI's report points out to a transformation first and uptake later of Healthcare Concierge services. These services provide continuous care through a dedicated doctor, nurse and infrastructure. When they started, several years ago, they targeted a very small -and very rich- constituency with a price tag between 10,000 and 50,000$ per year. More recently, the use of software and computers enables the delivery of very similar services (the perception of having a doctor at your disposal 24h a day) at a much more affordable rate (like the 2,400$ per year charged by the Lanby club).

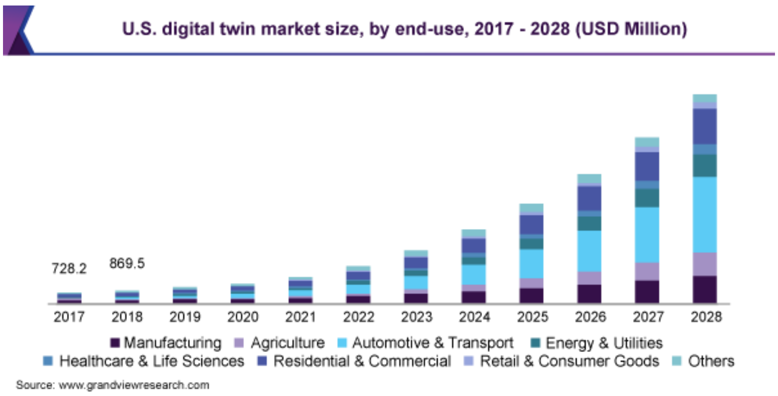

Figure 22. The Digital Twins market in the healthcare sector is still small, as represented in this graphic based on US data. It lags behind automotive, residential and commercial, manufacturing and agriculture. In the second part of this decade the market relevance should grow significantly, powering a revolution in healthcare. Image credit: Grand View Research

When you subscribe to a concierge service you get a full biometric body screening, a genome sequencing and genetic analyses, blood panel and skin screening as well as a mental assessment. This information is encapsulated in a digital twin of yourself. Wearables and other ambient sensing devices at home and at the office keep feeding data to your digital twin and software applications keep crunching the data contained in your digital twin (both those reflecting your present situation as well as those accumulated over time) to make sense out of them, detect potential dangers and even prevent potential dangers in the future.
Concierge services may go (they usually do) hand in hand with some form of insurance policy, The problem here is that most likely the insurance premium is tied to your level of wellness (and risk…) as well as to your conforming to the guidelines you are given. Is your circulatory system in need for a brisk walk 10 minutes a day? Your digital twin is going to inform you of that, but at the same time it is going to report to the insurance company your lack of compliance and that might result in an increased premium (since you are presenting an increased risk).
Digital twins are seldom used today in healthcare monitoring and support (they are used to monitor and operate hospitals, medical equipment…) but this is going to change significantly in the second part of this decade (see the expected market

growth in the US in figure 22). The pandemic has accelerated this transition although in many Countries it is facing strong obstacles related to privacy concerns. The benefits deriving from the application of digital twins, however, are so huge that their use will become the new norm in the coming years. An appropriate management of the data and the level of disclosure of those data can overcome privacy concerns. The possibility to have the data hosted in your smartphone may further increase confidence and acceptability (of course a back up of those data in the cloud is a must but all access is mediated through your smartphone). The very idea of a digital international health passport is a first step in the acceptance of personal digital twins -PDTs. The existing (in several Countries) health digital record is a further starting point to create PDTs. Companies like Apple, Amazon, Google will provide support to the mass market for PDTs creation. In a way you can consider the PDT as the result of the convergence of market and technologies and as such it is inevitable. Take a look at the Philips vision on application of Digital Twins in the healthcare sector in this clip.
The work developed in the Digital Reality Initiative on the use of PDTs is clearly showing the benefits and how these can help in bridging the personal privacy needs with the societal benefits deriving from the sharing of (certain) data. You can watch the webinar explaining the use of PDTs in the context of an epidemic here.

7. Smart Homes, Smart Neighbourhoods

Figure 23. The integration of home appliances has just begun. Open Source Shelly provides support integration with Apple Homekit. Image credit: SmarterHome

The FTI's report dedicates one full chapter to the expected evolution of the home; of course the trend is towards smarter homes and, interestingly, the trend is also towards the aggregation of smart homes in smarter neighbourhood (and further up into smart cities and smart Countries).
The path towards smarter homes begun in the 80ies with first ideas of robots that could help in home chores. At that time they were mostly toys, by the turn of the century home-robots started to merge with appliances, vacuum cleaners, cooking devices…
In parallel we have seen the integration of media and communication systems in the home, fostered by the penetration of personal computers, home LAN, smart television and smartphones. Media centres (powered by microchips and with growing storage capacity) seemed to be well positioned to become the hub for the smart home but the emergence of smartphones, of smart routers (gateways) and of smart controller (taking care of home surveillance and extending to illumination, blinders…) blurs the landscape.
More recently the appearance of smart assistants, like Alexa, Siri,… has further modified the landscape and brought Amazon, Apple and Google (in the Western Hemisphere, Alibaba, Xiaomi and Baidu in China) to the centerstage to the point the the FTI's report calls the new Smart Home the GAA Home (Google, Amazon, Apple Home).

The problem with the emergence of these Assistants, that started as Natural Language interface and are now growing into home intelligence learning about the home dwellers habits -basically developing a Digital Twin for each dweller- and a conceptual map of the home, its appliances and the way they are used, is that they are supporting vertical silos that are not communicating with one another. This might find a solution in the growth of open software, like the Shelly platform that in principle could play the role of an umbrella virtualising proprietary systems into a single system.
It is not a given that this will be the way forward. Players (and their devices) in the home environment need to be trusted, even more so as they are harvesting more and more “private” data that can be converted into very sensitive information. The vertical integration provided by a single company is likely to offer the perception of higher security and therefore to gain stronger trust. It remains to be seen. For sure we are no longer considering media centres, smart routers nor smart home controllers as the future smart orchestrators of our homes. Notice the recent announcement of AirTag by Apple, providing further data onto what is in the home and how we use the “tagged” object. Of course it is not a given that AirTag will reach a massive deployment (there have been and there are on the market alternative tagging solutions, some significantly cheaper), only time will tell. Also, notice the way AirTags work: an AirTag is paired with your smartphone and is attached to an object (like your keys). The communication is over Bluetooth and a nice software in your smartphone by measuring the Bluetooth signal strengths and its direction (analysing in a very smart way the info provided by the accelerometer sensor, GPS and compass in your smartphone) can point you to the AirTag (and the attached object. The whole thing is integrated in the FindMy app. Here comes the interesting part. You may not be in range with your AirTag, suppose you are back home and discover you can’t find the keys to open the door. A look at the FindMy, a tap on your key AirTag and you are shown that the keys are at your friends home, some five miles away, under your friend couch! How could it be? Surely there is no way that the Bluetooth signal travels that far (it works in a range of a few meters).

Figure 24. An Airtag can be monitored from the iPhone to track its position. Image credit: Apple

Well, the way it works is two fold:

- your smartphone FindMy app can track the position of the AirTag as long as they are within reach and records the last known position. When you left your friend’s home it lost the connection but still remember their last position;
- your AirTag may no longer be in touch with your smartphone but can be in touch, even for a very short time, with some other people smartphones and the location info is sent over the internet to your smartphone. Basically you are using a (virtual) mesh network of (other people) devices to remain in touch with your AirTag. Apple ensures that your information is protected and no-one, but you, can know where your AirTag is at any moment. Still this is both amazing and scaring!

The same strategy adopted for AirTags to overcome distance issues can be used to cluster smart homes in smart neighbourhood sharing some data (whilst protecting sensitive information) and through data analytics and AI provide awareness on the neighbourhood.

7.1 Smart Home construction

We spend a good portion of our life at home, we are there for shelter, for entertainment, for care and of course to eat and rest. No wonder that there is a lot of effort in making homes better and better. We have technology today, like 3D printing, that can enable the customised construction of a home in less than a week (the "box" can be built in 24 hours, the other 5 days are for trimmings and decoration…). In building a home from scratch we can use advanced materials and design the best infrastructure lay-out. Building a home with 3D printing technology started as a way to build quickly and cheaply and was targeting developing countries where 3D printed homes are aiming to replace shacks and huts. As 3D technology progressed better results can be obtained and in February 2021, a US company started to build custom made homes using 3D printing technology to deliver high quality dwellings that can interest a well-to-do market.

Figure 25. The future of smart home will be characterised by seamless smart interfaces. This one was proposed at CES 2020 providing the possibility to interact with a glass wall. Image credit: Telstra Exchange

We can expect further, and rapid, progress of this technology because it results in a construction that is:

- cheaper
- faster
- highly customisable

The 3D printing a home requires only 3 people supervising the machine. A small basic quality home may cost as little as 10,000$, the one in this clip was sold for 300,000 (much more but still half the price of an equivalent -size/quality- home). For a few examples and related cost look here.
What can be expected is that these new ways of construction will deliver homes that embeds a variety of sensors, that are fully wired as they are built, resulting in a new generation of smart buildings, at first in developed Countries where price is not critical, and then, as technology price decreases, also in many more areas. This is what can be called a top down approach: you build a smart home from scratch.
However, by far, most of the time the point is not building a new home, rather refurbishing the one we have. The life time of our homes is measured in decades (I am living in a house that was built in 1861 and when I was in Venice I lived in a

house built in 1468!). Hence, we cannot look at smart houses by building them from scratch.
What is being done, in these last years and for the coming decades, is turning an existing home into a smart home from inside out. We start by buying smart appliances (here the life time is measured in years, not in decades) and as orchestrator we turn to software (here the life time is measured in months).
By placing sensors in our home we can harvest the data and have some software to make sense of them providing insights and intelligence and making us aware of what is going on and what could be improved. What kind of sensors? We can start from the ones we have, like ambient temperature, humidity, light sensors (we have light sensors in our television, in our computers, in our smartphone), image sensors, vibration (we have this kind of sensors in our smartphone), intrusion control, …. Actually, our smartphone has plenty of sensors that could be harvested, including its microphone. Expect over the coming years to see these sensors becoming accessible by apps in our smartphone.
In this early stage the possibility of influencing our home will be limited, again our smartphone (apps) may connect to some of the home appliances to regulate the temperature, humidity, light, … but most likely it will be us that can take action. As more appliances and home infrastructures become interconnected and can be controlled from the network, the more the intelligence gathered from data will be enacted automatically.
As shown in figure 25, we can expect better and better interface to display the status of our homes and to let us interact with its various components from everywhere in the home as well as from outside the home. Some of the appliances are already making use of AI to understand our habits and adapt to them (like the robot vacuum cleaner that can spring to action cleaning the kitchen once we are done with the dinner and there are likely a bit of crumbles on the floor…). As mentioned in the previous post, the control of appliances through an orchestrator, using natural language interaction, is already a possibility and will likely become the standard way to communicate with appliances in the coming years,
However a smart home in the next decade will be much much more as discussed in the following.

7.2 The making of a Smart Home

Using smart materials it will be possible to build walls that change their characteristics, like become more or less insulating depending on the inside-outside temperature and the one we feel comfortable with, thus decreasing the use of heating/cooling. They can also change their surface reflectivity, again to improve insulation as well as to change their appearance. What if we already have a wall? New technologies can let us change its characteristics, at least to a certain extent. Look at figure 26. Nanoleaf has demonstrated at CES 2020, and is now selling, tiles that can be glued on a wall to create light patterns. The tiles can be controlled by an application (of course they provide you with an app for your smartphone) that can change the colour and light intensity of single tiles to create any type of patterns. The app can also offer you some pre-defined patterns that are supposed to "create and atmosphere" and can learn over time what your tastes are. Connected to Alexa it can work out, using Alexa capability of assessing your mood, the light patterns that would create a fitting ambience for your mood (or, even better, to improve it!).

Figure 26. A wall of your living room covered with LED tiles that can change their colours to match your mood and create a new ambiance every day. Image credit: Nanoleaf

Expect to see evolution of these tiles: in the coming years they will get smaller and smaller (and cheaper of course) to increase the resolution of patterns to the point of becoming a screen. Once that happens your walls can become windows extending your room into the cyberspace, into a virtual reality that can take your room everywhere. You may want to wake up on the seaside looking at waves gently rolling up to the foot of your bed (without splashing it!) or you can have your living room right by a waterhole in Zambia to watch wild animals at a waterhole -and unaware of being watched by you. There are already several webcams providing hi-res video streams from several water-holes, I just finished watching a herd of elephants at the Tau Waterhole on my laptop as I was preparing for this ebook.

Of course these screen-walls might extend your living room to the one of your friends once you decide for a remote, but intimate reunion. It is like video conference on steroids. The big difference is the perception it creates of sharing an ambient.

I guess this will become a standard feature of homes in the next decade as our ever larger television screens will end up merging into the wall.

Sensors will increase in number and in quality making the home more and more aware through intelligent applications that will be in connection with the dwellers digital twins, thus customising the home to the specific need of each dweller (and solving conflicts when two of them are sharing the same space…). Most important, the software will be able to monitor, from a healthcare standpoint, each dweller, picking up telltale signs of potential problems. Going to a hospital for testing will become rarer and rarer, whilst, at the same time, testing will become a daily (unperceived) occurrence. Future homes will be hubs for personal healthcare. Notice the use of the word "hub". It will no longer be a place for "tele-medicine", rather healthcare is local -particularly the proactive part- and connection to remote

sites is used to bring in what is needed rather than to have remote expertise monitor what is going on. The personal digital twins will have a major role in this transformation.
The increased home flexibility will be used to morph some of its spaces into an office that will aggregate, in the cyberspace, with other colleagues offices and with clients' spaces providing a real sense of co-presence.
Of course, this enhanced flexibility needs orchestration and companies like Amazon are well positioned to play the orchestrator role, as foreseen in the FTI's report. The orchestrator is bridging the house characteristics into the home for that specific dweller(s). The more the services we will enjoy in our home will be provided through the cyberspace, the more we can "port" these services from one house to another, taking the "home" along with us as we change our physical location. This is the harbinger for a revolution in the concept and perception of "home".
Imagine a time (some 10 years from now) when AR devices will be seamless. The digital twin of your home, along with the digital twin of yourself, could recreate on spot whatever type of home decor you may like, paintings from Van Gogh hanging (virtually) from the living room wall, a cinema size screen in front of you -at the appropriate distance – as you sit on the couch. You may share this augmented view with your guests while your children may play around seeng a completely different ambient that fits their fantasy… If you want to go deeper into what this evolution may lead to … take a look at this article and watch this clip. It does not really seem plausible to be imagining, as discussed in that article, that the value will be shifting from the physical house to the digital home that some service provider would be able to deliver to you using various forms of AR. It seems too far fetched. Yet, part of that vision may become reality as we are shifting from today's Reality to tomorrow's Digital Reality.

7.3 Sustainable Homes

One point raised in the FTI's report is the one of a possible change of paradigm, from "forced obsolescence" to "prolonged life span" for appliances and devices in our home.
The theory, and practice, of "forced obsolescence" goes back to the increased production capacity that required industry to sell more and more products to exploit that capacity (and therefore to cut amortisation and capital cost). This was/is also sustained by the continuous improvement of products, deriving from a relentless improvement of technology. Part of this is the design of appliances and devices without considering repair feasibility (sometimes even hindering). A good example is the design of smartphones that has made the change of battery, display, antennas tricky to the point that several users decide to change their smartphone when the battery starts to show depletion. Current lifespan of smartphone averages between 2 and 3 years depending on the geographical area and users' age (getting

shorter in the Far East Asia and in the 20-40 age range to average around one year).

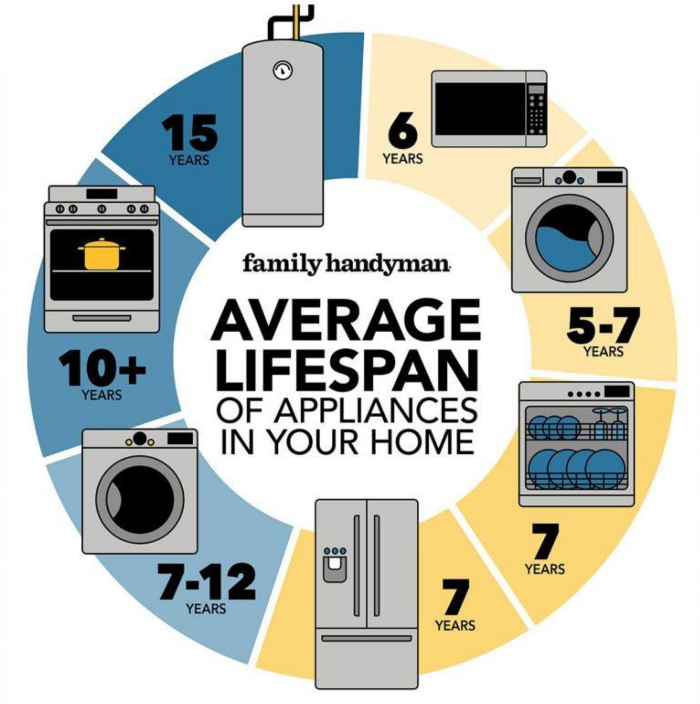

Figure 27. Average life span of several appliance types in our homes. Newer models may have a shorter life span since it may be impossible to find replacement parts in case of breakdown. Image credit: Family Handyman

The average lifespan of white goods appliances is shown in figure 27. Their life span could be extended if repair parts are available but usually we hear from the repairman that either the needed replacement part is no longer in production or that it is better to buy a new appliance (the repair may be more expensive or may not ensure a significant extension of the life span). Couple this with our desire (duly increased by commercials) of getting a “newer” model and you have all the ingredients for increasing waste.
The issue is just going to get worse, if left unchecked, because our homes are hosting more and more “devices”. This is particularly so for the electronic ones, since the rapid evolution of technology tends to make them obsolete in shorter time frames. The possibility of upgrading their features through software updates is not particularly interesting to companies that have their biz models rooted on selling “boxes”. A shift towards selling services (and the software upgrade can be offered as a service) is probably the way to go but it faces opposition from consumers that have become used to “free software patches”. Additionally, this goes against the general rule of economy stating that the price tends towards marginal cost (and the marginal cost for a software upgrade is “zero”).
It is worth noting, as highlighted in the FTI’s report, that the progression towards smarter and smarter appliances is leveraging on software capabilities. Today we are forced to replace our old PC because the newer software is no longer compatible with it (first is the OS that does not run on the chips of our PC and then the apps that would not run on the old OS). Imagine what would happen once your smart fridge can no longer support a new OS. Will you be forced to replace it?
The issue is a complex one since manufacturers have all the incentive to push for replacement, Additionally they have very little incentive of up-keeping costly spare parts warehouses that eventually will just undermine their sales market.
The pandemic, however, has steered several Governments in the direction of supporting, enforcing, sustainability and that involves decreasing the use of resources (materials and power). This has the additional benefit of decreasing waste on one side and on the other the design of repairable products eases their recycle (since a product can be split into more manageable components).

It remains to be seen to what extent Governments will be willing to enforce regulations forcing companies to release products with an extended life span. Clearly this would be a game changer.

8. Communications Infrastructures

The FTI's report dedicates one full section to the evolution of network infrastructures, noticing how much the pandemic has emphasised the importance of having a pervasive, scalable network.
As you read the report it becomes clear they are recognising that for the coming years 5G will remain the focus. Big Telcos are still claiming that 5G is the solution to all known needs, as well as to those not yet known (this is important since most of today's known needs would be satisfied by LTE and this "old" system is expected to dominate the market for the first half of this decade, 5G might take the upper hand in 2027 – the actual date will vary depending on the region, 2027 is for the European region).

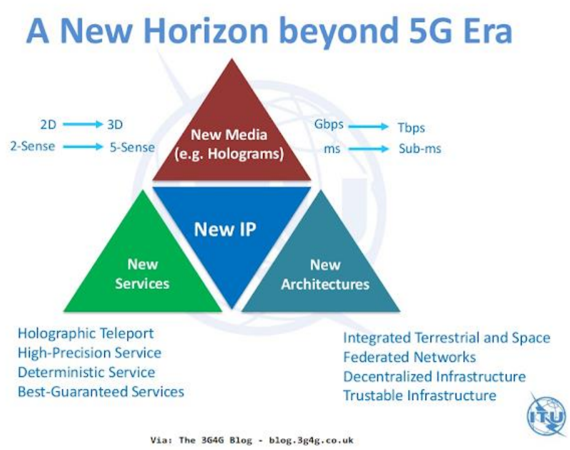

Figure 28. A new graphic to mark the "need" for a more advanced wireless network. Image credit: ITU

The current wireless network, a melange of 2-3-4 Gs (5G is marginal), has been able to face the challenges posed by the pandemic in most Countries. In Italy traffic has doubled on the fixed network, with a sharp increase in conference calls that are particularly demanding in terms of network quality, and has increased by 50% on the wireless network with no significant glitches. The Telco Operators have been able to double in a matter of hours (48-72 hours) the capacity of their backbones to face the surge of traffic showing that current networks can scale … graciously. This emergency also showed that the "current" networks are ok and this is somehow embarrassing since it has been claimed in the past two years that only the deployment of 5G would meet the increasing demand ….
On the other hand researchers have started to look into what might be coming next (the name is already clear, 6G, what it should deliver is also clear: more capacity, lower latency… exactly the same stuff that has been claimed for 4G, 5G and that will be claimed for 7G!) and this is double embarrassing since it underscores that 5G is not the solution! Don't worry, it is all a deja vu.
The report is trying to surf on these two embarrassments, the focus on 5G and the trend towards the 6G.
5G, particularly used as an alternative to fixed networks, FWA – Fixed Wireless Access-, is a great solution particularly for those (many) areas that are not covered by an efficient wireline network (fibre) and even more for those that are not covered at all. This again varies from Country to Country and from region to region. In Italy we still have several areas that are not well covered and that would be too expensive to cover with a fixed network. A broadband wireless solution (still

requiring a fixed network but a much more smaller and cheaper one) is a good alternative. Likewise for several sparsely populated areas of the world where satellite networks could meet the demand.
Now, meeting the demand is really the crucial point and in several cases the problem is not the network coverage but the lack of (sufficient) demand. In some cases it boils down to the chicken and egg problem, there is no demand hence Operators are not investing in the network, but if there is no network there's not going to be a demand.
If you look at the image proposed by the ITU, figure 28, as justification for research on 6G, you'll see that the demand side has names like holographic media, holographic services… That is nice and true: holography requires plenty of bandwidth, in the Gbps, and very low latency. However, devices supporting holography are what is needed most. And they are nowhere to be seen. May be ten years from now we will have holographic projectors in our homes, may be in twenty years time we will have holographic contact lenses…
Hence the question: When fast is fast enough?
The answer is … it depends on what your devices and your needs are. With present devices (smartphones) 4G is plenty in terms of speed. Not necessarily in terms of capacity, since the throughput of the cell is shared among the users of that cell at that particular time. LTE Advanced (that is the latest version of 4G) supports 300 Mbps of download speed and 150 Mbps of upload speed. If you can show me a service that needs more let me know. I would love to discover it.
Of course there is more than smartphones. I keep hearing of robots in assembly lines needing very low latency, future cars that need to talk with one another again with very low latency and why not, drones that are also (supposedly) requiring very low latency.
Now, with 4G you have a minimum (average) latency in the order of 50 ms, with 5G you can have a minimum (average) low latency of 5 ms. The point here is the "minimum". The fact is that what you get in terms of latency depends on many many things: is the server busy? Latency can go up to seconds. Is the network congested? Latency can go up to seconds again, for sure to hundreds of ms. Notice that these are not dependent on the G version, they apply equally to 4, 5 and whatever G.
Also, the distance from the source of data/services introduces a delay that becomes more significant as latency decreases: if you have a great 5G connection introducing 5ms delay and you are in Rome whilst the server you are accessing is in the UK you add, courtesy of the electromagnetic field propagation, some extra 5 ms, hence you double the latency. If the server is in New York you add some 21 ms and if it were in Sydney you'll add 55 ms, that is over 1,000% increase. Again this has nothing to do with the "G" being used so if you are starting from a 4G 50ms latency you have a 10% increase when connecting to London and a 100% increase when connecting to Sydney.
As you see the point of latency becomes relevant when we are looking at short distances, basically at the network edges (and this is why there is so much interest in edge cloud, edge computing…) but this does not require a mammoth network deployment to serve very specific edge requirements. Industry is looking at local solution for their factories, with local private networks tailored to their specific need.

Engineering (and paying for) a Country wide network to meet requirements for just a few users in very specific areas does not make any (economic) sense.
The conclusion? Unless we are going to have in the mass market devices that require speeds/capacity in the 10 of Gbps range we really don't need a 6G network.
On the other hand there are still two triangles to explore, the ones pointing to new architectures and new IP.

8.1 Communication Fabric

The architecture of networks used to be a top down activity, usually carried out by a Telco Operator (clearly standardisation always played a major role). The overall structure was hierarchical because hierarchy greatly simplifies the rules that each equipment has to follow (considering that those equipment in the past were electromechanical and you appreciate the importance of a hierarchical architecture).
The progressive penetration of electronics, and computers, in the network equipment and later in the control of the overall network, has led to much less hierarchical networks and added plenty of flexibility (interestingly those first steps were tagged as "intelligent network" in the middle on the 80ies).
Wireless networks came to life in the last 40 years, 30 if we look at their massive deployment, and therefore benefitted from the presence of computers in their architecture (the whole mechanism of the Home Location Register and Visitor Location Register is one of the example of the use of computers in the design of the architecture). For the ones in the field the 2G acronym, GSM, was known as Great Software Monster, underlining both the massive use of software and the suspicious attitude of engineers facing this software avalanche for the first time.
Even before the massive deployment of wireless networks a completely new type of network was being created, most of it as a virtual network overlaid on the telecommunications network(s): Internet.
Internet was designed as an aggregation of nets (Inter-Net) resulting in a very flat architecture where control (if one wants to call it control) was (is) completely distributed. Each "net" needs to have a sort of awareness of its "local" context and based on that it hands over packets to neighbouring nets letting them take care of forwarding those packets towards the intended destination. It is a sort of architecture that would not be possible without computers and it is an architecture

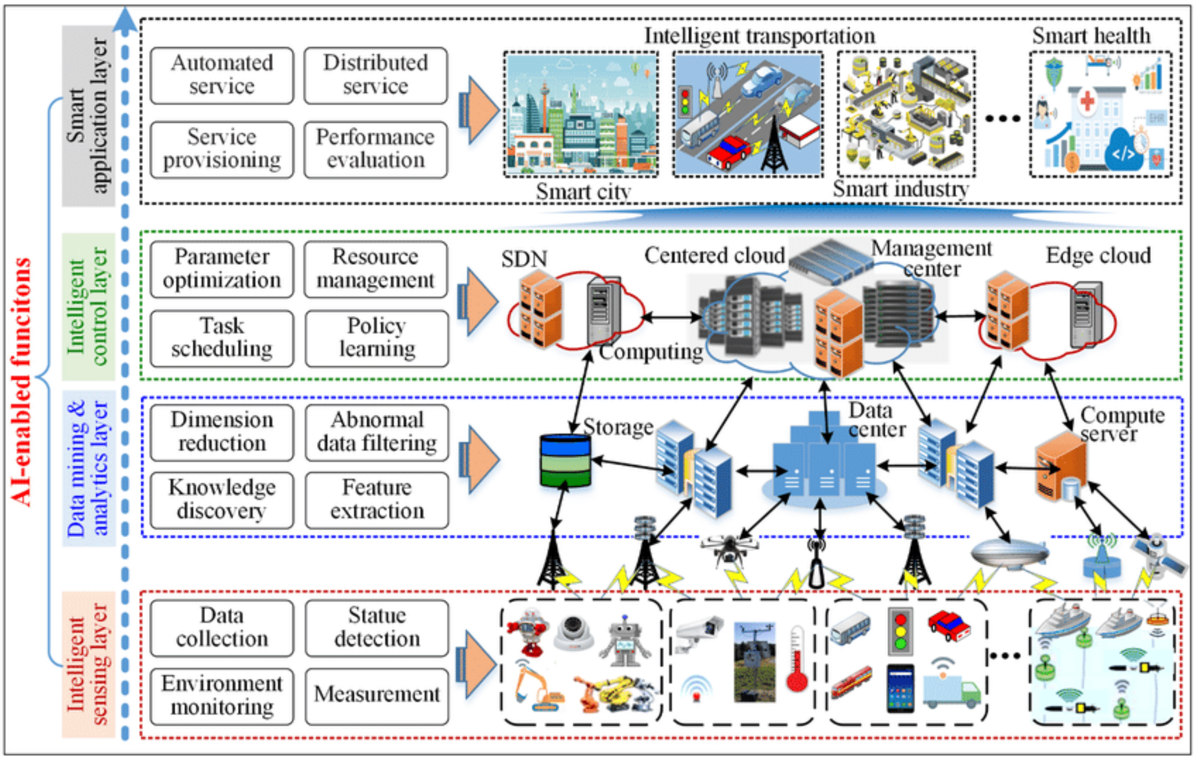

Figure 29. Future networks will make use of pervasive artificial intelligence, from the edge to the core and on to the vertical sectors. This will redefine both the network architecture and the players, completely changing the landscape. Image credit: Zehui Xiong et al., Artificial Intelligence-Enabled Intelligent 6G Networks

that would not have been considered by Telecom Operators since it relies on "chance" (nicely called "best effort"). Telecom Operators have always had QoS (Quality of Service) as their guiding beacon and setting up an architecture that was providing no guarantee whatsoever was just out of the question. The fact is that as technology progresses and network resources delivers more and more capacity with high reliability the "best efforts" gets pretty close to, undistinguishable from, predetermined QoS. It does not just become very close, in several situations it becomes better and achieves that through an architecture that is cheaper.
Today, telecom networks are also based (to a good extent) on this (virtual architecture): your smartphones is using the Internet Protocol for both voice and data communications.
Third element to take into consideration is that beginning in the 80ies computers started to be connected, creating "computer networks" using their own communications protocols (like the token ring protocol proposed by IBM in 1984).
Computer networks evolved and over time these three "networks":

- telecommunications network
- Internet (virtual network)
- computer network

converged into a "network of networks", resulting, from the application point of view, in a single heterogeneous network.
This long preamble to point out that networks have been evolving towards flatter and flatter hierarchies, moving towards the control to the edges and most importantly enabling applications to control the network (SDN and NFV are, to a

certain extent a Telecom solution to distribute the control at the edge, although most Operators are using them from the core to make the network more flexible and less capital intensive, i.e. to save CAPEX by increasing the effectiveness of network resource usage).
5G includes in its architecture several of the aspects mentioned. It is of course IP based, it offers the possibility to hand over the session control to the applications at the edges and enables the selection of network facilities from the edge (network slicing). Again, these 5G features today are controlled by the Telecom Operators that use them to offer better service and reduce its operating cost. Competition, in the second part of this decade will make these features available to the edges (and to applications) thus furthering the ongoing commoditisation of the network.
Given this trend it should come to no-one surprise that the 6G is being designed to enable:

- full control from the edges;
- creation of bottom up inter-networking (i.e. fostering the creation of connectivity by aggregating local networks into larger and larger clusters);
- data based infrastructure, where data are seen as encapsulated entities belonging to data spaces and perceived in terms of their semantics;
- increased awareness at the local level on what an application needs in terms of communication resources, considering these needs in a dynamic way. This points to an increased intelligence at local level and the capability to create a global intelligence out of these massively distributed intelligence.

Intelligence is, therefore, the keyword for 6G, as well represented in figure 29 stacking:

- Intelligent sensing layer
- Data mining and Analytics layer
- Intelligent control layer
- Smart application layer

Notice how intelligence is distributed in all layers and networking is achieved through an interplay among all components.
Interestingly, the network (at the edges) is being created autonomously by the presence of the entities using the network, like saying that your smartphone, or your car, a robot, a drone, generates a multitude of local area networks that dynamically cluster creating a larger and larger communication fabric.
The way these entities will communicate with one another and will act as nodes in the communications fabric will need to be defined and may eventually result in an evolution of the internet protocol (IPv6) used today.
There is still quite a bit that needs to be discussed and defined but the evolution trend is clear, involving a much greater role of the edges and of the devices (hardware and software). This will create a major disruption in the telecom business.

8.2 Edge Computing

As mentioned in the previous section, and as pointed out in the FTI's report, the evolution trend for communications networks is shifting the focus to the edges.

Hence, in this decade we can expect a growth of data processing at the edges, both in devices and in hubs aggregating devices' data (micro clouds / fog) and processing them.
If we look at devices, like a smartphone, a television set, a home assistant or, even, a car, we see that the increase in processing power and storage over the last twenty years has been amazing and it is not relenting:

- smartphones: they are computers and there are even adds on, like keyboard and connection to displays that transform them into a portable computer. They already have all the processing power you may need, plenty of storage capacity (new models support TB cards, with price of 30$ for 512GB!) and of course a broad stack of connectivity options (Bluetooth, NFC, WiFi, Cellular Network…). The trend towards increased capacity (processing, storage, connectivity) will continue and new wireless systems will support their aggregation into local processing hubs, into fog;
- televisions: smart TVs pack a lot of processing power both to process the television signal (it has become normal for the latest sets to convert a HD signal into a 4k video and the next step is to upscale to 8k video (if you bought a recent 8k television) and just that calls for plenty of processing power. Additionally, smart TVs run a broad range of applications and interface with the internet. Storage capacity is usually limited but most models can connect to local storage (flash drive and hard drive). Expect this trend to continue in this decade;
- home assistants: we are becoming familiar with Alexa and the likes. These devices are connected to the Internet and a good portion of the required processing (like the one for natural language processing and understanding) takes place in the (big) cloud. However the trend is towards embedding more and more capacity locally and to perform local processing. As an example, new Alexa devices (Echo and the like) are powered with the EZ1 neural edge chip and this will make voice interaction much more fluid since processing takes place inside the device. I wouldn't be surprised if the uptake of Personal Digital Twins will foster even more this "local" evolution, with the home assistant becoming the host (and enabler) of PDTs;
- cars: car manufacturers are already more focussed on processing power than horsepower for their new models. NVIDIA is expecting to generate some 8 billion $ from chips designed for advanced in car-processing and Volvo announced (April 2021) a partnership with NVIDIA to include new generation chips in their models starting in 2022 to provide sufficient processing power to support the "software" evolution towards autonomous driving. For a nice infographics showing the number of lines of code in a variety of "systems", including cars click here. On average the estimate is in the range of 100 million lines of code in a car and a processing power that is in the order of trillions of computation per second (a fully autonomous car will likely be in the range of hundreds of trillions of FLOPS with TBs of storage).

As you can see there is plenty of technology at the edge to support processing (edge computing). Yet, what I just listed are not the devices that are fuelling the uptake of (and transition to) edge computing, although by the end of this decade

they will represent the lion’s share of edge computing (because of their sheer number).
Edge computing is being driven, today and in the coming three years, by industry, notably manufacturing, warehousing, big construction sites, refineries, mines,…

Figure 30. Amazon Snowcone is a rugged box designed to provide edge computing in the field, extending the AWS services at the edge by creating a local cloud with processing capability. Image credit: Amazon

The big guns, like Amazon, Microsoft and IBM (in the Westerns world) are scrambling to provide edge computing solutions. Amazon, as an example, is investing 29 billion $ in its Snowcone edge computing project (29 billion! In Italy we are discussing what is the value of the whole telecommunication infrastructure of the Incumbent and the range is between 12 and 18 billion $ – for the whole network!). In addition to these edge cloud and edge computer extensions to the big cloud services we should consider platforms like Mindsphere (Siemens) supporting what is called the Industrial Edge, that is the infrastructure aggregating IoTs, processing, storage and data analytics (AI). That’s not all.
Telco Operators are now trying to exploit the 5G capabilities (and ORAN – Open Radio Access Network) to provide cloud and edge computing to their clients (biz clients).
The evolution that we are going to see in the coming three years fuelled by biz applications (and by emerging data architectures like Gaia-X) will set the scene for the last years of this decade when massive distributed AI leveraging on fog and edge computing (with the edge extending in the devices) will dominate the landscape shifting the evolution focus onto the residential market.
The (incomplete) list of “residential/mass market” devices that I provided today are marginally connected and are more independent silos than part of a single environment. I can view clips that are on my smartphone on my television screen, I can use Alexa to activate my media centre… but they are really separate pieces with different applications and managing different data spaces. By the end of this decade the situation will change. All these devices will become components of a single ambient where all data are shared as well as applications will interoperate and leverage on the whole capacity offered – i.e. they will create the cloud and the edge computing environment (in the Apple “silos” we are already seeing this happening with the new M1 chip able to run the same apps designed for the iPhone, the ones designed for the Mac and the ones designed for the iPad – I guess the Apple TV will follow suit).
New programming paradigms are being investigated to allow the design of software that can be deployed -dynamically- on any device belonging to a given environment, Notice the change: rather than having a cloud deployed at the edge, the devices at the edge will create their own cloud!

9. Robotics

Figure 31. Human robot collaboration is increasing in many sectors eventually leading to augmented humans. Image credit: Universal Robots

Robots have become pervasive in many sectors and their presence and capabilities are going to keep increasing in the coming years.
The FTI's report includes several areas of evolution, made possible by technology increased capabilities.
Indeed technology has been, and still is, the driving force in the evolution of robotics with artificial intelligence having the lion's share in the present and coming years.
In the following I provide a list (addressed in the FTI's report) adding to each area the technology driving the evolution:

- Robots as a Service – RaaS: Cloud, Edge Cloud, 5G, Digital Twins, Artificial Intelligence
- Cobots: Artificial Intelligence, Natural Language interface, Digital Twins, Augmented Reality, Edge Cloud, Smart materials, 5G
- Robots Swarms: 5G, Digital Twins, Artificial Intelligence
- Smart Dust: MEMS, nanotech, Smart Materials, low power communications
- Self Assembling Robots: smart materials, Digital Twins, Artificial Intelligence
- Soft Robotics: Smart materials, flexible/printable electronics
- Robot Compilers: Artificial Intelligence

As mentioned, notice the (almost ubiquitous) presence of artificial intelligence.

a) *Robots as a Service*

The growing use of robots in manufacturing, warehouses and logistics has led to an effort of simplifying the creation and management of robotic environments. Platforms developed by Amazon (AWS Robomaker), Google (Cloud Robotics) and others allow developers and system integrators to create a virtual ambient to test and operate clusters of robots. Some of the functionalities can be offered as a Service, thus minimising capital investment and accelerating deployment. Notice that as robots are more and more software based machines, subject to continuous evolution (deployment of new software releases) their management in terms of virtual objects becomes very important since a specific (user) company does not need to keep abreast of software changes but can simply refer to the RaaS platform.

b) *Cobots*

Collaborative Robots, aka Cobots, represent both an evolution of robots in the industry sector and a trend towards human augmentation. More specifically, they are a departure from industry robot because cobots:

- are designed to be safe for humans in their proximity (they don't require any "fencing" to avoid contact);
- are designed to complement human actions by collaborating to achieve the end goal (whereas industrial robots are designed to carry out a specific task in a sequential way, when they are on the task there is no human around on the same task)
- require a seamless interface to interact with humans in the "team", more and more using natural language interaction;

Cobots are evolving in three steps:

- becoming more aware of their environment, including more aware of the humans in the team, and able to adjust, autonomously, to changes;
- becoming able to learn from their team participants (e.g. by observing humans in the team they learn and adapt);
- becoming able to "teach" to other members of the team (tell humans what to do to improve the teamwork);
- act in symbioses with a specific human resulting in a seamless extension (augmentation) of that person capability.

Artificial intelligence is one of the main steering enablers for the evolution of cobots, since it supports the ambient awareness and seamless communications "in the team". 5G, particularly private 5G, may also become a strong enabler providing low latency connectivity across the team and supporting augmented reality visualisation. Digital Twins are also a growing component in cobots as they are bridging the various team participants through the cyberspace.
According to the International Federation of Robotics 2020 Report, the cobots market share is still tiny, 4.8% in 2019, but it is the fastest growing segment, so it makes sense to pay attention to this segment in the coming years.
Although there has been a slow-down in the acquisition of industrial robots in 2020 (-12%), because of the pandemic, it is expected a prompt recovery, as already been seen in China leading to an acceleration in the adoption of robots, as part of the lessons learnt from the pandemic and impact on the work processes.
Look at the AURA Cobot in this clip created by Comau as an example of current cobots.

c) *Robots Swarms*

Robots are growing in number and they are learning to cooperate. As the number of cooperative robots involved in a specific task grows, their coordination becomes more and more tricky. However, we have examples in nature where seemingly low-intelligence entities manage to cooperate achieving impressive result as a whole. Bees and ants are obvious examples and they are not alone. Aggregation of

independent living entities often generate complex structures (let's not forget humans that manage -often without directions- to achieve impressive results that would seem to derive from some organised control Think about walking in a crowded street: you are usually not bumping on other people as both you and them take avoidance action to avoid collision and that is done without any "rule" nor coordination).
Scientists have discovered that group behaviour can derive from some very simple rules that are shared among the group and enacted independently by each entity in the group. Take a look at this clip, showing the choreography by a flock of starlings. There is no orchestra director, each bird is on its own, yet together they create an amazing performance.

Figure 32. Kilobot Robot Swarm
Image credit: asuscreative

Now researchers are working to use similar approaches to enable cooperation among hundreds of robots. An example is Kilobots, shown in figure 32. They have been developed by researchers at Harvard at a cost of 14$ per unit. They are so cheap because each one of them has stripped down functionality but they can act as a single body and all together can perform complex activity. This is (was) just a sort of possibility demonstrator, but the idea is catching up.
As reported by the World Economic Forum, Walmart filed (2018) a patent for autonomous robot bees to serve as pollinators (this may turn out to become a crucial technology as bees are being decimated in some parts of the world and bees are a fundamental cog in the food chain).
The creation of a robot-swarm needs to take into account distributed decision making, based on individual decisions, including:

- consensus: a general algorithms supports individual decisions that converge onto a specific goal. Decisions may differ (like one robot decides to go left, another to go right) but they all result in a convergence towards the goal;
- tasks allocation is distributed to maximise the global efficiency and does not require a single control point. Allocation results from local awareness (like I am overloaded you are not….);
- collective fault detection: each robot in the swarm is able to detect if the behaviour of the neighbouring ones can be trusted (in other words if they are functioning as expected) and automatically exclude those perceived as "aberrant" from its set of relationships;
- continuous resynchronisation leading to a dynamic local change of behaviour that creates ripple and reaches all corners of the swarm (this is exactly what happens in flocks: local changes result in a wave of change affecting the whole and in turns creating a feedback on the local environment).

For an interesting overview/roadmap of robot-swarm evolution take a look at this document.

d) *Smart dust*

Figure 33. A solar powered mote (smart dust) with bi-directional communications and sensing (acceleration and ambient light) 11.7 mm3 total circumscribed volume ~4.8 mm3 total displaced. Image credit: Joseph M. Kahn and Brett A. Warneke, University of California at Berkeley

Take a robot and squeeze it to the sub-millimetre scale (even to the micro scale, and to exaggerate to the nano scale), then multiply it by thousands or tens of thousands: what you get is smart dust, tiny speckle of silicon that embeds sensing, micro-processing and local communications capabilities. Their very existence (and mutual position) correspond to a state of the swarm.
Smart dust was imagined over twenty years ago and their properties demonstrated in the lab (Berkeley). At that time they were "big", like a cubic cm, but the idea was to have them much much smaller, the size of a dust particle (hence the name). They have already shrunk to the sub cubic millimetre and in the second part of this decade they will get even smaller. The bigger ones, in the mm range are also known as "motes".
According to the FTI's report they will find application in several fields, including sensing the brain activity and interacting with peripheral nerves in bioelectronic applications (neural dust). Sensing in various fields is likely to remain their main area of application, flanking the IoTs and extending their application. Military, agriculture, factory automation, healthcare are seen as the main areas of application in this decade.

e) *Soft Robotics*

Robots have been associated with something "hard", most likely because their roots are in the world of mechanics, being built with cogs and bars. That was clearly setting them apart from living things that are all made by some soft substance (we call it flesh….). Yes, most living creatures have had to develop some sort of scaffolding (internally, like our bones, or externally like the insects' exoskeleton).

Only those floating in water, like jellyfish and octopuses had been able to make do without hard stuff.

Figure 34. It looks like an octopus yet it is a robot, developed with EU funding in the research project (would you guess?) OCTOPUS. Image credit: Scuola Superiore Sant'Anna

Researchers have worked in the last twenty years to find some "soft" materials that could be used as a wrapping for robots, a sort of robotic skin that could be used as a sensing interface or just to provide a more pleasing interaction for those robots that are designed as human companions. That has required finding materials that can be resistant to continuous deformation as well as able to accommodate electronic components (plastic electronics).

The FTI's report dedicates some thoughts to soft robotics because of its potential to extend the area of application of robots in the coming years. Soft robots would be able to change their shape and adapt to tricky environment much better than their hard siblings. Also, several types of biomedical applications (like prosthetics) would benefit from soft robotics.

In figure 34 the photo of Octopus, a soft robot developed with European research funding by the SSSA in Pisa. It can float and move in the water and like the real octopus can use its tentacles to grab stuff and move them around. An interesting twist of soft robotics is the focus on developing robots that could self repair. Of course the very first step in self-repair is to be aware that there is something you need to fix. Artificial intelligence and sensors that provides the equivalent of our sense of pain are being used. The next step is to have some material with self-healing properties and this is a whole new area of material science that is joining forces with soft robotics. Here again there is a significant role to be played by artificial intelligence since repairing something requires an understanding of the goal (how is the repaired stuff supposed to be? This goes both for the form and the function). It also involves design approach, robots have to be designed with self-repair in mind, hence the interest in soft robotics since "soft" its easier to handle (from a repair point of view) than hard.

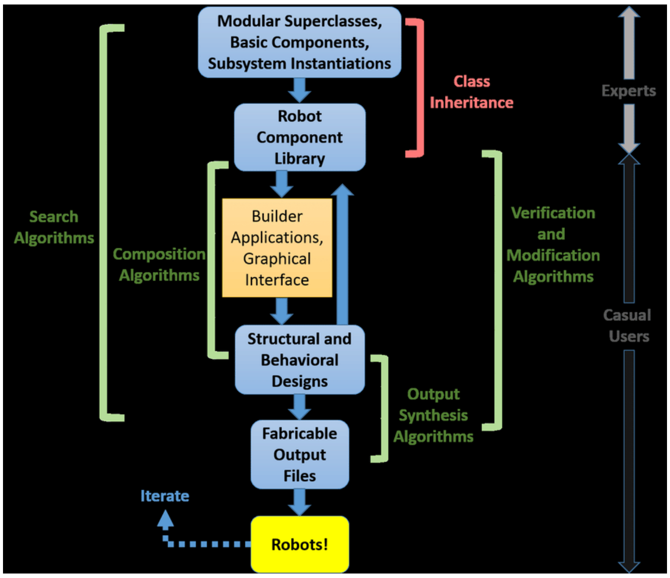

Figure 35. The robot compiler foundation consists of expert-defined superclasses that can be hierarchically composed into increasingly complex electromechanical designs by casual users. This creates a library of parts, each of which can be compiled into fabricable outputs. Suites of included algorithms operate in each phase of the process. The rapid and intuitive nature of this process encourages an iterative design approach. Image credit: Joseph DelPreto, MIT

f) *Robot compilers*

The need to design self repairing structures, hence understand the function required and how to implement them, set the stage for systems that support the creation of robots, the so called robot compilers, since a good portion -more and more- is about designing the software (if I may, software for a robot is what a soul is to us…it provides the operating framework, and its execution, i.e. the functionality).
There is quite a bit of (research) work going on motivated by the expected increase in robots adoption and the need to enable users to customise their robots to their specific needs (give them the soul). The ultimate goal is to be able to develop mass market programmable robots, as today we buy PCs and then customise them (with software and data) to fit our needs.

10. Logistics

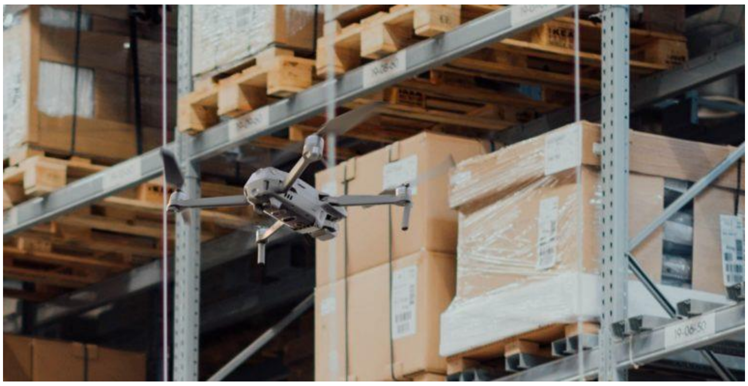

Figure 36. A drone scanning pallets for real time inventory. Several companies are offering warehouse inventory based on drones. Image credit: Aptuser.

Autonomous Mobile Robots (AMR) and Autonomous Guided Vehicles (AGV) are becoming more and more common and the FTI's report foresees a significant increase in their deployment in the logistics, most notably in warehouse automation. However, as flexibility increases and cost decreases, we can expect to see them used in several other areas, including manufacturing, healthcare, agriculture, retail, disinfection, security and cleaning. Logistic is likely to remain the top application and the one steering their evolution.
The use of AMRs and AGVs in warehouses is increasing automation, leading to a 70% decrease (job loss) in labour resources. Also, it is expected to provide more efficient use of the space (denser shelving).

Their evolution is made possible by artificial intelligence and better data harvesting resulting from image recognition and LIDAR. 5G (in particular private 5G) may also be instrumental in increasing their spatial control (although in many warehouses WiFi 6 is likely to dominate the communications landscape). This is particularly important for the increasing interest in using drones inside warehouses for inventory as shown in the picture (watch this clip).

I am currently involved in the definition of a lab for manufacturing and autonomous driving in Turin, involving the participation of several industries, and one of the focus is the trial of AGVs in manufacturing and warehouses ambient, also through federated lab, so I can tell from first hand experience the strong interest of industry in this area.

According to the latest ResearchAndMarkets report their value should reach 13.2B$ by 2026 with some 1.5 million installed over the next 5 years. Interestingly, their report is titled: The new Normal in our day-to-day operational activities. Looking further ahead, the expectation is to have some 6 millions AGVs in operation in the coming ten years.

Considering the increasing automation of warehouses, the streamlining of the supply and delivery chains with a decreasing number of warehouses and the push towards customisation at the point of sales and the message is clear: the number of jobs in this area will continue to decrease, in spite of the uptake of the eCommerce. The pandemic has seen a surge of eCommerce, hence the increased demand for workers to handle orders. In turns this has accelerated the drive towards automation and eventually this will result in a sharp decrease in jobs.

Another interesting trend emerging from the pandemic is a growing attention to the “cold chains”, that is the distribution chains that have to ensure a maximum temperature throughout the whole chain. Vaccines have placed strong demand, most of all the Pfizer one, requiring very low temperature from production to the end delivery point. It is not just vaccine, of course. Your sushi, as an example, is travelling thousands of miles before reaching your plate and it also requires a good cold chain. Artificial intelligence in the cloud is tasked with monitoring temperatures along the cold chain and finding alternative paths/rerouting in case the handling becomes risky. Also, a whole evolution of packaging is on the way to better protect products from temperature variations as well as to act as sensors for temperature monitoring.

The drone sector has evolved in a complex ecosystem including thousands of companies catering from manufacturing to operation, software development for control and for deployment in different fields. According to Forrester, drones are enabling the Digital Automation in the air.

The FTI’s report highlights the disruptive impact that drones are having and will have in several sectors. One of the interesting points arising in the report is the expected growth of drones’ fleets and drones network that will support a DaaS, Drone as a Service, model. Companies like:

- ZipLine - Delivery at speed of light, that’s their tag line, and their focus is on delivering emergency wares, like vaccines in remote areas-,
- Anduril - security through UAS -, Terra Drone -drone service provider for aerial survey-,
- Hemav - data harvesting through drones and AI analytics- and
- Matternet - drones delivery network-

are the harbinger of what can be expected in the second part of this decade.
As shown in figures 37, drones are expected to fly in a reserved airspace between 50 and 150m, placing them above (most) residential buildings and well below airplanes traffic (of course keeping them away from landing and take off corridors in the vicinity of airports).

Figure 37. A rendering of a drones network that can be used on demand for a variety of needs, from inspection to delivery. Image credit: Drone Watch EU

However, the sheer number of drones that are expected to buzz over our heads in the coming years, including big ones like taxi-drones, requires a completely new approach to traffic control: enter the new area of drone-swarms. The military sector, as pointed out in the report, is leading the way, although there are now several examples of drones swarms used in entertainment (well known is the one created by Intel at the opening ceremony of the 2018 Olympic Games). The most recent drone swarm show took place in Shenzhen with over 3,000 drones (new world record in 2020, watch this clip… However, records are made to be broken and in 2021 a new world record with 3,281 was set in Shanghai, watch this clip).
A massive use of artificial intelligence is required, but this is a sort-of new AI, since it is based on a multitude of local very-low level of intelligence that results in an emerging intelligence at the swarm level, similarly to natural swarms (of bees and other animals). Intelligence is a costly business and you need to achieve a significant level of computational ability. This is costly. An alternative is to use many points of low level intelligence and cluster them to create an emerging intelligence. Drones in a swarm have, relatively speaking, a higher IQ than a single bee (or ant or a grasshopper…), but there are so many more bees in a a bee swarm so in the end the emerging IQ may still (today) favour the bees. But in the coming few years, within this decade, the expectation is that drone swarms will significantly increase their IQ to the point of reaching “swarm autonomy”, as an example becoming able to self-route their movements in a complex environment, like goods delivery in a city, without having to resort to a centralised intelligence (control).
An interested approach is the one of “leveraging diversity in the control policy“: basically each drone starts with a slightly different program resulting in a different behaviour. These different behaviours are evaluated in terms of result by the swarm leading to fine tuning of the individual behaviour and in self-learning of the overall swarm (if this sounds similar to the GAN approach it is because it is!). It is a fascinating area of research that promises to impact the evolution of artificial intelligence and the way it is applied.

11. Autonomous mobility

The trend towards autonomous mobility, in all sectors, is “unstoppable” leveraging on several technologies that have been evolving in the last decade and that are

promising to become affordable in the current one. Automation in mobility feeds on the same forces that pushed automation in manufacturing: better and consistent performances and lower human involvement (that implies lower risk of harm to human operators, lower cost in operation and training, higher flexibility, no distractions nor tiredness…).
The reasons why we have been waiting for so long in pursuing autonomous mobility is quite simply that it is much more difficult to manage an ever changing situation (as you move around the context is bound to change) and it requires a higher degree of awareness on the overall situation plus on the evolution of the situation, as actions are taken by anybody in that context.

Figure 38. A robot is sitting on the pilot seat. There are already a number of airplanes that are able to fly and land in an autonomous way (departure remains tricky) but for airplanes without this capability a robot impersonating the pilot may do the job. Image credit: DARPA with Aurora Flight Sciences

Advanced sensors, signal processing and artificial intelligence are the crucial ingredients (and of course effective actuators!). This also requires quite a bit of processing power, more than was available (at an affordable cost) only few years ago. The processing in principle could be located outside of the autonomous "moving" device but in that case the latency in the communication channels (both the one connecting the device to the processing point and the other from the processing point to the device) should be kept below a given thresholds, depending on the situation (the type of environment and the speed of the device…).
This is the reason why the (potential) low latency of 5G and the deployment of edge computing and edge cloud to bring processing closer to the final user is so interesting.
However, the advance in processing performance, at affordable cost, is now co-locating the required processing inside the device, leaving to the edge cloud/computing the role of global/local awareness and supervision (like to understand the overall traffic in a given area). In perspective, early next decade probably, we might have so much processing power within each single autonomous device and a pervasive device to device communications fabric that the need for an edge computing may relent (welcome to 6G).
The first approach to remove the humans from the wheel is based on inventing something that can replace the human, like the PIBOT robot (watch this clip). At KAIST researchers have created a robot that can sit at a pilot seat and fully control the plane from take off to landing. It has been designed with the goal of replacing a pilot for missions where a pilot would not be able to operate the plane (imagine a nuclear accident where a pilot would not be able to get close to the accident site because of radiation). Previous versions were designed to help the pilot acting as "second officer" (as the one shown in figure 38).
The interest in this approach (having some artefacts impersonating the pilot at the wheel) has the advantage that it could be applied to existing vehicles (you just need

to design it in such a way that it can fit). However, if you can start from scratch the best approach would be to “remove the wheel”! This is what the FTI’s report predicts for the coming years.

Figure 39. Missing something? This car has no steering wheel. That is the idea of car by General Motors. Image credit: GM

There are already plenty of devices without a steering wheel! Think about the old Roomba, the autonomous vacuum cleaner introduced back in 2002 by iRobot. Well, it bumped on chairs and walls but that was not a big deal. Upon bumping it backtracked and changed its direction: no problem! Subsequent releases learnt to recognise obstacles (including cats, although I am pretty sure cats were able to spot an approaching Roomba well before Roomba spot them). I mention Roomba because it was probably the first mass market fully autonomous vehicles and it embedded an amazing (for the time) set of sensors and smart (intelligent) software.
Of course, roaming in a flat with licence to bump here and there, is quite different than roaming in a city, at much higher speed and with no bumping permission. Hence, no surprise that fully autonomous vehicles are still scarce. Scarce but real! Zoom, by Amazon, is an example of an autonomous vehicle designed from scratch. It has no steering wheel (like the prototype GM car in figure 39) and I found interesting hearing the impression of its passengers (watch this clip). I already tried a number of self driving cars (in dedicated spaces, not open to normal traffic) but most models I tried had a steering wheel and even if I did not touch it during the (short) drive I found that its mere existence gave me a stronger sense of security. The only one without a steering wheel was the one in Masdar, Abu Dhabi (it looked a lot like a Zoom). It didn’t give me the creep mostly because it was driving underground in what looked like designated lanes. I am pretty sure I would feel uncomfortable experiencing a normal car without a steering wheel in normal traffic, like I am missing something (important). My feeling is that we will have to wait a few years before fully autonomous cars become common, and even more before they lose the steering wheel. A different story applies to VTOL -Vertical Take Off and Landing- taxi drones that should be starting service in some areas (Dubai, Singapore) already this year at a price point, this is the interesting part, that compares to the one a a normal taxi during peak hours.
On the contrary, fully autonomous vehicles for freight transportation, both land and air transport, are likely to become common during this decade to the point that we won’t be paying any more attention to an autonomous delivery of pizza by the end of this decade.
Based on the FTI’s report we can expect, also fostered by the pandemic lockdown in several areas, an uptake of last mile delivery based on autonomous vehicles. JD.com, a big Chinese eCommerce, has delivered over 13,000 packages covering close to 7,000 km in lockdown areas during the pandemic. Clearly they had benefited from much lower traffic but still it has been quite a trial and learning

experience. According to the WEF, the surge in eCommerce will lead to a 36% increase in delivery vehicles by 2030 with last mile delivery increasing by 78%. This will increase pressure in developing effective autonomous vehicles for goods transportation.
The increasing use of autonomous drones for infrastructure inspection will stimulate evolution in image recognition and related AI. In turns this will result in better "follow-me" capabilities (already available in mass market drones for photography).
It is not all bright. As we are seeing on recent newspapers articles, and pointed out in the FTI's report, privacy concerns are rising against police using autonomous drones and robots for patrolling and following people. The recent EU document on ethical use of AI is explicitly classifying the use of surveillance based on AI on autonomous vehicles as a High Risk application.

11.1 Reinventing the car

Figure 40. An interested graphic, posted in 2016, on the leading company that would shape the car today. Although it has not turned out exactly as foreseen there is still a lot of it that is both valid and a harbinger of what is to come. Image credit: Prathyush Devadas

One of the interesting part of the FTI's report is the one focussing on the evolution of the transportation sector that will change the status quo of manufactures as well as the value perception of the market. If you think about it, for decades the competition among manufacturers has been among similar, and they all have been addressing the same value perception of a growing market: cars were a status symbol as much as a transportation means. That pushed the offer towards more and more fanciness in cars (luxury, speed and acceleration as emotion engines) and more and more efficient cars (lower consumption, higher safety, …).
The pandemic and the lock-down has accelerated a change in value perception that had started in the second part of the last decade: as shown in figure 40, by 2016 a new idea of car, and related players, started to emerge. The car was transforming its essence:

- at the mechanical level by moving to an electrical powered engine. This changes the components (reducing their number and types) affecting the manufacturing value chain. The key player in 2016 was expected to be Tesla and indeed, in 2020, Tesla was the key player with a (inflated) capital value exceeding the one of General Motors. On January 1st, 2020, the Tesla market capitalisation hit 89 billion $, 2 billion $ more than the combined market value of GM (50B$) and Ford (37B$);
- at the "driving" level, by progressively shifting to an assisted and then autonomous driving. In this area we have seen huge technology advances (smarter image recognition, AI, affordable LIDAR) that as a matter of fact would support a level 5 autonomy (full autonomous driving) but that, in practice has not been supported by regulatory acceptance (also because, let's be honest, it has not reached the safety level -way way higher than

human drivers- required to be accepted). Google was expected to lead, in a way its spin off Waymo is among the leaders (I love their tagline: “we are building the world’s most experienced driver”!). In a way Tesla is also being perceived as the company leading in autonomous driving. What we have seen, as for the case of electrical propulsion, is that most of the big car manufacturers are pouring money on autonomous driving research. The side effect has been a sharp increase in the features for assisted driving that are now, to different degrees, a standard in new models;

- at the engagement level by becoming an entertainment hub. The expectation, back in 2016, was to see Apple taking the lead. In a way they have released a number of interfaces that create a seamless continuum between the car (basic and not evolving) entertainment system and the smartphone (Android phones have followed on the iPhone trail). Several car manufacturers are now offering as an “add-on” Apple car play features (and Android features) recognising that the evolution is definitely in the hands of the Apples, Samsungs and the likes for what is personal services (they go well beyond entertainment to include navigation, information services, communications…). The perception of value provided by these services is so strong that there is a recurrent rumour of Apple entering the market of car manufacturing (so far it seems they are much more interested in reaping - indirect- revenues from their products expanding their usage within the car than investing huge money in what remains a very low margin market);
- into a transportation service. Huber (and the likes) have demonstrated in these last five years that there is a revenue opportunity in the car as a service space.So far the dent created in the overall car market has been marginal. Huber has today a market capitalisation of 1.4 B$, 0.3% of car manufacturing companies and has probably not decreased their market value. In the longer run, the confluence of self driving cars with the car as a service model is going to affect car manufacturers production volume. In this decade the production volume is expected to grow by a small 2% pulled by increasing demand from emerging markets (declining in advanced economies although sustained by a demand for cleaner vehicles). The situation will change for the worse in the following two decades where a sharper decrease in production volume can be expected. The world production of cars peaked in 2016 with 100 million vehicles, in 2019 it was down to 92 million (in 2020 it plummeted to 78 million but it is expected to recover in this year and the next ones). By

2050 the total volume may be below 60 million (more use of car as a service and longer life span of electrical cars).

Figure 41. The MIT Smart Cities research team's car. Image credit: Franco Vairani/MIT Department of Architecture

If you want to see how wild our imagination could be about the future of car, just browse the web. You'll find futuristic supercar that fall in the category of "faster, luxury, amazing, wow", as well as cars that are designed to fit a specific function, like saving parking space (like the ones from MIT shown in figure 41 that can change their shape and be staked one on the other).

Most of what you see is just not going to happen, because they would cost too much and would remain a toy for the ultra-rich, or because they are not appealing and would fit more an industrial deployment rather than a consumer market.

As mentioned in the previous section, our cars and, most importantly our perception of what our car should be, will change significantly in the next decades. It will be, however, a relatively slow process so that it will be impossible to put a date on this change. Slowly today's cars, and the way we use them, will morph into something different. Keep in mind that the economic forces (manufacturers goals) will remain in place with a strong push to sell hence a strong advertisement to convince us to buy.

Nevertheless, the shift towards CaaS, Car as a Service, will be unstoppable. The shift towards self driving cars, the enforcement of policies to decrease pollution (it goes hand in hand with power consumption) are converging and transforming our perception of cars from a personal status asset into a commodity that takes us from a to b at a pace that will no longer be controlled by us.

As pointed out by the FTI's report what we call today a car will become a pod that is part of a global transportation system. This pod may be loaded onto a gondola for transport in underground tunnels or be picked up by a drone to be flown to the other side of the city (watch this clip). As such most of these "pods" will be commodity that are available for use, not personal properties, although there might be a significant market for personalised pods. Actually, the Covid-19 has shown a desire to use a personal transportation means, increasing the perception of safety. Some car manufacturers have started to advertise HEPA filters to make your car a protected biosphere. There will always be a luxury market offering, with "golden pods" (or possibly more likely pods with the Armani brand -or the likes), like today hotels are a commodity but you have hotels in all range of prices.

The infrastructure supporting mobility and inter-mobility is the real game changer, it is the one that is delivery efficiency, low carbon footprint and business value. It is notable to see how China is investing in transportation infrastructures from high speed rail to metro underground, from communications to artificial intelligence. Notice that all of them are integral part of the future of transportation, the former

providing physical transportation the latter virtual transportation. And the future of transportation is a mixture of both, as the pandemic has started to show us. Another crucial difference, already in the making, is that we will be transforming the pods (the cars) that will happen to use with our very presence. The entertainment and the interface with the car mediate environment will be brought on the car by ourselves, possibly embedded in our smartphone and in our digital twin. Amazon, Apple and Google are competing to deliver the personalisation that we desire (think about Apple's car play, Google's Android Automotive OS and Amazon's Echo Auto).
Most of the services we will be enjoying in our pods will not be provided by the pod manufacturer, rather by third parties service providers (most likely seen through the Apple/Google… brand) using edge computing, edge cloud and our own devices to deliver the customised experience. The Personal Digital Twin will also be a major component in the rendering of the experience and it remains to be seen who will be supporting it (creating, operating, growing…). For sure it will not be a car/pod manufacturer.

11.2 Car as data generator

I mentioned in the previous section how the car will be transformed becoming a pod that flows on a transportation infrastructure. Seen from the "outside" a car will become a data generator and in turns these data will feed a growing ecosystem that will contribute to change our perception of a car and its value.
This is pointed out in the FTI's report and even better, in the way it goes into the implications of this transformation by the recent McKinsey report "Unlocking the full life-cycle value from connected-car data", both with a 2030 horizon. If you have an interest in the digital transformation of the automotive sector that is the reading for you.

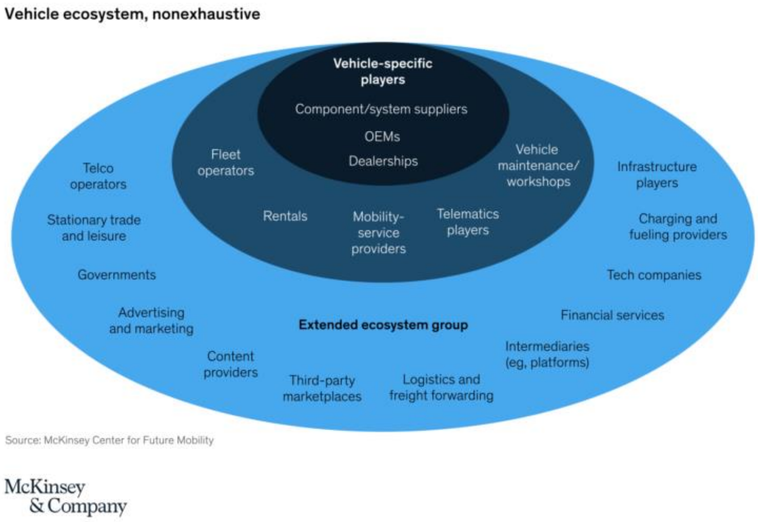

Figure 42. The broad ecosystem created by the data generated by cars. Image credit: McKinsey

Figure 42 shows the extended ecosystem that is fuelled by data generated by a car through its life-cycle (most of them connected deriving from its operation) and in turns the ecosystem generates further data in a never ending cycle. So far data have been siloed, basically each chunk invisible to third parties and that has stymied their value. The siloing of these data is rooted in history (the way they are generated) and has persisted more because of the concern of hacking (hence safety) than in preserving their ownership. However, once the safety could be ensured, ownership will come to the fore, since at that point the sharing of those date will generate value and the owners of those data would surely want to reap part of that value.

It is interesting to note that one of the main driver to overcome the current barriers to data access is market competition rather than value generation: according to polls in several Countries customers are stating that they are ready to switch to a different brand if that would result in accessing better services (driven by data) with an average of 37% and a peak of 56% in China. In other words, data value may overtake, or at least become an important differentiating factor, the value of the mechanical part of the car.

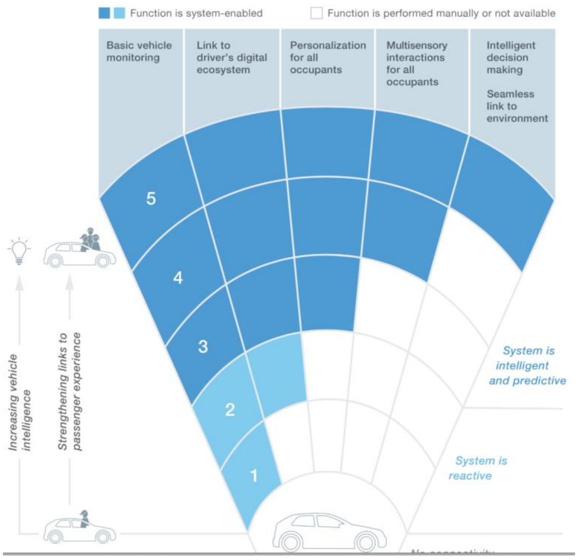

Figure 43. The growing volume and impact of data on connected car customer experience. Image credit: McKinsey

According to the McKinsey report the revenue potential per vehicle per year in 2030 would be in the range of 130 to 210$ for a basic car connectivity (levels 1 and 2) and raise up to 400 to 610$ for advanced connectivity (level 4 and 5). Additionally, the use of data through the car life cycle is expected to result in an average cost saving of 180$ per vehicle per year. Globally this means a value between 250 and 400 billion $.

The graphic in figure 43 explains the 5 levels of connectivity relating them to the customer experience:

- Level 1: supports basic vehicle monitoring, like analyses of the data generated by the engine, by the suspensions, by tyres, autonomous driving data …;
- Level 2: in addition to level 1 data it integrates the ones of the driver's digital ecosystem. Up to this level the flow of data is only in the direction from the car to the edge;
- Level 3: in addition to all above data there are data related to the passengers' digital sphere and data will be flowing into the car to provide personalisation of experience. At this point the system "car-environment" becomes intelligent and predictive;
- Level 4: supports multi-sensory interactions for all car occupants (cars are likely to be fully autonomous once this level is achieved). Augmented reality, micro ambients will become the norm;
- Level 5: supports a seamless continuum between the inside and the outside of the car; a distributed intelligence decision making is the norm (involving the car, the other vehicles in the surrounding space and the environment).

By 2030 95% of vehicles being sold will be connected and of these some 45% will be endowed with advanced (level 4-5) connectivity. Today's, less than 50% of cars are sold with some level of connectivity and basically nome with advanced connectivity.

The shift towards industry 4.0 and its way of delivering connected products plus the growing “servitization” of products will contribute to widespread connectivity for cars as well as to an increased flow of data. Among these the ones used for the updates and upgrades of software (hence the features of the car that to a certain extent will be provided as “services”).
What volume of data are we talking about? The estimate at 2030 is between 1 to 2 TB of data per car per day! Today’s connected car have over hundred sensors and the estimate is a production of 25GB per hour. A mind boggling figure. At least four questions arise from these numbers:

- how can a car generate that amount of data?
- are all those data meaningful (i.e. do they have a value)?
- how can the network possibly manage that deluge?
- who owns those data?

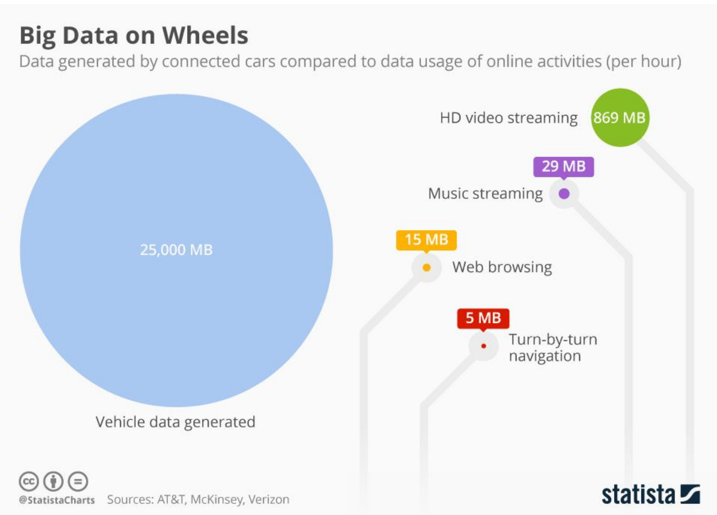

Figure 44. Today’s connected cars generate an impressive volume of data, estimated in 25GB per hour. In this graphic the comparison of data generated by a car with the ones we use in a variety of services, all in a 1 hour window. Image credit: Statista, data sources: AT&T, McKinsey and Verizon

a) *Amount of data*

A 2020 model of connected car is estimated to generate some 25GB of data per hour of use. That is quite a lot but it is nothing if compared with what it is expected by 2030: over 1 TB! Where are all these data coming from? Depending on the model there may be between 60 to 100 sensors in a car today and this figure is expected to reach 200 sensors by the end of this decade. These sensors are quite different in terms of data produced: an oil temperature sensor may generate a few bytes per minute, on the other extreme a LIDAR sensor (watch this clip) generates GB every second. Overall a car may produce several TB of data in a single day (an estimate is up to 4TB per hour of use if one takes into consideration the raw set of data generated). With the progress in image recognition (and so far the much lower cost of image sensors with respect to LIDAR sensors) some self-driving car will rely on this technology to detect obstacles and be aware of the surrounding. A full HD stream of data from the video cameras on a self-driving car (a Tesla is equipped with 9 of them) can generate a flow 10 GB per hour.

b) *Are all those data meaningful?*

Well, it really depends what you mean by meaningful. In a way, yes, if these data are generated it is because they serve a purpose. However, most of those data can be processed locally and the result of the processing is a meaning that can be coded in a much more limited amount of data. As an example: through the use of LIDAR or video cameras the image of a stray cat is captured and that may involve hundreds of MB. However, those data are crunched by image recognition software (and GPUs) resulting in the detection of the cat. This information can be represented by very few data, a few bytes to indicate you are talking about a cat, plus a few more indicating where is the cat with respect to the car and its direction of movement (or a trace of its movement in the last few seconds to predict its likely next steps). You see, with processing and AI a huge amount of data can be reduced to a very little amount.

Clearly, the value is not in the data themselves, it is in the meaning of those data and in the relation of that meaning with what matters to a specific entity (person, institution, application). Our grandparents used to say that the "beauty is in the eye of the beholder". That is still valid today. The value is not in the data per sé but in the answer to the "so what?" resulting form the capturing of the data. This is where artificial intelligence dominates.

Notice that this is exactly what happens to all data that continuously stream towards our brain: we get a few (equivalent) GB of data harvested by our senses (here again vision has the lion share with an estimated bandwidth of 10 Mbps connecting each eye to the brain) but all these data are squeezed into meaningful chunks of information, like "That's a cat" a meaning (most often coded in wording -can you think without placing your thoughts in words?) that can be stored in an equivalent of a few bytes. This compression is the magic of intelligence.

A good deal of "semantic" compression can be done at the sensor level or in its proximity. The problem is that compression usually discard some potential useful bit, the problem is that you may not know if it would be useful and to whom it might be useful. This is why a balance should be achieved between compression and preservation of raw data. Data that would be completely useless to the car, like the presence of a shop – shops don't move around so they don't need to be taken into account by the driving application-, can be useful to a third party that is interested in what shops are out there, what merchandise they display on their shelves…

The definition of what should be preserved and shared is called a "data space" and this is the kind of work being done, as an example, by the Gaia-X working group on the automotive data space.

c) *How can the network manage all these data?*

It can't. There are going to be thousands of cars packed in a small urban area competing for network access. Current networks would be overwhelmed and it will be hard to deliver the quality of service that some of the applications involved may require. However, as cars will become more "chatty", the network will evolve, particularly in its edge architecture. Edge cloud and edge computing will both shorten the distance between the car and the data crunching, thus keeping the latency low. The "intelligence" will likely be shared among the cars and the edge cloud and there will likely be a continuum of the cloud spanning from the edge to the core (or service centres). By 2030 the 5G will be a pervasive reality and we will likely be bombarded by the marvel of 6G. The denser network sustained by the 6G architecture with cars playing the role of network nodes will provide all the network

capacity and cloud processing capacity (federation of edges and devices) that will be needed.
The management of the distributed applications, federated data spaces and the emerging intelligence out of a multiplicity of local intelligence will require new software architectures and paradigms (to manage massive parallelism and increased complexity) and this is what research is focussing on today. Hence I do not expect any stumbling blocks on the way from a technology point of view. The main problem will be finding business models that can sustain the growing investment in a scenario of flat (being optimistic) revenues on the telecommunication side.
The massive volume of data and the intelligence that can be derived from these data will make both privacy and security major issues, most likely the most difficult ones to address.

d) *Who is the owner of the data?*

This is a very difficult question because the raw data have a well defined source, and as such one could associate a owner (even though there is a fuzzy area around this, such as: are the data generated by my car mine, or are they owned by the manufacturer, or by the dealer that sold me the car, or by the application provider that is capturing those data?). However, most of the data are meta-data, that is they are generated through data analytics, often applied to different streams of data (owned by different parties). More than that. These meta-data are produced by software that has been created by a third party and has been paid by another one. So who is the real owner of the data? Once data are shared, data spaces are federated, there will be very little control on the meta-data that can be arising form them. Additionally, a good portion of the data are environmental data (like the data on traffic in a given area at a given time) and it would be difficult to associate an owner to them. I could, in a way, claim that the data on traffic are, at least partially, owned by me, since I am the owner of the car that is detected by ambient sensors and contribute to the information of traffic. I understand that this is really stretching the point but still… it emphasises how difficult it is to sort out the ownership of data (once these are shared). Likewise, from data analytics and artificial intelligence the generation of meta-data can (and will) create privacy issues that again will be very tricky to address.
The ownership of data is not a theoretical issue: it has very solid economic implication. Who will be reaping the benefit that McKinsey estimate in 400+billion $ in 2030? The very concrete risk is that those revenues will end up in the pockets of parties that neither own the data nor have invested to make this economic value a reality.

11.3 Interacting with the car

Cars generate more and more data, process them and derive meaning. Additionally, they are going to receive more and more data from the environment (including data from other cars). This deluge of data needs to be translated into information that is helpful. In turns, this requires the information to be meaningful, timely and most important “digestible”. One of the big issue, already confronting the design of interfaces for pilots in modern airplane is not the lack of information rather its abundance and the cognitive load all this information is creating.

Figure 45. Head Up Display showing the distance from the vehicle ahead, the path leading to the overtaking and information on the road. More advanced HUD can display the full path, showing when the overtake will be completed and the car can return back to the original lane. Image credit: WardsAuto

Consider the image of a HUD -Head Up Display-. HUDs can display a variety of information on the windshield (assisted driving) to increase the driver awareness and help in taking decision. One of the problem is the different reaction time of humans and computers. A computer can evaluate changing parameters and -basically- instantaneously change the information displayed. A continuous change cannot be managed by a human, part of the changes will just go unnoticed, part will create confusion. Hence, the software needs to take into account the cognitive load and the human reaction time when displaying information.

The use of augmented reality, as in the case of part of the info being displayed through a HUD, like the path of the car, clearly helps in reducing the cognitive load and in part the reaction time. However, the software has to become smarter and smarter to avoid confusing information (the car path is clearly visible in the image because the colour used stands out, but what if for some reason the road pavement happened to be greenish? What if there is some glaring from an external light or from sun's rays interfering with the displayed path? The software has to adapt the visualisation to the context, something that requires a higher level of intelligence, not available today). Panasonic announced, earlier 2021, an advanced HUD, based on AI, that may become part of new models starting in 2024 (watch this clip).

As more information and more intelligence become available in the car, our perception of what it means to travel as drivers and passengers will change. Digital Twins (already taking shape in top of the line car models that can offer personalisation to the driver and passengers of several car features (like the setting of the seats, the temperature, the entertainment system, …) will become the interface with the ambient, including the car experience.

Augmented Reality and more in general the possibility to access and contextualise/personalise information will also be exploited for advanced entertainment services, as outlined in the FTI's report. In turns, this will expand the transportation ecosystem, further changing the perception of value and of what it means to travel in a car. Expect significant disruption in the whole automotive market, from the supply chain to the fruition experience. I was talking with a sales director of a company producing components for the powertrain and he told me they are very concerned because they see a major portion of their demand fading away as the automotive industry shifts towards electric cars and these look more like washing machines from the powertrain perspective, no longer needing the rich set of components required today.

11.4 Flying cars

50+ years ago when men first landed on the Moon, newspapers were full of forecasts of cities brimming with flying cars at the turn of the century.

Figure 46. A flying car prototype that is scheduled to hit the market in 2026. Image credit: ASKA

Traffic jams would have been a thing of the past since most people would be flying from home to office and to shopping malls.
50 years later we have a few flying cars prototypes, a merge of a car with a drone, and still a promise that in the next future there will be flying cars.
The FTI's report provides an optimistic, a neutral and a pessimistic view of flying cars, thus underscoring that the evolution in this area remains fuzzy. For sure, technology has progressed significantly, the morphing of cars into drones was not speculated fifty years ago. This is the result of better batteries able to drive electrical motor for an extended period of time and computers to control all flight parameters. This has resulted in lowering the cost of flying cars (in the range of a hyper-luxury model cars) and in a much easier, if not completely automated, driving/flying.

a) *Optimistic scenario*
Flying cars will become affordable (in the range of 40,000$) by the end of this decade, hence becoming adopted more and more and leading to a significant reduction of road traffic in urban areas. Flying cars like ASKA, see figure 46, have a range of 250 miles. That is plenty for a car used for commuting, also taking into account that such vehicles can take the shortest path from A to B. Even large cities like Los Angeles can be covered edge to edge with 50 miles or so. The problem with ASKA, and the likes, is not their range, rather their price tag: 789,000$ (you can pre-order now with 5,000$, the rest to be paid in 2026 upon delivery). Expecting a sharp decrease in price to reach 40,000$ by the end of this decade seems really ambitious.
This optimistic scenario is also assuming that the uptake of flying cars will push regulators and insurance companies to create the required framework sustaining their operation. Notice that the traffic of thousands of flying cars during peak hours is something that has never been seen before. Even the most busy airports have basically five to six aircrafts flying in their local airspace (landing/departing) at the same time spaced by a few miles one from the other!

b) *Neutral scenario*

Whilst in the optimistic scenario basically anybody would be allowed to "fly" a car, that is the usual driving licence will provide the required permission (also because flying cars will be autonomous vehicle and they will be transporting passengers, the so called driver will just have responsibility to input the point of arrival information), in this intermediate scenario skilled pilot will be required to operate the flying car. In this scenario flying cars will be considered like helicopters and will have to follow the same rules applied to them. These flying cars will have a lower price tag, probably in the range 0f 100,000-150,000 $ (helicopters price is from 250,000$ up) and will be flying from many more places to many more places (i.e. they will not require helipads for take off and landing). Some changes to regulations will also be required to allow for higher traffic density. Only very affluent people will be owning one although several people may be using them as "flying taxis". A ride from Manhattan to JFK is estimated in the 70$ range, taking 6 minutes. That is bargain if compared to the current 56$ ride taking close to an hour at peak time.

c) *Pessimistic scenario*
Flying cars will not make a dent in the transportation market and will be owned in a few pockets by really affluent people. Flying taxi services will be available in selected areas for selected routes, like airport to downtown, but the price of the ride will be significantly higher than the one of a land based taxis.

For the coming 2 years we can expect flying taxi services being experimented in cities like Dubai (watch this clip) and Singapore. What will happen after that will depend on the capability of both regulation and technology to evolve. I won't be surprised if within this decade the neutral scenario will be the one to materialise. For the optimistic one I think we will have to wait till 2040 and beyond. Hence, do not expect flying cars to have any impact on our traffic jams for the foreseeable future.

11.5 Reinventing the plane

If there is an industry that has been severely hit by the pandemics that is the airline industry and its value chain (including airports, airports services, catering, manufacturers…). The drop in traffic has been so dramatic and lasted so long that its effects will be felt for the next five years (a full recovery is not expected till 2026). This might seem strange since one would expect that once the pandemic is over, or well under control (let's say by the end of this year) everything will go back to "normal". The problem is that regaining trust won't be easy and even more

important business may have adopted new way of working (with more extensive use of remote working) that traffic will take longer to go back to 2019 levels.
Most companies have scrapped their wide bodies from their fleet (747 and A380) and they wont be reinstated. The use of smaller planes, requiring shorter runways, will also reshape the routes system changing the overall topography of flying.
It is in this new framework that SE Aeronautics is proposing a revolution in the air: the SE200 (look at figure 47 and watch this clip).

Figure 47. The new three-wing plane prototype promising a 70% reduction in fuel consumption. Image credit: SE aeronautics

SE Aeronautics has unveiled their design for a three-wing plane, a wide body able to carry over 260 passengers. It packs several revolutionary concepts:

- the fuel is no longer stored in the wings but in a bladder on the upper part of the fuselage. This allows the construction of a thinner and more air-efficient wing design;
- the lift is provided not by the usual pair of wings but by three pairs. This makes for shorter wings, taking less space at airports and better aerodynamics;
- the stabilisation is provided by double tail fins mounted over the two engines;
- the whole fuselage is made by a single piece of carbon composite - monocoque- providing more strength with lower weight.

All together it is claimed to result in 70% lower fuel consumption, a range of 10,500 miles (you can get anywhere from anywhere with that kind of range (it is the distance between London, UK, and Sydney, Australia). More than that! They are expecting to halve the construction time compared to a similarly sized aircraft.
Ready to buy a ticket on the new plane? Don't rush. It will take several more years to move from the design board to the tarmac. Yet, it is nice to see a radically new design for the first time in decades.

12. Energy

The pandemic impact has been so big that recovery will require "tons" of money. The decision on how to invest this money is a political one and most Countries have decided to steer the flow towards a greener and more sustainable economy.

One of the fundamental component is energy: how to capture energy, transport and store it.

Figure 48. Tesla Model S standard 100kWh battery pack.
Image credit: Insidees

Renewable energy is typically fleeting, now you have it, now you don't (think of wind, sunlight, tides…) so that when you have it you should be able to capture as much as possible and store it for later use when demands surges. This is extremely tricky. The electrical grid is a marvel (mostly unappreciated) of engineering, able to match demand with offer. Every time you switch on your oven the grid will match that request with access to the required power (it is not exactly like that, when you start your oven the voltage on the grid decreases by an infinitesimal amount and then it recovers as new power becomes available; similarly when you switch off your over the voltage goes up…).
Energy storage is crucial to create a buffer that can deliver power on demand. Batteries are a good way of storing energy but their capacity is limited and they cost quite a bit. This is why, as an example, a hydroelectric power plant transform the kinetic energy of water flowing from a dam into electrical current and if that current is not needed (it is not matched by demand) then it is used locally to drive pumps that will pump the water up to the (artificial) lake where it came from. In other situations, like when using solar power, the sunlight can be used to heat up a (huge) mass of sodium nitrate to use that hot molten salt when power will be needed (this trick can double the effectiveness of solar power, like having the Sun shining through a good part of the night).
In many situations there is no substitute for batteries, like in the case of our smartphone. Electric cars are another obvious example. Here the situation is more difficult than with our smartphone. A car needs much more power (hence many more batteries, look at figure 48) and in several cases you don't appreciate having to wait a few hours for it to recharge. Also, very important, replacing the whole set of car batteries means big bucks and a car is supposed to last much longer than your smartphone (I have heard quite a few people saying "I need to buy a new phone because the battery is depleted").
Indeed batteries are seen as a major focus of investment in this decade to make faster recharge possible and extend their lifetime, according to the FTI's report. Tesla announced in September 2020 their Million Miles battery project, aiming at developing a battery with a life time matching the one of the vehicle (and EV cars have a longer life time than today's combustion engine cars), hence a battery that could operate without significant performance loss for 20 years. Today it looks like science fiction. Yet the goal is to make this reality in the next few years. Notice that Tesla claims for their new models a battery life-time of 300-500 thousands miles (1/3 to 1/2 of the new goal). Also notice that an average combustion engine car has an average life of 150,000 miles, or 11 years.

Tesla is not alone in pursuing longer battery life for cars. Contemporary Amperex Technology, a Chinese company that supplies batteries to several EV car manufacturers (including Tesla) has announced the capability to deliver batteries lasting for 2 million km (1.2 million miles) with a price increase of just 10% (currently they deliver batteries with a promise to last 150,000 miles or 8 years).
It is also interesting to notice a study by MIT proposing to reuse depleted EV batteries (you normally have to replace them when they degrade to 80% of their original capacity) as storage for electricity produced with solar power. According to the study these batteries could be used for several more years and would have a cost that is half the one of a newly minted battery, serving equally well in the case of solar power buffer.
The worldwide market value in 2027 of lithium-ion batteries for devices (like our smartphone) is estimated in 129 B$, the ones of EV batteries in 133 B$. That's big bucks!

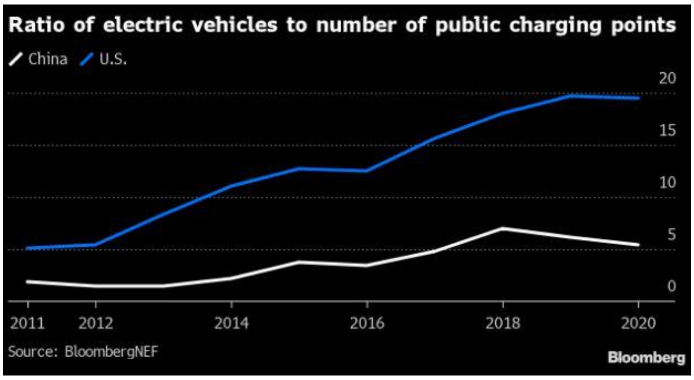

Figure 49. Graphic showing the ratio of EV versus public charging points. The blue line refers to US, the white one to China. There are many more EV in US per charging points than in China. Image credit: Bloomberg

The second crucial aspect hampering the uptake of EV is the time needed to recharge the battery and the availability of recharging points (see figure 49). Both are related to the way an EV is used. If you are using the car for home to office travel, e.g. you have a daily travel span that is well within the range of your car's batteries, all you need is a recharging point at home and the recharging time is not really a major factor since you can hook her up the whole night. Several companies are starting to equip their parking slots with EV charger (Google has already installed over 1,000 charging points at their HQ in Mountain view adding some 20 more each month) and several municipalities are funding the installation of EV chargers.
The deployment of country wide EV charging infrastructure is one of the 7 infrastructures priority in China. They already have over 800,000 public charging points, in December 2020 they added 4,000 more per day, in addition to 900,000+ private charging points making China the owner of 2/3 of EV chargers in the world (at the end of 2020 there were 78,000 charging points vs the 1.7 M of China). The plan calls for a 900B$ investment over the next 5 years to deploy EV chargers AND to increase the capability of the power grid. In the US, ChargePoint (currently the major player in charging station with 53,000 out of 78,000) is planning to have 2.5 million charging stalls deployed in the US (by that time China should have over 9 M points but if you make the comparison based on the number of vehicles / people you get that US and China by 2025 should be on equal footing).
In Europe there were some 250,000 charging stations by September 2020 and the target is to have 1 M points by 2025, requiring some 3,000 points deployed every week (compare this to the 4,000 per day already being deployed in China!). A recent report from EU auditors is highlighting the shortcomings of current EV

charging points (compatibility, great variation in density in different Countries…) and asks for prompt action.
Overall, worldwide, it is expected the need for 14 T$ investment in upgrading the power grid over the coming three decades. If you do the math, China 2 power infrastructures initiative (they have included within the 7 target infrastructures the ultra high voltage for power distribution and the EV chargers) compress this investment in this decade, letting China to advance in the transportation electrification well ahead of most other Countries.
The FTI's report is foreseeing a significant acceleration in the EV infrastructure (power generation and chargers). In turns, this will have disruptive effects on the petrol/gasoline stations that have already experienced a severe hit during the lockdown in several Countries. The shift towards EV is going to radically change the whole system of power distribution. According to the report, the pandemic has accelerated the transition to EV, Governments are steering investment towards green and sustainable and most car manufacturers are now committed to operate in an EV market, with a 225B$ investment in EV in the coming 5 years. The 2030 horizon has been anticipated to 2025.

12.1 Clean Energy

The quest for clean ways of transforming energy is relatively recent.We usually talk of "clean" energy but the point lies in the "transformation" of energy and whenever we are transforming energy the second law of thermodynamics rules. In lay terms this law states that the process of transformation always result in some waste, in the increase of entropy or, in more understandable terms, in the creation of heat. Hence, as a general rule, the fewer transformations the better!
When we use an EV, like an electric vehicle, we are transforming chemical (lithium-ion battery) into electromagnetic energy and then into motion (kinetic energy) plus some heat -the battery warms up as well as the car and the tarmac because of

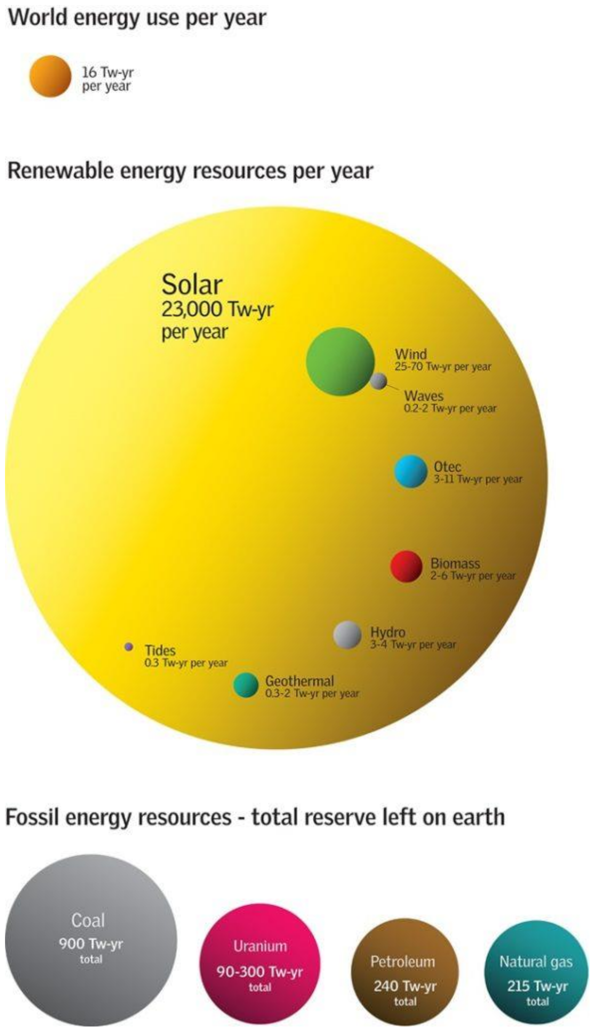

Figure 50. Energy sources on Earth. The Sun is the true energy source, it is the Sun that creates the wind, the water circulation and tides (this together with the Moon). Geothermal energy is due to radioactivity of the Earth core but its contribution is marginal in terms of accessible energy. The Sun has also been responsible for all fossil energy. The graphics shows the amount of energy available (per year for renewable energy and as existing reserves as fossil energy). Image credit: Europe Energy Portal

drag. But that is not the whole story! The energy had to be placed in the battery converting it from electrical into chemical (and in the process the battery warms up). Of course, you have to have electrical (electromagnetic) energy and there are many ways to produce it, using the kinetic energy of water, wind, thermal (from geothermal, gas, coal, atomic fission…), solar (photovoltaic) and more.

We need to understand that most of our energy derives from the Sun. Figure 50 is showing, in relative proportion, all energy sources that we are using, the Sun has the lion's share. More than that. Consider that all fossil energy (bottom part of figure 50) have been created by chemical conversion of the sunlight energy over millions and millions of years. Also this fossil energy is "renewable" but it takes hundred of millions of years to renew it, so in practical terms it is not. On the other hand Sun energy is not renewable, in some billion years it will be over, but again for practical purposes it is unlimited and the various transformation of sunlight energy as it interacts with the planet (biomass, hydro, wind, tides…) are renewed every single day.

The challenge is how to tap into the various energy sources and how to make them usable. In general we need to find ways to transport it from the source to the point of use (and this is not free! Transportation implies using part of the power, electrical wires heat up consuming power, transporting gasoline with trucks requires energy and so on). The second issue is to store energy till the time it is needed. Electricity can be stored in batteries (as discussed in previous sections) or by converting it into other forms of energy.

12.2 Hydrogen

Hydrogen is another way to store energy and potentially a very interesting one:

- Hydrogen has a very high energy density (120 MJ/kg), three times more than gasoline and diesel (45.8 and 45.5 MJ/kg respectively). This means that you can pack more energy per kg of weight. By comparison a lithium-ion battery has an energy density that is 0.3MJ/kg, 100+ times less than gasoline and 300+ times less than hydrogen.

- When we use the chemical energy of hydrogen by "burning" it, we get as waste H_2O, that is pure water (you could drink what gets out of the exhaust pipe – a bit hot, not advisable…).
- the "burning" of hydrogen is done through fuel cells and this process is twice as efficient as the one of burning gasoline in a combustion engine, hence 1kg of hydrogen is equivalent to a gallon of gasoline in terms of energy but can run your car twice the distance of where you get with 1 gallon of gasoline.

Sounds great, doesn't it? Not really. The problem is that 1 kg of hydrogen (basically equivalent to 1 gallon of gasoline in terms of energy) is difficult to store. Hydrogen, at atmospheric temperature is a gas, and a litre of hydrogen at this pressure weights 90mg. In other words, if you were to store 1 kg of hydrogen at normal temperature and pressure you would need a tank that is 100 cubic metre! (an average car is about 5 cubic metres, hence you would need a volume equivalent to 20 cars to store the energy equivalent to one gallon of gasoline!).
The trick is to compress the hydrogen, squeezing it into a narrow space but in doing that you increase the pressure. Specifically, current squeezing can pack in a tank designed for a car some 5kg of hydrogen at a pressure of 680 atmosphere (that calls for a very robust tank!). An alternative would be to liquify the hydrogen but that requires to lower its temperature to minus 252 degrees and that is not just difficult, it is very expensive. OK if you want to go the the Moon, but unsuitable for cross country.

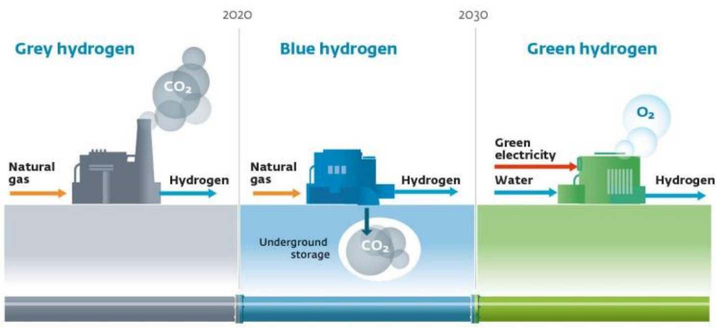

Figure 51. The three main colours of hydrogen, associated to the way it is produced, and the relative impact in terms of CO_2 emission. Image credit: Gasunie

The many colours of hydrogen

There is plenty of hydrogen around, all waters you see around is a reservoir of hydrogen. Natural gas contains hydrogen, several life forms produce hydrogen. The problem is how to extract the hydrogen. As an example we can use electrolyses to separate water in hydrogen and oxygen but this requires quite a bit of energy, actually much more than the energy that you can extract from hydrogen using fuel cells (the second law of thermodynamics is there, no free lunch!).
There are several ways to produce hydrogen and they are tagged with a colour:

- Brown: the process uses coal and its gasification. This results in a massive production of CO_2.
- Grey: the process uses natural gas (steam methane reformation) and it produces plenty of CO_2.

- Blue: the process uses any form of non renewable energy but capture the CO_2 created and stores it.
- Turquoise: the process uses pyrolysis on methane and creates only a limited amount of CO_2 waste.
- Green: use of water electrolyses with electricity provided by renewable sources. It does not create any CO_2.

As of 2019 the world production of hydrogen totalled 8 million tons. Almost all of that production is using fossil fuels and resulted in 830 million tons of CO_2.
The net result is that you are green at the point of use and very-very black at the point of production!
The FTI's report foresees significant investment on Blue and Green hydrogen in this decade on three directions:

- lowering the cost along the whole value chain -extraction, transportation/distribution, utilisation to reach a price point comparable to the one of gasoline by decade end (with a target of 1$ per kg by 2050);
- development of green hydrogen production plants (France is committing over 7B€ in the next 4 years for green H, aiming to increase H use by industry reaching 10% in 2022 and up to 40% by 2027 of power needs);
- development of a distribution infrastructure that can serve commercial traffic (trucks). As part of the recovery fund, Europe is accelerating the plan for a European Hydrogen Infrastructure, seen as a crucial component to meet the 2050 goal of zero climate impact. Additionally Europe has launched a Hydrogen Mobility Initiative, H2ME, to foster the deployment of refuelling stations along the main commercial traffic highways.

12.3 Electrical Power Transport

In several Countries what has hampered the shift towards renewable energy is the distance between the source and the point of consumption. Tides can generate electrical power but transporting it across a thousand of miles results in a big waste. Solar power can be easily harvested in deserted area, like the Sahara) but transporting the generated power to Europe (as an example) would result in a significant loss, making the whole point of generating power useless.

Figure 52. The 1,100-kV direct-current Changji-to-Guquan project stretches 3,293 km (2,046 miles). It is currently the world biggest UH voltage direct current power line. Image credit: Qilai Shen, Bloomberg

According to the World Bank we are wasting in transmission, worldwide, an average of 8.2% of the power generated. If we were to use longer transmission lines the waste would increase. Notice that the loss is due to impedance and resistance and these are dependent on the frequency and on the current (respectively). As the line gets longer another factor kicks in: the length of the line approaches the wavelength of the AC (alternate current) and the whole line becomes a giant antenna that starts to radiate electromagnetic field, resulting in further energy loss.

One way to reduce the loss would be to use DC (no more impedance nor radiation effects) but the cost of transforming a high DC voltage to one acceptable for end users has been high (with AC you place a nice transformer -you also waste some power in the process, read heat- but overall it works fine). Another problem with DC is that you need to use very high voltage (to keep current low), higher than AC.

Figure 53. Active and projected UHVDC infrastructure in China. Notice the very long span of the power lines connecting deserted areas to cities where electrical power is needed. Image credit: the Economist

As noted in the FTI's report, in the coming years several Countries, with China leading the pack having already invested 88B$ in UHVDC grids, will start to exploit new technology that makes conversion of Ultra High Voltage DC into low voltage AC affordable. The use of UHVDC makes it possible to extend the length of power lines, as shown -figure 52- in the photo of the Changji to Guquan power lines stretching for over 3,000km, a length that would have been impossible just few years ago. The UHVDC infrastructure, figure 53, is among the 7 focussed China's investment over the coming 5 years. The plan is to connect areas like the Gobi desert where there is an abundance of renewable sources to cities thousands of miles away. More than that. China is seeing the UHVDC as an infrastructure to deliver electrical power to Countries along the Silk Belt, to the point that, as noted in the report, 50 years from now many parts of the world will be relying of China as energy source as today many parts of the world are relying on the oil from the Gulf.
UHVDC is going to change the rules of the game: the value will rely on the capability to generate high volume of renewable energy, independently (almost) of the location. Deserts will become an asset!

13. Climate

That the climate is changing is part of the folk tradition. I remember my grandparents telling me when I was a kid that "there is no longer the weather, the seasons, we used to have…".

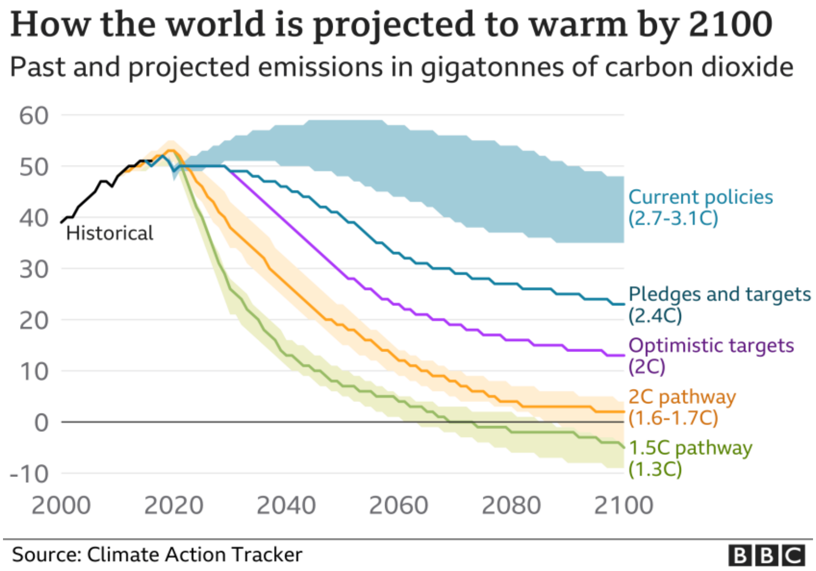

Figure 54. Representation of possible evolution in this century of carbon emission -CO_2. The upper blue part represent the current trend, leading to a 3°C increase of the planet temperature. Based on the agreements signed so far the trend would lead to and increase of 2.4°C. The lowest line represents the “green alternative” leading to an average temperature increase of 1.3°C. Image credit: Climate Action Tracker

As a matter of fact our perception of the weather is very much tied to the present. Hence you hear people after an unusually cold week (or a snowstorm – like the recent one in Mongolia) saying: what is all this talking about the planet warm up? It is pretty cold, actually colder than usual! We are not, as single humans, reliable sensors of weather change, We have to turn to science and to precise global measures, particularly looking at ice coverage (glaciers) and ocean temperatures. If we look at these parameters there is no possible doubt that our planet is warming up, see the graphic in figure 54, the first part showing the increasing temperature in the first 20 years of this century (and simulated scenarios for the rest of this decade).

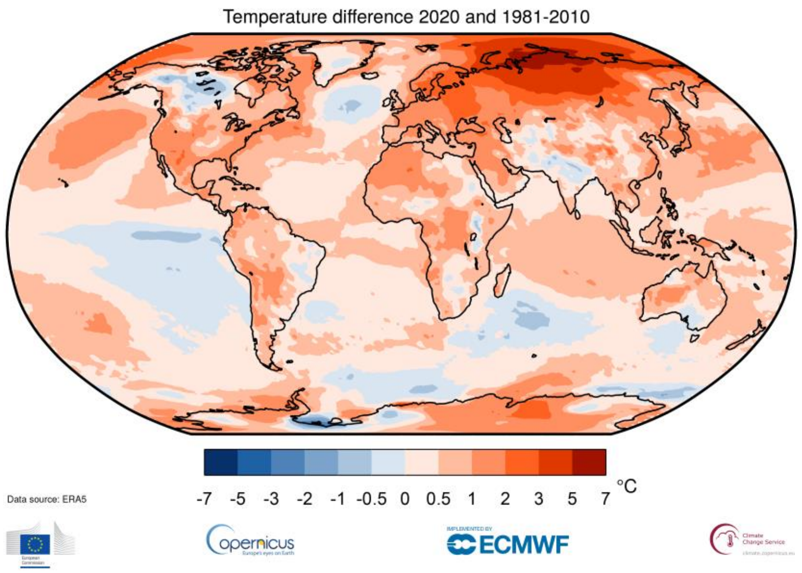

Figure 55. Representation of average temperature change over the past 40 years. Image credit: Copernicus

The graphic, Figure 55, generated by observations from Copernicus, shows the average increase in temperature in various areas over the last 40 years. The blue (pale blue actually) areas represent parts of the globe where the average temperature have decreased (slightly). The overall image is reddish, clearly showing the increasing temperature (notice that the pale blue areas are in the oceans and the decrease is due to the warming up of polar regions resulting in the melting of polar ice caps with cold water flowing into the oceans and cooling it a little bit).

If there cannot be doubts on global warming the discussion rages on the reason for it, on its impact and on the actions that could be taken to stop/reverse its progress.

One of the problem in identifying the cause of the global warming is that we have

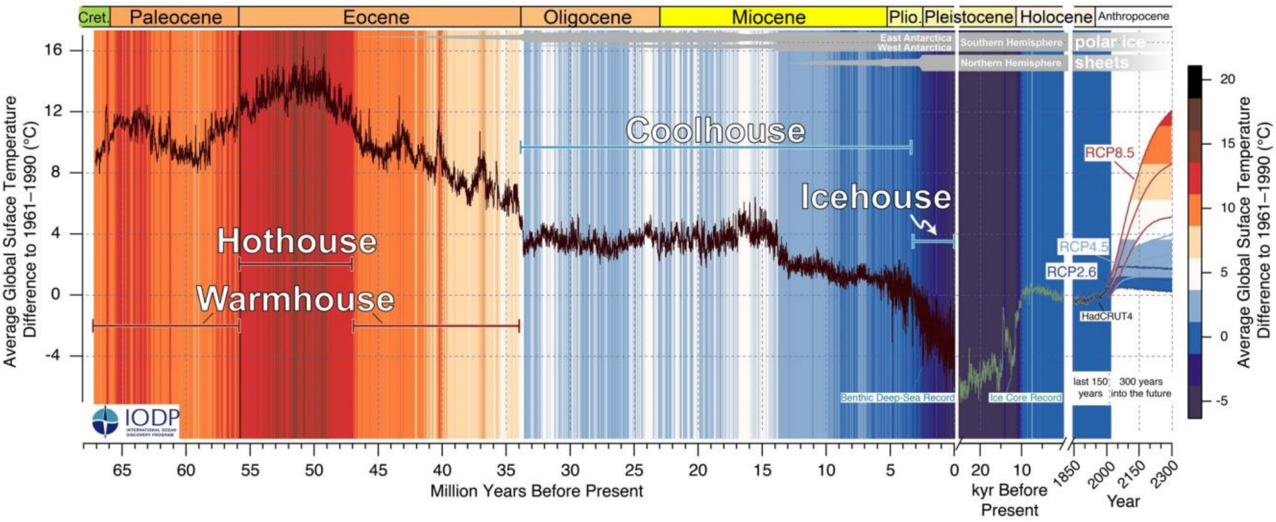

Figure 56. Average, estimated, Earth temperature over the past 66 million years. The reference point is taken on the average in the period 1961-1990. As it can be seen the planet was way hotter in the far away past with an estimated max of +15°C over the 1961-1990 reference. Notice, however, that for the past 12,000 years the average temperature was below the present one. Image credit: University of California, Santa Cruz

quite accurate data on the average Earth temperature (see figure 56).
You might wonder, as I did, how can we have a good estimate of our planet's temperature 10,000 years ago, when thermometers did not exist nor any written report was possible, not to mention the temperature 60 million years ago! Well, scientists are able to get a good estimate of past temperatures by measuring the oxygen isotope in deep ocean sediment left by foraminifera and more accurate estimate for the last 25,000 years from ice core records. We have historical records from a growing number of areas starting from 1850.
It is obvious that 66 million years ago humans had nothing to do with the planet's climate, our history on the planet is way way shorter than that. Dinosaurs were roaming the planet and most likely they enjoyed those higher temperature. We have been witnessing the last ice age, 20,000 years ago, and our ancestors took advantage of the lower sea level (because a lot of water was trapped in ice) to roam the planet moving from Asia to America and hopping the shorter distance that existed from Indonesian islands to Australia.
What is also clear from the graphic is that in the last 200 years there has been a marked increase in the planet's temperature and the projections indicate an even accelerated warming.
What are the reasons for this changing temperature over the millennia? Here there are several hypotheses:

- the Sun is becoming hotter and increasing its luminosity (emission). At present the increase is in the order of 1% per 100 million years;
- the Sun orbits the Galaxy and it takes it (and the Earth) some 250 million years to go full circle. In this circling it goes across areas of interstellar dust that can decrease the amount of energy (solar light) reaching the planet, leading to a cooler period;

- the Earth orbit, its axial tilt (precession), changes over periods on thousands of years. This has an effect on the climate;
- the quantity of CO_2 and other greenhouse gases changes over time (in these last 200 years with a strong contribution of human activity) and this decreases the heat dispersion increasing the planet temperature;
- temperature in the oceans affects the evaporation of water (increasing the greenhouse effect) and decreases the adsorption of CO_2 by the oceans, thus increasing the green house effect. In addition it changes the currents and this has local climate effect on landmasses;
- plate tectonics (shift of continents) and volcanic activity releases dust in the atmosphere decreasing the amount of light reaching the planet resulting in a decrease in temperature;
- biomass extension and location have a strong impact on local climate and eventually affect the whole planet.

All these factors, and more, have influenced the climate change in ways that are very complex and this is why there is no consensus on the long term effect of specific parameter impact.
What is sure is that human activity has increased CO_2 in the atmosphere and this steers towards an increase in temperature.
Being a complex landscape it is also difficult to predict the exact impact of a single factor variation on the overall climate change. We are getting better in assessing this impact using supercomputers. The new exascale computers will be used to simulate the impact on climate of possible actions we can take .
The FTI's report is foreseeing a growing effort in this decade to understand and control climate change with significant impact on business.

13.1 Technologies for a Green Environment

The pandemic hit the economy worldwide, possibly even more, in economic terms, in developed Countries. The post-pandemic recovery will be steered by political decision to focus on addressing some crucial -long term- issues, among these the climate change. The huge amount of money (at debt) poured into the recovery stimulus will influence research, processes and culture towards sustainability, circular economy and green.
Climate is dependent, as addressed in the previous section, on many factors and we can control only a few of them. Yet, there is consensus on the fact that anthropic activity has increased the CO_2 -and more generally greenhouse gases emission. In turns this contribute to the warming of the planet activating a self sustaining spiral towards warmer and warmer average temperature:

- the more CO_2 (and greenhouse gas) emissions the less heat can dissipate to the outer space making the planet warmer;
- the warmer the planet the warmer the oceans. This decreases their capacity to adsorb CO_2 (the cooler the water temperature the more CO_2 can be dissolved in the water). Notice, however, that the more CO_2 in the oceans the more acidic they become and this affects -mostly negatively- the ambient of many species;
- the warmer the planet the more ice is melting and the more glaciers are shrinking. This in turns decreases the quantity of light reflected and further

increases the adsorption of sunlight energy resulting in a further increase of temperature.

As pointed out in the FTI's report, the focus on climate change will steer investment to reduce the anthropic impact by both decreasing green gases emission and developing technology to adsorb and dispose of CO_2.
There are a number of technologies (already in use) to capture CO_2 generated by industrial processes. These technologies transform CO_2 (at the expense of energy) into other substances, like fertilisers, concrete, fuel that can be used in a variety of areas. Notice the "at the expense of energy": we can have a net gain only if energy is tapped from clean renewable sources, otherwise more CO_2 will be emitted in the process of producing the power to be used in CO_2 transformation…
At the same time. as noted in the report, new technologies are being pursued, like the genetic modification of bacteria (escherichia coli) to produce enzymes that convert CO2 into harmless bicarbonate.

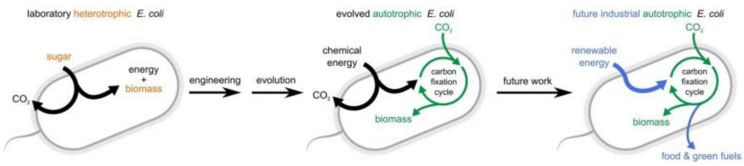

Figure 57. Schematics of the attempt to create a bacteria that uses CO_2 for its metabolism. Currently bacteria (as multicellular living beings like ourselves) generate CO_2 as metabolic waste. Bio-engineers are "re-programming" the bacterial DNA to support the bacteria metabolism using -consuming- CO_2. The third step aims at creating a bacteria that uses CO2 and does not generate CO_2 as metabolic waste. Image credit: Gleizer et al.

Researchers are looking forward to the possibility of re-engineering the metabolism of bacteria (E. coli is the usual target) in such a way that it can use CO_2 as bases for its metabolism. The CO_2 would become fixed into bacteria -alas transformed into different molecules- and the bacterias could be used as fuel…. Amazing!

Shading the Planet

If we could just shut off the Sun for half an hour a day the problem of climate warming would be solved (actually, it would take less than that) but of course it is not easy. However, as it is noted in the FTI's report, in the coming years several techniques that have been developed in the past are likely to reach a point of fruition. They aim at shutting off the sunlight by placing something in between the Sun and the planet surface.
We are actually experiencing this (partial) blocking of sunlight when the sky is overcast, clouded. So the researchers have been looking for ways to create clouds on demand (and why not, also rain on demand).
Basically, given the right mixture of humidity, temperature and "dust" infinitesimal water droplets aggregate to the point of becoming clouds (if the process continues you get rain/snow/hail depending on temperature).

Figure 58. Ships sailing across the oceans are followed by a plume of cloud forming as the aerosolised sea water created by the ship movement mixes with the dust particles spewed by the diesel engines. This cloud reflects sunlight cooling the ocean below it. Image credit: Pacific Northwest National Laboratory

Researchers, as an example, have noticed that ships sailing on the oceans live a plume of cloud behind them. This cloud, as shown in the picture, forms when the aerosolised sea water created by the movement of the ship mixes with the smoke produced by the diesel engines, smoke that contains a huge amount of tiny particles, fine dust, acting as magnet on the aerosolised water. The plume is shielding the water below from the sunlight. So, the researchers reasoned, can't we do something like this and create a cloud blanket over the oceans? That would reduce the amount of sunlight, the water temperature, increase the adsorption of CO_2 by the oceans…
Indeed, this is what researchers at NOAA are studying.They have received a 4M$ grant from the US Congress to look at how to use sea salt vapour to create clouds and at the university of Washington researchers are looking at how to use seawater to increase the whiteness of clouds, making them more light reflective.
At Harvard scientists are planning to take the idea of "clouding" to the stratosphere. Their idea, so far at the study level, is to use stratospheric balloons that can release fine dust of specific materials in the stratosphere. This fine dust would interact with high energy sun- rays altering the penetration of sunlight, basically creating a shield. The project, SCOPEX, Stratospheric Controlled Perturbation Experiment, is raising doubts and concerns (mostly on the "controlled" part) so for the time being it is taking place in small steps with the aim of increasing our understanding of the stratosphere. The goal is clear: be able to interfere with the amount of energy reaching the planet regulating it in time and location. If this would eventually become feasible, it would be possible to increase the energy reaching a certain spot whilst decreasing the one reaching a different spot. This unbalance would create winds and lead to rain. We would basically have a magic wand to create the kind of climate we want/need at the place we want it. As with any powerful technology (and this indeed would be the most powerful we have ever had!) there are plenty of risks and a lot of potential political turmoil, hence the concerns…
This is the birth of a new science, geo-engineering. Its proponents are claiming that even in the best scenario by 2050 we will reach a net zero carbon emission thus stopping the anthropic impact on the climate but this will not stop the climate change, since there are several other factors involved that are independent of human activities. Hence the need to develop a geo-engineering science that ultimately would allow us to create the desired climate at the desired place at the desired time. Looks like an impossible dream, as it was an impossible dream to reach the Moon only a hundred years ago.

In between the control of climate by influencing the stratosphere and the creation of artificial clouds there are studies to place some reflectors up in the sky to divert sunlight so that it would not reach the planet surface.

14. Synthetic Biology

The last Megatrend presented in the FTI's report focusses on Synthetic Biology and its application in Agriculture. Synthetic Biology is the idea, now a practice, of being able to create/modify life in a bottom up way, composing the strand of life, DNA and in some cases RNA, in ways that result in a living "thing". Sometimes this new living thing might be the result of a modification of an existing living thing or it can be a chimera, resulting from the mixing of parts taken from several living things. Notice that all of this has happened, is happening in Nature. Life is the result of random combination of molecules that by chance reached the stage where they could self replicate, modify and become selected through external forces. New bacterial species are born, at this very moment, by being infected by viruses and inheriting their brand new DNA from both the infected bacteria and the virus DNA (or RNA). You don't need to look far to see a chimera organism: we are just that. Our DNA is a mixture of our father and our mother, our mitochondria DNA derives from our mother and from bacteria that have become embedded in our ancestors' cells.

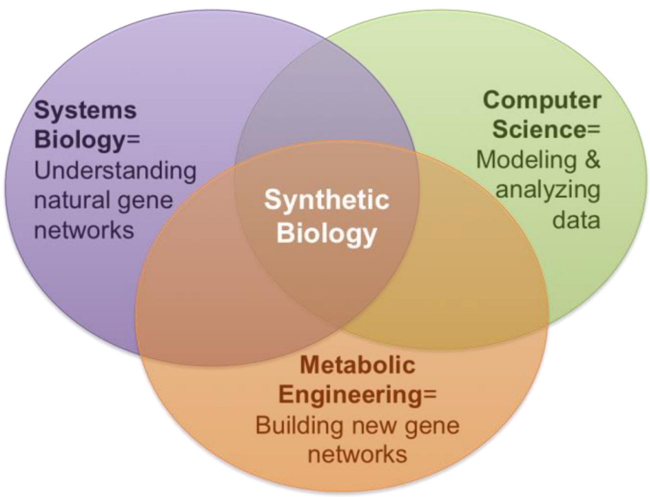

Figure 59. Synthetic biology is picking up stream by the convergence of increasing understanding of systems biology – natural genes interactions resulting in the phenotype-, metabolic engineering - creating new genes networks-, and computer science – enabling creation of meaning out of data. Image credit: Cornell Alliance for Science

What is new with synthetic biology is the acceleration of change. What would have taken hundreds of thousands, million of years, may be accomplished in a few hours. What we are seeing today is the result of this continuous change, we call it evolution, What we are not seeing is the much much broader set of "mistakes" resulting from combinations that were not fit for the environment and died out.

The big issue is exactly this one: by applying synthetic biology we can create something new but … we are not sure what we are creating. As Nature did in the past, and it is still doing every day now, the creation of new species is blind. It is only afterward that one can assess the impact.

At the core of the Natural evolution is the random change/swap in genes. However, the selection does not depend on the genes per se but on the way they concur to create the phenotype, that is how that living thing interacts with the environment. Our understanding of the relation genotype-phenotype is still very limited: we have the tools to modify a gene (changing a single base, a codon or a fragment) as well as to add/delete a gene from a genome but we do not know how this is going to impact the phenotype (i.e. what the result is going to be).

The increasing availability of data derived from the sequencing of the genome (by the way, in 2021 we have finally sequenced the whole human genome, although its sequencing was announced some 20 years ago!) and the use of artificial intelligence is expected to result, by the end of this decade, into a much greater understanding of the relation genotype-phenotype. If this will happen (there is no doubt this will be -eventually- the case, the big question is “when?”) we will be able to design life. We already have an increasing powerful toolbox allowing us to “cut and paste” DNA and RNA strands, thus to modify the genome. Let’s not forget the amazing success of the Covid-19 vaccine. Using modified mRNA researchers have been able to instruct our cells to produce the virus spike protein that in turns stimulates the creation of B and T (cells) antibodies. This is a first example of synthetic biology: we are teaching our own cells what to do (in this case produce a new protein -the spike protein- that they never produced before, missing the instructions to do so).
Notice in this example, that I am using to emphasise the value of synthetic biology, the use of:

- system biology, our understanding of the working of our cells and the way they produce proteins – by decoding the mRNA;
- metabolic engineering, used to create the mRNA that is injected as vaccine, that in turns entering cells will instruct them to produce the spike protein;
- computer science, the whole process of designing and manufacturing could not be done without massive use of computers and computer science

The FTI’s report predicts that mRNA will be the way forward for vaccine. Being designed by software it can also be changed in subtle ways, as an example to respond to virus variations. The limited changes makes it possible to reduce the testing in-vivo (a good deal of testing is done through AI in a matter of days). The Covid-19 crises has accelerated the deployment of mRNA: in its absence it would have probably taken five to ten years to move from the lab to clinical practice. This acceleration will lead to a variety of other vaccines, with a malaria mRNA based vaccine already in the making (in 2019 over 400,000 people died of malaria and there were over 200 million episodes of malaria globally).

14.1 CRISPR-CasX

The CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) – Cas (CRISPR Associated Protein) system was discovered, and invented, in the last century, the first reference is found in an article in 1987. The CRISPR was discovered in bacteria: they are short DNA sequences that bacteria have inherited from viruses (bacteriophages – literally bacteria eaters) that infected them. Rather than being killed by the viruses these bacteria hijacked part of their DNA and used it to recognise those virus and destroy them using an associated protein, Cas, that would chop the virus DNA into pieces. Conceptually it is very similar to a vaccine and it provides immunity to the bacteria.

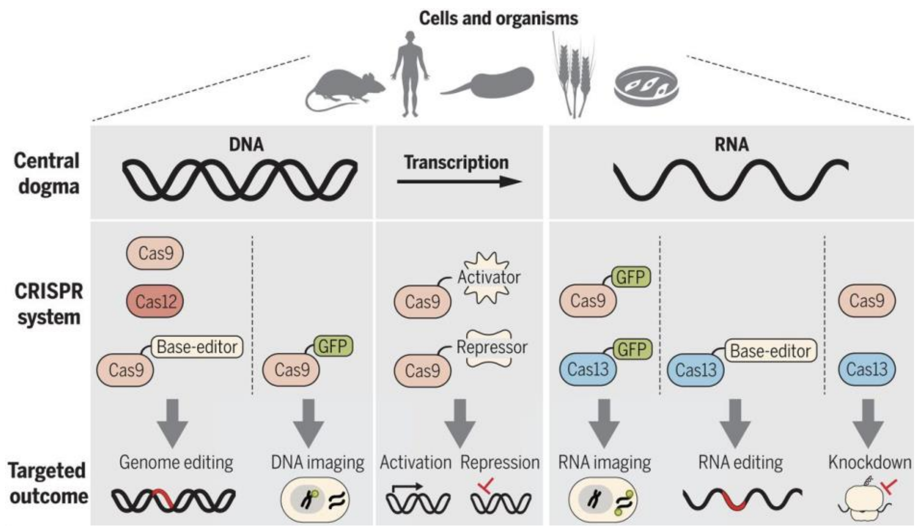

Figure 60. Schematic representation of the many variants of CRISPR to change the DNA and the RNA. Different Cas are being used depending on the type of action desired. More Cas will likely be found in the coming years, broadening the toolkit for gene editing. Image credit: Gavin J. Knott and Jennifer A. Doudna, AAAS Science

The crucial feature of CRISPR-CasX (X is actually a number, see fig. 60) is its ability to cut the DNA/RNA strand in specific (desired) points. Once the DNA is broken a set of codons can be inserted / removed changing the "instruction". If the change takes place at the DNA level it will become part of the cell code (and possibly will be inherited by offsprings), if it takes place at the RNA level it will only be effective for a limited time (the RNA is used to code a certain protein and then it disappears).
Several "Cas" have been discovered (the first was Cas9) and they serve different purposes (look at figure 60). CRISPR-CasX are already used in a variety of field, from agriculture (creating GMO) to environmental care (e.g. modified bacteria are used to remove oil spills from the sea). More recently CRISPR-Cas has been used to create mRNA vaccine (if you are interested in this area watch this clip. It is a long one but it guides you to understand the various aspects of using CRISPR for vaccine).
The FTI's report foresees a growing application of CRISPR-CasX to healthcare that by the end of this decade will make possible to address pathologies that so far have been out of our curing capability like congenital blindness, muscular dystrophy, Alzheimer's disease, and sickle cell anemia. Some form of cancers might also be addressed with CRISPR-CasX. It seems science fiction, manipulating the cell DNA to teach it how to fight a specific disease. Yet it is science.
In 2020 for the first time CRISPR-Cas9 has been used to treat a person with a genetic condition leading to blindness by inserting the appropriate "instructions" in that person's retinal cells.
The big issue with using CRISPR-CasX is that biology is not like engineering. In the latter you can replace with certainty a specific "cog", in biology you are statistically replacing / deleting a specific DNA/RNA strand, meaning that in the millions of replacements most will be on target but a few will miss. What happens to those that miss? Most likely nothing of concern but there is always the potential of unexpected side effects. More than that. We know of course that a given strand of DNA is responsible for an undesired effect (a genetic disease) and by replacing it we will fix the problem. However, most of the time (at least today) we are not sure if that

particular strand was also involved in other biological processes, so that once it is removed/updated we are fixing a problem but we may create a new one. As an example, many animals (ourselves included) have a gene (Hox gene) that results in the formation of five fingers and five toes. It would be possible (and most likely happened many times in Nature) to change it and get 6 fingers – an additional thumb might come handy in doing some repair job, wouldn't it? The problem, and the reason's why we do not see people with 6 fingers is that the Hox gene is also involved in our reproduction process. You change it and you get six fingers but you are no longer able to generate offsprings (hence any random variations of that gene will not be transmissible to further generations).
The evolution in the coming years will follow two paths:

- discovery of new Cas that can be used to better operate on some DNA/RNA strands (be more precise and focussed, fewer missing), thus allowing the replacement/deletion of different specific parts of the genome;
- understand the relation between the genotype and the phenotype, using AI, so that we can be sure of the implications deriving from changing part of the DNA/RNA strand. Notice that changes in the RNA are less impactful since they are restricted to that specific individual, whilst DNA changes could propagate to offsprings…

All DNA manipulation is fraught with ethical issues and there is no clearcut dividing line between what should be permissible and what should be banned. It is more of a grey fuzzy area and more than this, it is an area that shifts over time.

14.2 From cells to organs to bodies

In the last few years we have increased our understanding of the way the expression of the genes regulates the development and up-keeping of life. It is a complex web of interactions and as data and knowledge piles up the reliance on computers and software becomes ever more essential. Supercomputers and AI are being used to understand, and simulate, the folding of proteins providing researchers with tools to create certain specific types of interactions, thus intervening within the network of metabolic life, addressing specific genetic diseases. Look at AlphaFold for the latest on protein folding and AI.
What has started as a focus on single cells metabolism is now evolving into the broader set of interactions among cells within organs and interactions among organs within a body, with a growing level of complexity –metabolome.
An emerging technology SNP – Single Nucleotide Polymorphism profiling allows researchers to change a single base (A-C-G-T) in codons (the gene's elementary instruction set). A growing data base of variations is available. As of January 2021 it contained over 900 million variations found in the human genome (supported by the US National Centre of Biotechnology Information – watch this clip). The goal of this growing ensemble of information is to discover the effect of single/multiple variations and using CRISPR to restore the ones that are creating genetic malfunctions. As per the previous discussion on CRISPR this is a slippery slope since there is no clearcut boundary defining what should be considered as a malfunction and what is just a variation. I guess no-one would claim that blue eyes are a "malfunction", yet they derive from a change that most likely occurred some

6,000- 10,000 years ago, a mutation in the OCA2 that switched off the capability to create brown eyes.
It is, and it will become easier and easier, to introduce the mutation at will so that future parents may steer their offsprings towards blue eyes…
According to the FTI's report SNP is not foreseen as a technology for cosmetic manipulation, rather as a technology that could decrease the risk of heart disease or diabetes. However, this is a Pandora box, once you open it, it might become impossible to reseal it.

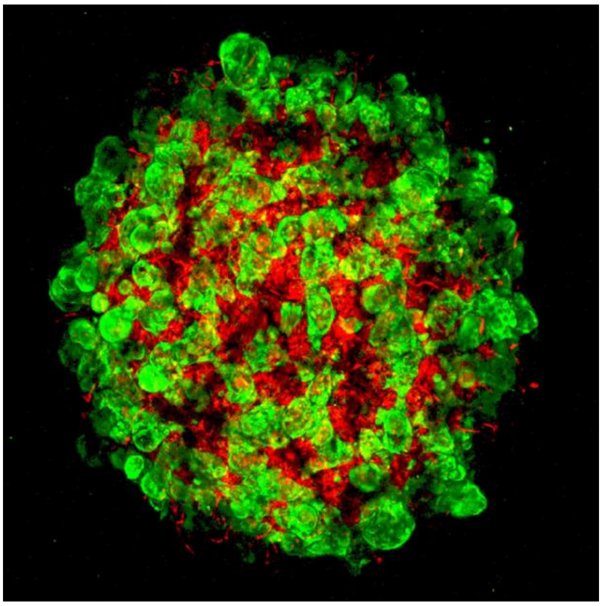

Figure 61. This Colorful confocal microscopic image shows detailed development of a human liver organoid that was tissue-engineered by scientists with human pluripotent stem cells (hPSCs). Green sections of the image show forming hepatic tissues and red sections show developing blood vessels. Reporting their research results in Nature, scientists are developing the miniature organs for their potential to study and treat liver disease. Image credit: Cincinnati Children's/Max Planck

Research is progressing in moving from the cell to the organ, cluster of cells with a structure that serve a specific function. In the past we have seen the use of stem cells to develop liver, kidney, heart tissue with the same characteristics found in the respective human organs. These organoids are used by pharma to study the impact of a drug on the tissue as a whole. This is really crucial because a drug affecting a cell is also affecting its metabolism and new molecules may be released as a side effect, that, in turns can affect nearby cells with effects on the function of that organ.
More recently stem cells have been used to create cerebral organoids, creating cerebral tissue. This is also being used to study brain functions and some manifestations like autisms. The recent pandemic has stimulated research of effects of Covid-19 on lung and brain: organoids are being used to study them.

14.3 Computational Biology

As remarked in the previous sections on Synthetic Biology, no progress would be possible without the support of computers and AI. More than that: in the last few years progress has been fostered by computational approaches to the point of creating a new discipline, computational Biology. As shown in figure 62, taken from a European Research Council article presenting the funding dedicated to synthetic biology, Computational Biology is applied to, and leverages on, a variety of technologies.

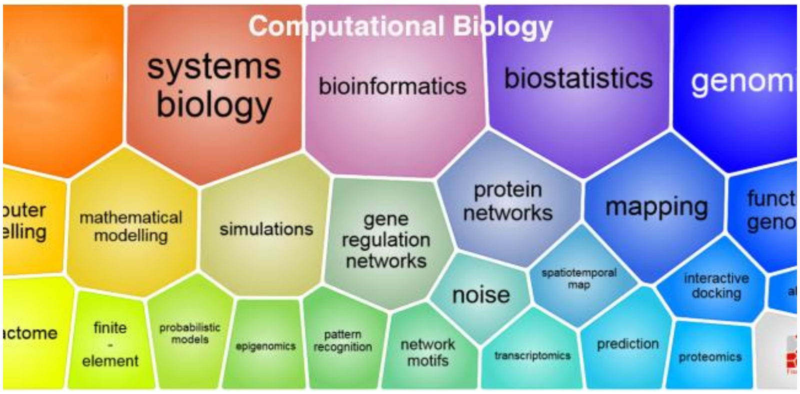

Figure 62. Clusters of most used keywords in ERC projects in the field of computational biology. Image credit: ERC EU

The FTI's report highlights several -expected- advances of Computational Biology in the coming years, from the possibility to predict the protein folding that will be crucial to the design of new drugs (watch this clip and get more info on AlphaFold) to super-fast molecules discovery that can be manufactured by modifying bacteria. The MIT-Broad Foundry was enrolled by DARPA to prove that it is possible in a short time (three months) to re-engineer bacteria to produce new molecules (not known in nature). The challenge was met by the production of 6 new molecules (out of 10) within 90 days.

Modifying a cell, using CRISPR as screwdriver and computational biology to figure out what to change, is an established technology whose progress will continue through his decade both in improving the "screwdriver" and the knowledge derived from computational biology. The next step is, obviously, start from scratch to design first, and then create, a brand new cell having a specific set of desired property. This is what is usually called Designer Cells. The name wants to highlight that these cells do not exist in Nature, they are the result of a design (cells derive from random mutation and selection leading to evolution, there is no "design" involved in a cell). The amount of cell diversity is staggering, yet what we are seeing is a tiny fraction of the gazillion of cells that random mutations generated in the last 3.6 billion years. However, this gazillion cells are not exhausting the complete set of cells that would be possible given physical and chemical constraints. For a cell to exist you need to have a parent cell: gaps are not possible in the landscape of evolution. This is not so for designer cells since you can design any type of cell from scratch as long as it is compatible with physics and chemistry and the ensemble can work as a single piece. This dramatically expands the set of possibility (whilst modifying a cell is just "accelerating" the creation of a new cell).

Indeed, technology makes it possible to create a synthetic cell "cloning" an existing one. Researchers in Switzerland and in the US (North Carolina) have been working to create a synthetic version of the Covid-19 virus as a way to accelerate its study. The DNA of the virus is now available on line and with the kind of synthetic biology toolkit around (and a limited understanding on how to use them) you can create a synthetic version with as little as 30,000$. This is a little amazing and a lot scaring! According to the FTI's report we should be seeing in the coming years the creation of cells, of life, out of the blue. This is also another case of opening a Pandora's vase and both ethical and safety issues arise.

14.4 Molecular Robotics

The progress of technology that allows us to manipulate the DNA, CRISPR and others, is allowing researcher to create DNA that can serve specific purposes, outside of its usual cell environment where it is used to create copy of mRNA that are used by the cell to build proteins.

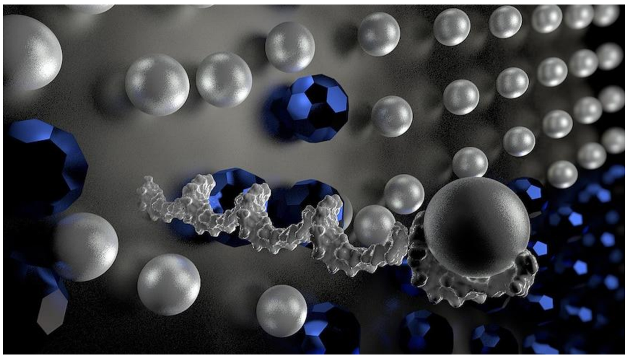

Figure 63. Rendering of a strand of DNA engineered to act as a robot, moving in a nanostructure to build a complex molecule. Image credit: Scientific Illustration

A single strand of DNA, the one forming our genes is a double strand, the double helix, tends to look for pairing molecules and by bringing them in close proximity can have them stick with one another. In practice it behaves like a searcher and a builder. Researchers have discovered, and can create, specific snippets of DNA to serve specific functions like search for a given molecule, once it is found go on and search for a different one. It works this way: the DNA strand in a random way moves in a solution or on a nanostructure -as represented in figure 63- and once it gets in proximity to the desired molecule the part of the DNA that has been designed to search for that molecule sticks to it. This sticking blocks the part of the DNA that was "looking" for that molecule and frees the next strand of DNA that will be in charge to perform the next action, like searching for the next molecule. Once this is found it sticks to the related DNA strand and placing it in proximity with the previous found molecule and this leads to their binding. The molecular robot has built an entity made of those two molecules, and so on. Further actions may require to transport this created ensemble to a different place where a specific molecule is found (notice that all these operations are based on random movements, exactly as it happens within our cells). In a way, molecular robotics is about building a DNA tool having hands and legs plus a "mind" deriving from the sequence of actions designed that can operate on its own.

This, in a nutshell, is the basic of molecular robotics a new science/technology that has been gaining steam in the last decade and that, according to the FTI's report, will make significant progress in the coming years.

Researchers are creating origami using DNA strands that fold in desired ways to implement a sequence of activities. Libraries of these origamis are becoming available giving rise to more and more complex sequences "ready to use" (watch this clip).

Molecular robotics is a further toolkit that adds on to the growing set of technologies in the nanotechnology domain.

Molecular robotics can also be based on RNA. Both RNA and DNA robots can operate inside living cells and the expectation is to have them applied to cure diseases (beyond genetic diseases where the goal is to modify the cell DNA), including some types of cancer. The recent success of mRNA based vaccines is a proof of the potential of this technology, although this represent a (relatively speaking) easier case study since the mRNA enters into the cell and relies on the cell metabolic organisation to create the spike protein.

It is also expected to see growing application in agriculture.

14.5 From Genome Sequencing to Artificial Human Genome

The progress in genome sequencing has been so significant that in 20 years we have moved from a billion $ endeavour to obtain the first genome sequence to a mass market offering of sequencing (see the decreasing cost of sequencing in figure 64). There is still quite a bit of confusion on the meaning of genome sequencing:

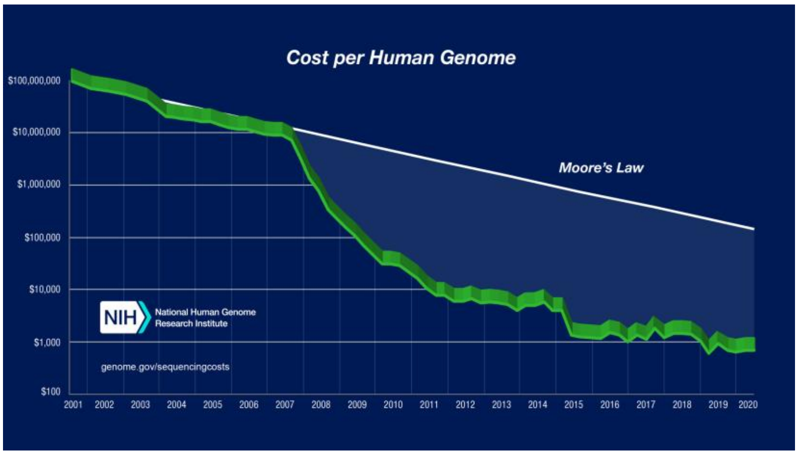

Figure 64. Decreasing cost per human genome sequencing. Notice how, since 2007, the cost decrease has accelerated way beyond what predicted by the Moore's law. Also notice the flattening out since 2015. Image credit: NIH

- The first human genome sequencing was declared "completed" in April 2003 (sequencing started in 1990 and overall saw a 2.3 B$ investment), yet last May 27th the T2T, Telomere to Telomere, consortium announced in a paper pre-print the completion of the sequencing (and actually there is still a tiny bit on the Y chromosome that remains to be sequenced);
- The human genome consists of 3.2 billion pairs (according to the Human Genome Project) and that would require less than a GB of storage (compressing the data), however the average size of the data set representing the genome is a few hundred GB (Google and Amazon are willing to store it for you at a cost around 3$ per month). The issue is in the understanding of the genome and this requires correlation with many others. The NIH SRA – Sequence Read Archive- is stored in the AWS cloud and contains (and the figure is growing every day more) some 40 PB of data (they are freely accessible).
- The cost of sequencing, as shown in figure 64 has gone down, first following the Moore's law (because the cost of processing kept decreasing according to Moore's) then it fell dramatically in 2007 as a new approach to sequencing was invented, to stabilise in 2015 around 1,000$. However, this cost does not take into account the mapping (that is crucial to understand the sequencing) and this is around 2,000$ -basically stable, although the use of AI will decrease it.
- The genome sequencing mass market by companies like 23andMe and AncestryDNA is offering the sequencing for 40 to 200$, however they are not sequencing the whole genome (as noted the complete sequencing has been just announced!) but only some parts of it and they match it against some very specific domains, like the geographical region where a given DNA strand is found to tell you about your ancestry. Nebula Genomics offers a more

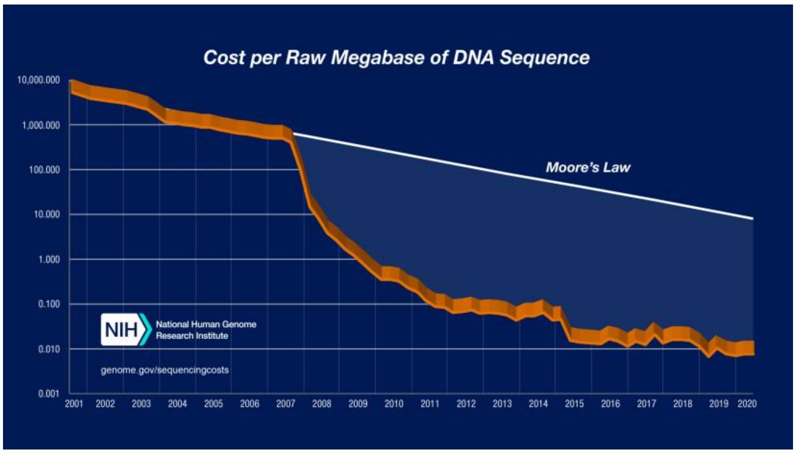

Figure 65. Cost to sequence 1 million bases of the genome. It went down from 10 million $ in 2001 to 1 cent of a dollar in 2020. Image credit: NIH

extensive sequencing for 299$ (their ultra deep analyses is offered at 999$). The graphic in figure 65 shows the cost per Megabase, that is how much it costs to sequence a million of bases. As shown, the decrease in price has been staggering (the pattern, as expected, is the same of the overall genome sequencing), being now around 1 cent per Megabase. This means that as in most situation the interest is focussed on a very specific gene, or a pool of genes, that can be involved in a (genetic) disease or in the reaction to a drug, it becomes possible to restrict the sequencing to the areas of interest, thus dramatically decreasing both the cost and time needed to sequence.

The genome sequencing can be applied to embryos and there are companies, like Genomic Predictions, that offer prospective parents the possibility to analyse the genome in (in vitro) embryos to detect potential genetic diseases as well as diseases that are influenced by genomic predisposition. As knowledge on the correlation between the genotype and the phenotype grows (leveraging on AI applied to the SRA and medical records) the accuracy and breath of predictions will grow. These companies, so far, are only looking at diseases related predispositions but in principle they could also highlight other phenotype characteristics, including shape of the body, potential level of intelligence and so on. Obvious the ethical implications in this -potential so far- possibility to "customise" a baby (in addition to the selection of an embryo destroying the others…).
From the analyses of a genome to the manipulation of a genome the (technical) step is not a big one (not so for the ethical implications). However research is progressing, as pointed out in the FTI's report, with the goal of creating variation of the human genome, resulting in an artificial genome, for studying purposes. An interesting goal (due to its practical implication) is the discovery of the "fountain of youth" within the DNA, that is what are the genes that are involved in ageing and how a modification to these genes could lead to a slowing of the ageing process and even to a reversal (here again we are stepping in a forest of huge ethical issues).

15. Wrapping up

Several parts of the world are -slowly- getting out of the pandemic and containment measures are loosened to various degree. The mass vaccination is working, even better than expected, and in a matter of months most people on Earth will have the opportunity of receiving a shot. The war is not over but we know how to fight and win it.

I am closing this ebook on post-pandemic scenario with the first indications available on the way business is reacting to the end of the pandemic. The pandemic's countermeasures (lock down, social distancing, increased sanitation, shift of value perception, automation) have induced a surge of digital adoption and a corresponding change of the way of working with most companies moving to remote working as much as feasible (and we learnt, in the process, that current technology can support remote working, can scale graciously to support the increased internet traffic, and people can adapt to the new working setting, some liking it more than others).

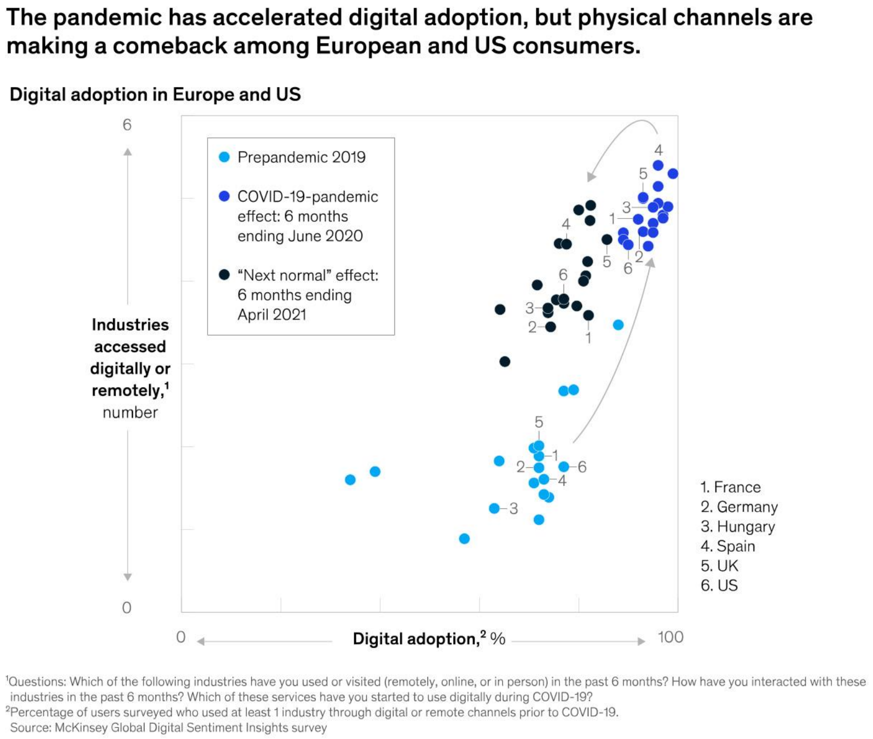

Figure 66. The pandemic's effects on the business have been huge, as situation is slowly going back to normal the business readjust again but it seems from the first available data, as shown in this graphic that the "new" normal is not like the "old" normal. Image credit: McKinsey

The graphic in figure 66, created by McKinsey, analyses the changes in a few Countries in Europe and US during the pandemic in terms of increase in digitalisation and relying on remote access adding the most recent information on changes as the containment measures are being relieved. It makes for some interesting considerations. Notice that the graphics has been designed from the end user perspective (but also notice that a shift to remote access by the user/customer steers towards delocalised work from the company perspectives since there's no more a need of presence on the company premises to meet the user):

- the first observation is about the leap that all considered Countries had in shifting to digital access and remote access (the y axes) on a scale from 0 to 6. The containment measures pushed the remote /digital access from around 2 to close to 5 with some Countries approaching 6;
- the second observation is an increased use of digital channels to access companies, increasing from an average of 70% to close to 100%.
- the third observation is that once the containment restrictions have been released (or loosened) the use of digital channels has decreased but not to the point they were before the epidemic, remaining somewhere in between (85%), whilst the digital remote access has decreased but not that much, remaining significantly higher than it was before the pandemic.

This users' snapshot is reflecting (and steering) a change in the way of working and in the way companies are presenting themselves to the marketplace.
The remote working has meant a sharply reduced demand for office space and companies have been moving from the personal office space to a shared space, thus reducing the number of workstations required, dramatically reducing real estate cost and operation cost. This has become a very interesting proposition for companies bottom line and most companies that during the lock down had moved to telework are now reopening their premises with greatly reduced shared floors, demanding their employees to be back at company premises between 2 and 3 days per week, thus almost halving the need for space. At a cost of 500+$ per desk per month this rapidly adds up to big numbers (a saving of 3 million$ a year for a company with 1,000 employees) resulting in a few percentage points gain in productivity.
It is not just the companies bottom line that is steering towards a hybrid workspace, colocated and remote. Employees have appreciated the advantages of getting rid of commuting (although several lamented the office social space) and are pressing to keep the remote work option, at least part time.
In turns, this changed work modality is steering several of the Megatrends I have presented, with growing demand for better remote working support, increase in cloud functionality and seamless access, better ubiquitous communication facilities (in most residential areas the communications infrastructure has shown the capability to support any type of remote working but in rural areas issues have been present and need to be fixed).
The increased use of remote services are pushing towards better delivery and at the same time they have opened the door to an increased demand, investment funding and are resulting in an accelerated evolution, with healthcare leading the pack.
Most notably, the strong political consensus on leveraging the recovery as a way to steer the business and the societal culture towards a sustainable and green economy is changing the focus of research and technology adoption accelerating trends on clean energy, delocalized production, digital production and more.
These changes raise demand for continuous education and for a slate of new skills that will transform the education "industry" in the coming years as cooperation among human workers and intelligent machines becomes the norm. The whole role of artificial intelligence, becoming pervasive and flanking human activity is changing, shifting from a blunt replacement to a cooperation, at the same time raising issues of accountability and responsibility.

Activities of Digital Reality Initiatives will take these trends into account in their evolution in 2022. You are welcome to participate and contribute.