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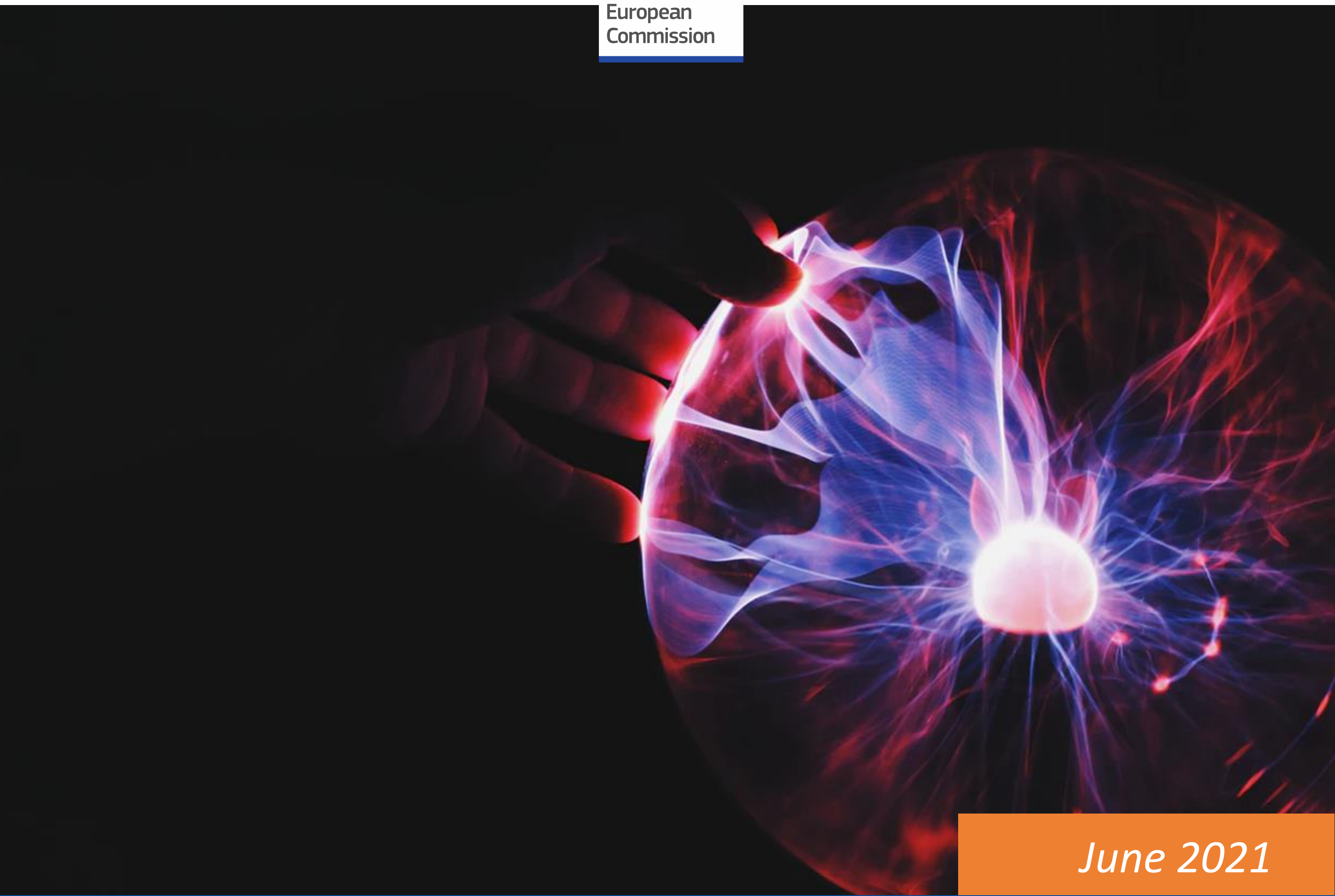

June 2021

Advanced Technologies for Industry – AT WATCH

Looking beyond the horizon

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EUROPEAN COMMISSION

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PDF ISBN 978-92-9460-772-0 doi: 10.2826/97694 EA-08-21-208-EN-N

Luxembourg: Publications Office of the European Union, 2021

June 2021

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Section 1

1. Introduction

This Advanced Technology Watch report has been developed in the framework of the 'Advanced Technologies for Industry' (ATI) project, initiated by the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs, and the European Innovation Council and Small and Medium-Sized Enterprises Executive Agency.

The AT Watch report series is meant to play a complementary role to the other analytical, policy and statistical reports of the project, focusing on market, business and socioeconomic trends driven by technology innovation. This Advanced Technology Watch therefore encompasses the whole spectrum of advanced technologies that are a priority for European industry policy. These technologies enable process, product and service innovation throughout the economy, thus fostering industrial modernisation. As part of a series of analytical reports on advanced-technology trends, **this report focuses on a new wave of emerging technologies that will accelerate industry modernisation and the overall process of digital transformation across organisations and businesses in Europe**.

The qualitative and quantitative analysis included in this Advanced Technology Watch is specifically designed to provide novel insight and up-to-date content to technology users across the whole spectrum of European industries, with the aim of revealing potential opportunities emerging from the most recent applications of advanced technologies.

The AT Watch report series targets:

- A primary audience of industry stakeholders, including SMEs, and industry associations interested in learning about upcoming technology trends and business opportunities
- A complementary audience of national, regional and local policy makers interested in supporting industry in the exploitation of technology innovation and emerging business opportunities by removing barriers and creating favourable market conditions
- A complementary audience of research and technology stakeholders interested in the applied research challenges to be solved to capture emerging business opportunities

This report is thus structured in two main sections:

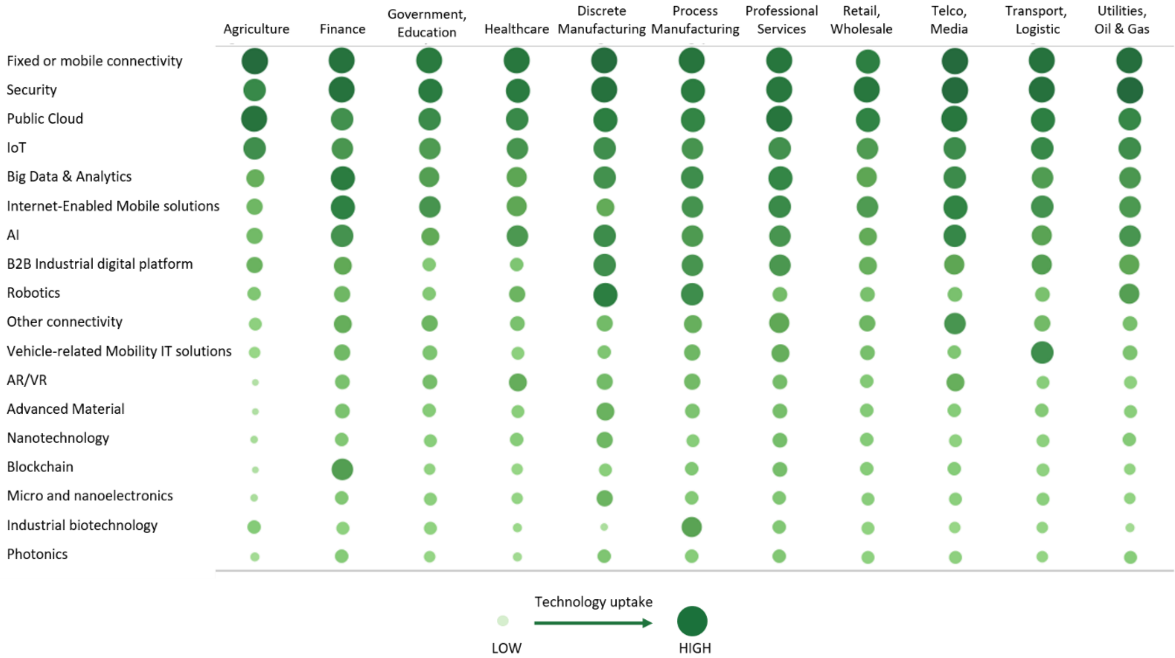
- A brief overview of all advanced technology uptake and demand trends by industry (Section 1)
- An in-depth analysis of some of the advanced technologies beyond the horizon, selected because of its relevance in terms of emerging business opportunities and disruptive potential (Section 2)

1.1. The Advanced Technologies for Industry landscape

The digitalisation and industry modernisation processes in Europe are progressing at different speeds across various industry sectors, driven by a whole set of changing priorities, challenges, and use cases. Advanced technology adoption has been impacted by the pandemic, resulting in a slowdown, which is necessary to allow companies to focus on more business contingency-related initiatives. At the same time, COVID-19 has sped up the adoption of some specific technologies through the forced digitalisation of customer and supply-chain interactions and all the related internal processes. These technologies are acting as return-to-growth accelerators, making businesses and organisations as a whole more resilient for the future scenario. However, along the entire path to recovery, the focus will be more on safe bets than on big bets.

The different mix of advanced technologies adopted in each industry is visualised in Figure 1. The figure shows the percentage share of enterprises in each industry adopting or planning to adopt each technology. (The size of bubbles corresponds to the level of uptake, with the highest value being 85%) The data is based on the Advanced Technologies for Industry Survey (November 2020)[1] and on a sample of European enterprises from 7 Member States, representing more than 60% of EU GDP in 2020. This is an updated version of last year's ATI Survey, conducted in July 2019.

Figure 1: Advanced Technologies uptake by European industries, 2020



Source: Advanced Technologies for Industry Survey November 2020, (N = 1 547).

Note: Bubble size represents the % of enterprises in the industry adopting the technology in the same row. The maximum value is 85%.[2] Technologies are ordered top-down based on the total sample average adoption.

The visualisation highlights how a distinct group of technologies **features a marked horizontal diffusion** across all industries (general purpose technologies – connectivity, security, public cloud, mobile solutions, big data & analytics, Internet of Things (IoT), and industrial digital platform): They represent the technology portfolio necessary (but not sufficient) for digital transformation. **Other technologies clearly display a niche or industry-specific orientation**. However, this does not mean that they do not provide opportunities for investments outside their main industry niche. Robotics is a very interesting example: The technology was initially developed in manufacturing, where it served as a substitute for the human workforce in several time-consuming tasks, helping humans to save time and speed up production. New areas of application are now emerging, and multiple novel use cases proliferate, driving business value in other industries. For instance, in manufacturing, robotics is used for a wide variety of tasks, from shop floor production automation to warehouse inventory management. Similarly, robotics exhibits great potential in the healthcare sector, where it can be used to support the

[1] The survey interviewed a sample of 1,547 enterprises with more than 10 employees in DK, DE, FR, ES, IT, PL, and SE.
[2] The technology definitions can be found in the methodological report, at https://ati.ec.europa.eu/reports/eu-reports/advanced-technologies-industry-methodological-report.

medical personnel enhancing procedures' safety, reducing operative costs, disinfecting rooms, preparing and storing medications, and much more. Compared to the results of the previous survey, industries show some similar technological patterns: Connectivity, public cloud, and security technologies are among the most adopted technologies, with small differences across industries, while advanced materials, nanotechnologies, and industrial biotechnology are common in specific sectors, such as manufacturing and healthcare. Compared to 2019's results, IoT and AI show an interesting increasing pattern in transport and healthcare, while B2B industrial digital platform is quickly gaining ground in manufacturing and agriculture. Firms in the finance sector are more and more interested in robotics, which represent the highest increase in adoption rates across industries, proving the high potential this technology can provide to the sector. Referring to robotics, respondents mainly referred to robotic process automation (RPA), which finds very fertile ground in this sector. On the other side, some technologies are slowing down: While industrial biotechnology is increasingly adopted in manufacturing, it is decelerating in utilities. A similar trend is shown for the public cloud in healthcare and retail.

When looking at the European industries in more detail, we observe that:

- The operational excellence that the **manufacturing industry** is looking for will be achieved through the adoption of advanced technologies. This operational improvement will be of paramount importance in ensuring performance during the next normal. In fact, COVID-19's impact on trade caught many firms unprepared, with negative consequences on supply chains. This event drastically changed the focus from a low-cost country sourcing mantra to a more resilient and simpler network. Implementing new technologies is turning supply chain processes and activities towards less uncertainty and complexity. Technologies like **robotics, AI, IoT, blockchain, and edge computing** are the key drivers to achieve these goals, together with efficiency benefits and zero-touch production (ZTP) processes, the latter being pushed significantly during the pandemic and becoming a strategic asset for the future of enterprises. Efficiency is also fostered by **AR/VR** solutions, which enable experts to provide remote support to on-field operators and provide step-by-step instructions. **B2B digital platforms** are also a key trend in the manufacturing industry, pushing for a more collaborative relation between colleagues, peers, and employees. This opportunity is deeply connected to **Big Data/analytics** technology, which allows the user to track and analyse processes, improve operational visibility, and understand improvements and trends. **3D printing** has shown its huge potential in creating and modifying manufacturing and healthcare products during the pandemic and is likely to be a key trend in the coming years. Product innovation is also driving the adoption of **advanced materials, micro- and nanoelectronics, nanotechnologies, and photonics** with the aims of improving products and reducing costs.

- In **finance,** besides operational efficiency, the other main business goal driving investments in advanced technologies is the need to attract and retain customers. This is pushing the industry towards piloting new service delivery models. **AI**, **Big Data,** and **blockchain** are among the most promising technologies for the industry, as they enable the automation of internal operations, improve customer service, and enhance protection against security threats. To counter the uncertainty of the new reality and improve loan portfolio health, **advanced analytics** is making it possible to analyse every payment that a corporate or small business makes and receives. Key AI trends in the industry include the automation of IT operations and opening new digital channels to improve customer experience leveraging voice banking and chatbots. Blockchain's main applications include, for example, cross-border payments and settlements. **Robotics**, mainly in the form of robotic process automation (RPA), is changing how banking and finance companies carry out business through fraud detection, auditing, and reducing time-consuming workloads. To keep pace with the information security risks, **security technology** represents a key element for the financial sector. The industry has also been central to the emergence of a new digital economy, open banking, which is connected to the European payment services directive (**PSD2**[3]). Customers will therefore look for more suitable and personalised products and services, not being obliged to use what the traditional financial institutions provide to them, and they will drive the next wave of growth of the fintech sector.

- For **telecom and media** providers, new technologies and new customer behaviours are generating several opportunities to boost current income sources and generate new revenue streams. **5G technologies,** for example, are expected to provide many monetisation opportunities for telcos, although the pandemic has led to a delay in the technology's rollout as a result of the post-crisis economic condition. **Robotics and blockchain** reduce error rates,

[3] https://ec.europa.eu/info/law/payment-services-psd-2-directive-eu-2015-2366_en

enhance data quality, improve customer service, ensure transparency and efficiency, and significantly reduce operational costs. The provision of the necessary network infrastructure and **connectivity** for voice, data, media, and other related services will become even more important in coming years, given that businesses have become more distributed than ever since the COVID-19 pandemic outbreak. To ensure that their infrastructure will meet the need for digital initiatives in the coming decade, enterprises and service providers are reconsidering how their networks are architected. The increasing volume of personal data gathered in this sector is pushing towards more and more sophisticated **security** solutions, making it a real priority even among other high-risk industries. Interesting pockets of growth can also be found in investment in other advanced technologies, such as **photonics**, which are supporting the development of fibreoptic network communications. As said at the beginning, media transformation processes have been driven by changing customer needs and behaviours: Innovation in the industry has been driven by new channels and platforms for distributing, accessing, and producing content. Streaming, content-as-a service, and new technologies for creating engaging entertainment experiences, such as wearables and **AR/VR** technologies, are major trends under the spotlight.

- **Utilities** and **oil & gas** show interesting opportunities in terms of many advanced technologies, but the pandemic outbreak inevitably cooled European utilities' IT spending ambitions. In this context, **artificial intelligence** and **cybersecurity** competencies are requested more than ever as a fundamental asset to come out of the current crisis and be ready for the next normal. Hotspots in the industry are the **e-mobility revolution** and **AI-powered home energy management**. Electric vehicles are expected to be a mass-market revolution, driven by increasing sustainability concerns and blurring industry boundaries between power distribution and retail, transportation, and automotive. The quest for **alternative and sustainable energy sources** is also paving the way for the use of advanced technologies such as **photonics** and **nanotechnologies** for power generation and for new and more efficient lighting solutions. **Robotics** and **IoT** are fast spreading in these sectors, increasing productivity, lowering labour costs, and – most importantly – keeping workers safe for dangerous tasks, providing a high degree of accuracy and efficiency. The second mass-market revolution is the smart home ecosystem, where utilities can play a big role in providing advanced home energy management solutions and automation functionalities using devices such as smart plugs, smart thermostats, and smart lighting for optimising energy consumption and gaining insights into consumers' habits.
- The **healthcare industry** shows some interesting investments in **AI, robotics, AR/VR, nanotechnology, and advanced materials**, compared with other industries. The uptake of advanced technology in the industry is strictly linked to the need to innovate and improve patient care, providing integrated and personalised services. The outbreak of COVID-19 has put enormous pressure on many European healthcare systems but has triggered unprecedented demand for digital health technology solutions at the same time. **AI, automation,** and **advanced analytics** are not just solutions to put on top of a technology stack, but the intelligent core of a new enterprise platform. **Robots**, especially for surgery and logistics purposes, are becoming more affordable, and hospitals will start to invest more significantly in the upcoming years. Investments in **wearables, IoT, and AI** are growing with the need to monitor patient behaviour and accidents for elderly people with medical conditions to provide prompt emergency help. **AR/VR** devices are helping doctors improve surgery and diagnosis and are also used for therapeutic purposes (e.g. rehabilitation).
- COVID-19 has disrupted the **retail** sector, with different impacts depending on several variables (brick-and-mortar versus online shops, essential versus non-essential stores, and small versus large retailers). Overall, the industry impact has been significant, although advanced technologies have played a key role in supporting organisations in the industry along their COVID-19 reaction initiatives. The **e-commerce** channel – where consumers can finalise their purchases using their PCs or **mobile** phones – remains a priority for retailers and a successful strategy during the COVID-19 pandemic crisis. A key focus of retailers as an immediate crisis response was accelerating the implementation of retail commerce platform capabilities, providing retailers with the foundations for the execution of new commerce-everywhere business models. As more customers are switching to mobile commerce, customer assistance and support are also changing. Through **AI-enabled chatbots**, customers can contact

companies on social platforms to track shipments, request product refunds, or raise complaints. COVID-19 will have a long-lasting effect on customer experience, and, in the years to come, it will push retailers to permanently integrate contactless solutions into their customer experience road maps. A growing opportunity in the industry is represented by **real-time contextual personalisation** for the customer, which allows retailers to shape the customer experience in relation to multiple parameters, such as demographics, location, day/time, weather, and purchasing patterns. **Advanced analytics and Big Data** are crucial to achieve this degree of personalisation. **Photonics** is also gaining ground compared with other industries, helping for example retailers of consumer packaged goods (CPG) and customers to judge the ripeness of fruit and vegetables, and so reduce the percentage of discarded food, or through more dynamic use of displays.

- The pattern of technology adoption in **government** and **education** is influenced by the national context and the coronavirus crisis. Public sectors of all countries tried to cope the best they could with the current downturn, through massive injection of resources to support the economy and by putting in place multiple advanced technology-enabled emergency solutions. Governments are working to streamline internal bureaucratic processes through **automation** to speed up critical government work, resulting in more agile access services. **AI** solutions will support citizens with the right level of speed, quality, and personalisation, while it will provide remote management of the workforce. After the emergency-driven experience of distance learning during the lockdown period, **education institutions** in Europe are prioritising investments in **mobile solutions** – for example, investing in the provision of mobile devices. Lessons are carried out via **distance learning,** with the development of online platforms and e-learning apps for students. At the same time, some changes accelerated by COVID-19 are likely to become permanent: Governments are moving towards **permanent remote working**, whereby secure remote access to data and applications and collaborative tools enable employees to work across departmental silos. **Smart city** projects, combining **mobile, IoT, and Big Data/analytics** solutions, are expected to push investments in technology, especially for safety purposes (such as video surveillance) and for public transport optimisation. **Security** of digital services are therefore a top priority, as these enable both citizens and civil servants to trust these services' reliability and the handling of sensitive data. Another driving trend in the industry is represented by **open data portals**, with the aim of improving transparency, openness, and interaction by sharing public data with citizens.
- Although the pandemic outbreak significantly tested **professional services** firms, they reacted with agility, evolving their services and business models to cope with the changing environment. Despite considerable challenges, this sector performed quite well — mainly, because these companies had the technological infrastructures to continue their daily business processes and operations. Professional services firms are carrying out their activities in a more agile and flexible way, such as **working from home**, which is supporting investments in devices (laptops, smartphones, and tablets), collaborative apps, video linking, cloud, and content sharing. Tech providers in this industry are also under considerable pressure to provide strong digital platforms and will be required to enhance their existing **cloud solutions**. As a data-intensive vertical, the professional services sector is responsible for an important share of investments in security, driven by the implementation of the General Data Protection Regulation (GDPR). This has driven industry players to raise technology barriers to protect client sensitive information and avoid data breaches. The pandemic has changed the relationship between customers and services providers, but **Big Data/analytics** – along with **AI** and machine learning – are enabling the deep analysis of customers, leading to more accurate customer-intention prediction and competitive advantage. Digital technologies are changing the industry in their client-facing and back-end activities. For example, advanced technologies will be able to automatically process documents such as legal, shareholder, and market reports, impacting positively on timing and freeing staff from tasks that can be automated.
- **Transport** has been one of the industries most affected by the pandemic, squeezed between safeguarding workforce health and keeping a core transportation system operational. However, this crisis is expected to accelerate the digitalisation of mobility. **Cloud** computing and **Big Data/analytics** are playing a crucial role in collecting, sharing, and analysing real-time data, providing an effective way to identify and quantify disruption. This data will also enable the restoration of adequate transport services to meet the increasing demand as we move towards

a new normal. Mobility as a service is offering people an alternative to get around safely during the pandemic. Other technologies, such as **IoT** and **AI**, will keep playing a key role in supporting industry companies to regulate traffic flows, streamline security checkpoints with biometrics such as facial recognition, and reduce the number of lost bags using electronic luggage tags. In logistics, heavy workloads can be eased by introducing solutions to create collaborative environments in which **humans coexist with robots**, with the latter taking over heavy, repetitive, and time-consuming tasks.

- The pandemic has exacerbated the challenges **agriculture** was already facing, including increasing demand for food and lack of workers. This is the reason this sector has to rely even more on advanced technologies, which will increasingly play a fundamental role in addressing these issues. **Data-driven innovation** is transforming farm management through the so-called **precision agriculture** approach. By leveraging **satellites, drones, and IoT sensors**[4] in farm equipment (such as tractors), an unprecedented amount of data can be collected to monitor the conditions of the crops, soil, and other key elements for cultivation, as well as cattle. **Cloud computing** – which is finally taking ground in this sector, especially among large players – will help aggregate all the data gathered, allowing farmers to manage irrigation, fertilisation, and all farming processes in scientific ways, minimising costs and the use of pesticides and maximising outputs. Without a solid **connectivity** infrastructure, a successful application of all these innovations is unthinkable. The digitalisation of farming processes also represents the first step for the emerging food track-and-tracing systems developed to guarantee quality and safety, highly appreciated in the food-agriculture value chain. Advanced technologies show interesting uses also in fighting **climate change and related risks** (such as the loss of arable land and increased urbanisation). For example, a growing trend is represented by **urban or vertical farms,** leveraging technologies to minimise the use of natural resources such as soil, water, and energy. This is done by using **IoT** and **photonics** to manage parameters such as humidity, light, and irrigation to get the most out of crops. **Industrial biotechnology** also shows promise for obtaining alternative healthy, protein-rich, and nutritionally balanced food raw materials in response to the expanding population and increasing food demand.

This overall picture of the deployment of advanced technologies in European industry is, to a certain extent, reflected in the analysis of the demand and supply of advanced technology skills, as carried out for the General Findings report within the framework of the present project[5]. In terms of skills supply and based on the profiles of registered users on LinkedIn, the share of advanced technology skilled professionals (vis-à-vis the total number of professionals) in select industries reveals that Europe's manufacturing industry absorbs the highest number of skilled professionals. This is particularly true for the automotive sector, where technologies such as advanced manufacturing and IoT are clearly instrumental in the development of Industry 4.0 strategies.

Other industries, such as electronics and, to a lesser extent, chemicals, employ a large number of skilled professionals, especially for technologies like advanced manufacturing and IoT (in electronics) and advanced materials and industrial biotech (in chemicals), confirming that manufacturing as a whole remains at the forefront of digital transformation and modernisation processes in the European Union.

In terms of skills demand, manufacturing exhibits high levels of hiring positions, as measured by the number of online job advertisements requiring specific skills. Again, the automotive sector requires specific skills in advanced manufacturing, AI, and robotics, just as the electrical & electronics exhibits strong demand for skills in advanced materials, micro-nanoelectronics, nanotechnologies, and robotics. The prominence of the manufacturing industry is challenged only by the finance sector, where – both in banking and other financial services – specialised skills for Big Data, blockchain, cloud computing, and cybersecurity are very much in demand across the European Union.

Advanced technologies are rapidly evolving. Technologies identified in the ATI project are leading the way to an innovation-infused acceleration for the European digital landscape, but others are appearing at the horizon and beyond. This AT Watch report focuses on those technologies that are still at a very early stage – if not still at the R&D lab stage – providing an in-depth overview of what is next in terms of emerging technologies and their European market disruption potential effect.

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4 ATI Product Watch (D3.6) "Satellites and drones for less intensive farming and arable crops", January 2021, https://ati.ec.europa.eu/reports/product-watch/satellites-and-drones-less-intensive-farming-and-arable-crops

5 ATI General Findings (D3.4), Section 5, June 2020, https://ati.ec.europa.eu/reports/eu-reports/report-technology-trends-technology-uptake-investment-and-skills-advanced. An updated version of this report including the AT skills analysis will be published this year (2021).

Section 2

2. Beyond the Horizon of Advanced Technologies

2.1 Introduction

We are in the middle of a transformational turning point for European industry. A moment when European organisations are now called to accelerate along their road to post-pandemic recovery, enabling a new business resiliency scenario – unshakable by the continuous volatility that will characterise the next few months – and leveraging digital technologies to react and reignite their growth. Advanced technologies, building upon a backbone of established traditional technologies, play key accelerator and enabler roles in this context. They accelerate organisations digital roadmaps but also unlock a plethora of digital use cases that would not be possible without them.

While several advanced technologies are high on the innovation agenda of European organisations – such as IoT and its hyper-automation impact and AR/VR solutions opening new opportunities for customer experience (see Section 1) – a new wave of emerging technologies and tech paradigms is already on the horizon, preparing the ground for the 'next big wave'. **Looking at and beyond the advanced technology horizon is paramount for European organisations that are eager to accelerate their digital roadmaps and for European policy makers in their efforts to maintain Europe's leading position in the global digital landscape.**

These 'beyond-the-horizon advanced technologies' are at a much earlier maturity stage than the advanced technologies analysed in the previous chapter. They are not fully ready for broad commercialisation or business application yet, since many of them are still at the research & development lab level. In a nutshell, these are the common traits they share:

- **Beyond the conceptual to the research & development phase:** These technologies have already moved beyond the purely conceptual stage[6] to the research & development phase, with effort now on testing them in real-life business and societal scenarios, improving and fine-tuning them to make them broadly available, marketable and scalable across organisations and final buyers.
- **Changing the status quo:** These technologies are changing current economic and social scenarios, making available new ways of working and living and generating new opportunities for businesses and households. Quantum computing, for example, is bringing a real revolution in calculation speed, making it possible to analyse and process a huge amount of data in no time. This will change the way many operations are carried out, from speeding up training for machine learning algorithms to improving financial risk assessment in the finance sector.
- **Fast maturity evolution:** These technologies are maturing quickly and are proving revolutionary on several fronts, from deployments in specific industries to implementations in different contexts of daily business. This ultimately means a rapid rate of change in capabilities in terms of price/performance relative to substitutes and alternative approaches.[7] The main core of drones, for example, is similar to those of smartphones, for which investment in research & development has enabled significant price reductions over recent years, making them easily accessible to consumers and businesses. Moreover, drones' performance is improving at a fast pace – partly, due to the implementation of other technologies, such as AI, enabling the resultant data to be stored and managed.
- **Broad impact and uptake still uncertain:** These technologies need to be broad in range in terms of companies, industries, products and services. The overall effect is, however, hard to define due to uncertain or contested knowledge concerning the applications and impacts of these new digital solutions. Biometrics, for example, has a wide range of use, from fostering security by verifying identity with a tangible real-world trait to increased accountability by keeping accurate track of employee movements and activities. On the flip side, broad impact is uncertain

[6] Stahl, B. C. (2011). What does the future hold? A critical view on emerging information and communication technologies and their social consequences

[7] McKinsey Global Institute (2013). Disruptive technologies: Advances that will transform life, business, and the global economy

due to several factors, from the significant investments needed to deploy a given technology to the risks associated with privacy.

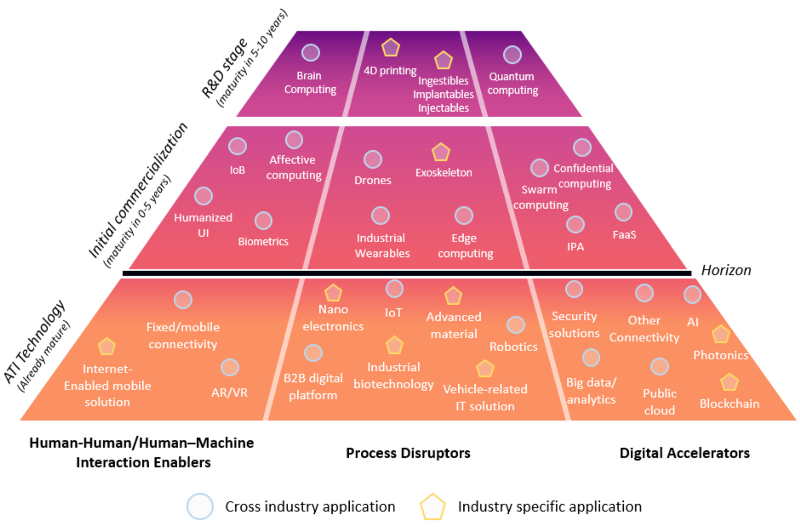
From this perspective, beyond-the-horizon advanced technology can be described as a radically novel and relatively fast-growing technology characterised by a certain degree of coherence with the potential to generate considerable social and economic effects. Its most prominent impact, however, lies in the future. In the emergence phase, it is still somewhat uncertain and ambiguous.[8]

Although it is difficult, if not impossible, to **provide an exhaustive list of all those advanced technologies beyond the horizon, the following emerging technologies are certainly part of the 'next big wave'** (see the Appendix B for full detailed definitions):

- 4D Printing
- Affective computing
- Biometrics
- Brain computing interfaces
- Confidential computing
- Drones
- Edge computing
- Exoskeleton
- Function as a service (or serverless computing)
- Humanised UI
- Industrial wearables
- Ingestible, implantable and injectable tech
- Intelligent process automation (IPA)
- Internet of Behaviour (IoB)
- Quantum computing
- Swarm computing

These forward-looking technologies are represented in the figure below, together with the already considered ATI technologies. Technologies are plotted based on their time to maturity along a three-group timeline, which also shows their key impact roles and application focuses across industries.

Figure 2: Looking beyond the horizon of advanced technologies



Source: IDC Emerging Technologies Research, 2021

[8] Rotolo, D. et al. (2015). What Is an Emerging Technology?

2.1.1 Time to maturity

The first dimension relates to the **time to maturity of each technology**, i.e. the time needed to become highly competitive and safely integrated into products and processes.[9] In this context, three phases can be identified – already mature technologies, technologies in the initial commercialisation phase (i.e. that are expected to mature in a range that spans from less than a year to five years) and technologies that are still in the research & development phase (expected to mature in a range that spans from five to ten years).

In the **first group**, all the ATI technologies are included, from AI and IoT to micro/nanotechnologies and public cloud. These technologies, although still emerging and far from full maturity, are all on the market and already beyond the early-stage pilot phase across business activities and industries.

The **second group** includes those emerging technologies that have just entered or are almost ready to enter their commercialisation phases and are expected to reach full maturity within five years. Among them are edge computing and biometrics, which are already fully on the market with concrete impacts across industries. Others, like confidential computing and affective computing, are currently being tested via early-stage real-life pilots and will require a few more years before they are full exploitable.

Finally, the **third group** encompasses those technologies that are still in the research & development phase and are expected to fully mature in a longer timeframe (from five to ten years). Technologies such as quantum computing, 4D printing and brain computing are still in a very embryonic phase, with limited commercial applications currently available. As an example, see a detailed overview of quantum computing further in this report.

2.1.2 Industry suitability: cross-industry deployment or industry-specific focus

The second graph dimension analyses how technologies are deployed across different industries. Some of them have a **cross-industry application**, meaning they can be deployed across multiple sectors and industries in a mix of horizontal and industry-specific use cases. Examples include:

- **Quantum computing** will have implication across all industries, from the healthcare sector, where quantum computing will improve the analysis of medical images and risk predictions, through to quantum-enhanced machine learning techniques[10] and the development of a traffic management system to provide more precise calculations for urban traffic volumes, transport demand and travel times in the transportation industry, making both private and public transportation more efficient.
- **Biometrics** and **affective computing** will leverage AI to create important new outputs. Biometrics technologies will provide next-generation security for financial data and identity protection solutions, as well as new ways to manage employee IDs across all industries. More specific-industry use cases include those related to the retail sector, where big players are experimenting with biometric identification systems for payments, promotion targeting and theft reduction. Still in the retail sector, affective computing algorithms will provide scope to improve customer sales.
- **Drones** are unmanned aerial vehicles that have a variety of purposes. Numerous applications are quickly changing daily work in some industries, such as in the insurance industry, where drones are used to inspect damaged assets, and in the agriculture sector, where they are used to monitor crops and collect data on soil. Drones are also revolutionising transportation, where they are used as navigational aids, moving above or in the water in front of ships, as well as the energy sector, where they are used as a tool to inspect infrastructure and maintain compliance with regulations and standards, replacing manual work.
- **Industrial wearables** are devices that are worn by the user, either directly (e.g. as an accessory) or as part of other materials (e.g. clothing), which are connected to other devices and perform many different functions by exchanging data between a network and the device. This technology offers interesting cross-sector applications, such as tracking a patient's medical condition in the healthcare industry and developing smart personal protective equipment (PPE) solutions, such as glasses and gloves in the manufacturing industry to ensure employee safety.

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[9] Rodríguez Salvador M., Lezama Nicolás R., Río Belver R.M., Rodríguez Andara A. (2019). Lessons Learned in Assessment of Technology Maturity

[10] IBM Institute for Business Value (2020). Exploring quantum computing use cases for healthcare

Although wearable solutions for consumers are already widespread, industrial wearables are still gaining ground, generating a wide range of new opportunities.

Some technologies are more **industry specific**, with their application limited to a single or a few sectors. Among many technologies, this group includes:

- **4D printing**, enabling the creation of special materials with new features. These materials will find their application mainly in specific sectors, such as in manufacturing, where some organisations have developed an inflatable material that can change shape and size when triggered by air pulse,[11] and in healthcare (new artificial tissues and organs).[12]
- **Blockchain** is applied mainly in the finance sector, where it is used for payments and securitisation, as well as to lower costs,[13] speed up transactions, improve the transparency and auditability of operations, and much more.
- **Ingestible, implantable and injectable** solutions are initially used primarily in the healthcare sector for diagnosis purposes.

2.1.3 Technology application impact

The third dimension considered, beyond maturity timeline and industry breadth, relates to **the potential application and impact of each technology**. In this regard, three groups have been considered – **human-human/human-machine interaction enablers, process disruptors and digital accelerators.**

Technologies in the first group focus on fostering interaction between humans or between humans and machines. In this scenario, **AR/VR** is a representative technology: Augmented reality solutions allow users to live an enhanced experience with other people or objects and can be used in many different contexts, from transforming customer experience in the retail sector to advanced learning in the education industry. Other technologies in this area are still in the commercialisation phase, such as **affective computing** and **Internet of Behaviour (IoB)**. Affective computing technologies are used to recognise, interpret, process and simulate human effects to understand a person's emotional states and facilitate interactivity between a human and a machine (e.g. by adjusting the presentation style of a computerised tutor when a learner is, for example, not interested)[14] or humans in general (psychological health services[15]). IoB technology collects and exchanges information to understand the different behavioural patterns of users. The data provided from this kind of human-machine interaction is used, for example, in the retail industry to profile consumers and personalise advertisements. Finally, technologies such as **brain computing** are still in the R&D phase and will reach maturity in the medium to long term. Brain computing technologies represent a direct communication pathway between an enhanced or wired brain and an external device. There are many potential applications for this future technology, making it a real game changer. For example, brain computing will likely represent a revolution in the future of work, where employees will be able to carry out tasks just by using their brain activity.[16]

The second group – process enablers – includes those technologies whose primary focus and impact is on business processes performance enhancement and operations efficiency. **Robotic** solutions, for example, allow for more accurate work and higher quality products by automating processes and reducing manual work. In the short to medium term, **drones** will more and more support humans in difficult tasks, such as power grid inspections and the real-time monitoring of construction sites and structural maintenance, with a significant improvement in employee safety in dangerous working environment. **Exoskeletons** will increase human strength and endurance, with a real application in different phases of manufacturing processes, from raw material extraction (where heavy-duty exoskeletons are appropriate to handle heavy components) to assembling goods (with modular exoskeletons suited for car assembly work).[17] Finally, **4D printing solutions** are expected to

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[11] BWM Group (2018). Pushing material boundaries. BMW and Massachusetts Institute of Technology Self-Assembly Lab collaborate to design the first printed inflatable material
[12] ABB (2020). 4D printing
[13] PwC (2017). Blockchain: A new tool to cut costs
[14] Zhou, Y., Tao, X. (2020). A Framework of Online Learning and Experiment System Based on Affective Computing
[15] Daily S. B., et al. (2017). Affective Computing: Historical Foundations, Current Applications, and Future Trends
[16] Harvard Business Review (2020). What Brain-Computer Interfaces Could Mean for the Future of Work
[17] Fox, S. (2019). Exoskeletons: Comprehensive, comparative and critical analyses of their potential to improve manufacturing performance

significantly improve performance and efficiency by supporting the planning, simulation and control of lean manufacturing (manufacturing focused on minimising waste within manufacturing systems)[18] or drug design.[19]

The third group – digital accelerators – includes those technologies that, when combined with other technologies, can accelerate and augment specific digital scenarios. Technologies such as **artificial intelligence**, public **cloud** (which represents the backbone of modern infrastructure and an accelerator of different technologies) and **quantum computing**, bringing a new level of computational capabilities across technologies, are included in this group.

2.2 Europe providing fertile ground for growth

As beyond-the-horizon advanced technologies mature, the European Union provides fertile ground for their development and broader adoption across organisations. Key aspects making Europe fertile for the next big wave of advanced technologies are:

- **Global-leading industries**: Energy, manufacturing and healthcare are the three industries in which Europe is world beating. These industries are at the forefront of the adoption of future-oriented advanced technologies – to improve productivity, enhance efficiency and increase safety at work. Industrial wearables, for example, find numerous applications in manufacturing, where wristbands, connected clothing and headwear are used to present safety and environmental information to the wearers. Drones can replace employees in inspecting transmission and distribution lines in the utility sector, providing a quicker, more accurate and less costly way of maintaining the power infrastructure. Future-orientated advanced technologies like ingestibles and implantables find their natural cradle in healthcare. Regarding the manufacturing industry, European manufacturers are among the largest international innovators, globally recognised as running some of the most important advanced and innovative production sites.[20] Apart from the existence of dedicated large manufacturers and programmes to defend the regional primacy (e.g. EIT Manufacturing),[21] the European Union supports manufacturing SMEs through specific initiatives to help companies test and adopt the most innovative and ground-breaking technologies.[22] Healthcare organisations and research centres are considered references at the global level for their level of patient services and research quality. Similarly, European utilities have put in place innovative programmes (e.g. smart-meter roll-outs, renewable energy efforts, grid monitoring and mobility electrification) over the past few years that are top-notch in the global scenario and trailblazers for companies in other industries around the world. Such advances have been accelerated by the EU's unique climate strategy, which is a testament to the sustainability focus of the region. The predominant regional role in these leading industries is that of a perfect seeding ground for the application and proliferation of beyond-the-horizon advanced technologies.
- **Next Generation EU stimulus and advanced technology focus**: While the pandemic crisis has significantly harmed the European economy, it also proved to be a strong catalyst from a digital perspective. Indeed, Member States are working on national plans to recover from the crisis and return to growth. The five-year €750 billion Next Generation EU (NGEU) plan will be used for several projects to create a greener, more digital and more resilient society, including green and smart transportation support, digitalised public administration, broadband rollouts and the investigation and usage of new clean technologies. IDC estimates that more than €150 billion in new digital investments will be generated in next 5 years across the European Union thanks to NGEU-fuelled national recovery plans.[23] A relevant part of these investments will be devoted to advanced technologies (e.g. AI for advanced electric-vehicle solutions, edge computing, IoT for smart buildings and high-performance and quantum computing for the next level of infrastructure computing) and R&D activities (e.g. to investigate beyond-the-horizon

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[18] Ghi, A, Rossetti, F. (2016). 4D Printing: An Emerging Technology in Manufacturing?
[19] Fourches, D. (2019). 4D- quantitative structure–activity relationship modeling: making a comeback
[20] World Economic Forum (2019). Fourth Industrial Revolution: Beacons of Technology and Innovation in Manufacturing
[21] EIT Manufacturing, https://eit.europa.eu/our-communities/eit-manufacturing
[22] European Commission. ICT Innovation for Manufacturing SMEs
[23] IDC (2021). Next Gen EU: Recovery and Resilience Country Plans Steering Digital Investments

digital solutions). This represents a unique accelerator for the in-region growth of advanced technology uptake.

- **Talent & skills initiatives in the region**: Another important element relates to several initiatives and projects the EU is working on to create and enhance the development of the right skills and knowledge for the full exploitation of emerging technologies. For example, the European Union has allocated specific funds to recovery after the pandemic crisis – specifically, to the implementation of reskilling projects in each European country. Moreover, Europe can count on a top-notch talent marketplace and R&D ecosystem, being home to 5 of the top 10 global computer-science universities[24] and a third of the world's top 100 universities in engineering and technology. Talent and skills that are crucial conditions for the evolution of advanced technologies.
- **The most vibrant start-up and tech vendor ecosystem ever**: In the European tech landscape, the connection between venture capital, private equity and public markets is growing, creating more opportunities for merging and acquisitions, and a systematic recycling of experienced talent to build new generations of companies. After an impressive 40% increase recorded in 2019, and despite the pandemic crisis, European tech companies managed to hit a new high record in investment in 2020, at approximately €34 billion, at a time when funding for US and Asian start-ups stagnated.[25] Surging interest in purpose-driven technology and European tech's central role have been invaluable, with purpose-driven companies representing 12% of all capital invested in Europe in 2019.[26] The start-up ecosystem has therefore been heating up over the last few years, although some major challenges still persist, such as a fragmented domestic pool. For example, when operating in the European market, tech companies face a number of different languages, customer behaviours, governments, regulations, etc.[27] Indeed, the role the European Union is playing in supporting the growth of the European start-up scene is crucial and is well represented, with several programmes and initiatives in place, such as Startup Europe.[28] This fast-evolving and vibrant European start-up and tech ecosystem featuring many beyond-the-horizon advanced technology players places Europe in a very prominent and strong position. (See the following chapters for examples.)
- **Public-private connection**: The strong public-private partnership in which the European Commission has invested in recent years will play a key role in the evolution of future-orientated advanced technologies. This strategic approach will include research and innovation funding, as well as providing the right framework for international companies to invest more in technology development in Europe.
- **The demographics of SMEs in Europe**: Around 99% of European organisations have fewer than 250 employees.[29] While, traditionally, SMEs are a little more reluctant to innovate than large organisations, more and more digital-native SMEs are emerging across industries. These SMEs, which are innovation-orientated by nature, encompass the organisational agility needed to 'test, fail and succeed' with future-orientated technologies in real-life business scenarios.

All these elements considered, the **European Union represents a perfect playground to enable beyond-the-horizon advanced technologies to grow and thrive**.

2.3 Focus on select beyond-the-horizon advanced technologies

Among beyond-the-horizon advanced technologies, **some deserve a special in-depth view: quantum computing, ingestibles/implantables/injectables and exoskeletons**. Not only do they show very promising market opportunities, but they are also characterised by a vibrant European tech-provider ecosystem and early-stage pilots across industries.

[24] https://2018.stateofeuropeantech.com/chapter/research-development/article/mobilising-europes-rd-talent-pool/
[25] The State of European Tech, Atomico (2020)
[26] World Economic Forum (2020). Europe can be at the heart of tech with purpose
[27] McKinsey (2019). Europe's start-up ecosystem: Heating up, but still facing challenges.
[28] https://digital-strategy.ec.europa.eu/en/policies/startup-europe
[29] European Commission. Internal Market, Industry, Entrepreneurship and SMEs, https://ec.europa.eu/growth/smes/sme-definition_en

2.3.1 Quantum computing

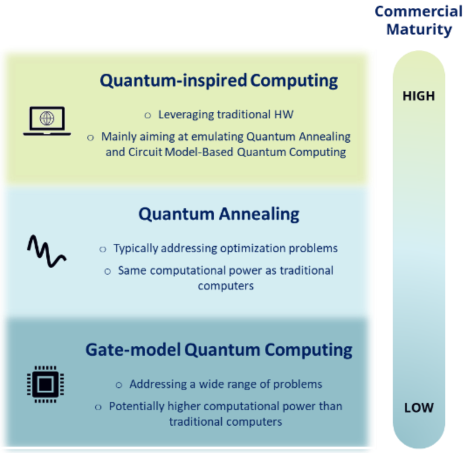
The market landscape and expected evolution

Even though quantum computing is still far from maturity, the rapid progress seen over the past two years in particular has given a glimpse into the enormous potential of this technology. This new way of computation could in fact address specific sets of problems, which would take months or even years for the world's most powerful supercomputer to solve, making classic computing impractical.[30]

Quantum computing is defined as a technology that harnesses and exploits quantum mechanics like superposition and entanglement to manipulate enormous combinations of states at once for computations and to process information on a large scale.[31] However, in addition to the two main 'pure' quantum computing approaches (i.e. quantum annealing and gate-model quantum computing), it is also worth including quantum-inspired computing technologies, which are playing a pivotal role in the development of actual quantum computers. The following are typologies of quantum computing technologies that are now being developed and tested:

- **Quantum-inspired computing:** Computing technologies that are based on traditional hardware and mainly aim to emulate the behaviour of quantum annealers and gate-model quantum computers
- **Quantum annealing:** Computing technologies that implement quantum annealing, a mathematical technique that leverages quantum fluctuations to explore a finite set of possible solutions – typically used to address optimisation problems and have the same computational power as traditional computers
- **Gate-model quantum computing:** Computing technologies that perform calculations by manipulating quantum states through quantum circuits (gates) operating on qubits – potentially able to address a wide range of problems and to have a higher computational power than traditional computers. A first proof was achieved by Google in October 2019.[32]

Figure 3: The three main typologies of quantum and quantum-inspired computing technologies



Source: IDC European Quantum Computing Launchpad, 2021

The achievement of this future 'quantum advantage' by gate-model quantum computers is already pushing the development of a vibrant European ecosystem, which is steadily growing. This comprises global players and local start-ups, as well as universities and research centres, which, altogether, contribute to moving quantum research forward and help to translate it into tangible use cases for businesses.

However, despite this increasing effort by both companies and institutions in Europe, quantum computing's centre of gravity still remains North America. Both big vendors like IBM, Google, Microsoft and Honeywell and emerging ones such as Rigetti, IonQ and D-Wave are based in and build their quantum computers in the US. Despite the efforts of public institutions and companies like Atos and Finnish IQM, the number of quantum computers in Europe is still limited. Examples are represented by the quantum computer made available in the cloud by Austrian Alpine Quantum Technologies (a

[30] Ladd, T., Jelezko, F., Laflamme, R. et al. (2010). Quantum computers
[31] IDC's Worldwide Quantum Computing Taxonomy (2019)
[32] Arute, F., Arya, K., Babbush, R. et al. (2019). Quantum supremacy using a programmable superconducting processor

University-of-Innsbruck spin-off) in 2019 and by Dutch research consortium QuTech in 2020. A collaboration between IBM and the Fraunhofer Institute will lead, in 2021, to the installation of the first quantum computer in Germany. The quantum computer fleet of IBM – one of the undisputed leaders of quantum computing worldwide – in Europe already includes quantum computers in Dublin, Paris, Athens and Rome.

Given the prohibitive price of on-premises quantum computers (millions of euro) and the immaturity of the technology, the vast majority of European organisations are accessing quantum computers in the cloud thanks to platforms made available directly by research institutions (e.g. QuTech) and companies (e.g. Microsoft Azure and IBM Cloud). This is facilitating the access of European companies to the technology (71% of European organisations would utilise quantum computing as part of managed cloud services, according to IDC's *Managed CloudView Survey*, August 2020) and will be crucial in the development of relevant business use cases over the next few years.

It is clear that quantum computing should be considered more a long-term challenge than a short-term bet, since the real progress of quantum applications and their use in everyday business are still a long way off. Indeed, this will only be possible when current major technological challenges have been addressed and measurable benefits have been achieved and made replicable on a large scale.

Drivers of adoption

IDC's survey data shows growing interest in quantum computing among European companies, especially in industries like finance and telecommunications, where quantum computing could potentially have the most disruptive effect. Some 7% of European companies are already doing some quantum computing research or pilots.[33] Despite the immaturity of the technology, the following factors are driving the choices of European companies to start experimenting with quantum computing applications via cloud computing (IDC's *Managed CloudView Survey*, August 2020):

- **Accelerating decision making**: Quantum computations will allow faster calculations and hence the chance to take decisions in a faster and more reliable way. This is the case of patient disease analysis in healthcare, through the fast elaboration of huge amounts of data.
- **Resolving complex problems:** The resolution of problems that were not addressable by classic computers will also enable the development of new products (e.g., materials for energy) and the dramatic improvement of existing ones (e.g., batteries for electric vehicles).
- **Improving productivity:** Quantum computing is expected to have an impact on the productivity of tasks and processes that are now addressed through approximated algorithms, which is the case regarding the optimisation of warehouses (e.g., in retail) and routes (e.g., in transportation).
- **Improving artificial intelligence/cognitive capabilities:** Quantum computing could expand the computational capabilities of artificial intelligence algorithms, whose implementation is now hindered in many scenarios by the current limitations of classic computers.

Main barriers and challenges

The road to the use and spread of quantum computing is still a long way off and is paved with challenges. Three major hurdles can be identified:

- **Hardware:** Hardware challenges are the most problematic and binding in terms of the development of quantum computers.[34] According to the international quantum computing community, the biggest ones are as follows:
    - *Qubit quality:* the development of stable and reliable qubits (the basic information unit of quantum computers, as opposed to 'bits').
    - *Error correction:* the correction of the error generated by qubits themselves needs to be addressed through proper algorithms, which are currently anything but mature.
    - *Qubit control:* the full command of qubits so as to be able to deploy complex algorithms as well as error correction procedures.

[33] IDC European Tech and Industry Pulse Survey, 2019

[34] A. D. Córcoles, A. Kandala, A. Javadi-Abhari, D. T. McClure, A. W.Cross, K. Temme, P. D. Nation, M. Steffen, and J. M. Gambetta (2020). Challenges and Opportunities of Near-Term Quantum Computing Systems

  - *The optimisation of control wires:* control wires associated to qubits become hard to design and implement with an increasing number of qubits in the chip.
- **Software:** The two main problems to be addressed in parallel with progress in hardware are as follows:[35]
  - *Development and Enrichment of Quantum Software Development Tools:* These are the quantum software development kits that many quantum computer developers provide.
  - *Development of algorithms able to model and address real world problems*. The ability to design and implement those *ad hoc* algorithms, which significantly deviate from the classical approaches to software development, will be fundamental to make the most of the quantum hardware available at the time.
- **Business:** In addition to the technical challenges associated with hardware and software, two key business challenges need to be addressed:
  - *The Availability of Skills*: While research institutions and IT vendors are accumulating the quantum skills to advance the technology, end-user companies that will adopt quantum computing will have to build their own competences in order to translate specific domain problems in quantum algorithms and interpret the results.
  - *The Identification and Development of Business Use Cases*: Despite the huge potential of quantum computing for many data-intensive applications, the suitability and effective achievement of 'quantum advantage' should be evaluated on a case-by-case basis. The set of real use cases that will benefit the most from quantum computing is still far from being identified.

The main use cases and business applications across industries

Quantum technologies have many areas in which their superior power and intelligence can be leveraged, from technology and hospitality to defence and construction.

- **The simulation of physical systems:** One area in which quantum computing has already seen some progress is the application of simulations of physical systems. Examples include simulating battery processes, which can help developers understand the technology and can contribute to the development of a new generation of batteries, thus significantly improving today's energy crisis.
- **Optimisation:** Optimisation on a scale never before possible is also possible with quantum computing. One example is in robotics design and the movement of robots, resulting in more human-like robots with greater capabilities and the optimisation of robots that work on factory production lines.
- **Machine learning and artificial intelligence:** Another paramount application of quantum computing is in machine learning and AI, where quantum algorithms have the potential to more closely map and accurately reproduce human-like behaviour that today's machines cannot hope to replicate, not only helping to refine certain processing, like defining speech patterns, but also optimising pre-existing machines.
- **Cryptography:** Finally, quantum computing can have uses within security and cryptography, creating theoretically secure data on public networks, meaning that hackers are unable to create vulnerabilities within the network path. This will greatly improve the usefulness of large data transfers on networks and opens up greater opportunities within more consumer-focused applications like e-commerce.

Even though experimentation has just begun, some interesting business use cases are already being developed and/or tested in Europe. These use cases can be classified according to the two following dimensions:

- **Use-case maturity:** This relates to the commercial readiness of the use case. Just few use cases leveraging quantum-inspired computing and quantum annealing are already in production environments. The majority (and all those leveraging gate-model quantum computing) are completely in the R&D phase. However, even though the commercial readiness will be higher for some use cases and lower for others, no quantum use case has yet reached 'quantum advantage' – i.e. performance not achievable by traditional computing technology.

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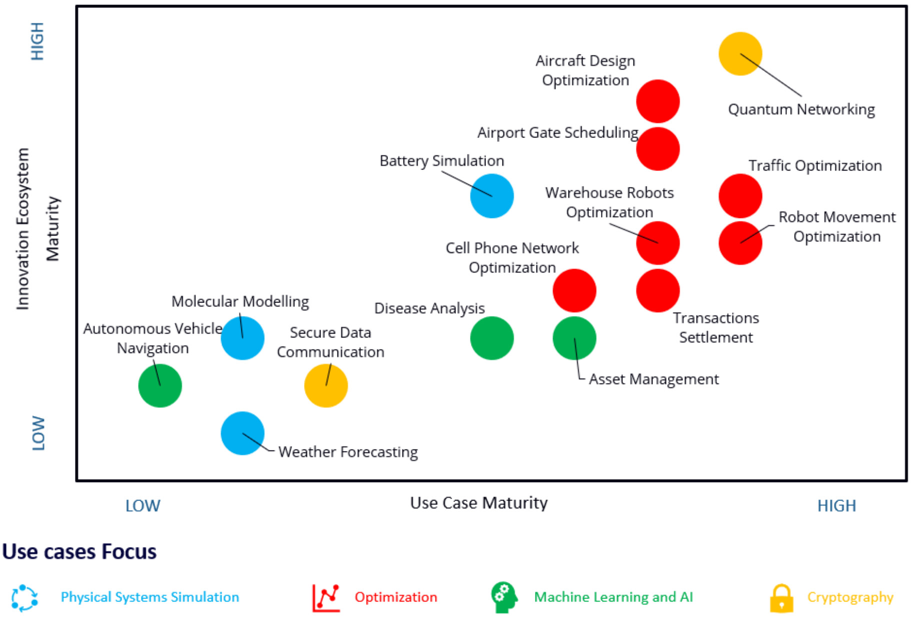
[35] Biamonte, J., Wittek, P., Pancotti, N. et al. (2017). Quantum machine learning

- **Innovation-ecosystem maturity:** This relates to the current number and strength of R&D partnerships developing use cases. The number and strength of organisations and projects working on the use cases are key elements for evaluating the future potentialities and business opportunities of each use case. In addition, the effort behind each use case is a solid indicator of the current business appeal of the given use case.

In Figure 4, the two abovementioned dimensions have been combined to map the overall maturity of the main current quantum use cases in Europe. Different colours refer to different macro areas of the use cases, i.e., physical system simulation, optimisation, machine learning and AI, and cryptography.

Figure 4: European quantum use cases maturity chart 2021



Source: IDC European Quantum Computing Launchpad, 2021

Optimisation and networking use cases have the highest levels of maturity. For optimisation use cases in particular, this is due to the use of quantum-inspired and quantum annealing technologies, which do not yet outperform traditional computing technologies, even though they can guarantee advanced performance. The simulation of physical systems and machine learning & AI applications are usually less mature yet more promising in terms of exceeding traditional computing performance.

By reviewing the use cases, we see that manufacturing, transportation, telecommunications and finance are the frontrunner industries. In particular, manufacturing and telecommunications are pulling ahead of all the other verticals. Other industries – professional services, healthcare, retail, utilities/oil and gas, and government/education – are currently clearly behind and are just taking their first steps in the field. Among the latter group, healthcare and utilities/oil & gas have a significantly different trend when compared with North America, where hospitals and oil & gas companies in particular are playing a primary role in R&D on quantum technologies from the end-user side.

2.3.2 Ingestible, implantable and injectable technologies

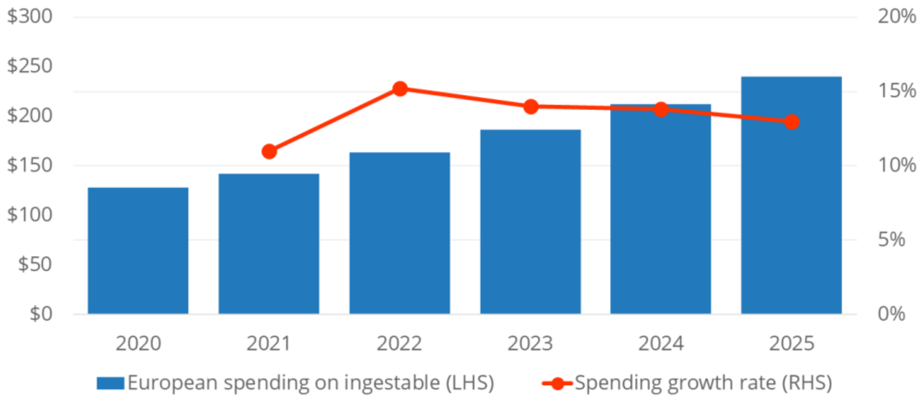
The Market landscape and expected evolution

Given the fast progress in technology, in the future, we will witness an uptake of nanotechnologies that will revolutionise the healthcare sector. As hospitals and private and public clinics are looking at ways to innovate and deliver superior patient care, healthcare will look at next-generation technologies to tackle issues such as post-COVID-19 medical service backlogs and long patient waiting times. COVID-19 has put a strain on the healthcare sector, and pressure will be felt for at least a couple of years. As hospitals try to deliver cancer treatments and other medical screenings that have been postponed during the pandemic, augmented humanity technologies will play a role in enabling the post-crisis response.

Hospitals are looking at technologies such as **ingestible** devices to speed up routine and emergency screenings, while turning invasive in-hospital procedures (such as endoscopies or colonoscopies) into at-home stressless patient experiences. Ingestible technologies are small, pill-shaped and presumably waterproof electronic devices. The current hardware works via Bluetooth and connects to wireless devices equipped with particular applications. The ingestibles market is healthcare dominated, with hospitals, clinics and research institutes driving demand for 'smart pills'. Although this is a niche market, many projects are already in place around Europe. For example, capsule camera procedures have been launched in Germany to perform capsule endoscopies, which is nowadays becoming a modern method to run medical screenings.

Although the ingestibles market is currently valued in the millions of euro in Europe, its growth is expected to accelerate at a double-digit rate through to 2025. Efforts around creating next-generation diagnosis systems and drug delivery methods will sustain demand for these medical devices.

Figure 5: European ingestibles market, 2020–2025, million USD)



Source: Augmented-Humanity Market Forecast, IDC's Augmented Humanity Launchpad, May 2021

Injectable and implantable devices represent nanotechnologies that will be normalised in the years ahead, across both the healthcare sector and the consumer segment. Each implantable and injectable device is implanted or injected in the human body, contains a microchip, is connected to an external system or network, and remains in the same place in the human body permanently or semi-permanently.

The healthcare sector will account for virtually all demand for implantable devices, which include smart medical devices such as smart continuous-glucose-monitoring (CGM) devices, Bluetooth-enabled insertable cardiac monitors (ICMs) and implantable cardiac defibrillator (ICD) systems. Europe is witnessing the rise of R&D hubs working on injectable and implantable devices. For example, IMEC is working to bring the power of chip technology to the world of healthcare. IMEC leverages its expertise in chip design to develop innovative tools for life sciences, pharma R&D, clinical diagnostics, therapeutics and surgery, biopharma production and analytics biochemistry.[36]

On the injectables side, we can distinguish between consumer injectables and medical injectables. Consumer injectable devices are micro-chips that can be injected under a human's skin to serve a wide range of consumer use cases, such as access control (gym, offices and home), device log in, social media launching, smart payments and wallet. Sweden is at the forefront of this *cyborgification* trend, although the adoption of this technology is very limited and is not expected to grow at a fast pace. On the medical side, injectable devices are used to monitor glucose and hormone levels and, lately, also to produce alerts and early diagnosis for COVID-19. Although medical-related injectable devices can benefit societies by delivering faster healthcare tracking services, 'microchipping' humans, even for medical reasons, spurs privacy concerns. As a consequence, nanotechnology providers have not yet developed products that are attractive to a large slice of the population.

Drivers of adoption

Some nanotechnologies will help healthcare providers serve many use cases – including enhanced patient experiences and employee augmentation – as the sector strives to digitise through next-

[36] https://www.imec-int.com/en

generation technologies. The drivers that will sustain investments in ingestible, implantable and injectable devices in the years ahead are as follows:

- **Employee augmentation:** Organisations will look at technologies as a way to streamline employees' workloads, enhance their capabilities and create technology-driven patient experiences. In particular, hospitals will look at ingestible and implantable devices as ways to enhance healthcare services and speed up diagnosis and treatment, complementing doctors' expertise to achieve the most effective outcomes.
- **Innovation:** Healthcare organisations are stepping up efforts around digitalisation and advanced support for cancer services, investing significant resources in next-generation smart diagnostic equipment and COVID-19-friendly cancer treatments that spare patients' immune systems and reduce hospital trips.
- **Backlogs and waiting times:** Healthcare providers are facing huge backlogs for diagnostic testing and referrals from General Practitioners (GPs), sparking concerns there could be significant numbers of undiagnosed cancers. For that reason, smart diagnosis devices will see an increase in adoption, helping hospitals reduce pressure from backlogs and reduce patient waiting times for healthcare services.
- **Faster diagnosis:** The imaging technology used within smart capsule cameras can provide a diagnosis within hours, lowering the risk of late diagnosis.
- **Experiences:** Many humans are already using injectable microchips to streamline their lives and create 'sci-fi'-like experiences by enabling wallet and next-generation payment capabilities through microchips injected in their palms.
- **Automation:** Humans constantly strive to reach a high automation level and save time. Automation needs will support investments in nanotechnologies that enable humans and businesses to achieve goals faster and more efficiently.

Main barriers and challenges

Although nanotechnologies can enable faster diagnosis and can enable and enhance human skills, as well as helping society to be healthier, the adoption of ingestible, implantable and injectable devices is low. Investments in these areas will not reach the billion-dollar-per-annum mark in the near future for the following reasons:

- **Invasiveness:** Injectable devices require an injection to be implemented and being 'micro-chipped' essentially remains a process that leaves many individuals sceptical, raising health and safety concerns among the population.
- **Supporting systems and related costs:** Smart pills are not costly per se, but hospitals must be ready to meet the costs for the entire ecosystem of technologies necessary to support smart diagnosis (software, platforms and accessories), which, when added up, could be in the €8 500–13 000 range.
- **Privacy and safety concerns:** Human micro-chipping is always associated with GPS tracking, raising many doubts and concerns about privacy and data usage. As nanotechnologies are still not widely adopted, humans are also concerned about the effects and impacts of implanting microchips under their skins.
- **Replacement cycles:** Injectable devices might need replacing and, because microchips are inserted under the skin, not many people are willing to undergo the replacement process, especially for use cases that enable experiences rather than new capabilities.
- **Low acceptance:** Because nanotechnologies are not deployed at scale, adoption is slow and will grow only for specific solutions that are able to add value to human life. Technologies that enable consumer-related use cases will be accepted less readily than those enabling healthcare services, as consumers can rely on alternatives and less invasive technologies, such as biometrics, to enhance their capabilities or enable tech-driven experiences.
- **Regulations and approvals:** Gaining market approval for medical devices is a long process and requires many checks and standard fulfilments. This highly limits wide scale adoption and produces a concentrated market that is dominated by a handful of big players.

Main use cases and business applications across industries

According to IDC's Augmented Humanity Launchpad, spending in Europe on ingestible devices will reach about €120 million in 2021 and will grow at a double-digit rate for the next few years.

The market opportunity for ingestible technologies is and will remain highly concentrated in the healthcare sector, including hospitals and clinics that are using or trialling such tech, although some research institutions are studying the technology and will thus account for some demand.

The most popular use cases that will be enabled by ingestible capsule cameras are:

- **Non-invasive screenings:** Ingestible devices use visualisation technology to produce images of the small and large intestines to enable doctors to spot abnormalities, monitor disease activity and assess treatment efficacy.
- **Patient health tracking:** Capsules measure the blood pressure, pH level and temperature of the patient to provide doctors with diagnostic information about gastrointestinal tracts.
- **Smart drug delivery:** After the capsule is swallowed and it reaches its destination, the wirelessly powered ingestible capsule releases medicine and sends a notification/an alert to both the healthcare facility and the patient to verify that the medicine has been released into the patient's body.

Injectable/implantable device use cases can be divided into consumer and healthcare.

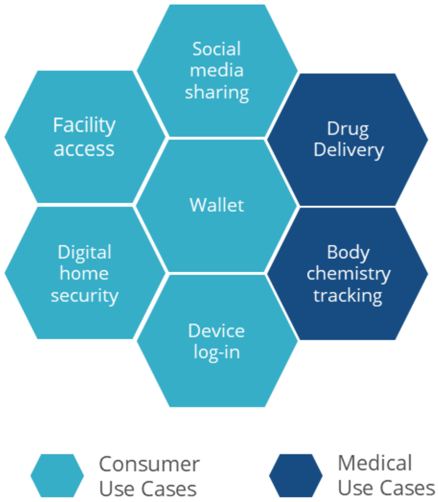
On the consumer side, the most popular usage of injectable/implantable technologies will be:

- **Social media sharing:** The user can connect a microchip to their social media account and use this functionality to share their accounts – for example, by tapping their hand against an external mobile device to be taken straight to their social media profile.
- **Facility access:** Injectable Radio Frequency Identification (RFID) chips are used for access control purposes and allow users to access facilities such as gyms, offices and other spaces that support the technology.
- **Digital home security:** Microchips enable the digital control of home devices, enabling users to set alarms and control home digital security systems.
- **Device log-in:** Users can use microchip implants to gain access and log in to devices such as secured printers, smartphones and smart vending machines.
- **Wallet:** Injectable microchips allow users to replace traditional wallet uses with chip-to-skin digital wallet experiences, such as by storing tickets and enabling secure payments using only their hands.

On the medical side, injectable/implantable technologies will enable the following use cases:

- **Body chemistry tracking:** Injectable biosensors stream personal medical data to external devices, providing insights and continuously measuring and monitoring body chemistry, such as oxygen and glucose levels.
- **Drug delivery:** Soft implantable devices with drug-diffusion channels enable the controlled release of medication. The tech is integrated wirelessly with external devices to enable communications and alerts.

Figure 6: Key injectable/implantable device use cases in Europe



Source: Augmented Humanity Market Forecast, IDC's Augmented Humanity Launchpad, May 2021

2.3.3 Exoskeletons

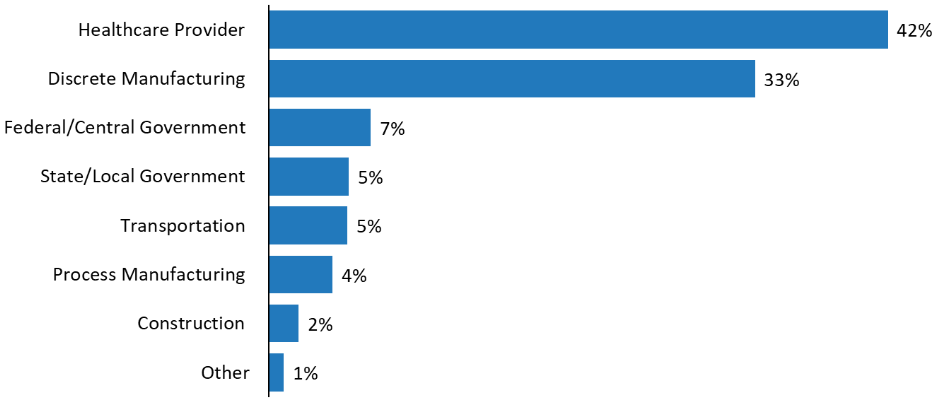
The market landscape and expected evolution

Less than ten years ago, we witnessed robots and humans working together for the first time. We are now getting used to seeing robots in real-life and business scenarios, especially in the manufacturing industry.

Wearable robots are best known as **exoskeletons** – external devices (hardware) that support, cover and protect the user, giving greater levels of strength and endurance while performing specific tasks. Exoskeletons are made to provide back, shoulder, waist and thigh support, to sense the user's motion and to assist movement for lifting and holding heavy items, thus lowering back stress.

Because of their capabilities, exoskeletons are both enabling human skills, for example allowing people to walk after injuries or surgeries, and augmenting them, for example by elevating their existing capabilities such as lifting or transporting items. Exoskeletons connect humans' work with existing technologies – robots and wearable smart devices (such as smart helmets) – thus introducing to the market a new technology, the 'wearable robot'.

Figure 7: European exoskeleton market by industry, 2021



Source: Augmented Humanity Market Forecast, IDC's Augmented Humanity Launchpad, May 2021

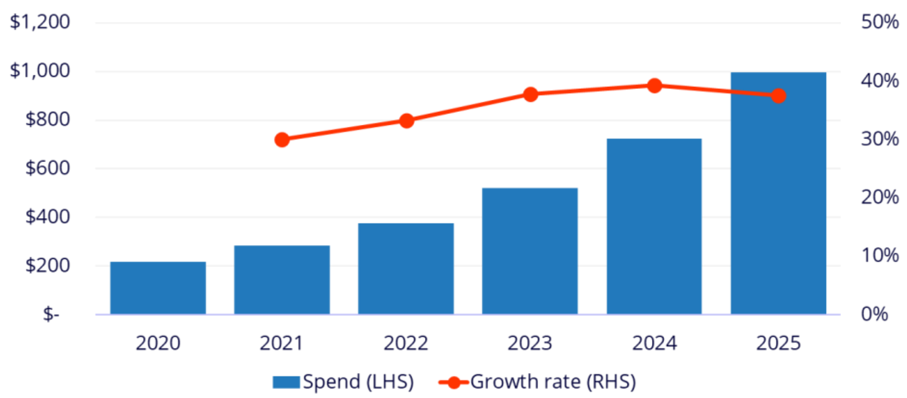
Early applications of exoskeletons have focused on military and medical applications, but the number of uses has exploded in recent years. Military applications were intended to support defence forces with the movement of heavy supplies and equipment in the field. In 2021, the government sector will continue to represent a solid market.

Nevertheless, the main applications are in the healthcare space, which is driving 2021 spending, representing more than 40% of the market. The medical field has been able to provide patients with exoskeletons that allow paraplegics, amputees and others to walk again. A leading European player in this area is represented by Ottob Bock, a German manufacturing company that specialises in orthotics, prosthetics and rehabilitation solutions. Another example is provided by French company Wandercraft, which offers therapeutic solutions for both patients and their physiotherapists, enabling rehabilitation and patient autonomy.

Healthcare is followed by discrete manufacturing, where exoskeletons assist workers to assemble, install, maintain or repair equipment. Exoskeletons are often used in the automotive and aerospace industries.

Logistics and transportation firms see exoskeletons as technologies to enable faster and more efficient workers for warehousing and fulfilment applications. As an example, the French Ergoskel is an 'ergoskeleton' designed to help warehouse workers lift while reducing physical strain. This exoskeleton was developed and patented by FM Logistic and the University of Technology of Compiègne (UTC), France. In the agriculture industry, farmers can use exoskeletons when significant manual labour is required.

Figure 8: European exoskeleton market, 2020–2025 (million USD)



Source: Augmented Humanity Market Forecast, IDC's Augmented Humanity Launchpad, May 2021

Drivers of adoption

The adoption of exoskeletons is spreading. In recent years, the number of uses has exploded. Here are the drivers that will sustain investments in exoskeletons:

- **Technology evolution**: Predictive algorithms and artificial intelligence now enable the faster response of exoskeletons to workers' movements. As a result, exoskeletons now function intuitively, in real time, based on each worker's movements, nearly eliminating the learning curve.
- **Productivity focus**: Manufacturers are striving to achieve their KPIs, such as increased productivity and lower production times. Exoskeletons are enabling employees working in asset-heavy industries, such as automotive and aerospace, to reduce assembly times.
- **Workplace safety**: Lowering plant and factory incidents due to employees not being appropriately equipped to carry out their tasks is a key priority for any organisation. Investments in exoskeletons will enable companies to reduce health and safety concerns and incidents.
- **Accessibility**: The healthcare sector is looking at exoskeletons to reduce physical barriers that are precluding individuals from opportunities. Healthcare facilities are using exoskeletons for rehabilitation purposes and to increase human quality of life.

Main barriers and challenges

Although exoskeletons are designed to enhance strength and endurance – and the benefits of adoption can surely be more than barriers – some challenges may affect investments in the years ahead:

- **Weight and still limited mobility**: Although exoskeletons improve wearers' capabilities, users need to be trained on how to use and move with exoskeletons on their bodies, as exoskeletons' weight can often slow users' movements.
- **Power**: Despite battery design improvements and lighter batteries, powering an exoskeleton often requires the worker to be tethered to a power source, thus limiting their spatial movement. Some improvements are underway, but this still can be a barrier to the adoption of specific models.
- **Initial upfront cost**: The initial investment associated with the implementation of exoskeletons is very high and requires a big economic effort. This has kept many manufacturers out of the market.

Main use cases and business applications across industries

According to IDC's Augmented Humanity Launchpad, European spending on exoskeleton will reach around €338 million in 2021. Although many challenges related to cost will constrain market penetration, the market will experience sustained growth as exoskeletons overcome barriers to accessibility and allay health and safety concerns in the workplace.

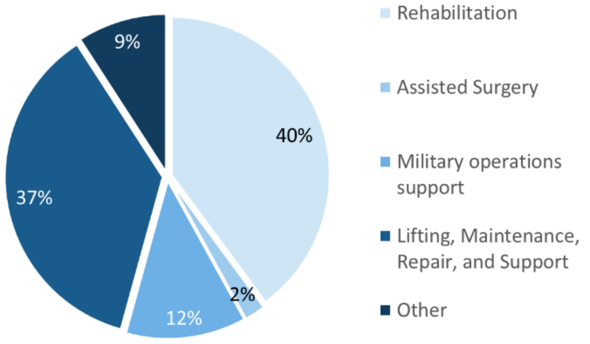
The market opportunity for exoskeletons is varies by industry, but it will remain concentrated in the healthcare sector – mostly, for rehabilitation purposes – and in industries in which heavy lifting and logistic tasks involving heavy items are required, such as manufacturing, transportation, construction and utilities.

The most popular use cases that exoskeletons will enable are:

- **Rehabilitation:** Exoskeletons provide support to patients during rehabilitation, enabling or enhancing their physical capabilities. Exoskeletons using sensory-guided motorised lower or upper limb assistance allow patients with mobility impairments to undergo intensive task-specific locomotor training using typical limb movement patterns[37]. The use of exoskeletons to assist with mobility-related and neurological rehabilitation is gaining traction and is transforming both healthcare services for physiotherapists and experiences for patients.
- **Assisted surgery:** Exoskeletons support and assist doctors during prolonged surgeries. Hospitals are always looking for new technologies to support doctors, especially surgeons, to help them deal with fatigue. Exoskeletons designed to support the lower limbs and pelvic region will help doctors reduce fatigue and improve surgery performance, resulting in higher surgery success rates and decreased chances of surgery incidents[38].
- **Lifting, maintenance, repair and support:** Spring-loaded arm exoskeletons are used to support employees moving heavy components. These exoskeletons are very popular across industries that require overhead component assembly, such as automotive. The exoskeletons are linked to a lower body exoskeleton and a counterweight. The heavy component weight is transmitted to the ground. This allows organisations to reduce factory incidents and improve employee performance. Asset intensive industries are using exoskeletons to help technicians and assistants maintain correct posture, gain a stronger grip on tools and get more body support and extra strength while performing maintenance and repair tasks. They reduce the load on the back muscles when bending down.
- **Military operations support:** As governments step up efforts to provide defence forces with next-generation technologies to refine their capabilities, military exoskeletons are helping armed forces improve endurance and safety, increase mobility and reduce fatigue. This will allow soldiers and first responders to improve mission success rates while walking and carrying essential heavy equipment[39].

[37] Shi, D., Zhang, W., Zhang, W. et al. (2019). A Review on Lower Limb Rehabilitation Exoskeleton Robots
[38] The medical futurist (2019). Exoskeletons: Robotic Structures Making Paralyzed People Walk Again
[39] Proud, J. K. et al. (2020). Exoskeleton Application to Military Manual Handling Tasks

Figure 9: European exoskeleton-enabled use cases market, 2021 (share, %)



Source: Augmented Humanity Market Forecast, IDC's Augmented Humanity Launchpad, May 2021

2.4 Conclusions

European organisations are adopting more and more advanced technologies (e.g. AI, IoT, AR/VR and public cloud solutions). The European Union is thus setting the basis for the next wave of digital innovation, in the direction of **Beyond-the-Horizon Advanced Technologies**, from affective computing and drones to exoskeleton, 4D printing and quantum computing. These advanced technologies are not yet fully mature; they require a few years before they will reach a maturity inflection point and full business and societal impact.

These technologies have been analysed in this report via **three dimensions**: their time to maturity (the time needed for them to become fully mature and to have a concrete business and societal impact), their industry-related deployment (whether the technology is broadly applicable across industries or has a more industry-specific focus) and their potential application and impact (whether the technology fosters human-human/human-machine interaction, enables process disruption or is a digital accelerator).

Among those beyond-the-horizon advanced technologies, we have focused on: q**uantum computing, ingestible/implantable/injectable devices and exoskeletons**. Not only do they show very promising market opportunities, but they are also characterised by a vibrant European tech-provider ecosystem and early-stage pilots across industries.

The vibrant advanced-technologies landscape will continue to evolve. Future-oriented technologies will rapidly reach the advanced maturity levels needed to have a concrete business and societal impact. In order for European countries and governments to seize the beyond-the-horizon technology wave opportunity and thrive in the advanced-technologies space, **regional and national policy makers need to:**

- **Double-down on hard and soft skills enablement initiatives.** In-region talent resources and skills will make the difference in the advance-technologies landscape. Two skill types are needed. Firstly, hard skills are needed related to technology expertise in developing, implementing and running both emerging technologies and the hyperconnected digital platforms behind them. Secondly, soft skills are needed, from the business acumen to build a business case and a cultural mindset with an appetite for risk – a fail-fast-then-succeed approach – to the ability to embrace change.
- **Enable a solid common infrastructure backbone.** Advanced technologies can only exist with the support of a solid and modern technology infrastructure backbone, one able to ensure intelligent computational and analytical capabilities, while enabling frictionless data exchange. Initiatives like GAIA-X[40] go exactly in this direction, enabling an open and transparent digital ecosystem on which advanced technologies can thrive.
- **Nurture start-ups and the emerging-tech vendor ecosystem.** Start-ups and emerging-tech vendors have a key driving role behind advanced technologies, and this is particularly true regarding beyond-the-horizon technologies. New digital companies will be success makers for advanced technologies and the tech giants of tomorrow. Expanding and boosting this fast-growing ecosystem, with financial stimuli and dedicated venture initiatives, is key for the region's success in the technology space and for achieving a world-leading position in the future.
- **Strive for a trust-infused future.** Data is a common denominator for advanced technologies – a continuous flow of structured and unstructured information, with different characteristics and complexity. Data not only needs to be analysed to provide insight in support of action, but it also needs to be managed and distributed across multiple stakeholders in a secure and threat-proof way. Having in place legislation and standards that grant a high level of data security and privacy is paramount. Europe has always been at the forefront of this 'Future of Trust', and trust will certainly be a differentiator in support of the development of advanced technologies in the region.

[40] https://www.data-infrastructure.eu/GAIAX/Navigation/EN/Home/home.html

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Appendix A: Advanced Technology uptake

Figure 10: Advanced Technologies uptake by European Union industries – Question: Which of the following technologies is your organisation using or planning to use?

Technology	Financial Services	Gov/Edu	Healthcare	Manufacturing discrete	Manufacturing process	Professional Services	Retail, Wholesale	Telecom, Media	Transport, Logistics	Utilities, Oil, Gas	Agriculture
Fixed or mobile connectivity	84%	78%	81%	88%	82%	81%	75%	89%	84%	86%	88%
Security technology solutions	84%	78%	78%	84%	77%	81%	80%	88%	85%	89%	68%
Public cloud	63%	66%	68%	76%	71%	82%	72%	80%	75%	69%	83%
IoT	58%	55%	60%	64%	60%	63%	55%	66%	68%	65%	64%
Big Data and analytics solutions	77%	53%	48%	63%	65%	70%	47%	66%	55%	58%	41%
Internet-Enabled Mobile Solutions	74%	60%	47%	44%	61%	67%	55%	72%	62%	57%	36%
AI	61%	45%	57%	66%	56%	59%	44%	69%	49%	59%	34%
B2B industrial digital platforms	46%	24%	27%	64%	60%	58%	40%	47%	53%	47%	39%
Robotics	36%	25%	38%	76%	65%	33%	30%	29%	29%	52%	26%
Other connectivity	42%	37%	29%	33%	41%	46%	37%	59%	34%	31%	19%
Vehicle-related mobility IT solutions	35%	28%	19%	27%	36%	42%	30%	26%	65%	28%	14%
ARVR	29%	32%	42%	33%	34%	33%	24%	41%	22%	19%	5%
Advanced materials	29%	23%	21%	39%	28%	31%	24%	22%	24%	21%	6%
Nanotechnology	25%	21%	22%	36%	21%	32%	23%	18%	19%	23%	9%
Blockchain	53%	17%	15%	21%	25%	31%	22%	22%	18%	17%	6%
Micro and nanoelectronics	25%	20%	16%	38%	24%	26%	21%	20%	20%	17%	8%
Industrial biotechnology	19%	18%	13%	8%	49%	26%	18%	15%	16%	11%	23%
Photonics	23%	16%	11%	27%	22%	25%	19%	19%	16%	22%	10%

Source: Advanced Technologies for Industry Survey, November 2020

Legend: sum of % of respondents already using or planning to use the technology

Appendix B: Definitions of beyond the horizon technologies

4D printing

3D printing technologies which provide objects with the capability to change its shape by itself over the influence of external stimuli, such as light, heat, electricity, magnetic field, etc. It is referred to as 3D printing transforming over time, which represent the fourth dimension. A 4D printed object is printed just like any 3D printed shape. The difference is that the 4D Printing technology uses programmable and advanced materials that perform a different functionality by adding hot water, light or heat.

Affective computing

Technology that enables computers to understand the emotional states expressed by the human subjects in front of the screen, so that personalised responses can be delivered accordingly. The field of affective computing encompasses both the creation of and interaction with machine systems that sense, recognise, respond to and influence emotions.

Biometrics

Technology that analyses virtually any measurable aspects or features of a human that provides, either by itself or in combination with other traits, a unique profile for an individual.

Brain computing interfaces

Interfaces that measure brain activity, extract features from that activity, and convert those features into outputs that replace, restore, enhance, supplement or improve human functions. Therefore, brain computing interfaces enables its users to interact with computers by mean of brain-activity only.

Confidential computing

Confidential computing is a computing technology that isolates sensitive data in a protected CPU enclave during processing. The contents of the enclave - the data being processed, and the techniques used to process it - are accessible only to authorised programming code, and invisible and unknowable to anything or anyone else, including the cloud provider.

Drones

Drones can be defined as flying agents performing a specific task in any given area. It includes both the remote controlled, semiautonomous or fully autonomous unmanned aircraft and the associated control system and elements.

Edge computing

Technology that performs action outside of the centralised datacentre, where edge is the intermediary between the connected endpoints and the core IT environment.

Exoskeleton

External devices or hardware equipment that support, cover and protect the user, giving greater levels of strength and endurance while performing specific tasks.

Function as a service (or serverless computing)

Cloud services that enable serverless app development and management. FaaS (Function-as-a-Service) gives users the option to execute code such as Javascript, Linux or HTML in response to events – without having to build any infrastructure (i.e. the infrastructure associated with building and launching micro-service apps). It is often associated to serverless computing, although the latter specifically focuses on particular service categories, e.g. database, messaging, application programming interfaces (APIs) or storage.

Humanized User Interfaces

Interfaces that use human voice, natural gestures and other common behaviour to allow users interact with technology. Humanized User Interfaces intuitively identify input/output of the system, distinguishing itself from traditional computer interface that requires training and practices (e.g. learning what right mouse click is or how do ctrl, alt, shift, tab keys mean and work).

Industrial wearables

Wearables are electronic devices incorporated into items that can be worn on a body. They have sensors gathering data of daily activities, with the possibility of synchronise them with other devices, such as mobiles or laptop computers. Industrial wearables are those wearables applied in industrial scenarios, different than consumer personal life ones.

Ingestibles/Implantables/Injectables Technologies

Ingestible: small, pill-shaped, presumably water-proof, electronic devices. The current hardware works via Bluetooth technology and connects to wireless devices equipped with particular applications.

Implantable/injectable: Implantables and injecatbles cover all the technologies that are to be implanted or injected in the human body that fulfil the following characteristics: have an internal logic on-board, have a connection to external systems or networks and have the purpose of being inside the human body in the same place on a permanent or semi-permanent basis.

Intelligent Process Automation (IPA)

IPA is a technology that combines fundamental process redesign with robotic process automation and machine learning. IPA mimics activities carried out by humans and, over time, learns to do them even better. Traditional levers of rule-based automation are augmented with decision-making capabilities thanks to advances in deep learning and cognitive technology.

Internet of Behaviour (IoB)

IoB refers to those technologies and processes by which user-controlled data is analysed through a behavioural psychology perspective. With the results of that analysis, it informs new approaches to designing a user experience (UX), search experience optimisation (SXO) and how to market the end products and services offered by companies.

Quantum computing

Technology that harnesses and exploits quantum mechanics to manipulate enormous combinations of states at once for computations and to process information on a large scale.

Swarm computing

Computing systems composed of many devices that coordinate using decentralised control and self-organisation. Swarm computing applications include optimisation algorithms, communications networks and robotics.

About the 'Advanced Technologies for Industry' project

The EU's industrial policy strategy promotes the creation of a competitive European industry. In order to properly support the implementation of policies and initiatives, a systematic monitoring of technological trends and reliable, up-to-date data on advanced technologies is needed. To this end, the Advanced Technologies for Industry (ATI) project has been set up. The project provides policymakers, industry representatives and academia with:

- Statistical data on the production and use of advanced technologies including enabling conditions such as skills, investment or entrepreneurship;
- Analytical reports such as on technological trends, sectoral insights and products;
- Analyses of policy measures and policy tools related to the uptake of advanced technologies;
- Analysis of technological trends in competing economies such as in the US, China or Japan;
- Access to technology centres and innovation hubs across EU countries.

You may find more information about the 16 technologies here: https://ati.ec.europa.eu.

The project is undertaken on behalf of the European Commission, Directorate General for Internal Market, Industry, Entrepreneurship and SMEs and the European Innovation Council and Small and Medium-sized Enterprises Executive Agency (EISMEA) by IDC, Technopolis Group, Capgemini, Fraunhofer, IDEA Consult and NESTA.

June 2021

EA-08-21-208-EN-N

Publications Office
of the European Union