VTT

Trend report 2024

Reimagining resilience

Contents

Preface

Navigating the tides of change – the intersection of turbulence, resilience and technology

In a time marked by unique challenges, we take a moment to look at the complex series of global events that shape our times. This report explores what resilience means in today's world and looks ahead to what the future might hold.

In this report, we aim to provide a summary of some of the major development patterns of today, from complex questions of security, sustainability and health to the future of knowledge sharing, intelligent systems and connectivity.

We examine how the aftermath of the pandemic and ongoing geopolitical tensions, like the war in Ukraine, not only test but also fortify our collective resilience. We then probe deeper into its relationship with technology. In the contemporary world, technology is a transformative force, shaping the foundations of societal resilience. The role of technology is both multifaceted and profound.

Throughout this report, we encourage you to reflect on the interplay between these themes, seeing how resilience acts as a guiding light in restless times, how global events frame our collective experiences, and how technology can be our ally in building a resilient society. We hope you will take a moment and think about what all this might mean.

Laura Juvonen, Senior Vice President, Strategy, VTT

Introduction

Methodology

The selection of featured megatrends involved a comprehensive review of hundreds of diverse information sources, including the latest market data, patent records, scientific journals, news articles and reports, spanning the past few years. Through a thematic qualitative analysis of these sources, several key themes emerged. These themes were approached from the angle of resilience and then validated and refined through collaborative discussions and evaluations with **GlobalData, Catapult International Oy** and the **Finnish Innovation Fund Sitra**. The research for this trend report was conducted in the fall of 2023.

How to read this report?

The report is divided into five thematic sections, each featuring

1) **an introduction to a megatrend**,
2) **a highlighted tech topic** and
3) **an emerging technology**.

Megatrends are large-scale changes in the external environment that affect various aspects of society in a profound way, whereas the highlighted tech topic displays trending technologies that have a significant impact. Lastly, emerging technologies depict new and developing technologies that may hold great potential, but also some risks.

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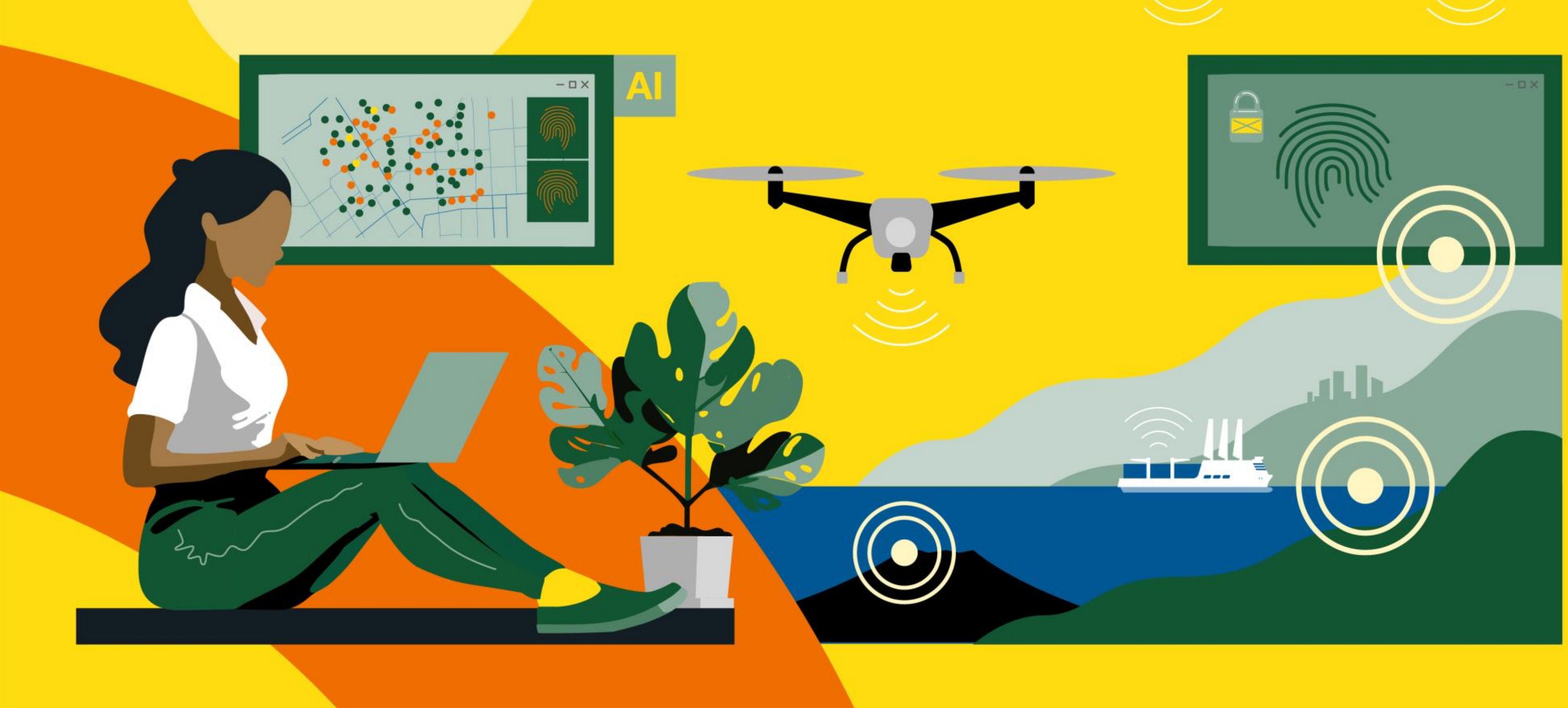
1 Unstable times challenge global societies



Unstable times challenge global societies

1.1 MEGATREND INTRODUCTION

The past couple of years have been marked by environmental and societal crises, driven by underlying geopolitical and economic trends. Global stability and security are decreasing as nations become increasingly insular and focus on nationalistic agendas. The erosion of social cohesion and the rise of societal polarisation are profoundly impacting communities, leading to increased civil unrest, hindering effective governance and weakening collective responses to crises.[1] In extreme cases, it can even threaten the very integrity of a nation as polarised groups struggle to find common ground on critical issues.

The frequency and intensity of natural disasters, largely driven by climate change, are also on the rise.[1] Disasters ranging from hurricanes and floods to wildfires and droughts pose immediate and long-term threats to societal safety. The increasing regularity of these events strain emergency response systems and hampers long-term recovery efforts, leaving societies more vulnerable to future crises.

In the increasingly digital world, cybercrime and cybersecurity have emerged as major threats, targeting critical infrastructure such as power grids, water supplies and healthcare systems.[1] Safeguarding this infrastructure and data becomes even more crucial during emergencies, necessitating digital resilience to employ digital technologies effectively in preventing and confronting crises while maintaining stability.[2]

To navigate these uncertainties and threats, societies are relying more than ever on technology. Sensors are used to predict and prevent natural disasters, while drones can protect humans and the environment. Even the most remote and challenging locations can now enjoy high-speed internet access through satellite communication, giving citizens better opportunities to engage in societal discourse and decision-making.

While innovation and technology help societies better understand and adapt to modern challenges, a more fundamental shift in managing unpredictability is still needed. Resilient societies must anticipate disruptions, not just react to them, and importantly, learn from past crises and disruptions to better cope with future uncertainties.[3]

Key technology trends

- **IoT technology and sensors to prevent natural disasters**
- **Drones for protecting humans and environment**
- **Post-quantum cryptography to secure sensitive data**
- **Online platforms for civic engagement**
- **AI-based systems for improving digital security**
- **Satellite communication for maintaining connectivity in challenging environments**

Standards for strengthening cyber resilience

1.2 HIGHLIGHTED TECH TOPIC

In the era where software and robotics control the industrial machinery needed to operate elevators, ships, autonomous vehicles and various automated functions, cybersecurity is a vital component in supporting societal resilience. While there is a significant overall increase in digital crime, operational technology (OT) systems have been hit hardest in the recent years, with the manufacturing industry being targeted in every fourth cyberattack.[4]

OT cyberattacks tend to have higher, more negative effects than those in IT do, as they can have severe physical consequences such as shutdowns, outages, leakages and explosions.[5] As industries increasingly rely on interconnected systems, the importance of cybersecurity grows.

Cybersecure product development of industrial automation systems ensures the smooth operation of production and logistics. A breach in one part of the value chain can have cascading effects, disrupting the smooth operation of supply line and manufacturing processes. In the worst-case scenario, this could result in economic losses and logistical nightmares, or even a full paralysis of societal functions.

Therefore, effective cybersecurity is crucial, not only for data protection but also for ensuring the operational integrity of vital services and the physical safety in a connected world. The IEC 62443 standard series[6] was developed for just this purpose: to secure industrial automation and control systems. Now, the European Commission's new Machinery Directive pressures companies to comply with these standards to maintain market competitiveness.

VTT, along with its partners, is co-innovating cybersecurity methods and practices to facilitate the development of IEC 62443-based environments and cost-effective implementation of the required secure life-cycle development. Additionally, VTT is working to establish a unified language for information sharing throughout the development process and with various stakeholders. These efforts not only enhance industry-wide cybersecurity resilience, but also shape the future of secure industrial automation in the evolving landscape of digital threats.

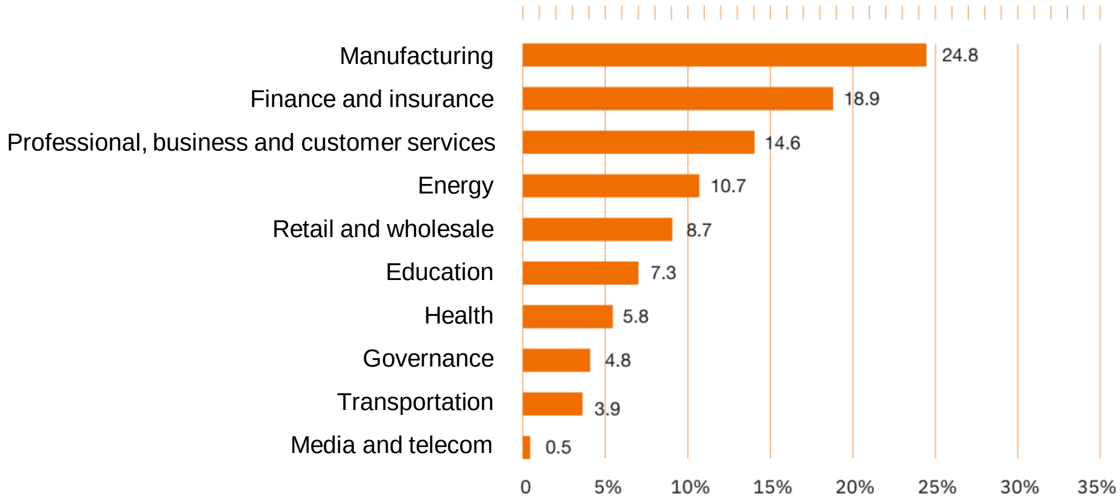
> **Effective cybersecurity is crucial, not only for data protection but also for ensuring the operational integrity of vital services and the physical safety in a connected world.**

Standards for strengthening cyber resilience

1.2 HIGHLIGHTED TECH TOPIC

While there is a significant overall increase in digital crime, operational technology systems have been hit hardest in the recent years, with the manufacturing industry being targeted in every fourth cyberattack.

The global distribution of cyberattacks in 2022 across various industries



Modified from: IBM (2023), X-Force Threat Intelligence Index 2023

A dual force in the cyber arms race

- **Predictive cyber risk management**
- **Effective threat identification**
- **Automated incident response**

- **Accelerating malware**
- **More sophisticated cyberattacks**
- **Regulatory challenges**

Cybersecurity AI

AI in cybersecurity allows for more efficient and effective defence mechanisms against cyber threats, transforming the way cybersecurity is approached.[8] AI's automation and analytical power enable the rapid identification of potential threats, often spotting anomalies that human analysts might miss. This heightened detection capability is crucial in a landscape where threats are constantly evolving and increasing in sophistication.[7]

Conversely, AI technology can also be exploited by cybercriminals to develop more advanced hacking techniques, such as self-evolving malware, which makes cyber-attacks more difficult to detect and prevent. [9] The use of AI by attackers leads to an ongoing arms race between cyber defenders and cybercriminals, each leveraging AI to outmanoeuvre the other.[7] Moreover, as AI systems often require access to vast amounts of data, including sensitive information, there will be an increasing need for robust frameworks to ensure that this technology is used responsibly and ethically.[10]

Potential impact

The long-term impact of AI in cybersecurity is characterised by a continuous cycle of innovation and adaptation. As AI tools become more accessible and advanced, cybercriminals will increasingly use AI for malicious purposes, such as creating advanced malware, automating phishing attacks and developing more effective ways to breach security systems. This will lead to a more complex and challenging threat landscape, where the effectiveness of cybersecurity measures is constantly being tested and must evolve rapidly to counter new AI-driven threats.[9, 7] Additionally, pairing cybersecurity AI with other emerging technologies, like quantum computing, blockchain and the Internet of Things, could provide more robust and comprehensive security solutions but also introduce new complexities and challenges.

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2 The new intelligence era

The new intelligence era

2.1 MEGATREND INTRODUCTION

The new intelligence era marks a transformative phase in technological development, characterised by the integration of technologies, such as artificial intelligence, quantum computing, machine learning and expansive data networks. This megatrend represents a significant shift in the global technological landscape, driven by the capabilities of these advanced systems to simulate and enhance human cognitive functions.

In this era, artificial intelligence emerges not only as a tool but also as a fundamental driver of innovation, influencing everything from business models to political strategies. The integration of AI across various sectors is revolutionising established methodologies, for example, in decision-making, enhancing operational efficiency and redefining problem-solving paradigms, offering in-depth insights from vast amounts of data. Quantum computing, with its remarkable processing power, is thought to revolutionise fields such as cryptography, material science and complex system modelling, potentially changing the foundations of security and scientific exploration. Simultaneously, algorithms and microchips are becoming increasingly sophisticated, enabling systems to learn and adapt in ways that were previously the domain of human cognition.

However, this megatrend is also characterised by its unique set of challenges. The wider adoption of these technologies raises critical questions about, for example, data privacy and ethics. As stated by the World Economic Forum (2023),[11] it is crucial for global leaders and policymakers to foster a balanced approach that powers the innovation while still mitigating their risks. This involves crafting policies that encourage innovation and technological advancement, while also safeguarding data equity.[12] Additionally, these technologies are reshaping the labour market. According to McKinsey's report (2023)[13], generative AI and other technologies have the potential to automate work activities that currently take 60–70% of employees time. This shift requires a re-evaluation of skills and education systems to prepare societies for new kinds of jobs and challenges.

Ultimately, this megatrend offers an opportunity to harness unprecedented levels of intelligence and computational power. If navigated wisely, it can lead to a future where technology amplifies human potential and addresses some of the most pressing challenges of our time. However, a superficial approach may worsen societal tensions, decrease digital trust and hinder transparent decision-making.[11]

Key technology trends

- **Cloud technologies for remote computing services**
- **Generative AI for content creation**
- **Quantum computing for advanced computation**
- **Edge computing for decentralised data processing**
- **Chip development for advanced circuitry**
- **Neuromorphic computing for brain-inspired information processing**

Surging necessity of digital trust

2.2 HIGHLIGHTED TECH TOPIC

In a world full of information and increasingly reliant on digital technologies for economic transactions, social interactions and institutional functions, the importance of digital trust is fundamental. The World Economic Forum (2023)[14] defines digital trust as individuals expecting that organisations responsible for digital technologies and services will ensure the protection of all stakeholders' interests while also upholding societal values and expectations. It's a crucial part of the digital economy, as it affects how both individuals and organisations perceive and engage with digital service, platforms and technologies. The digital trust is stated to include dimensions such as accountability and oversight, security and reliability as well as inclusive, ethical and responsible use.[14]

According to the Stanford Institute for Human-Centered Artificial Intelligence (2023)[15], one of the widely discussed topics related to digital trust is data fairness and biased algorithms. Ensuring data reliability involves measures such as accurate validation processes and diversity in data sources to prevent inherent biases. Conversely, biased algorithms, if not addressed, can lead to unfair outcomes, discrimination and erode trust in digital systems, making constant monitoring and ethical considerations essential in algorithm development.

Additionally, transparency demands towards processes and AI generated content are constantly on the rise. Both individuals and different organisations are calling for more action regarding this topic, evidenced by the emergence of AI regulation (e.g., EU AI Act) and companies establishing responsible AI frameworks, aiming to help to mitigate these AI and algorithm risks.[16]

VTT is actively engaged in improving design processes, focusing on the ethical and socially responsible development of AI technologies. This includes practical dialogues about ethical considerations to shape the future of technological advancements. As we advance in utilising and generating data, it is becoming increasingly important to prioritise ethical and responsible data measures, to ensure a future where technology serves everyone's interest without harming any individual rights or societal values.[17]

In a world full of information and increasingly reliant on digital technologies for economic transactions, social interactions and institutional functions, the importance of digital trust is fundamental.

Surging necessity of digital trust

VTT

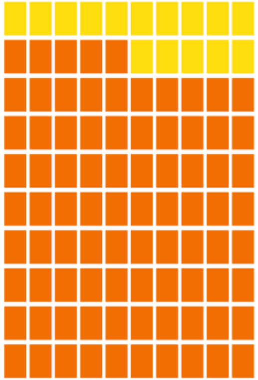
● ● ○ 2.2 HIGHLIGHTED TECH TOPIC

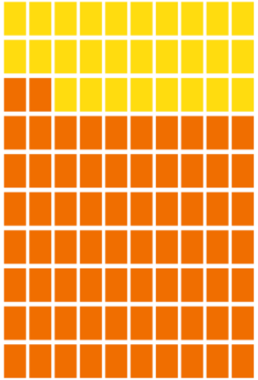
"Transparency demands towards processes and AI generated content are constantly on the rise."

Consumers would like to know more about companies' data and AI policies prior to making purchases.

"**85%**

of respondents say that knowing a company's **data privacy policies** is important before a purchase."





"**72%**

of respondents say that knowing a company's **AI policies** is important before a purchase."

Modified from: McKinsey & Company (2022), Why digital trust truly matters

The power of DNA

- **Capacity**
- **Durability**
- **Energy efficiency and sustainability**

- **Cost of synthesising DNA**
- **DNA file retrieval**
- **Security concerns and regulation**

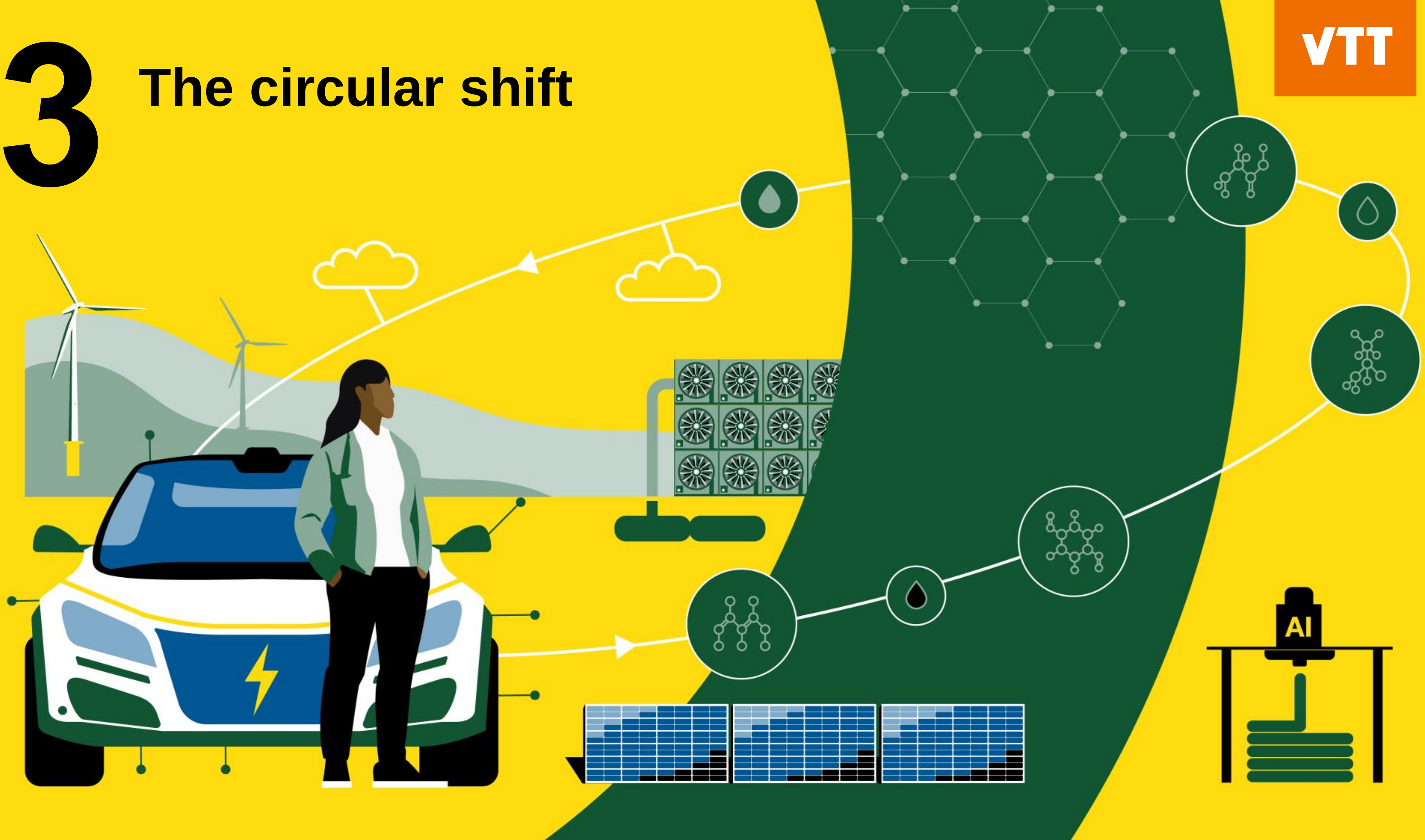
DNA data storage

As digital information continues to accumulate, traditional storage solutions face limitations. In this era of exponential data growth, scientists are turning to nature's own code – DNA nucleotides and synthetic DNA strands – to revolutionise how we store and access information. DNA, the blueprint of life, holds an exceptional density and stability for storing information. One gram of DNA can store approximately 215 petabytes of data, with a life span of, at least theoretically, thousands of years. Its ability to encode vast amounts of data in a tiny space makes it a great candidate for the next generation of data storage platform.[18] Some estimates even state that “a coffee mug full of DNA could theoretically store all of the world’s data”.[19] There are several organisations globally working around DNA as a data storage medium, including DNA Data Storage Alliance, initially established in October 2020 by Illumina, Microsoft, Twist Bioscience, and Western Digital. With the primary objectives of setting standards, promoting interoperability and outlining an industry roadmap for future developments in the DNA data storage field, the alliance also aims to generate practical use cases across diverse markets and industries.[20]

Potential impact

The immense growth in data creating and storage has significant implications and demand for data storage technologies. Statista has forecasted that by 2025, global data generation will exceed 180 zettabytes, creating a significant increase from the 64.2 zettabytes recorded in 2020.[21] Additionally, as much as 90% of digital data worldwide has been generated in the past years, and the pace of data generation is increasing.[18] DNA data storage holds potential applications in diverse fields, such as long-term archival storage for large datasets, data preservation in extreme conditions and compact storage solutions for industries with massive data needs, like genomics and healthcare. According to Gartner (2023)[22], as DNA storage matures, its impact could be transformational for fields such as data storage, parallel processing and computing.

3 The circular shift



The circular shift

With the limits of sustainability becoming increasingly evident, a profound shift in material use is driven and underway. IPCC's latest reports[23] stress the urgent need for regenerative practices as a response to climate change and biodiversity loss. According to the International Resource Panel and United Nations Environment Programme, our material use has more than tripled over the last 50 years, primarily due to the excess consumption in high-income countries.[24] Echoing the urgency, the Circularity Gap Report 2023 [25] reveals a critical decline in global circularity to 7.2%, underscoring the need for cutting our material footprint and alleviating the strain on Earth's resources. Over 90% of our materials are wasted, lost or remain unavailable, due to being tied up in long-lasting infrastructure, such as buildings and machinery.[25]

By continuing to follow the historical trends, our resource extraction could grow nearly 60% from 2020 to 2060, also aggravating the inequality in material use.[24] It is a call to action for systemic change, where circular and regenerative practices become the norm. To cultivate resilient systems that align with all business, societal and environmental interests, we need to transition from the traditional linear 'take-make-waste' supply chains to a sustainable, circular economy. This means eliminating waste and pollution, circulating products and materials, and regenerating the nature.[26]

While the future of re-everything still requires regulatory frameworks and major behavioural changes, companies are strongly incorporating circularity into their strategies, and enhancing collaboration across industries. The Platform for Accelerating the Circular Economy [27] is an example of how more than 100 organisations have come together to develop a Circular Economy Action Agenda [28], to assess the impact and circularity potential of key sectors. Changes are being made in food systems, energy production, built environment, manufactured goods, mobility and transport, where the innovation in material science and process design are creating brand new business models.[29]

Bio-inspired design, regenerative agriculture, slow fashion and modular construction are just a few examples of how we are moving towards more sustainable value chains, better climate management and biodiversity protection. According to the International Resource Panel and United Nations Environment Programme, by changing the historical trend to a Sustainability Transition scenario, we could reduce our resource use by 30%, energy demand by 27% and GHG emissions even by 83% by 2060, all while growing the economy.[24]

Key technology trends

- **Carbon capture, storage & utilisation (CCUS) and critical material recovery for resource conservation**
- **Biotechnology, advanced materials, and green chemistry as sustainable alternatives**
- **AI-material discovery and feedstock innovation to diversify resource inputs**
- **Precision agriculture, 3D printing and side-stream valorisation for material-efficient production**
- **Smart grids, waste to energy (W2E), renewables and sustainable storage solutions for green energy supply**

Bioeconomy in the resource-constrained world

As a central part of a regenerative future, bioeconomy builds on the sustainable use of renewable biological resources from land and sea, to produce energy, materials and food.[30] Biomass feedstocks, biorefining processes and bioproducts are all interconnected concepts of the bioeconomy that can support resource efficiency and circularity. The Bio-based Industries Consortium 2023 Trend Report [31] underlines that bioeconomy "can play a fundamental role in defossilising the materials and chemicals sector and in creating sustainable carbon cycles."

The demand for bio-based solutions, made with components comprised of biological or renewable materials, is growing rapidly as we seek alternatives to the traditional, non-renewable and fossil fuel -based resources. The global market for bioproducts is estimated to grow from USD 10.3 trillion in 2022 to USD 13.7 trillion by 2027. The demand for biomass alone is expected to increase from 25.6 billion tonnes in 2022 to 35.5 billion tonnes in 2027. [32]

VTT Bioruukki [33], one of Europe's largest open access pilot facilities, is an example of an innovative platform for new bio-based products and recycled raw materials. Some of the key infrastructures of the pilot facility include thermochemical conversions, industrial chemistry, hydrometallurgy and biomass processing, which allow companies to develop and scale up new low-carbon bio-products. The use cases for these facilities vary from waste recycling to metals recovery, sustainable chemicals, cellulose fibres and coatings, low carbon energy solutions, and new bio-based packaging materials – addressing some of the most challenging areas in our society today.

The demand for bio-based solutions continues to grow, as industries need to adapt to resource scarcity, regulatory pressures, consumer preferences and technological advancements. Despite the advancements in technology and increasing market demand, some challenges in scalability, supply chain management and regulatory frameworks still need to be addressed to fully realise the bio-based potential.[34]

> **The demand for bio-based solutions is growing rapidly as we seek alternatives to the traditional, non-renewable and fossil fuel -based resources.**

Bioeconomy in the resource-constrained world

3.2 HIGHLIGHTED TECH TOPIC

> **Some challenges in scalability, supply chain management and regulatory frameworks still need to be addressed to fully realise the bio-based potential.**

Green economy

Bioeconomy

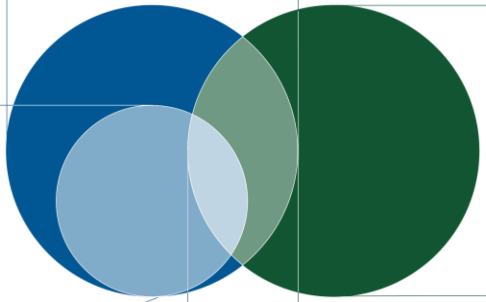
- Biomass production

Circular Economy

- High degree of recycling and reduction for materials and products
- Maintaining value of materials, products and resources
- Minimizing waste

Bio-based economy

- Processing of biomass
- Food and feed
- Textiles, wearing apparel, paper and pulp, furniture
- Biorefineries, biofuels, bio-based chemicals, bio-based plastics, biogas



- Replacing non-renewables with biological resources
- Cascading use of biomass
- Minimising bio waste

Modified from: Kardung et al (2021), Development of the Circular Bioeconomy: Drivers and Indicators

Crafting water from thin air

3.3 EMERGING TECHNOLOGY

- **Water conservation and accessibility**
- **Drought mitigation and wildfire suppression**
- **Agricultural resilience**

- **Scalability and low efficiency**
- **Water quality and airborne pollutants**
- **Competition from other water supply alternatives**

Atmospheric water harvesting

Atmospheric water harvesting (AWH) is a process of extracting water from the air, either by cooling the air below its dew point, or by using a material that can absorb water from the air. The different methods of AWH range from condensation, sorption and fog collection to cloud seeding. Each method has its own advantages and disadvantages, depending on the local climate, humidity, temperature and energy availability.[37] For example, cloud seeding, a weather modification technique introducing artificial nuclei into clouds, can offer a flexible and cost-effective approach adaptable to various cloud types and weather conditions, yet its effectiveness remains uncertain, influenced by natural cloud variability and seeding agent availability. The method can also have unintended consequences, such as changing the rainfall patterns and affecting the water cycle of the seeded area.[38]

Potential impact

Atmospheric water harvesting has potential applications in diverse sectors, including residential and commercial buildings, agriculture, disaster relief, military operations and regions susceptible to drought. The technology would allow us to minimise reliance on costly and vulnerable water transportation and storage infrastructure while integrating renewable energy sources, like solar or wind to reduce environmental impact and operational costs. According to UN-Water [39], four billion people experience severe water scarcity for at least one month each year, and over two billion people live in countries where water supply is inadequate. By 2025, half of the world's population could be living in areas facing water scarcity.[40] Atmospheric water harvesting can be a critical aid to provide a source of fresh and potable water in areas where conventional water sources are scarce or polluted. Yet, improving the efficiency of these technologies still requires further development. [41, 42]

4 Connectivity in digital-physical world

Connectivity in the digital-physical world

4.1 MEGATREND INTRODUCTION

Addressing global and complex challenges, such as social inequalities, pandemics and climate change, requires innovative approaches to thinking, collaborating and innovating that cross borders, sectors and disciplines. This is where the megatrend of connectivity plays a crucial role, which refers to the capacity to generate, access and disseminate information, experiences and resources universally, regardless of location or time. This concept is facilitated by technologies that bridge the gap between digital and physical worlds, such as Extended Reality (XR), the metaverse and digital twins.[43]

XR is revolutionising the way we interact with digital content. By blending the virtual and real worlds, they provide immersive experiences that transform, for example, education, entertainment and professional training. These technologies enable users to experience scenarios that are either impossible or too costly to replicate in the real world, making them invaluable tools for skill development and engagement. Furthermore, the metaverse offers a 3D platform where physical and digital realities converge, creating new opportunities for collaboration, entertainment and business in virtual spaces. Complementing these, digital twins create virtual models of physical systems, crucial, for example, in manufacturing, urban planning and healthcare for enhanced performance, predictive maintenance and improved resource management. Together, these technologies represent a significant leap in how we interact with and manage our digital and physical environments.

The integration of these technologies is a response to the global shift towards more integrated and efficient digital environments that expands our range of experiments. As McKinsey's report (2022) [44] emphasises, they collectively represent a leap forward in how we interact with technology and each other, offering opportunities for innovation and growth across various sectors. However, this rapid integration also brings challenges.[44] According to the Social Implications of the Metaverse report from the World Economic Forum (2023) [45], these include potential negative impacts on, for example, cognitive function and information overload. Balancing these opportunities with the associated challenges will be crucial in fully realising the potential of this connectiveness megatrend.

Key technology trends

- **Metaverse for virtual shared spaces**
- **Extended Reality (XR) for immersive interactions**
- **Digital twins for virtual replicas mirroring objects or systems**
- **Web3 for next-gen decentralised internet**
- **Haptic technologies for simulating touch sensations in virtual environments**
- **Blockchain for secure and transparent transactions**

Metaverse shaping industrial landscape

The metaverse, a transformative digital frontier, showcases remarkable potential across varied domains. This immersive digital space seamlessly blends virtual and augmented reality, transcending traditional online experiences. Its applications span across consumer, industrial and enterprise use cases - from reshaping communication and collaboration to revolutionising process manufacturing. Additionally, the metaverse introduces innovative business models, enabling the creation, trade and monetisation of virtual assets. Due to, for example, the vast variety of applications, as well as heavy investing from companies, McKinsey (2022)[46] forecasts that the potential economic value for the metaverse could reach up to USD 4 to 5 trillion by 2030.

Industrial metaverse refers to the integration of digital and physical worlds in the industrial context. Serving as a bridge between these two worlds, it facilitates real-time collaboration, data analysis and AI-driven problem-solving across diverse domains and locations. This interconnected system seamlessly integrates various technologies, human expertise, processes, materials and data in real time. Beyond enhancing efficiency and fostering innovation, the industrial metaverse holds the potential to mitigate negative environmental and social impacts associated with industrial environments.[47, 48]

VTT is also active in this area. For example, during the HUMIVERSE [47] project, VTT and 10 industrial partners initiated an exploration into the human-driven metaverse. The main focus of this initiative was to investigate the metaverse's implications for labour-intensive sectors, manufacturing, maintenance, construction, transport and logistics. As a result, scalable and innovative solutions were developed, addressing the needs of both domestic and global markets.[47]

According to the World Economic Forum (2023)[48], in the next 5–10 years, there is considerable potential for different industry players to expand and integrate various applications into a single industrial metaverse.

> **The potential economic value for the metaverse could reach up to USD 4 to 5 trillion by 2030.**

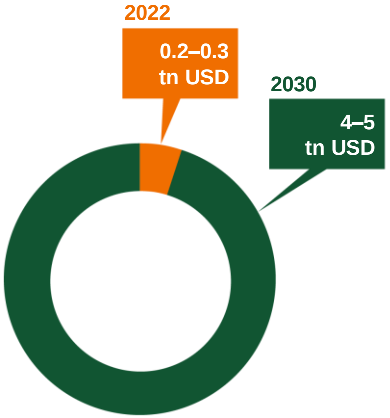
Metaverse shaping industrial landscape

4.2 HIGHLIGHTED TECH TOPIC

> **The industrial metaverse holds the potential to mitigate negative environmental and social impacts associated with industrial environments.**

By 2030 the metaverse could generate USD 4 trillion to USD 5 trillion across consumer and enterprise use cases.

Metaverse impact potential by 2030, USD trillion



Relative 2030 use case potential

● Low ● Med ● High

- Virtual assets
- Gaming
- VR/AR hardware
- E-commerce
- Live entertainment
- Education
- Health and fitness
- Ads
- Digital media

- Banking
- Construction
- Discrete manufacturing
- Education
- Central government
- Healthcare provider
- Resource industries
- Professional services
- Retail
- Investment
- Local government
- Telecommunications
- Transportation
- Utilities
- Wholesale
- Media
- Consumer services
- Process manufacturing
- Insurance

Modified from: McKinsey & Company (2022): Value creation in the metaverse

Bio-responsive digital worlds

4.3 EMERGING TECHNOLOGY

- **Enhanced immersion**
- **Personalised and adaptive experiences**
- **Improved effectiveness and outcomes**

- **Cost and accessibility**
- **Limited evidence and research**
- **Ethical considerations and regulation**

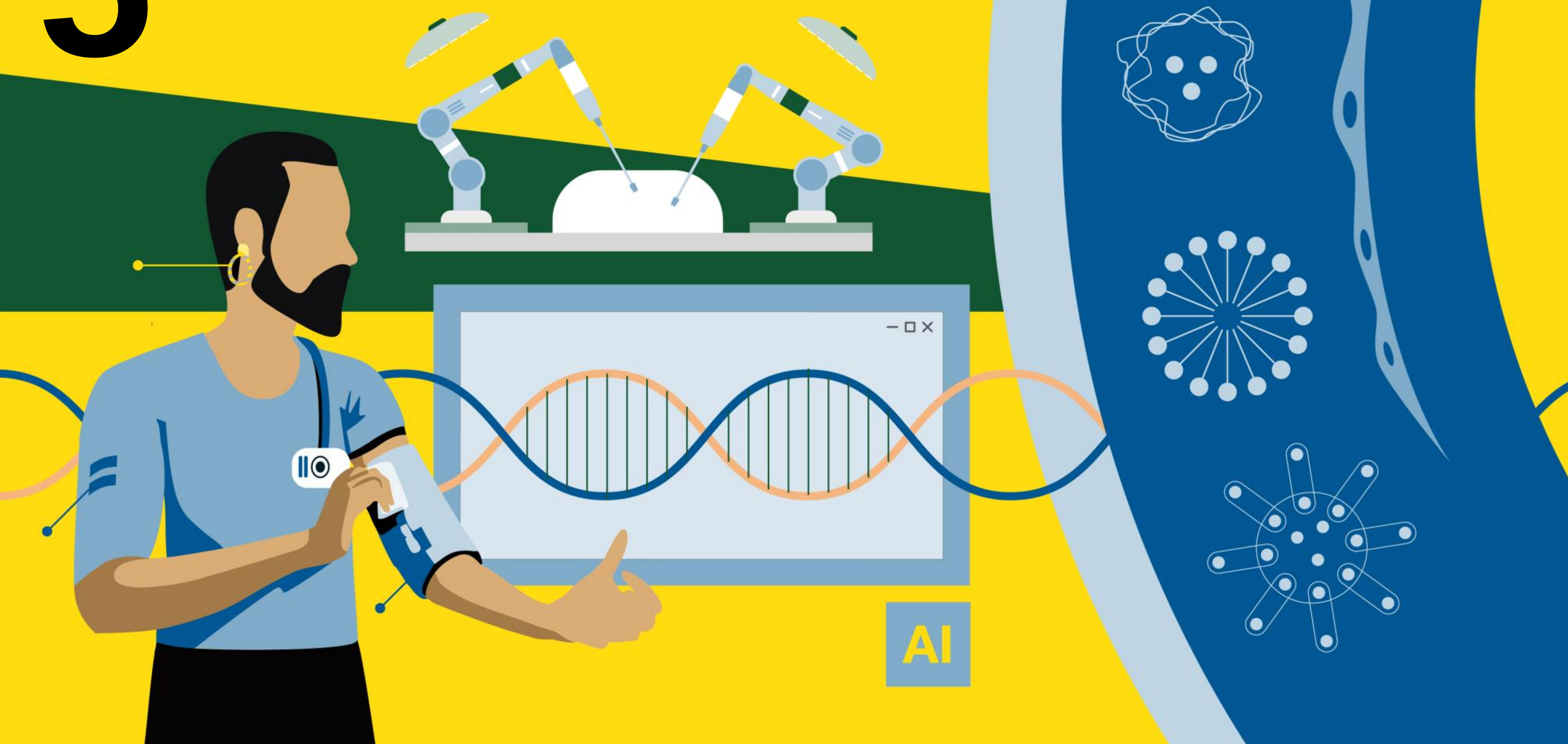
Bio-responsive VR

Bio-responsive VR is a type of virtual reality system that utilises sensors and the user's physiological data, such as heart rate, brain activity or skin conductance, to dynamically and instantaneously adjust to the virtual environment. By actively responding to the user's emotional and cognitive states, as well as considering their preferences and goals, this technology aims to elevate the overall immersion and engagement in the virtual context.[49] For example, virtual environments could be built to match and adjust the brain's mood. Imagine a virtual environment where different audio and visual elements are generated in real-time based on the user's EEG brain activity [50], or a game that teaches the user a breathing technique to help with anxiety.[51] This system could, for example, offer real-time feedback on internal states, such as stress, anxiety or attention levels. Such technology is not just a future concept - it's already achievable today. For example, Varjo and OpenBCI have joined forces and developed a product designed to bridge virtual reality and neurotechnology.[50]

Potential impact

The impact of bio-responsive VR or the Metaverse could be substantial, transforming various aspects of human interaction and experience. This technology has the potential to revolutionise entertainment, gaming, education and healthcare by providing personalised and adaptive content. Enhanced immersion through biometric feedback could lead to more engaging and effective virtual experiences. However, the extent of this impact will depend on widespread adoption, technological advancements and the successful resolution of privacy considerations [49]. Additionally, the area is still evolving, and research on the technology's impacts, among other aspects, remains limited.

5 Holistic health transformation



Holistic health transformation

Global healthcare is on a path of deep transformation, driven by the relentless pace of technological innovation, data-driven revolution, demographic shifts and the demand for more personalised, holistic care. The population of over 65-year-olds globally is expected to more than double to 1.6 billion by 2050 [52], which demands more innovative efforts to ensure the balance between comprehensive care and personal health. In the recent years, healthcare systems have already been burdened by the global epidemics that have exposed inequalities of systems worldwide, as well as the economic slowdowns that have now upended government plans to maintain pandemic levels of healthcare.[53]

Despite the ongoing and upcoming challenges, a lot has already been accomplished. According to the WHO's World Health Statistics 2023 Report [54], child mortality has halved, and maternal mortality fell by a third since the beginning of the millennium. The incidence of many infectious diseases, such as malaria, have also notably dropped, while the risks of premature death due to noncommunicable diseases or injuries has declined. All these factors have risen the global life expectancy at birth from 67 years in 2000 to 73 years in 2019.

The positive development can be owed to advancements in areas influencing general health, such as the improved access to essential health services. Slowly, mental health is also recognised as a health priority, opening doors to even more comprehensive care. Moreover, the digital health boom, driven by the increased adoption of telemedicine, remote monitoring and digital platforms, has created new opportunities for novel care delivery and innovation. Wearables, point-of-care devices and non-invasive testing are some examples of the steps already taken towards more flexible healthcare. Building on the trends of longevity and resilience, AI-driven diagnostics, blockchain and Internet of Medical Things (IoMT) are about to change our health data exchange, enhance the diagnostics and allow us to build smart hospitals.

These new technologies are presenting us unforeseen opportunities in the health horizons and enabling us to respond to the demand for predictive analytics, pandemic preparedness and empowered patients, but also personalisation and precision health. With the advances in technology, healthcare services can be made more accessible, affordable and of good quality for people around the world, all while enhancing both societal and environmental resilience to navigate the dynamic challenges.

Key technology trends

- **Wearables & sensor technologies for preventive healthcare**
- **Nano- and biomaterials for advanced drug delivery, medical implants and diagnostic tools**
- **Next gen DNA sequencing and CRISPR in targeted, personalised therapies**
- **Robotics for surgical procedures, rehabilitation and telemedicine**
- **Nutrigenomics for personalised, optimised health and nutrition**
- **Regenerative medicine for recreating tissues and organs**

Flexible sensing for modern, pre-emptive care

Flexible electronics play a central role in driving holistic, pre-emptive and accessible care. Bendable and stretchable sensors can be seamlessly integrated into wearable medical devices or conform to bodies, facilitating continuous monitoring and personalised health tracking. As one of the fastest growing application area, the global market for flexible electronics in healthcare is expected to reach USD 14.1 billion in 2026.[55]

Sensing solutions, wearables and smart patches have numerous possibilities in healthcare, from skin tattoos to smart textiles. With the small, detachable and reusable electronic parts made from renewable materials, flexible electronics can also support environmental resilience, by addressing the issues of electronic waste and critical raw materials. Researchers are looking into making these devices even more sustainable, through alternative power sources like solar energy, or by replacing non-rechargeable batteries and cutting the lithium use.

As for wearables' unobtrusive and convenient data measurement, a lot is already accomplished, and a wide range of information can be extracted for the user or healthcare professionals. VTT's roll-to-roll method [56] allows the production of adaptive flexible electronics that stay in place and are comfortable to wear. The low-cost manufacturing technique also provides higher levels of automation and throughput, while the advanced sensors enable users to extract more data from their devices. For example, VTT's patch-like solution FlexDot wirelessly measures motion and temperature with a Bluetooth connection to a device. The sensor can be placed on skin and connected to a smartphone application. Other examples of VTT's sensing solutions include smart clothes that measure breathing, bio-degradable ECG patches made from nanocellulose, and smart tattoos that measure cortisol and lactate from human sweat.[57]

These new technologies may soon leave many traditional laboratory tests to history, also displacing the rapidly generalised smartwatches. The new connected solutions allow for immediate access to health information, enabling faster and more automated analysis in the future. To add to the disruptive potential, some of the smart patches may be commercially available already within 1–5 years, with customer friendly pricing. The possibilities for flexible sensors in health and wellness seem endless.

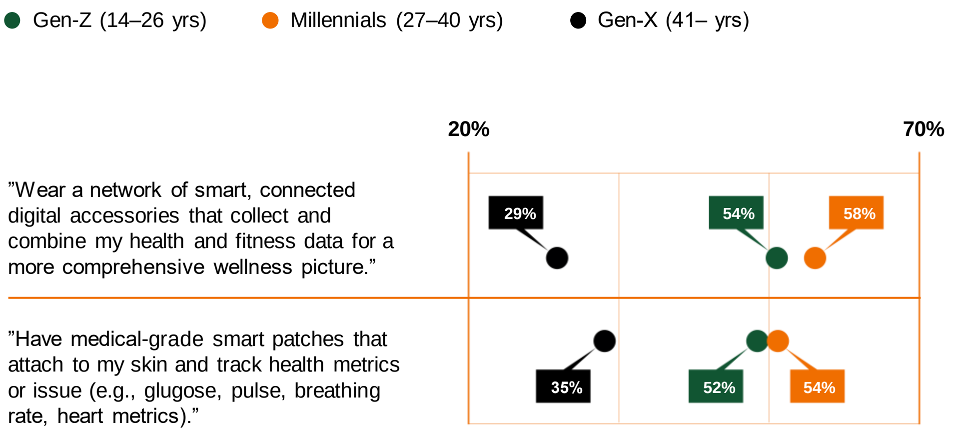
> **The global market for flexible electronics in healthcare is expected to reach USD 14.1 billion in 2026.**

Flexible sensing for modern, pre-emptive care

Smart patches may be commercially available already within 1–5 years, with customer friendly pricing.

Gen Z and Millennials show interest in futuristic health and fitness experiences, while older generations are hesitating.

Percentage reporting, they are very/somewhat interested in having following experiences in the next 3–5 years



Modified from: Deloitte (2023), Connected consumer study

Amplifying human potential

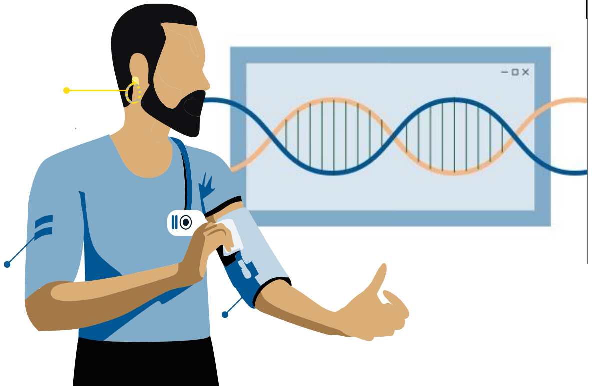
5.3 EMERGING TECHNOLOGY

- **Mind-controlled wearables and prostheses**
- **Neurofeedback for mental health**
- **Enhanced communication and augmented learning**

- **Technical hurdles, data security and user-friendliness**
- **Ethical challenges, informed consent**
- **Social challenges and potential stigma**

Full Brain-Computer Interface

Brain-Computer Interface (BCI) is a cutting-edge technology that allows direct communication between the human brain and external devices, enabling control and interaction through neural signals. The technology translates brain activity into responses or directives, such as controlling prosthetic limbs, wheelchairs, drones or, for example, video games through thoughts. BCIs could even provide feedback to the brain, enhancing memory, learning or attention. By capturing and interpreting brain activity comprehensively, full BCI aims to create seamless interaction with the external world, without relying on natural sensory or motor pathways.[59, 60, 61]



Potential impact

Even though BCI technologies are still in the early stages of development and testing, they have the potential to revolutionise healthcare. BCI-integrated systems could enhance or restore the capabilities of individuals with disabilities, elevate the performance and wellbeing of healthy individuals, and enable new forms of human-computer interaction, such as immersive virtual reality and brain-to-brain communication. The applications of the technology range from communication and control to health monitoring and cognitive enhancement.[59, 60, 61]

BCI holds great promise, but it also comes with substantial challenges and risks. Achieving full integration of BCI systems demands careful, collaborative research with various disciplines and stakeholders, including neuroscience, engineering, psychology, medicine, ethics, law and policy. The technical integration of BCI systems also demands a high level of accuracy, reliability, usability and safety, along with user acceptance and trust.[59, 61]

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