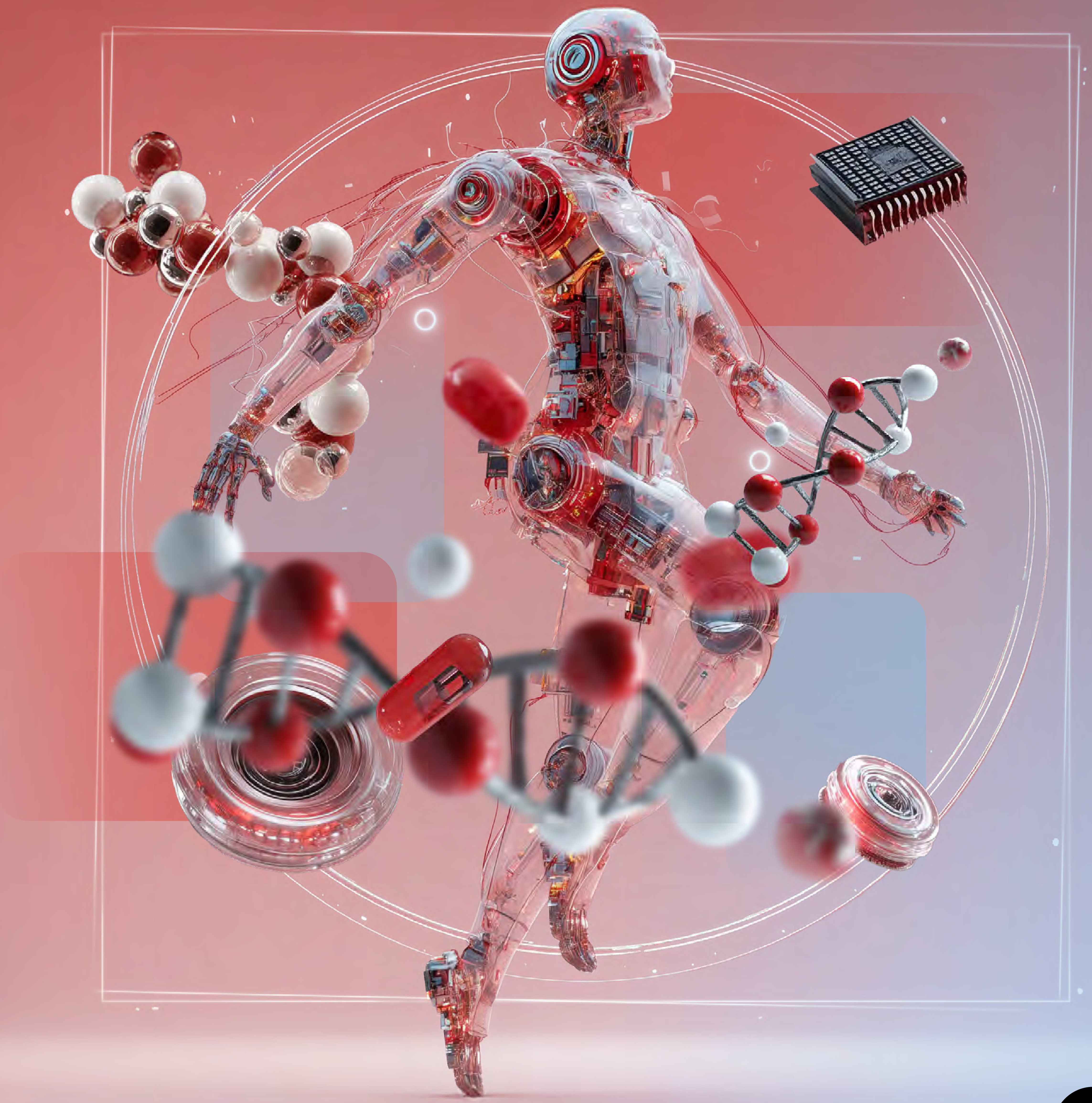
# Wildcards



# Introduction

Building upon the previous thematic chapters, this wildcard chapter offers a broader perspective by sharing a variety of emerging and potentially disruptive trends (the wildcards) to inspire the SURF cooperative.

Our society is built upon an important starting point – the human. With advancements in quantum, connectivity, and AI technologies, it's imperative to reflect on how these and other technologies will affect us as individuals. A society without healthy individuals – both physically and mentally – is one destined to underperform and feel less well connected to society and each other. Over the past 100 years, antibiotics, robotic surgery, and diagnosis technologies (such as MRI or CT scanners) have enhanced our ability to treat a multitude of physical conditions.

This trend of innovation in human healthcare continues unabated.

According to a recent study, almost 800,000 people in the Netherlands have had either a replacement hip or knee joint. Smart implant technologies will augment future hip or knee joint replacement performance, longevity, and the quality of mobility for individuals.

Technologies facilitate new experiences, and brain-computer interfaces (BCIs) – which consist of sensors to measure brain waves – will help people to interact with technologies whether to relax or in healthcare settings. Exoskeletons controlled by BCIs have been piloted, and look set to change the mobility possibilities for those with spinal cord injuries.

Smart implants and BCIs for exoskeletons focus on the physical health of the individual, but it's also imperative to consider well-being in this age of new technologies. BCIs can control technologies to enhance mobility, but they can also help those with locked-in syndrome to communicate with the world around them. Yet, as we immerse ourselves ever more in such cyber-physical technologies and the online world it's imperative that protocols are in place to promote and support proper digital well-being. The individual needs both a healthy body and a healthy mind.

In a world designed for and by humans, it's not surprising that humanity would create robotic technologies in their own image. Humanoid robots – robots that look like humans in shape and form – will be used in industrial production and work in environments too harsh for the fragile human body. Mass deployment in society is some time away, but the humanoids are coming.

For such human-focused technologies to develop and emerge in the European context, advancements in computing platforms are required. With the geopolitical landscapes constantly evolving, Europe needs chip competitiveness right at the doorstep of technological progress. Without reliable and advanced computing chips, our ability to enhance society for humanity including nature will stall.

TREND #1

# Advances in brain-controlled technologies

**Public Values**

| | | |
|---|---|---|
| | **Autonomy** | Privacy |
| | **Justice** | Accountability \| Transparency \| Integrity |
| | **Humanity** | Safety \| Well-being |

**Maturity** WATCH PLAN ACT

**Drivers**

**Compliance and Regulation; Mental health and well-being; Individualisation and Empowerment; Automation and AI; Biotechnology; Cybersecurity and trust; Digital Transformation**

Controlling actions or technologies through a digital interface using thoughts has been explored for decades. As of now, these brain-computer interfaces (BCI) are expected to gradually enter the market.

Non-invasive BCIs detect brain activities via electroencephalography (EEG) sensors placed on the cranial surface, making them cost-effective and wearable. In contrast, invasive BCIs require sensor implantation on or near brain tissue and mainly serve medical purposes.

Companies in the US and China are at the forefront of market development, with applications in healthcare, entertainment, and military sectors.

Technological advancements, such as improved signal processing and multi-sensor integration, could further enhance BCI capabilities.

Societal discussions about the BCIs must be comprehensive, considering ethical concerns like privacy, autonomy, and equality.

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## SIGNALS

### Brain-computer interfaces further explained

The history, current state and future possibilities of the non-invasive brain computer interfaces (sciencedirect.com)

From vision to reality promises and risks of brain-computer interfaces (consilium.europa.eu)

The future of BCI: breakthroughs, education and challenges (ru.nl)

### Companies and market developments

Top 10 global brain-computer interface companies in 2025 (alltechmagazine.com)

Brain-computer interface gains traction in China (chinadaily.com.cn)

### Application areas and developments

Introducing brain-computer interfaces for education and research: reimagine the human-computer interactions, for better or for worse (surf.nl)

Invasive brain computer interface for motor restoration in spinal cord injury: a systematic review (sciencedirect.com)

Passive brain-computer interfaces for enhanced human-robot interaction (frontiersin.org)

A fully implanted brain computer interface for an individual with locked-in syndrome (uu.nl)

### Societal and ethical aspects

The protection of mental privacy in neuroscience: societal, legal and ethical challenges (europarl.europa.eu)

Decentralising the self – ethical considerations in utilizing decentralised web technology for direct brain interfaces (link.springer.com)

Ethical considerations for the use of brain–computer interfaces for cognitive enhancement (journals.plos.org)

*“Understanding the functioning and limits of BCI is required to responsibly and fruitfully harness its power.”*

- **Prof.dr. Anne-Marie Brouwer**, TNO Human Performance and Radboud University, Donders Institute for Brain, Cognition and Behaviour

## IMPACT

### Education

- The fundamentals and implications of BCIs are relevant topics to incorporate in curricula on neuro and cognitive sciences, medical sciences and healthcare, engineering and digitalisation, sociology, and ethics.
- BCIs could also be used in education programmes for learning (experiments), although capital investment may be needed for certain versions of the technology.

### Research

- Brain research topics related to neurotechnologies and neurodata, experimental applications, and the societal implications, including ethical and legal aspects are natural research topics of study.
- Expected advancements in BCIs will lead to increased deployment as a research tool in the future for research activities. For instance, a researcher may use non-invasive BCI technologies for measurement and validation. Of course, such activities would be subject to ethical approval.

### Operations

- BCIs and other neurotechnologies are developing fast and as they do so, they raise several pertinent societal and ethical questions.
- Institutes will need to reflect on the institutional policies and guidelines for the use of these technologies, and how neurodata can be used for education and research.

TREND #2

# Cyber-physical technology calls for resilient minds

**Public Values**

| | | |
|---|---|---|
| **Autonomy** | Privacy | |
| **Justice** | Accountability \| Transparency | |
| **Humanity** | Safety \| Well-being | |

**Maturity** WATCH **PLAN** ACT

**Drivers**

Individualism and Empowerment; Mental health and Well-being; Community Dynamics and Social Cohesion; Automation and AI; Connectivity and Interaction; Cybersecurity and Trust; Ideologic Polarisation; Compliance and Regulation; Digital Transformation

Ongoing digital transformation requires an unprecedented level of cognitive adaptation from both individuals and society.

The convergence of profoundly intrusive cyber-physical technologies such as Brain-Computer Interfaces (BCI), Artificial Intelligence, and Extended Reality can and will continue to affect our mental and physical well-being. Their emergence is raising concerns over their pervasive influence, particularly in the context of applications with social media.

This new reality is motivating the need for urgent intervention measures such as digital detoxes, ethical design principles, governmental regulation and approaches for managing digital overload, all centred on protecting privacy and the psychological health of individuals and society.

By addressing mental health challenges and countering a growing appetite for our intimate data, these measures will help promote responsible, human-centred technology that preserves human values.

Ultimately, they aim to ensure technology supports – rather than undermines – our well-being and sense of self.

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## SIGNALS

### Impact of digital technologies on well-being

The impact of digital technologies on well-being: main insights from the literature (oecd.org)

Well-being and brain-computer interface in use case (researchgate.net)

### Digital transformation in education

Unpacking the impact of digital technologies in education: literature review and assessment framework (publications.jrc.ec.europa.eu)

AI report by the European Digital Education Hub's Squad on artificial intelligence in education (op.europa.eu)

A comprehensive review of key cyber-physical systems, and assessment of their education challenges (ieeexplore.ieee.org)

### Human-centred design of digital technologies and applications

Understanding human-centred AI: a review of its defining elements and a research agenda (tandfonline.com)

Embedding human values in the design of mixed-reality technologies (ieeexplore.ieee.org)

Responsible development and uptake of XR technologies by European project XR4 HUMAN (xr4human.eu)

Report on Virtual World trends and benchmarking by European project OpenVerse which has the vision to create inclusive, open, and ethically responsible European Virtual Worlds (open-verse.eu)

## IMPACT

### Education

Cyber-physical technologies have the potential to transform education by enabling immersive, personalised learning experiences. Although they can improve engagement, accessibility, understanding and knowledge acquisition, they also raise novel emerging privacy and security concerns. Ensuring ethical use is essential towards harnessing their benefits, while protecting students/ trainers' rights and well-being.

### Research

- BCI and other cyber-physical technologies can revolutionise research by enabling immersive data collection and new avenues for exploring the brain and human behaviour.
- Despite the enormous potential for innovative study possibilities in research, cyber-physical technologies bring with them a need for stronger cybersecurity, ethical guidelines, and advancements in our understanding of human rights.
- Future research should be driven by an interdisciplinary focus for securing these technologies and addressing privacy concerns.

### Operations

- Future campus environments can be transformed by enabling immersive learning, virtual labs, and enhanced accessibility.
- The cyber-physical transformation will give rise to privacy, ethical, and security challenges for institutions, thus requiring new policies. To maximise the benefits for the wider community, campuses must develop safeguards, ensuring safe, equitable, and ethical integration of these technologies.

TREND #3

# Rise of the Humanoids

**Public Values**

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|---|---|---|
| Autonomy | Freedom of Choice \| Independence |
| Justice | Accountability \| Transparency \| Integrity \| Equity |
| Humanity | Safety \| Respect \| Meaningful Contact \| Well-being |

**Maturity** WATCH PLAN ACT

**Drivers**

Demographic shift (ageing); Mental health & well-being Automation & AI; Connectivity & interaction; Service-oriented & value-based economies; Compliance & regulation

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Humanoid robots, built to resemble humans in appearance and movement, are helping to boost productivity and address labour shortages in various industries. They are highly flexible, capable of navigating complex environments, and adept at handling objects of different shapes and weights. Their human-like appearance can also make them more readily accepted in places such as hospitals, care homes, and schools.

Since the 1980s, advancements in artificial intelligence and robotics have dramatically improved their capabilities, prompting major investments from companies like Tesla, Boston Dynamics and UBTech, amongst others.

However, challenges such as high investment costs, energy efficiency, operational safety, and sophisticated software still limit their widespread use. Despite these obstacles, humanoid robots are increasingly considered for tasks that minimise risks to humans or fill workforce gaps.

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## SIGNALS

### Market developments related to humanoid robotics

**Position paper of International Federation of Robotics: Humanoid robots - vision and reality** (ifr.org)

**Future of robotics 2035: insights from industry experts** (hexagon.com)

**Humanoid robots - Game changer or hype?** (ipa.fraunhofer.de)

*“A humanoid only becomes interesting when its form factor truly matters, for example, in (social) interaction or when their task generalisation is sufficient for them to function in the everyday human world. After all, the human world is tailored to the human form factor.”*

**- Dr ir Mark Vlutters**, Assistant Professor, Biomechatronics and Rehabilitation Technology, University of Twente

### Reflections on technologies, innovation, and trends regarding humanoid robots

**Humanoid robots like Tesla Optimus and the future of supply chains: enhancing efficiency, sustainability, and workforce dynamics** (mdpi.com)

**Reality is ruining the humanoid robot hype: the obstacles to scaling up humanoids that nobody is talking about** (spectrum.ieee.org)

**Between fascination and discomfort: the new generation of humanoid robots** (ndion.de)

**Do people really want humanoid robots in their homes?** (spectrum.ieee.org)

### Societal reflections

**AI robots and humanoid AI: review, perspectives and direction** (ui.adsabs.harvard.edu)

**Artefacts of change: the disruptive nature of humanoid robots beyond classificatory concerns** (link.springer.com)

**The Robot Rights and Responsibilities scale: development and validation of a metric for understanding perceptions of robots’ rights and responsibilities** (tandfonline.com)

## IMPACT

### Education

- Across vocational, undergraduate, and graduate levels, robotics education may need to shift from siloed tracks (e.g. technology, psychology, or economy) and adopt a more inherently interdisciplinary approach. This would not just produce technical specialists, but adaptable innovators equipped to drive progress and implementation across fields for real-world applications.
- Humanoid robots themselves may eventually contribute to education, offering new forms of support for both teaching and learning.

### Research

- Humanoid robotics interconnects a wide range of research domains, and as humanoids enter workplaces, research must move beyond technologies and cost savings to broader use cases: sustaining productivity, enabling collaboration, and rethinking processes and (organisational) systems.
- Research on humanoids should address not just what humanoids can do, but how they can be accepted, usable, and valuable. Humanoids are a testbed for how we connect technology, people, and society, and how we can shape the future of work, learning, and innovation.

### Operations

- Institutions can support human-centred development and carefully consider the adoption of humanoid robots through collaborations with tech developers, use case organisations, and other stakeholders.
- Institutions might start to consider how they participate in the evolution of and the future of humanoid robots in the workplace, education and society as a whole.

TREND #4

# Smart regenerative implants in trauma care

**Public Values**

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|---|---|---|
| Autonomy | Freedom of choice \| Privacy |
| Justice | Transparency \| Accountability \| Equity \| Inclusion \| Integrity |
| Humanity | Personal development \| Meaningful contact \| Safety \| Well-being \| Respect |

**Maturity** WATCH PLAN ACT

**Drivers**

**Demographic Shift: Ageing; Biotechnology; Engineering Advances & Computation; Connectivity and Interaction; Automation and AI; Well-being**

Trauma patients require extensive treatments and the greatest attention, with about 80,000 cases annually in the Netherlands.

For example, when a trauma patient arrives at a hospital with multiple bone fractures, ruptured blood vessels, and damaged organs, they will require multiple surgeries for internal injuries and immobilisation of broken bones with a cast or brace.

So-called smart implants are now being developed that can stimulate bone growth, help regenerate tissue, and monitor patient healing in real time. Monitoring devices can be powered by blood flow, muscle movement, or even breathing.

In addition, smart implants to restore and support skeletal and muscular tissue can be made from biodegradable materials, which are then naturally excreted by a patient; thus eliminating the need for further invasive surgery to remove the implants.

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## SIGNALS

### Smart implant research

**Materials scientists, cell biologists, tissue engineers and medical scientists work together on the regeneration of tissue and organ function with intelligent, lifelike materials.** (tue.nl)

**Geometry-mediated bone formation. Geometry-driven osteo induction is enabled by high speed, high precision additive manufacturing** (tue.nl)

**Smart implants in healthcare to treat diseases, monitor patient recovery, and restore organ functionality are being developed by a host of organisations around the world** (sciencedirect.com)

**Beyond Tissue replacement: The Emerging role of smart implants in healthcare** (research.umcutrecht.nl)

### Biomechanics and regenerative medicine requires an interdisciplinary approach

**Project Brave is seeking to develop an innovative and smart implant for ischemic or coronary heart disease** (projectbrave.eu)

*"Smart Implant technologies could significantly improve quality of life and give healthcare providers better insight into how to accelerate recovery and optimise treatment strategies for patients."*

– **Dr Linda Chen-Zijlstra**, Research IT consultant, Department of Biomedical Engineering, TU Eindhoven

## IMPACT

### Education

- Innovation in smart implant treatments requires and needs collaboration across various disciplines – medicine, biology, chemistry, physics, materials science, and engineering (including e.g. data sciences for simulations). As a result, students must cover a broader range of fields and perspectives.
- Students will be provided with the opportunity to learn together, interact more closely, and develop a deeper understanding of how different disciplines connect. Traditional education models (in e.g. medical and health) will need to evolve – becoming more flexible and allowing students to cross boundaries between fields and disciplines more easily.
- Interdisciplinary thinking for the challenges of future smart implant-based healthcare and technologies, should in the long term, broaden career development.

### Research

- Considerable research on smart implants is already taking place both in universities and in research facilities at hospitals. For instance, smart bone-related implants are intended to replace the traditional inert metal-based implants currently used in treatments.
- Clinical implementation of such smart implants will need to follow a structured roadmap, while key issues such as the powering smart implants used for monitoring and understanding how native biological cells in the body interact with smart implants require further investigation.

TREND #5

# A growing urge for chip sovereignty in Europe

**Public Values**

| | | |
|---|---|---|
| Autonomy | Freedom of choice \| Independence |
| Justice | Sustainability \| Transparency \| Accountability \| Integrity \| Equity \| Inclusion |
| Humanity | Safety |

**Maturity** WATCH **PLAN** ACT

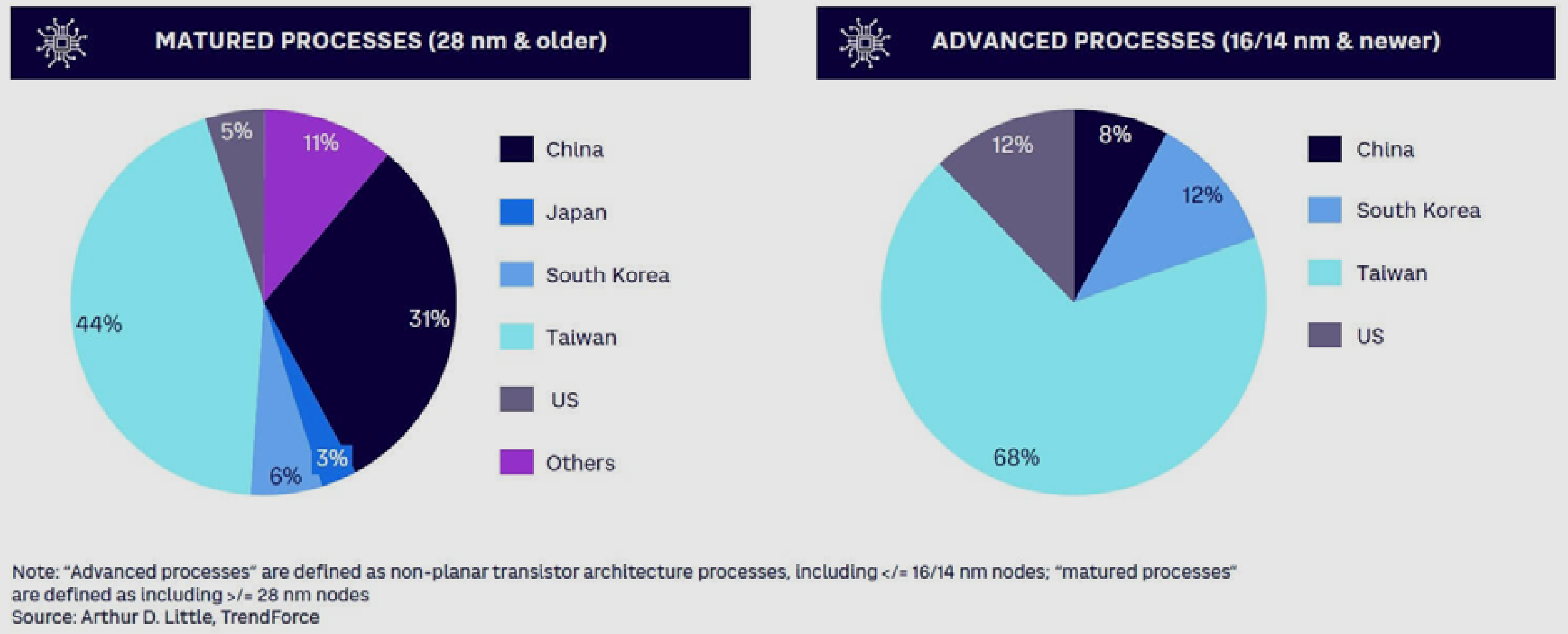
**Drivers**

Geopolitics & (digital) sovereignty; Compliance & regulation; Critical infrastructure; Automation & AI; Engineering advances & computation; Digital transformation; Global trade & tariffs

All devices require chips to function, and in the case of AI more specialised hardware (chips) are needed, and required, to accommodate the demand. Most of the chip manufacturing takes place in Asia, and with the current geopolitical dynamics, the supply chain for chips is under pressure. In combination with the scarcity of raw materials used for classical (and AI) chip manufacturing, have led several countries to rethink the supply chain.

One of the developments here is the European Commission's Chips Act, introduced in 2023. The ECA framework is set for revision, facilitated by broader consultation with stakeholders in late 2025, to ensure an EU-based microchip ecosystem.

Another noticeable shift is seen in research and development (R&D). More transdisciplinary research, beyond universities, takes place in collaboration with industry partners, to rethink and redesign chips by looking into the pipeline (from materials and architectures to software and memory) for more efficient and intelligent devices.




Distribution of foundry capacity by region, 2023 (adlittle.com)

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## SIGNALS

### Europe's drive to make microchips

An agreement between all EU member states as they all join the Semicon Coalition to secure the continent's technological leadership

- government.nl
- advisory.eib.org

The European Commission has launched a public consultation on the current ECA to address its current shortfalls in light of significant recent changes to the industry (September 2025) (digital-strategy.ec.europa.eu)

EU Chips Act comes into force in September 2023 (ec.europa.eu)

digital-strategy.ec.europa.eu

### Investments in AI chips

ASML invests €1.3 billion in the French-based company Mistral AI (asml.com)

fintechweekly.com

European Investment Bank (EIB) working on a new initiative to raise €70 billion by the year 2027 for AI and semiconductors (reuters.com)

*"True chip sovereignty means more than fabs — it's about creating the next generation of intelligent hardware. Europe can lead in brain-inspired, energy-efficient computing."*

– **Prof. Dr. Wilfred G. van der Wiel**, Director Center for Brain-Inspired Computing (BRAINS), University of Twente

### Quantum Europe Strategy or European Quantum Act

Launch of the European Commission Quantum Europe Strategy on July 2, 2025 which seeks to position Europe as a global lead in quantum by the end of the decade (digital-strategy.ec.europa.eu)

qt.eu

Europe's Quantum Leap – The new EU Strategy for quantum technologies up until the year 2030 (globsec.org)

Dutch positioning in the quantum ecosystem and alignment with the European Quantum Act (hollandhightech.nl)

## SIGNALS

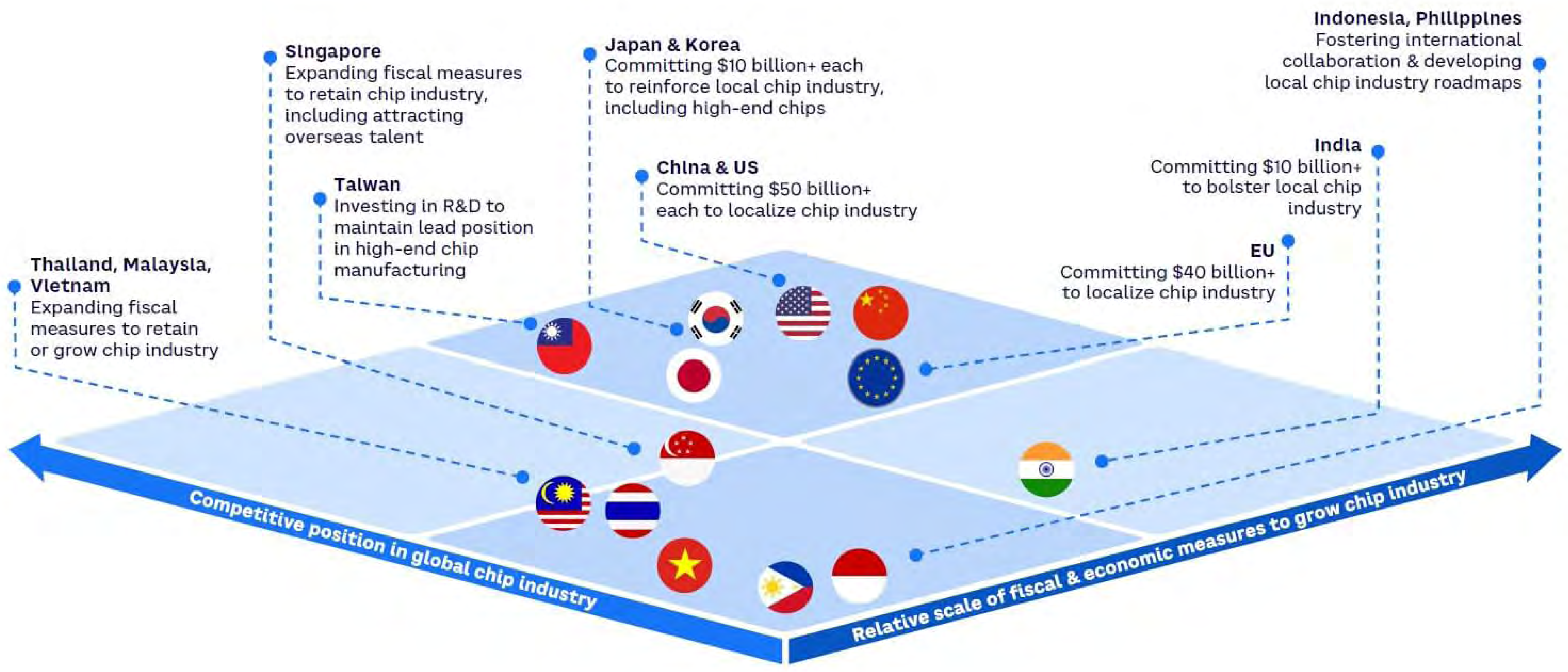
### Institutional movement

Material that listens: Twente breakthrough in speech recognition (utwente.nl)

Eindhoven University of Technology is establishing a new research institute dedicated to such as semiconductor, quantum, and photonics chips that aligns with recent policy initiatives such as the ECA and the Dragi-report (tue.nl)

Launch of the Casimir Institute at Eindhoven University of Technology (tue.nl)

### Fiscal measures committed vs. competitiveness in global chip industry (adlittle.com)




Source: Arthur D. Little

# IMPACT

## Education

- The European Chip Act will drive resilience and technological innovation in the broader chip industry within the EU. Nevertheless, it's impact on innovation will be influenced by geopolitical policies and the global technological competition.
- Talent is needed to guarantee the growth of the EU chip industry from a technological standpoint, but this talent should be made aware of the significance of EU policy and geoeconomics on the ecosystem.
- In some courses, these topics are covered implicitly. However, explicit coverage of these topics in dedicated modules that complement traditional technical modules would help to train a more balanced talent pool. This would be talent with the capability to innovate within the chip industry who are also aware of the influence of geopolitical change on their efforts.

## Research

- The pursuit for digital autonomy can drive research projects in fields pertaining to the chip industry – ranging from processes to materials, and logistics to synergy with artificial intelligence, connectivity, and data management.
- Collaborate beyond universities and across Europe with researchers, industry partners and society to develop (new) use cases.
- Specialised lab facilities to accommodate new developments in chip testing, manufacturing and knowledge transfer.

## Operations

- Talent development and housing will need to be prioritised and accommodated to scale the capability in the Netherlands.
- The implementation of new smart, energy-efficient IoT devices will require architectural focus for future campus scenarios.
- The transdisciplinary research projects require a trusted collaboration environment, allowing for industry partners to access knowledge.

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