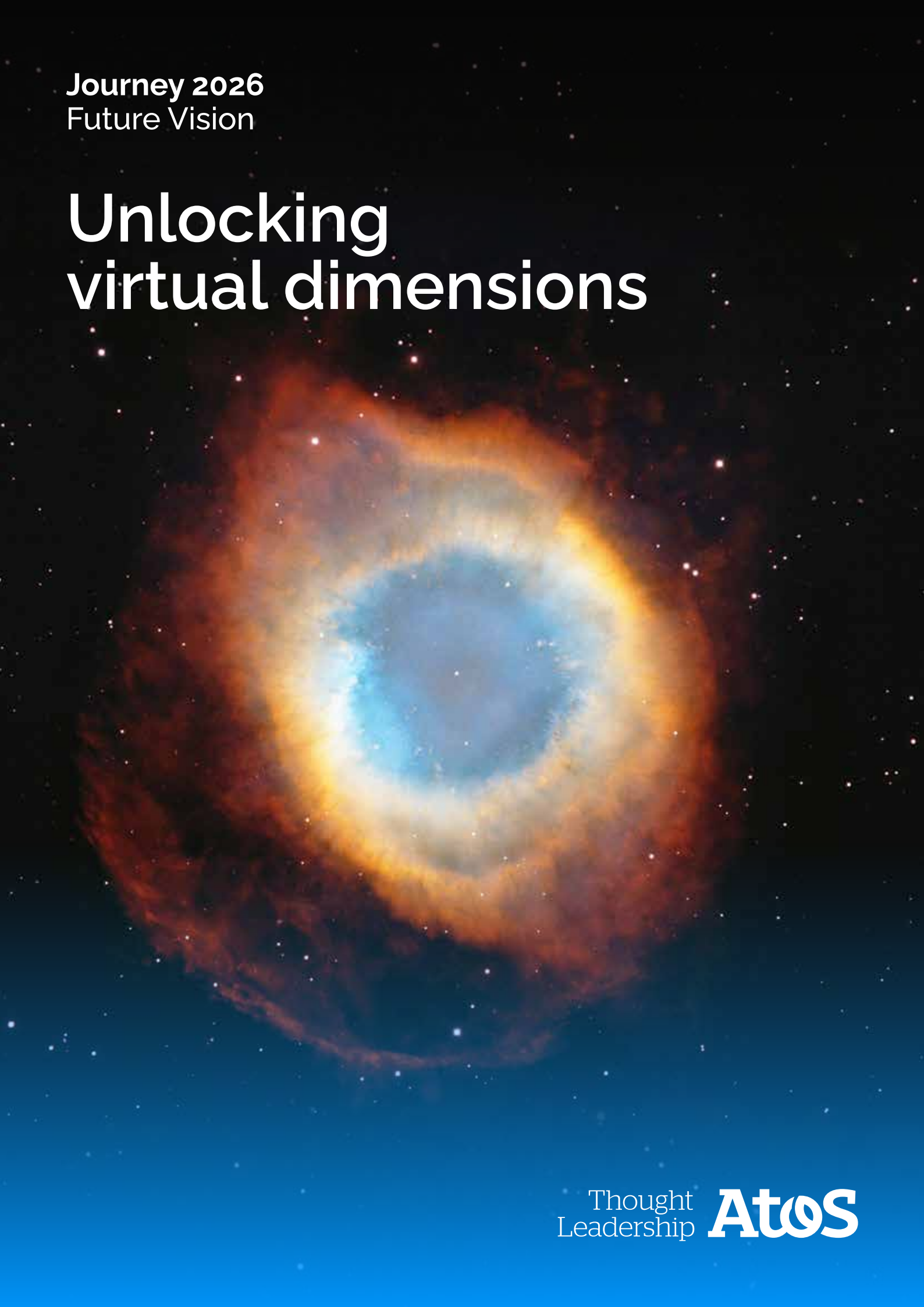
Journey 2026
Future Vision

Unlocking virtual dimensions



Thought Leadership Atos

Contents

Foreword

Welcome to Journey 2026, the Atos Scientific Community's perspective on technology driven trends that are expected to shape the evolving world of business and society. It provides a possible vision of the future and highlights some of the challenges and opportunities that could emerge along the way.

We feel such vision is more than ever needed in the context where the pandemic has driven huge changes across all areas of business and considerably accelerated the rise of the data economy.

Much of the current rhetoric coming from the world's leaders indeed refers to the fact that we are living in a time of profound change. The challenges relating to climate change, global pandemics, globalization of the economy and sovereignty all demand a new approach - and we are all having to learn quickly to respond. Failure to think differently and act differently could have lasting and destructive consequences. However, historically there has been a tendency for us to be constrained by so-called conventional wisdom - even with the adoption of new technologies, and especially in the areas of business models, value, and ethics.

We believe we have a good understanding of the world in which we live, but the reality is that much of the natural world remains unexplored and unknown, including ocean depths, outer space, 90% of our brains and 80% of the data we produce. As we look to wrestle with the grand challenges of our time, most of which are bound by our physical world and the continual stresses that we are applying to it, do we need to start exploring technology-enabled virtual dimensions for future growth opportunities? Digital has been hugely transformative in what we have been able to achieve so far, but to continue to realize benefits for our finite world, do we have to break free from some of its physical boundaries?

Atos Scientific Community proposes that "Unlocking virtual dimensions" offers the potential for new ways of relating, conducting business and even being. The research and thought leadership contained within Journey 2026 explores the ways in which the current boundaries of our physical world are being stretched, and how we need to appropriately deal with the societal, ethical, and economic consequences of breaking through into new virtual ways of operating. It will, we are sure, help stimulate your thinking as to what different technology-led approaches are opening up for businesses, governments and societal groups to maintain relevance and thrive in times of profound change.

Atos Scientific Community Editorial Board

Key takeaways for business leaders

Digital is so deeply embedded in our lives that we often overlook the magnitude of its transformative effect. Yet, beyond the realms of traditional digital transformation, trends are emerging that have the potential to disrupt conventional business and economic models, with even greater impacts on individuals and society at large. As we move from a "post-digital" era to the experience age, digital and real worlds converge to deliver hyper-personalized experiences that open up new frontiers that are no longer beyond our imagination.

Unlocking virtually limitless capabilities

From generative artificial intelligence (AI) to blockchain-based services, and the first hints of practical quantum supremacy, a new generation of breakthrough technology is beginning to unlock capabilities that exceed what we have experienced with previous digital transformations. Not only can we virtually replicate and optimize almost any process, but we are also starting to truly augment and even transcend the constraints of the physical world by exploiting the benefits of virtual resources and their interactions. This offers the potential for enabling zero marginal-cost[1] business, facilitating unlimited asset creation, and allowing interactions that are multiplied exponentially through network effects. It will expand our realms of operation with virtual assets, virtual personas, virtual organizations, and even virtual nations.

Reimagining the boundaries of conventional wisdom

We are now faced with a transformative opportunity to reimagine the boundaries of conventional wisdom. Eliminating or at least minimizing physical constraints through simulation and virtualization will surely help us to better understand and respond to global challenges such as climate change, healthcare, wellbeing, and equitably sustaining a growing world population. Virtual-world tools and techniques such as digital twins, augmented reality, and non-fungible tokens are starting to unleash a range of interaction and value exchange possibilities never previously available. However, with greater opportunity comes greater responsibility, and business leaders need to be aware that the freedoms of this new virtual dimension also bring new risks of social disconnection, digital divides and threats to ownership, privacy, and sovereignty. Solutions to these externality challenges must be found and effectively implemented.

Getting ready for 2026 and beyond

It is important for business leaders to assess the impact of these evolutions. We must rethink the ways we manage the lifecycles of physical goods, provide health equity, and even augment human capabilities — physically and mentally. This becomes increasingly important as intelligent edge technology brings a growing connection between the physical and virtual worlds.

We believe the new technology frontier will enable:

- New modes of operating, with the generalization of hybrid virtual/physical processes and the emergence of virtual shoring[2] that uses automated intelligent virtual agents.
- New modes of relating between humans and robotic entities, through an augmented reality (AR) metaverse, which will eventually incorporate brain computer interfaces (BCI).
- New modes of value and business, with the rapid rise of the data economy and a new generation of business ecosystems that leverage data marketplaces and tokenization.
- New modes of being and new virtual expressions of our human existence, from virtual learning to virtual incarnations of people who are living, fabricated, or even deceased.

It is essential to understanding how we effectively and safely manage the ways of negotiating and crossing the physical/digital divide. Major concerns include the complex inter-relationship between regulation and digitalization; growing cybersecurity risks (notably, the rise of autonomous AI cyberattacks); maintaining operational resilience; and the collective impact on how we think about corporate and citizen digital responsibility - including sustainability and decarbonization.

These questions must be answered by every industry sector, even though those most directly impacted by digital — such as media and finance — may be at the forefront.

Our changing world and the opportunities that technology-enabled virtual dimensions offer are causing organizations and society to fundamentally rethink how we perceive value, identity, processes and even purpose.

Such rethinking may involve:

- New strategies for hyper-automated business processes.
- Establishing new virtualized models for data-driven value exchanges within ecosystems.
- Fast-tracking the review and adoption of virtualization technologies, such as digital twins, augmented reality, asset tokenization and highly interactive remote collaboration.
- Moving from off shore delivery models to virtual shoring.
- AI capture and rendering of core business skills and IP.

For business leaders, leveraging these opportunities and addressing the risks will be critical to value creation on the journey to 2026. In an accelerating, fast-changing world, mastering the key trends will not only be essential to maintaining relevance and resilience, but it will also be the fundamental means of avoiding digital dissonance and disparity.

1.Zero marginal cost describes a situation where an additional unit can be produced without any increase in the total cost of production.
2.Where traditionally off-shored or near-shored outsourcing activities are now performed in the virtual domain.

Vision 2026
Unlocking virtual dimensions

“Will anticipated technology advances cause us to rethink our perceptions of the digital and physical world?”

Beyond digital

Redefining digital

The terms **digital** and **digital technology** have become so ingrained into everyday language that their meaning has been somewhat blurred. They have become all-encompassing terms that cover almost anything that makes use of electronics and data: whether it be the simplest of connected sensors or the most advanced high performance computers; the most basic of user apps or highly complex artificial intelligence.

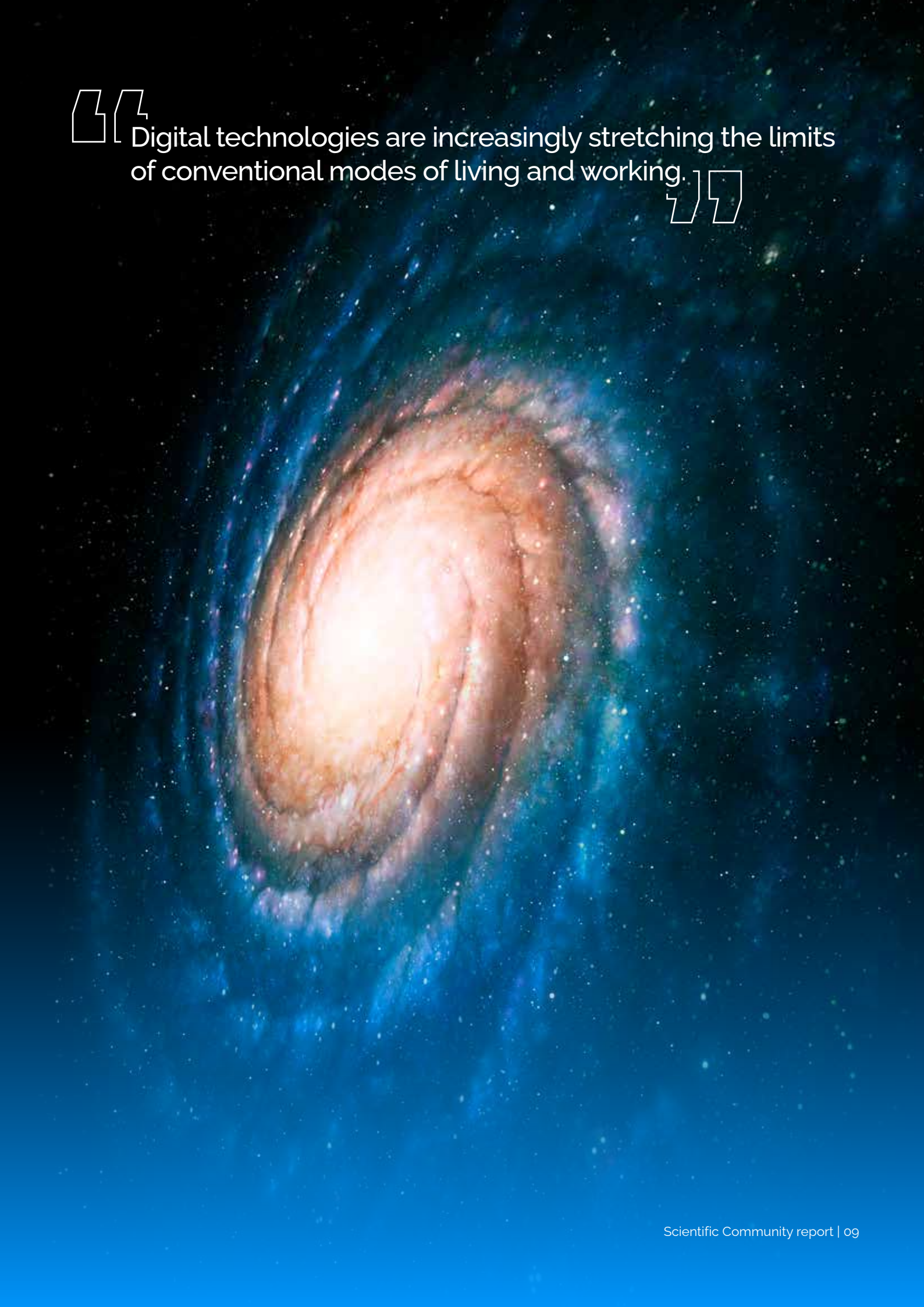
The potential applications of digital technologies have reached a point where they are seemingly limited only by our imaginations. Nevertheless, their practical understanding and usage is not always as diverse and impactful as their theoretical scope.
For some enterprises, the very heart of their business models is dependent on the possibilities of digital; for others digital transformation appears limited to the use of computer technology that executes traditional business processes in a more digitalized, connected way.
It is unclear when the term digital was first coined, but it surely has its roots in the binary system used by electronic computers. The use of 0 and 1 in the representation and computation of data might suggest that digital is synonymous with being exact and precisely replicable, even though quantized digital representations of the analogue natural world are often imprecise (e.g. music). But as certain digital technologies continue to develop, they are becoming less digital. Some solutions are more probabilistic than precise, making use of degrees of uncertainty that might previously have been thought of as very un-digital. Quantum computers rely on probability and analogue wave functions in their emerging models for representing data and solving algorithms; some approaches to machine learning make use of randomness to create stochastic algorithms that achieve results which deterministic models are unable to; and an element of randomness is an essential feature of cryptography (although true randomness is elusive in conventional digital computers). Digital is clearly no longer a term that sufficiently encompasses all current applications of related technology, let alone the emerging ones. **Is it time to rethink the way we perceive and apply digital technologies?**

Reimagining the boundaries of conventional wisdom

For many practical applications, the journey of digital exploration has been one that has progressed from Replicate (mimicking the physical, with emails and shopping baskets for instance), to Optimize (doing things faster and smarter), and on to Augment (extending physical capabilities through augmented reality and artificial intelligence).

As we extrapolate current thinking further, **we have to increasingly reimagine the boundaries of conventional wisdom**. Are we now entering an era that leads to a new dimension of operation? One that transcends the constraints of physical space and is characterized by truly exploiting the benefits of virtual resources and their interactions.
We foresee **virtual dimensions or domains that operate beyond direct physical constraints**, where virtual intelligence controls and transacts virtual resources, and where only at the boundaries with physical domains will real-world outcomes be affected.
We can see this concept already evolving in a number of areas: For nearly two decades the gaming and entertainment industry has used **virtual world** escapism through simulated environments and Massively Multiplayer Online Role-Playing Games (MMORPGs). But now we see the emergence of projects like StoryFile[3] through which living individuals are able to preserve their life story in a way that can be retold using AI technologies - even after the subject is deceased.
Companies like Ubiquity6 and Meta (formerly Facebook) are working on the creation of a **metaverse**[4] where people can communicate and work in virtual environments, with a view to unlocking access to a whole new realm of social and economic opportunities.
The potential of **digital twin simulations** is well known. For example, using computational fluid dynamics for aerodynamic vehicle design can often give better and more actionable results than real-world wind tunnel testing: simulation becomes the truth. At an extended scale, the UK government has launched a national digital twin program[5] to create a range of new business models, services and markets based on vast virtual representations of physical national infrastructure.
AI technologies are already being used to transform the way that employees are hired, managed, and fired and even to model the decision making of enterprises and governments. It is not such a bold leap to anticipate fully **virtual organizations** comprising AI managers and workers, trading in tokenized virtual assets, as the emergence of pioneer decentralized autonomous organizations[6] (DAO) show, for example, Dash[7] and Augur[8].
We even see the emergence of **virtual nations** like Wirtland[9] and even digital nomad status for real countries like Estonia[10], which are redefining the concept of citizenship and nationality by offering virtual residency, mapping borders around missions and values rather than land.

3. life.storyfile.com/
4. https://www.youtube.com/watch?v=gElfIo6uw4g
5. https://digitaltwinhub.co.uk/
6. An organization represented by rules encoded as software that is transparent, controlled by its members and not influenced by a central government.
7. bitcoinist.com/dash-original-dao/
8. https://augur.net/
9. wirtland.com/
10. e-resident.gov.ee/nomadvisa/



> Digital technologies are increasingly stretching the limits of conventional modes of living and working.

Beyond the physical

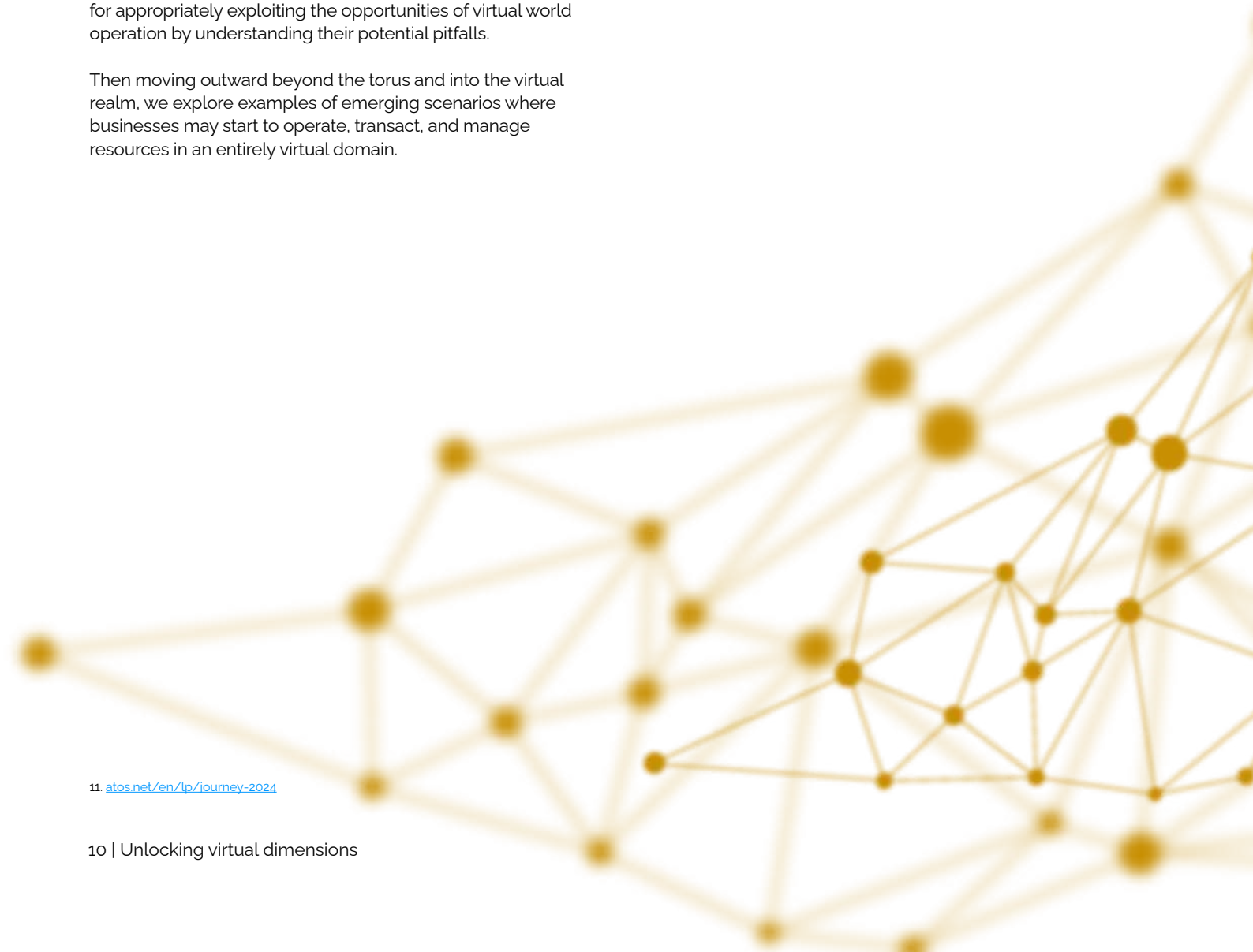
In exploring the potential of **virtual dimensions** from a business perspective, we have researched a number of emerging technologies and their implications. We have considered the ways that particular innovations are already pushing the boundaries of physical world constraints, and how they might lead to new possibilities in the emerging virtual dimension.

It is important to emphasize that we do not look at this new dimension as just a virtualization of the physical. Instead, **it is an opportunity to completely rethink some of the fundamentals of how we define value, identity, processes and even purpose** - concepts which we have already explored in Journey 2024 "Redefining enterprise purpose"[11].

To help contextualize our research topics, we use the torus model shown in figure 1. There are three distinct zones, with the torus itself representing the boundary or transition layer between the physical and virtual realms. At the center of our model is the physical realm. Here we consider the ways that selected technologies and their applications are stretching physical world boundaries in new and disruptive ways, including by acting as bridges between physical and virtual dimensions.

Moving outward from the center and into the torus itself, we consider the challenges and risks of negotiating the boundary between physical and virtual. We offer a balanced perspective for appropriately exploiting the opportunities of virtual world operation by understanding their potential pitfalls.

Then moving outward beyond the torus and into the virtual realm, we explore examples of emerging scenarios where businesses may start to operate, transact, and manage resources in an entirely virtual domain.



11. atos.net/en/lp/journey-2024

Figure 1: Physical, virtual and transition realms

Stretching physical boundaries

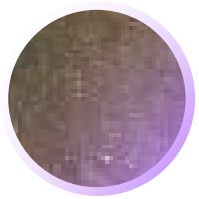
As technologies emerge and mature, supported by ever-increasing computing power, we see the realization of capabilities that were previously considered to be in the realms of science fiction.

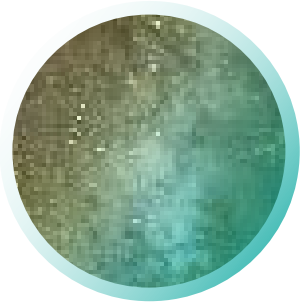
Across the planet, our use of technology is embroiled in the major macro-physical challenges of our time - climate change, healthcare and wellbeing, and the physical infrastructure development and operation required to sustain our population. We explore some significant opportunities to address these very personal and large-scale challenges with tools and techniques never previously available to humanity.

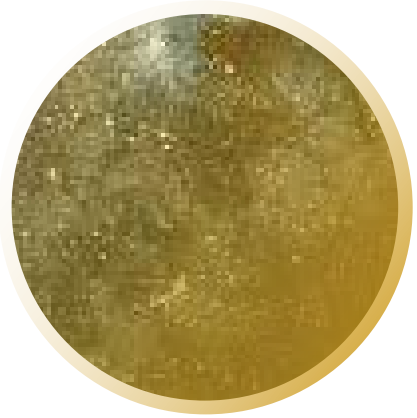
In Journey 2022 "Resolving digital dilemmas[12]", we considered the tensions arising from the opposing forces of the real-world and digital world. We identified a boundary of acceptability as the point at which the answers to the questions of "could we?" and "should we?" move out of sync. This tension is clearly manifested in certain current day responses to the way digital technologies are employed - and not always in the areas we might expect (challenging ethical or safety considerations). Some of the most significant emerging barriers and constraints relate to real-world sovereignty boundaries being applied to the use and accessibility of data.

From one perspective, the virtual nature of data enables borderless interactions, but from another, our human concerns over ownership, privacy and security of data could constrain the way that such interactions deliver new value. The Gaia-X[13] Foundation in the EU is trying to establish principles and standards that allow these different perspectives to operate in a healthy balance.

A significant question remains about whether such initiatives will be sufficient. It will be interesting to observe how these tensions will be worked out - if indeed that is possible. Of course, we must protect the security and rights of individuals, businesses and nations, but is there also an opportunity to rethink the way we operate and collaborate? In so doing, can we establish new approaches that are perhaps less sensitive to some of the more constraining real-world barriers?







12. cfdt-atos.org/wp-content/uploads/2020/09/Atos_Journey2022_web.pdf
13. https://gaia-x.eu/ Atos is a founding member of Gaia-X Foundation.

> Is it possible to break free from some physical world constraints by virtualizing the way we operate?

New virtual paradigms

We have considered four specific areas where we already see virtual dimensions in action, and where we anticipate greater opportunity for compelling and transformational developments in the future.

New modes of operating

Operating in the virtual dimension offers significant benefits in terms of simulating and anticipating outcomes (e.g. digital twins); reflecting a wider context of influencing parameters than those evidenced by the immediate environment (e.g. through IoT data insights and augmented reality); and operating beyond some of the physical world constraints (e.g. through virtual ecosystems and assets). Some of these benefits are reflected back into the physical world through optimized designs rendered by 3D printing; new molecules and chemical processes discovered through HPC or quantum computer simulation; and intelligent automation of physical processes.

The COVID pandemic has forced many organizations to rethink their ways of operating. Almost overnight, significant proportions of the workforce moved to virtual office mode. And it wasn't just businesses. Schools, universities, family gatherings, religious meetings, and medical consultations, all entered the virtual online world. Something that was previously felt to be too hard to achieve, suddenly became a reality. Even as lockdown measures relax, a significant number of engagement measures are remaining virtual, or at least are adopting virtual/physical hybrid models.

Individual experiences of this shift in ways of working have shown significant variation. Some people had been working from home for some time and noticed little change; others discovered a new freedom in flexible working and resisted a return to the old ways; and others still felt disconnected or disengaged and couldn't wait to get back to real-world interactions.

As we enter the third year of the pandemic it is evident that, where used appropriately, there are some clear and lasting benefits to be realized through exploiting new ways of working. Some businesses have achieved considerable cost savings by closing physical offices; new tools have emerged that make remote collaboration and virtual working more productive; virtual and flexible working has become an important vehicle for attracting and retaining talent; and less commuting has reduced costs and carbon emissions.

Much operational cost saving, and efficiency has already been enabled by the offshoring of tasks such as contact centers and procurement administration. **Will the next wave of efficiency be driven by virtual shoring as processes are automated and transacted in a virtual domain?**

By 2025, it's estimated that machines will perform more current tasks than humans[14] and 75% of customer interactions will be handled by automated platforms[15]. A different mindset is needed for organizations to fully appreciate the opportunities that intelligent automated operations open up through principles of frictionless[16] working that are unconstrained by physical barriers.

While many companies ask themselves today what can be automated, they should rather consider what can't be automated and why. Processes should be designed with automation by default, with human interaction only where necessary. But of course, such strategies also need to include the creation of new value adding roles to offset the displacement of lower skilled jobs.

New modes of relating

Although virtual reality (VR) has been around since the 1950s, it was not until the 2010s that commercially available VR technology became more widespread, and AR smart glasses were released. Since then, virtual experiences have evolved at an incredible rate and the pandemic has further fueled imagination of the art of the possible. AR and VR (and now AI) are being combined to create new waves of personalized virtual experiences. Such experiences range from mere escapist entertainment through to virtual expert interactions for highly contextualized business use cases.

Digital avatars already offer the potential for interacting with very lifelike on-screen personalities that are capable of dynamic human like facial expressions and speech. In most current practical use cases, applications tend to be limited to areas such as helpdesks, sales assistants, and healthcare coaches, but as the technology becomes more mainstream, further use cases will emerge such as virtual personal assistants, care givers or just a virtual friend to talk to. Initially these interactions will start like a Siri, Google Assistant or Alexa experience coming alive visually, but soon they can be expected to return full circle to the physical world in the form of fully-fledged robotic entities. Such solutions are already being hailed as a potential answer to the growing social care challenge faced by society[17].

Let's return to the StoryFile concept of creating virtual interactive representations of real individuals. Training AI models with someone's memories, behavior, knowledge, and character traits, will allow others to virtually interact with that individual, almost as if they were doing so for real. The popular music industry has already embraced such concepts with "From beyond" sets performed by holograms of deceased stars like Michael Jackson, Whitney Houston, and Elvis Presley. Virtual events even include holograms of living artists (e.g. ABBA) looking and performing as they did in their heyday. But such technology has so much more potential than replicating historical experiences and learnt behaviors. **AI models will allow the extrapolation and anticipation of responses to situations that were never experienced by the subject**. Could this lead to a situation where virtual facsimiles of trusted historical leaders offer perspectives and advice on present day matters? This would obviously raise questions around ethical and meaningful usage boundaries.

14. weforum.org/reports/the-future-of-jobs-report-2020
15. servion.com/blog/what-emerging-technologies-future-customer-experience/
16. atos.net/preparing-for-the-rebound-after-covid
17. newstatesman.com/spotlight/2021/03/automated-assistance-how-robots-are-changing-social-care

The emergence and maturing of brain computer interfaces (BCI), will further push the practical and ethical boundaries between the physical and virtual dimensions. VR experiences will extend beyond the basic transmission of vision and sound, to solutions that are capable of bidirectional sensory interaction, adjusting to your moods and triggering a wide range of brain responses. Organizations like DARPA, Meta, and the European Commission[18] are investing heavily in the development of BCI technology, and we anticipate significant advances in this area of the virtual dimension. There is expected to be particular focus on the benefits for people with disabilities, and on mental wellbeing.

Virtual experiences will take on a new dimension where no two experiences are alike, they will be customized and hyper personalized in real-time based on an understanding of an individual's persona, and signals from their body. As every product and services company fights to differentiate itself, imagine the marketing potential of products like holidays, retail and entertainment being enhanced by customized virtual interactions. Indeed, **it may eventually be possible to fully virtualize certain experiences by implanting memories and artificially triggering the release of the brain's natural endorphins, something that was achieved in mice nearly a decade ago**[19]. To some, this may be seen as a depressing form of synthetic living; for others it may be an opportunity to experience things that would otherwise not have been possible.

18. humanbrainproject.eu/en/about/human-brain-project-ec-grants/
19. xtremetech.com/extreme/162364-mit-successfully-implants-false-memories-may-teach-us-how-human-brains-form-false-memories

New modes of value and business

Gross domestic product has been a long-established measure of a country's size and health (both economic and physical). But such **traditional measures of value begin to break down for goods and services that have zero market price**. For example, how can the value of services like social media or query engines be appropriately assessed?

With the sales of non-fungible tokens[20] exceeding $10 billion in the third quarter of 2021 (a 500% increase in just 6 months) and the number of cryptocurrency variants reaching nearly 6,000, there are signs of change in the way that value is perceived. Regardless of whether such trends prove to be temporary phenomena, physical assets are clearly not the only measure of ownership and wealth - this is evident when we look at the economy of data (the evolution of which the Atos Scientific Community has tracked for nearly 10 years). Businesses are, for the most part, just beginning to understand the strategic value of the data they hold, and government and industry led initiatives like the EU's Gaia-X[21] are wrestling with how this potential value can be fairly unlocked and shared (and at the same time, protected). An interesting point to note is that most of these initiatives are still tending to look at the problem through the lens of data sovereignty within physical borders; **we perhaps need to consider how we can adopt more virtual world thinking in devising meaningful and sustainable solutions to the challenge of data equity**[22] and economic value.

If we want to create a fair and sustainable data economy, then data assets should be managed and traded in a way that incorporates equitable and trustworthy principles and practices throughout the usage life cycle. This is a nontrivial challenge since we are already faced with growing issues of privacy, fraud, anticompetitive behavior, and consumer/citizen manipulation. Extreme protectionist responses to such issues risk the formation of marginalized communities that are unable to benefit from the potential value of data value sharing. Conversely a lack of data equity controls will result in monopolistic behaviors and biased outcomes from those who are able to control data driven services, making it challenging for new players to enter markets and bring more of an equitable balance.

Data marketplaces that create ecosystems for businesses and their upstream and downstream partners, can help foster supply chains that are adaptive, interconnected, flexible, and collaborative. They enable organizations to trade data, not just physical assets. This supports the concept of tokenization, where sensitive data assets can be digitally represented and exchanged in a way that ensures their full meaning can only be fully attributed by those with the requisite permissions. In B2C and B2B interactions, the sharing and exchanging of data can be supported by the concept of an "attention token". The value of an attention token is incremented each time its associated data is exchanged, giving a relative measure of the data's tradable value.

Software driven smart contracts can be used to formalize commercial agreements and guarantee their execution in the virtual world (and hence any linked physical world actions). They are written in a way that helps drive autonomous business processes (across supply chains), while at the same time reinforcing security, trust, and transparency with the virtual partner ecosystem.

New modes of being

The prospect of establishing new virtual expressions of our human existence is exciting for some people and concerning or even abhorrent to others, particularly when they seem to offer a form of immortality. **Wherever the technical possibilities and ethical debates lead us, the journey of improvement and self-expression through the use of digital technologies is already well underway**. From virtual learning to virtual incarnations of personalities (living, dead and fabricated) and even the use of technology to directly augment our mental acuity and physical capacity, the domain of **digital being** is rapidly advancing. The quality of text generated by GPT-3[23] (the third generation of the AI Generative Pre-trained Transformer model) is so high that it is hard to distinguish it from that produced by humans. And GPT-4 is expected to have 500 times the capacity of GPT-3!

Access to the wealth of human knowledge and experience is available through ubiquitous, pervasive and ambient computing. The impact that virtual learning and development has had is already significant. Online training courses are easily accessible on virtually any topic from how to assemble flat pack furniture to how to program a quantum computer. With gaming technology and computer-generated imagery (CGI) having advanced to a level where it is sometime difficult to differentiate the artificial from reality, VR technology applications in business and education are expected to see a significant rise in adoption.

True learning is, of course, far more than just theoretical knowledge; it is also about experience and application. Augmented reality with haptic feedback mechanisms and even the triggering of emotions through brain computer interfaces, could take virtual learning to a new level with training programs covering situations that would be almost impossible in real-world settings. For example, dealing with nuclear power plant incidents, or driving tests that can evaluate responses to genuinely dangerous situations. What's more, neural implants already seem to be capable of implanting virtual memories of smells in mice and can be used to enhance short-term memories of actual experience. In some ways, the **virtual is becoming indistinguishable from the real**.

The virtual dimension can also act as a means of gathering and preserving the acquired knowledge and wisdom of subject matter experts. Many businesses wrestle with the challenge of losing years of acquired expertise when employees retire; if that knowledge could be cloned through virtual avatars that are available for future consultation, the need for training in niche specialisms that are only occasional called upon, could be reduced.

But there is also the negative side of such technology being used inappropriately: AI bots are capable of impersonating real people in online exams and deep fakes of politicians and celebrities influencing the thinking and behavior of sections of the populace. The virtual dimension may influence our physical lives in more significant and potentially dangerous ways than we currently anticipate. The fact that someone can implant fake memories, or create a form of pseudo-immortality, raises important ethical concerns.

20. A non-fungible token (NFT) is a unit of data stored on a digital ledger (blockchain) that certifies a digital asset to be unique and therefore not interchangeable.
21. gaia-x.eu/
22. A concept reflecting "shared interest" and "fairness" in data exchanges, first mentioned in atos.net/preparing-for-the-rebound-after-covid
23. openai.com/blog/gpt-3-apps/

> Operating in virtual dimensions brings consequences and externalities to be addressed in both the physical and virtual realms.

Crossing the divide

The astronaut Thomas Pesquet spent nearly two hundred days orbiting earth in the International Space Station. Having experienced this lofty and somewhat distant perspective, he commented: "From up there I could see the impact that we are having on the planet". As we stretch the boundaries and move into new virtual paradigms, we need to be mindful of the knock-on effects of each domain on the other.

Technologies may not overtly threaten our beliefs, wellbeing, or ways of living, yet their applications can have unforeseen harmful effects or be used for malicious purposes. Typically, new technologies must undergo the litmus test of societal acceptance before advancing to mainstream adoption in society; although as we have seen with cryptocurrencies and AI for instance, adoption in a limited form does not always imply wider acceptance. As formal regulatory controls typically lag behind fast-moving technology developments, ethical standards for how such developments are applied will initially be shaped by individual business purposes and values. At a basic level, we would consider the following as foundational principles for sustainable digital technologies:

- Align with generally accepted current and localized societal beliefs and values.
- Provide net benefit to the task of sustaining our planet and its natural resources.
- Engender fundamental trust between individuals and within collectives, avoiding threats to our wellbeing, privacy, and way of living.

These principles and broader feedback mechanisms are aligned to the torus in our model, the zone marking the transition from physical to virtual. We will see that the diversity of opinions (locally and globally), may obstruct generalized solutions for these principles. We see this playing out all the time in the discourse of societal conversation: whether through headlines in the news, impassioned beliefs shared and debated on social media, or discussions with family and friends, we form our opinions, individually and collectively. The mechanism for societal feedback can be quick and final, or slow and much debated. But inevitably laws and standards will be applied and governed by regulators and agencies to set the boundaries for the application of digital technologies. How this will work in the virtual dimension remains to be seen, but **it is expected that upcoming developments will stretch the guidelines of conventional wisdom more than ever**.

Landing the vision

The summary findings from our research tracks are presented from page 24 to 61 of this document. We have positioned all topics within one of the 3 zones in the torus model to help explain how they align with the overarching vision of this paper "Unlocking virtual dimensions".

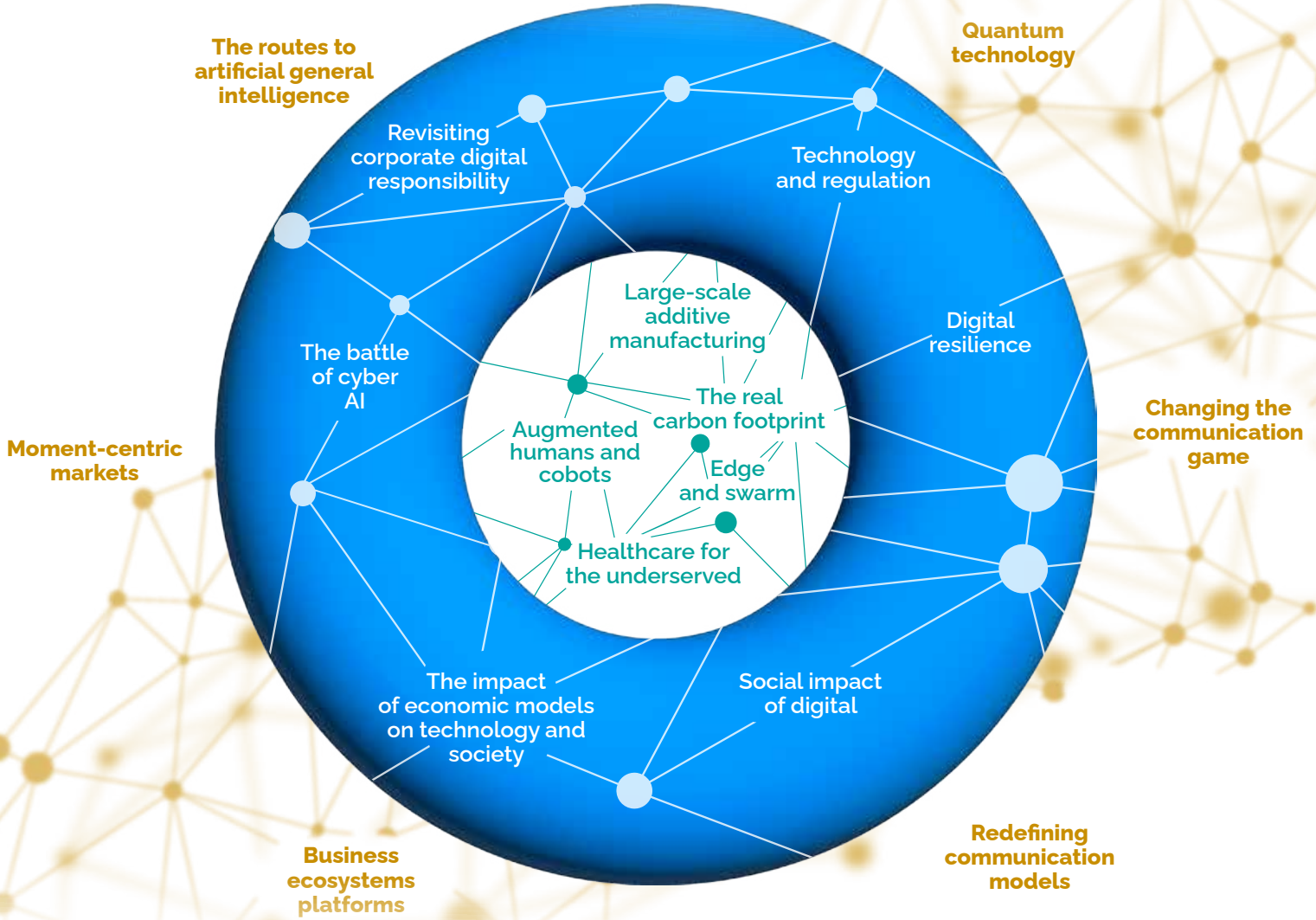


Figure 2: Alignment of Journey research tracks with physical and virtual dimensions

A number of our research topics have been placed within the center of the torus. They are firmly grounded in the realms of the physical and yet their directions of development are taking them into areas that are pushing the boundaries of physical possibilities:

- Augmenting our human capabilities, physically and mentally;
- Rethinking the ways that we manage the end-to-end lifecycle of physical goods and assets;
- Managing the rapidly growing connection of the physical and virtual dimensions through intelligent edge technologies;
- Collectively responding to our ongoing and growing responsibilities to look after each other and the environment.

How we respond to these will determine our ability to exploit virtual dimension thinking to address physical world challenges. Will we be held back by conventional thinking constraints, or will we be able to imagine different ways of working out our goals and purpose in life?

Perhaps unsurprisingly, a significant number of the topics align with the area that marks the transition between conventional physical operations and the virtual dimension. Governments and individuals alike are wrestling with the challenges associated with operating in the virtual dimension. Examples of these challenges are illustrated in figure 2.

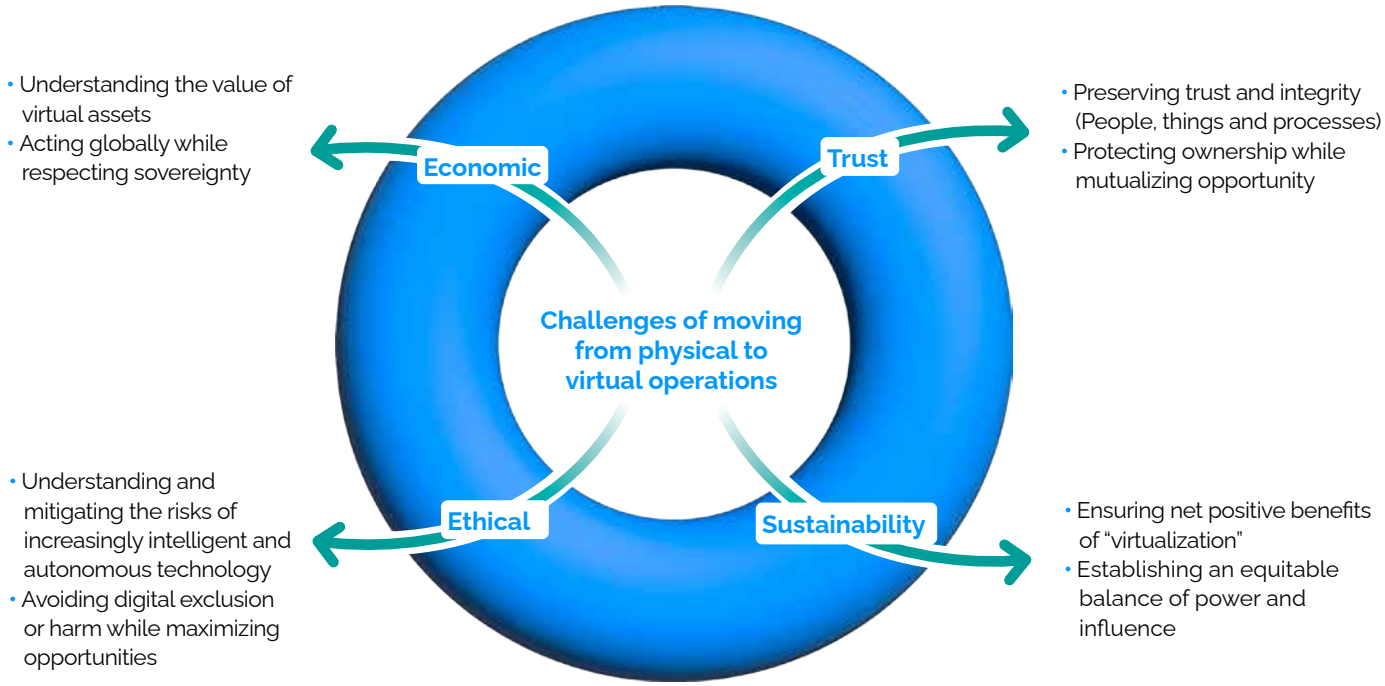


Figure 3: Examples of challenges with crossing the divide

For the topics that we have chosen to align with the virtual dimension, it is evident that they do not operate entirely in the virtual realm. At some point, there will always be physical world touchpoints and true value can only be realized by bridging the divide between counterparts in the physical and virtual. However, if we pursue the opportunities appropriately, they could take us to a different level in terms of our exploitation of technology:

- Enabling compute power;
- Understanding and realizing data value;
- Removing barriers to the way we communicate, collaborate, and interrelate;
- Moving toward the aspiration of true artificial general intelligence.

While exploring some of the possibilities and implications of operating in the emerging virtual dimension, we discovered some interesting parallels between the drivers of virtualization (in the broadest sense) and Maslow's hierarchy of needs[24] from his theory of human motivation. In the virtual realm, we see **new modes of operating** aligned with foundational physiological and safety needs; **new modes of relating** shaping our belonging and love needs; **new types of value and business** feeding our individual and collective esteem needs; and finally, **new modes of being** becoming a means of self-actualization.

In the virtual realm, we see these dimensions of need realization being a reinforcing continuum rather than a hierarchy. As the virtual art of the possible extends, new modes of thinking and being continually emerge and drive the need for fresh and increasingly robust thinking about physiological and safety needs. We already observe this manifested in the rise of cyber-bullying, digital identity fraud, and stress.

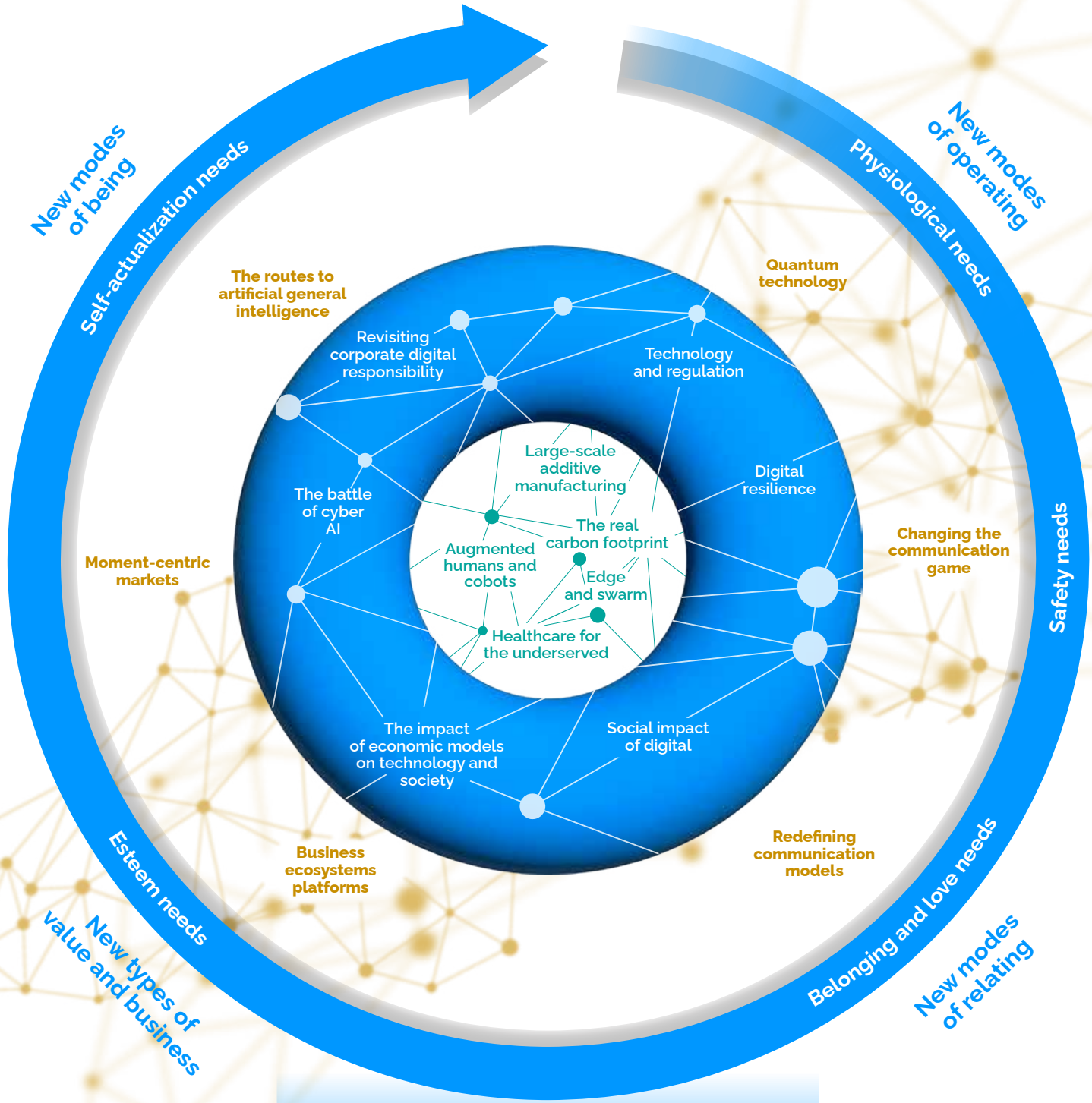
This leads to a highly significant conclusion that, despite what might be perceived in terms of the limitless boundaries of the virtual dimension, we cannot separate it completely from the standards and values that we hold to in the physical realm.

There is still a need for:

- getting the basics right,
- ensuring safety (and hence trust),
- establishing meaningful interactions and relationships, working toward a purpose that underpins our individual and collective self-actualization.

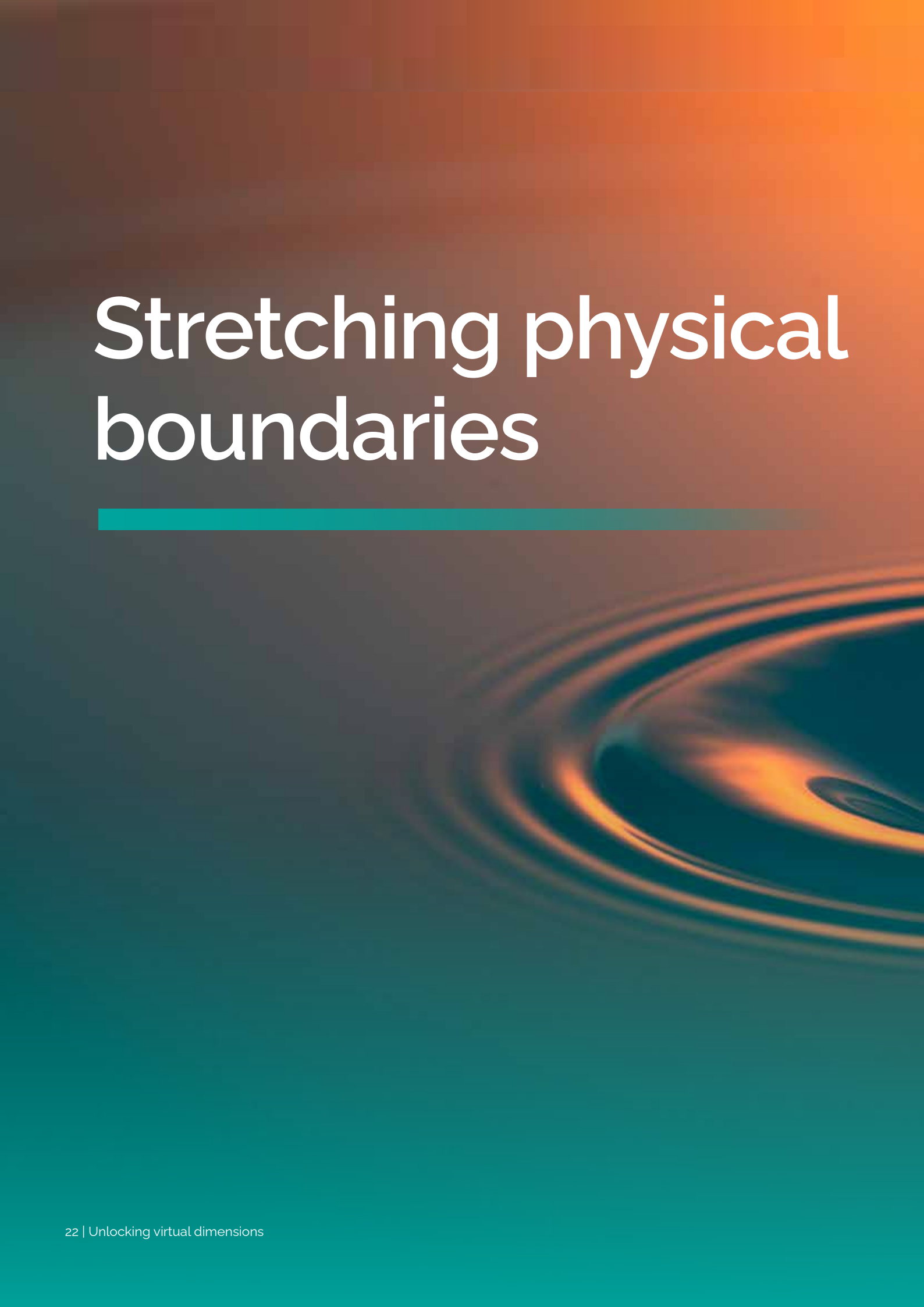
24. masterclass.com/articles/a-guide-to-the-5-levels-of-maslows-hierarchy-of-needs#what-are-the-5-levels-of-maslows-hierarchy-of-needs

Figure 4: New modes of interaction in the virtual realm.



The following sections in this document will take you through some high-level insights into a range of technology, business, and societal trends. Each one explores the related opportunities, challenges, and disruptions that we can expect as we journey toward 2026.

Stretching physical boundaries



How are industry and society pushing the boundaries of physical world operation?

Augmented humans and cobots

Ever since the development of the first basic tool, humans have been seeking to extend their natural capabilities. Human augmentation continues to drive the progress of life and businesses in the physical, and now the digital world. There are four current main areas of human augmentation (see figure 5), that collectively help to supplement, enhance, restore, replicate, and stimulate our natural capabilities and senses. Each of them has its specific but interconnected innovation roadmap and timeline.

Prosthetics and bionics

Advances in materials, design, and technology have evolved prosthetics from replacement of physical body parts into more sophisticated and intelligent bionics. Bionics provide muscular and neural interfaces, picking up biological (nerve or muscle) signals and mechanically or electronically converting them into machine movements. This includes the operation of exoskeletons for physically challenging jobs such as carrying heavy loads or working in extreme conditions in a variety of civil and military use cases.

While a large part of bionics development focuses on limbs, it is now progressing to other body functions, including orthopaedics, auditory, heart, and vision. In the next five years, bionics is likely to make further advances into supporting the functions of more vital organs (like liver, kidney, lungs), even replacing not just augmenting them.

Brain computer interfaces

Brain computer interfaces (BCI) capture and stimulate neuron signals, interpreting and driving responses as required. They lend themselves to the next stage of advancement in bionic devices. BCI enabled actions are driven directly by brain activity and not by indirect signals such as muscle movement and can help create critical feedback loops to refine bionic operations based on visual feedback and/or motor output. The human brain is the central control and decision system of our body but there are increasingly practical opportunities for interconnection with external devices - BCI and bionics can converge to create more capable and responsive augmentation solutions. Beyond various medical applications, BCI may extend into areas like security, education, entertainment, marketing, and interaction with smart environments.

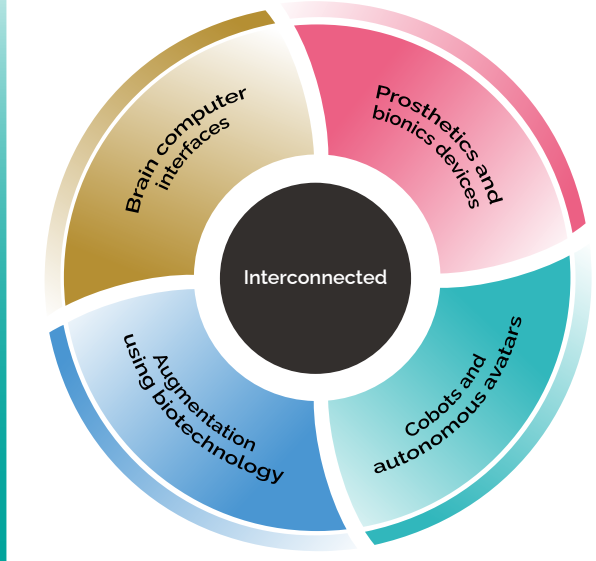
Cobots and autonomous avatars

Chatbots and digital sales assistants have already taken over certain routine tasks, helping humans to get their work done with more efficiency and consistency. We expect growing levels of sophistication in their interactions, with bots teaming up and interacting with each other when working on behalf of their humans. Bots and cobots may even analyze the behavior of human individuals and teams, detecting and alerting (mis) behavior, and offering hints and/or strategies to resolve or avoid such situations. Advanced, autonomous bots will execute predefined work tasks, behaving appropriately for a given context, respecting all human interactions, and collaborating with, or even supervising, other autonomous machines.

Augmentation using biotechnology

Biotechnology is another domain of application and research that contributes to human augmentation. Its landscape of opportunities includes mimicking nature to create efficient and biocompatible materials; reconstructing tissue, nerves and organs; and the use of genetic technologies to cure or protect against diseases (as recently demonstrated by the mRNA COVID-19 vaccine). Biotechnologies open the world of device miniaturization and cellular level interactions, connecting the domains of biology, mechanics and digital.

Figure 5: Interconnected areas of human augmentation



Key areas of human augmentation and how they build on each other

There is already a range of practical use cases for **prosthetics and bionic devices and autonomous avatars and cobots** - these will continue to grow and develop across diverse industry sectors. The incorporation of capabilities enabled by **augmentation using biotechnology, brain computer interfaces, neurotechnology** will further extend the boundaries of possibility but will also necessitate deep research into areas of ethics and human rights. Although the various domains of human augmentation have different time horizons, they are strongly interconnected and influence each other. For example, biotechnologies will help to create more sustainable and compact bionics capable of responding to brain signals, and even powering digital components.

With progress comes responsibility

Human augmentation bridges the gap between the natural capabilities and limits of our human bodies, and the always-on, scalable capabilities of digital and physical technologies. It helps to address the growing divide of a digital world that is driving humans to do more and more, by opening a new continuum of hybrid solutions. The question remains as to whether we do this responsibly through better life and work conditions, or if we end up subjugating one another.

Some grounding principles are required, such as:

- Awareness: knowing if interactions and experiences are real, virtual, or augmented.
- Choice: personal control over digital identities and degrees of augmentation.
- Compliance: internationally approved guiding principles that lay down a single view of what is acceptable/not acceptable or permitted/not permitted.
- Accessibility: new capabilities should be widely accessible, fostering collaboration and inclusion.
- Exclusion: human augmentation technology should not exclude or discriminate.

The role of human augmentation is likely to become prominent in our daily lives. Existing use cases and innovations present huge opportunities - businesses should explore how they can adopt and benefit from them.

As human augmentation technologies mature, attention and focus will shift quickly from technical to ethical questions. Our responsibility needs to grow at the same pace as our technical sophistication.

Edge and swarm

Edge computing has become the underlying fabric of the computing continuum - an all-pervading means of connecting, sensing, inferring and acting. It connects high-speed networks, multi-cloud services, data sources and data consumers - revealing opportunities for almost limitless new value propositions. The flexibility, functionality and reach of edge solutions is already transforming end user experience and industry solution capabilities; and the progressive convergence of cloud, network and edge (with resulting competitive overlap between cloud hyperscaler and telecom service providers) will further accelerate innovation and investment.

Routes to scaling edge solutions

However, the journey of exponential growth is increasingly constrained by the challenges of constant evolution of heterogeneous hardware and software stacks. So much so that we are facing an inflection point where further coherent expansion at the edge will be unsustainable without significant hardware and software innovation. These innovations need to address issues of lifetime operational support, security, data privacy and energy efficiency, as well as facilitate the move to dynamic edge ecosystems. We expect to see major developments as follows:

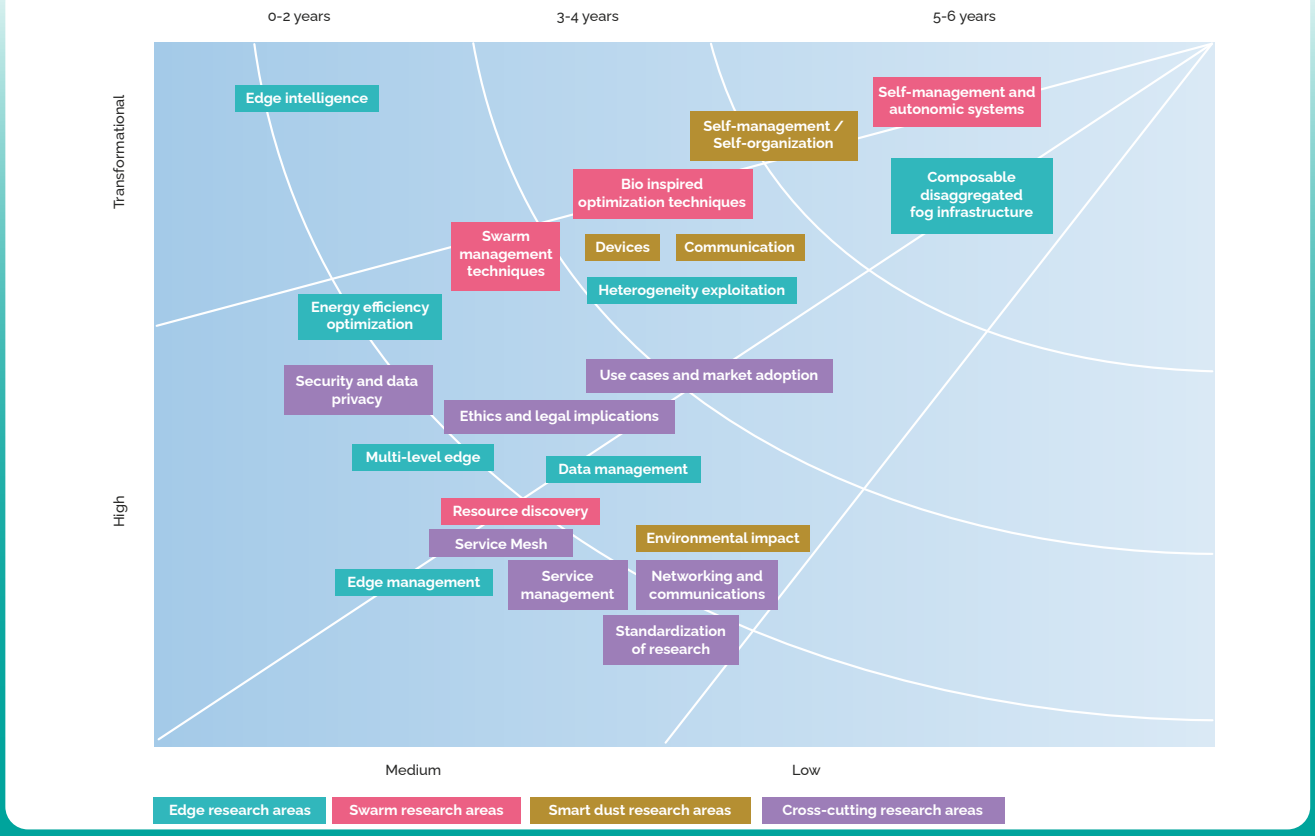
Security/identity

The edge security stack needs to support the identification and authentication of each physical device (ideally with hardware security modules), and support the end-to-end encryption of data transmission. Distributed ledger technologies will play a key role in the authentication and traceability of exchanges between devices. From an operations perspective, edge cloud solution providers will need to cooperate on threat identification and support distributed security operations centers.

Connectivity

A significant part of the value of edge solutions is linked to their geographical spread and reach. Good and ubiquitous connectivity is essential, but many edge deployments will be in remote locations, for example those that are monitoring and controlling utility networks. While the growth of public and private 5G networks will cover high density edge demands, we can expect emerging swarm satellite technology to fill in many of the gaps.

Figure 6: Impact of emerging edge and swarm research and development



Sustainability

One of the potential blockers to extreme scale edge deployments is their sustainability - in terms of raw material requirements for device production, the perceived disposable nature of some edge devices (particular as we head toward nanoscale), and the energy required to power networks and devices. We can expect smarter edge meshes that are able to optimize their collective operation, adapting their functionality according to workloads. Particularly at edge nodes, this will help minimize the requirements for deployed infrastructure. Edge meshes will operate similar to more conventional clouds where resources are activated and deactivated as required.

Operability and maintainability

As edge solutions become more dynamic and interoperable they will need to employ virtualization and abstraction tools - essentially micro containers. Lightweight, low ops solutions like Microk8s will help bring portability, deployability, upgradability and self-healing features to edge meshes.
Purpose-built programming languages and development kits will explicitly support and expose functional and non-functional properties covering areas such as privacy levels, quality of service, latency, and power consumption.
Smart orchestrator frameworks and algorithms will support composability and interoperability of device swarms.

Emerging trends

As the development areas mentioned previously come to maturity, we will see a number of emerging trends:

Swarm intelligence - The mesh of edge devices will become swarm intelligence, exhibiting the collective behavior of decentralized, self-organizing systems. Swarm intelligence will help shift the static IoT system architectures of device / edge / cloud applications to be more dynamic, and to more intelligently harness and manage the data generated by the rapidly growing edge use cases as they become live.

The autonomous interaction of multiple remote robots will help solve complex challenges that are not thought possible today. Swarm, or federated learning will use networks of localized agents that perform AI training at the edge, eliminating the need for central control. Restricted exposure of data will mean more secure applications and fewer privacy concerns.

Edge hardware and software will evolve toward smart hardware/ operating systems, which have characteristics of plug and play, self-configuration, self-management, and self-matchmaking. Advances in hardware like neuromorphic chips, that emulate the way human brains work, will make the edge devices even smarter. Artificial neurons and synapses packed into silicon will allow more efficient forms of neural networks to be executed with lower latency and power consumption. Such characteristics are ideal for edge AI scenarios.
Development of ultra-wideband sensors will bring solutions for precision detection and image sensing.

Smart dust represents a breakthrough that uses nanotechnology to take edge to new horizons. Already we are seeing the production of cameras with the size of a grain of salt, and functional molecules that are able to detect and neutralize cancer cells or viruses inside the human body.
Nanoscale energy harvesters will generate power from small movements and vibrations in their surroundings, opening up a whole new range of possibilities for micro-electromechanical systems (MEMS). We can expect the focus of early developments to be in the areas of space exploration, pest control in agriculture, weather forecasts, and equipment maintenance.
Despite all the exciting possibilities, we must not forget that the ecological and ethical impact of massive distribution of smart dust devices will have to be carefully monitored and governed.

Looking toward 2026

Edge technologies will grow in reach, functionality and intelligence. Collaborative swarms of connected edge devices ranging from autonomous vehicle platoons to smart cities, and even in-body hospitals will bring a new dimension of automation, insight and life enhancement. But as the edge becomes increasingly pervasive, the potential attack surface expands - security, privacy, resiliency and lifecycle management must be at the heart of future edge fabric architectures.

Large-scale additive manufacturing

Bridging the digital and physical worlds

Similar to the virtualization revolution in digital infrastructure provision, the digitalization of manufacturing faces a new wave of disruption from additive manufacturing.

Over the last forty years, additive manufacturing (AM) has been widely perceived as a niche technology used by hobbyists or in prototyping. However, advances in underlying process and material technology have led to a quiet revolution in areas as diverse as aerospace, healthcare, real estate, and fashion. Extrapolation of the potential that is already being realized suggests a future of large-scale additive manufacturing (LSAM) adoption.
Large-scale can be understood as large in physical size; large in volume (mass production); or large in reach (moving production to the edge).

From digital to physical

Additive manufacturing involves the successive layering of material along a 3-dimensional path defined by a digital representation of the object being created. Plastics, metals, concrete, resins and even living cells can be deposited by a robotic print head to form structures of any complexity. For further insights please refer to our whitepaper "3D printing[25]".

The drivers of change

Scale	Drivers of change	Example use cases
Large size	Design complexity; in-situ construction efficiency	Complex buildings; rocket casings; submarines, affordable housing
Large reach	Logistics optimization; customization; supply chain resilience	Spare parts; personalized consumer goods; medical applications; print on-demand
Large volume	Mass customization; material waste reduction	Large batches of customized dental implants; vehicle components, personalized medicine

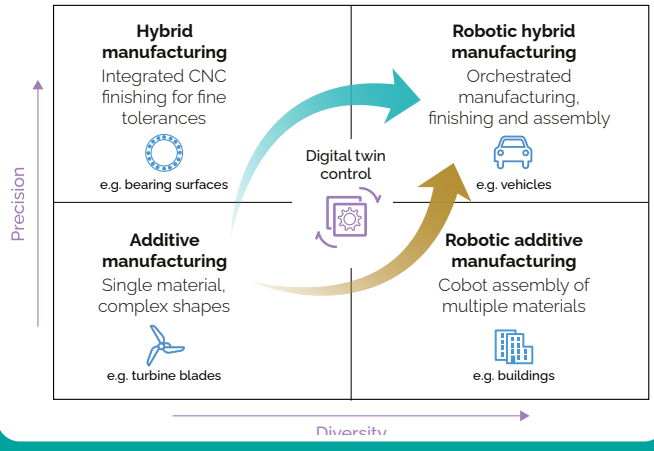
Implemented correctly, the focus on reduced waste, nearshore and even local manufacturing can bring environmental benefits, although these must be balanced against the energy requirements of raw material production / distribution and the AM process itself.

The routes to large-scale AM

We anticipate the emergence of **robotic hybrid manufacturing** that exploits the collective capabilities of additive manufacturing, subtractive manufacturing[26], and the flexibility of robotics to form and assemble complex and composite structures of all shapes and sizes. Digital twin technologies will play a key role in simulating, controlling, and assuring the lifecycle from digital design to physical product.

The evolution of precision and diversity in LSAM is shown in Figure 7.

Figure 7: The routes to large-scale additive manufacturing



25. https://atos.net/wp-content/uploads/2022/03/3d-printing-whitepaper.pdf
26. Where an object is shaped by removing material from a larger mass of material

Hybrid manufacturing: advances in AM technology and material science will drive improvements in quality of finish and dimensional accuracy. Nevertheless, it will be very difficult to deliver the precision required for things like bearing or sealing surfaces. In the short to medium term, at least, high tolerance finishes will require subtractive techniques like CNC[27] turning and grinding to be incorporated into the manufacturing process.

Robotic additive manufacturing: emerging AM techniques will progressively allow the combination of materials with very different properties, like metals and plastics. Complexity will be further enabled through orchestrated cobots executing additional production and assembly steps. For example, when 3D printing a building, concrete extruder head movements will be coordinated with robots that place windows, doors, and pipework.

Challenges and opportunities

Realizing the vision of LSAM will come through a range of technology and process developments:

Multi-tools	In-process printhead changes will combine different manufacturing methods. Fused deposition modelling heads will create base material forms, milling heads will refine critical surfaces, and paint heads will add surface treatments.
Multi-materials	Multiple printing heads will combine different materials, and fusing / feeding methods. 4D printing will produce objects that respond to external stimuli - e.g. adaptive medical implants.
Assembled structures	Robotic placement of standard parts like fasteners, shafts and complex electronic components will create complex assemblies.
Intelligent data gathering	AM quality assurance will require the automated collection and analysis of process data. Integrated predictive error screening and quality certification processes are essential for safety critical applications.
Quality and service assurance	Material voids and delamination will be avoided using in-process dimensional tolerance checking, video analytics, and auto print path adjustment. Purpose-built digital platforms will manage end-to-end process assurance.
Intellectual property	Techniques like threshold encryption of print commands, license tokenization, and embedded physical identifiers[28] will be used to ensure that products are only printed by authorized parties.
Security and safety	Digital security protects the integrity of end-to-end data paths. Physical security enabled by real-time video analytics, ensures the safety of those working near AM devices.
Standards	Orchestration standards for cross process and equipment domains are lacking and should be established to support the evolution of LSAM process.

A catalyst for change

We are reaching an inflection point where demands for product individualization, globalization, cost, speed etc. are hitting the limits of innovation and optimization in the manufacturing industry. LSAM can act as a catalyst for a next wave of change, particularly when combined with generative design[29] principles, and the complementary digital technology of digital twins. We can expect seamlessly integrated design, simulation, and production tools, capable of making context optimized products with complex geometries and innovative composite materials.

Manufacturing as code (MANaC)

Everything as a code is an approach to digital systems provisioning where deployment instructions are codified and automated for agility and efficiency. Similar principles can be adopted in the end-to-end control and orchestration of robotic hybrid manufacturing.

27. Computer numerical controlled.
28. For example, serial numbers or passive RFID tags rendered as integral parts of the physical object, with authenticity being validated against blockchain license ledgers.
29. Generative design uses software to conceptualize and iteratively optimize product design.

Healthcare for the underserved

The investments being made in digital health are setting foundations that will positively impact care equity, patient outcomes, and healthcare efficiencies. The technology interplay between patient, community, and provider will further improve responses to disease and illness.

According to the World Health Organization (WHO), "Equity is the absence of unfair, avoidable or remediable differences among groups of people, whether those groups are defined socially, economically, demographically, or geographically or by other dimensions of inequality (e.g. sex, gender, ethnicity, disability, or sexual orientation). Health is a fundamental human right. Health equity is achieved when everyone can attain their full potential for health and well-being[30]."

The COVID-19 pandemic has shown that we are far from this ideal. Disadvantaged population groups have been disproportionately affected[31] through an amplification of factors related to poor living environments and lack of access to quality public healthcare creating susceptible hosts and hot spots. The Digital Inverse Care Law states that people who are most in need of support (in particular, older people and those experiencing social deprivation) are often least likely to engage with digital platforms[32] - and yet health and wellness platforms have the potential to significantly unlock care services for those who arguably need them the most.

In addition, the European Parliament has estimated that losses linked to health inequity cost around 1.4% of GDP within the EU; this is close to the EU's total spending on defense, which is 1.6% of GDP[33]. There is a clear humanitarian and economic imperative to rebalance the situation.

Root causes of health inequity

The origins of health inequity can be attributed to two critical dimensions:

- Unequal resource allocation,
- Unequal social, economic, or environmental conditions, leading to greater overall disease susceptibility.

People with access to regular good quality care, especially primary care, are more likely to be diagnosed for chronic ailments earlier, resulting in better health outcomes and lower overall cost of care in the community.

Digital - A key enabler in addressing health disparities

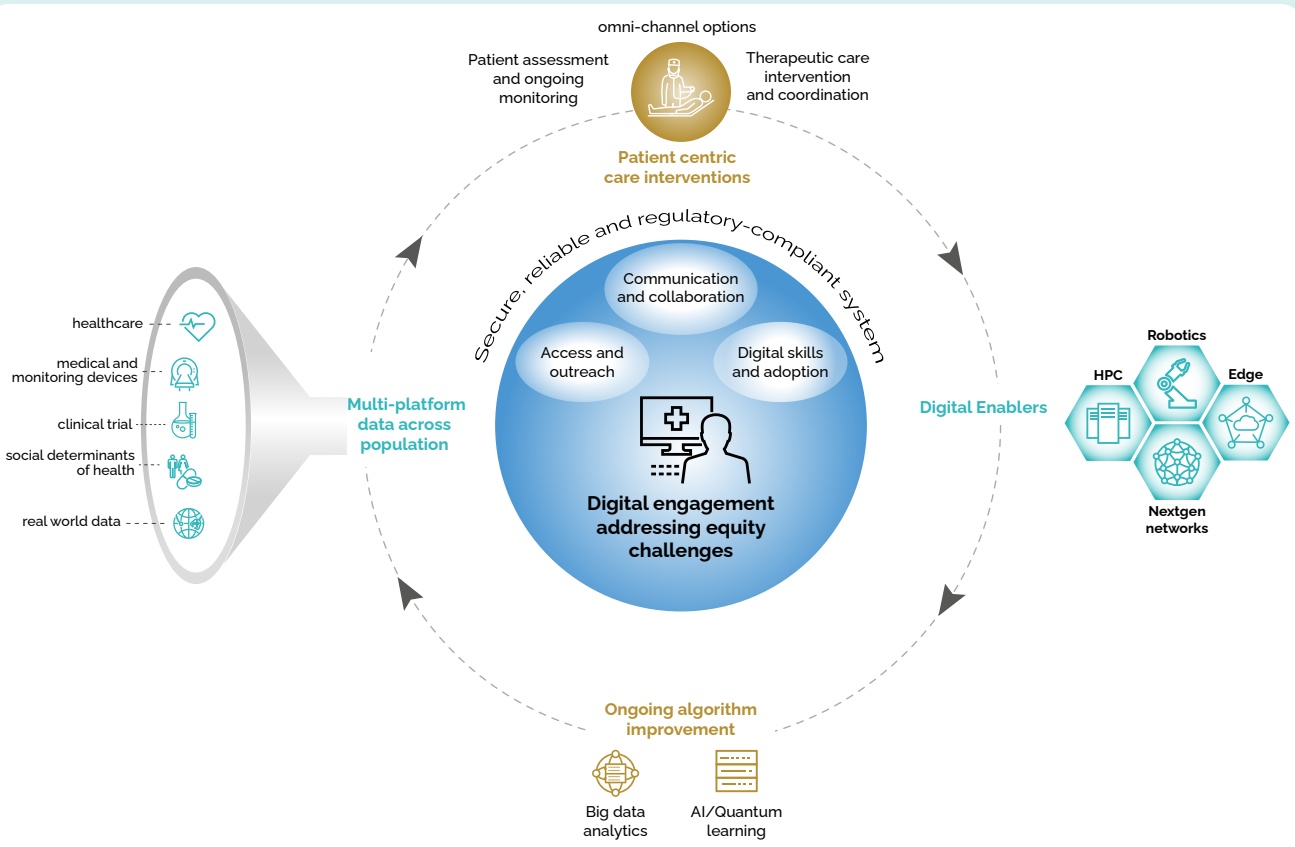
There is an increasingly critical role played by technology in facilitating health equity, especially as social determinants of health like employment, housing, and benefits move increasingly online. While the pandemic highlighted the role of the internet and digital technology in enabling us to live our daily lives, working and learning from home through the unprecedented lockdowns, it also shone a bright light on their roles in healthcare. Digital technologies have become key enablers in addressing care access through virtual care in ambulatory settings, information access through patient portals, omni channel patient centered care coordination, clinical research and transformation opportunities across the healthcare ecosystem.

30. who.int/health-topics/health-equity
31. Ali S, Asaria M, Stranges S. COVID-19 and inequality: are we all in this together? Can J Public Health. 2020;111(3):415-416. doi:10.17269/s41997-020-00351-0
32. https://www.who.int/news-room/facts-in-pictures/detail/health-inequities-and-their-causes
33. Davies AR, Honeyman M, Gann B. Addressing the Digital Inverse Care Law in the Time of COVID-19: Potential for Digital Technology to Exacerbate or Mitigate Health Inequalities. J Med Internet Res. 2021;23(4):e21726. Published 2021 Apr 7. doi:10.2196/21726 (nih.gov)

By 2026 there will be a much greater focus on building bridges or secure and regulated channels between discrete and distributed health data silos. Trusted and regulated data federation will unleash the potential of distributed data sources for connected and empowered ecosystems that include payers, providers, life science businesses and public health organizations. The supporting platforms will be fed (at scale) from numerous data sources and related pipelines. With remote patient access and monitoring capabilities, it is now possible to offer extended healthcare to the underserved communities, giving them the additional opportunity, if they wish, to participate in previously unavailable clinical trials. In turn, this provides an even richer set of social, medical, and genomic data.

Engaging people and communities through digital interventions enabled by data ecosystems will pave the journey to **precision medicine**: the right drug or treatment intervention to the right person at the right time. Ultimately, the combination of platform services capable of simulating the different processes in the human body could lead to the dream of creating a virtual digital twin of every individual. This would further enhance the opportunities arising from artificial intelligence, high performance computers and even quantum algorithms to analyze and predict outcomes, and hence achieve more effective interventions - including prevention.

Figure 8: Multi-platform data federation for healthcare equity



It is crucial to understand the underlying (and sometimes dynamic) factors contributing to digital inequalities in order to avoid their exacerbation. For example, addressing health inequities through proactive digital inclusion requires a conscious process to address user experience in accordance with individual digital literacy, maturity, availability, and affordability. Digital inclusion applies not only to the populations being served, but also to the providers and community caregivers, by connecting them to specialists and services not previously available.

In conclusion, facilitating digital access, infrastructure and connectivity will go a long way in addressing health disparities. Enabling communities and individuals to leverage technology to improve their knowledge of and response to disease and illness, will encourage healthy decisions based on environmental context and the resources available. The notable and growing investments that the market is currently making in digital health are setting the foundations for positively impacting care equity, patient outcomes and healthcare efficiencies for future generations.

The real carbon footprint

Decarbonization initiatives need to be looked at holistically rather than through single frames of reference. Substantial changes are required to the way in which innovations are made to work together for collective benefit in the war of decarbonization.

Raising the stakes

The impact of CO2 is no longer considered an externality[34] as it was during the first industrial revolution. It is now a fundamental part of our health and wellbeing responsibilities. Science and technology can bring significant contributions to **prevention, cure, and remediation** in the context of the environment, just as they continue to do for our human bodies.

Following the November 2021 COP26 conference in Glasgow, there is renewed urgency to limit the impact that humanity has on planet Earth. Revised targets, initiatives, and agreements seem to be emerging on a continuous basis, and there are grand visions for a future carbon-neutral world. Visions that embrace all manner of grand plan thinking from the electrification of everything, to carbon sequestration and the green hydrogen economy.

Responding to the challenge

While there is little doubt that such big picture thinking is required, most businesses are not able to directly contribute to such large-scale and transformative initiatives. So how can they successfully and meaningfully embark on their own journey to carbon neutrality? How can everyone play their part in contributing to the solution of a more sustainable future?

Despite the wide spectrum of opportunities to engage in green initiatives, the answer to these questions is perhaps not as straightforward as it may appear on the surface.

What cannot be ignored is that we are facing a system of systems problem. It is one with complex interdependencies that cannot be viewed from an isolated perspective. Any given initiative may appear to offer benefits from one frame of reference, but looked at holistically, those benefits may be reduced or even negated. By way of example: purchasing and running an electrical vehicle (EV) makes perfect sense in terms of reducing the need for hydrocarbon fuels, but the benefits are only realized if the electricity used to charge the batteries is generated carbon-free. Furthermore, a breakeven point must be passed before the carbon impact of manufacturing the EV is fully offset on a like for like basis compared to a petrol vehicle[35]. And this is without considering the wider sustainability and ethical implications of mining the raw materials for battery production[36].

Targeted decarbonization programs and regulations may help plug specific holes and drive societal change, but we must avoid unintended damaging consequences elsewhere. This demands a system of systems approach in our decarbonization strategies.

Understanding the dimensions of the decarbonization equation

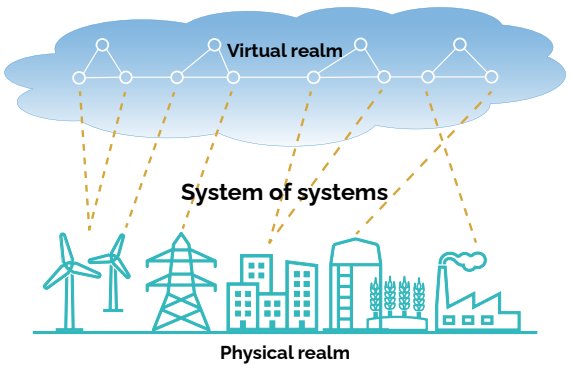
The decarbonization system of systems problem encompasses six primary dimensions:

- Technology - are proposed changes technically possible?
- Economics - how will transformation and ongoing operations be funded?
- Externalities - what are the wider implications of change?
- Regulation - how will operational changes be enforced?
- Ethics - how will human rights be impacted?
- Society - how well will the required changes be embraced and adopted?

All of these dimensions need to collectively demonstrate an overall benefit. For example, carbon sequestration in old underground mines[37] may offer immediate benefits - but are the long-term externalities fully understood, and could the process run into similar societal objections as fracking[38]? We must also not forget that, for certain economies, there may be no alternatives if globally agreed targets are to be met.

There is a compelling need for common ontologies to ensure that systems and targets talk the same language and are therefore aligned to common and consistent principles. We need the tools to provide the required big picture perspective, and we need to be able to do the math in understanding the interdependencies and externalities of decisions made and actions taken. Digital technology has a significant role to play in this regard.

Figure 9: Understanding real carbon footprints



Understanding the end-to-end impact of physical world operations, requires a system of systems approach. The virtual realm can offer valuable and actionable insights through simulation, prediction and optimization.

34. A cost or benefit caused by a producer that is not reflected in that producer's value chain.
35. reuters.com/business/autos-transportation/when-do-electric-vehicles-become-cleaner-than-gasoline-cars-2021-06-29/
36. borgenproject.org/alternatives-to-cobalt-mining/
37. reuters.com/business/cop/miners-look-carbon-capture-move-beyond-net-zero-andy-home-2021-10-29/
38. A drilling technology used for extracting oil, natural gas, geothermal energy, or water from deep underground.

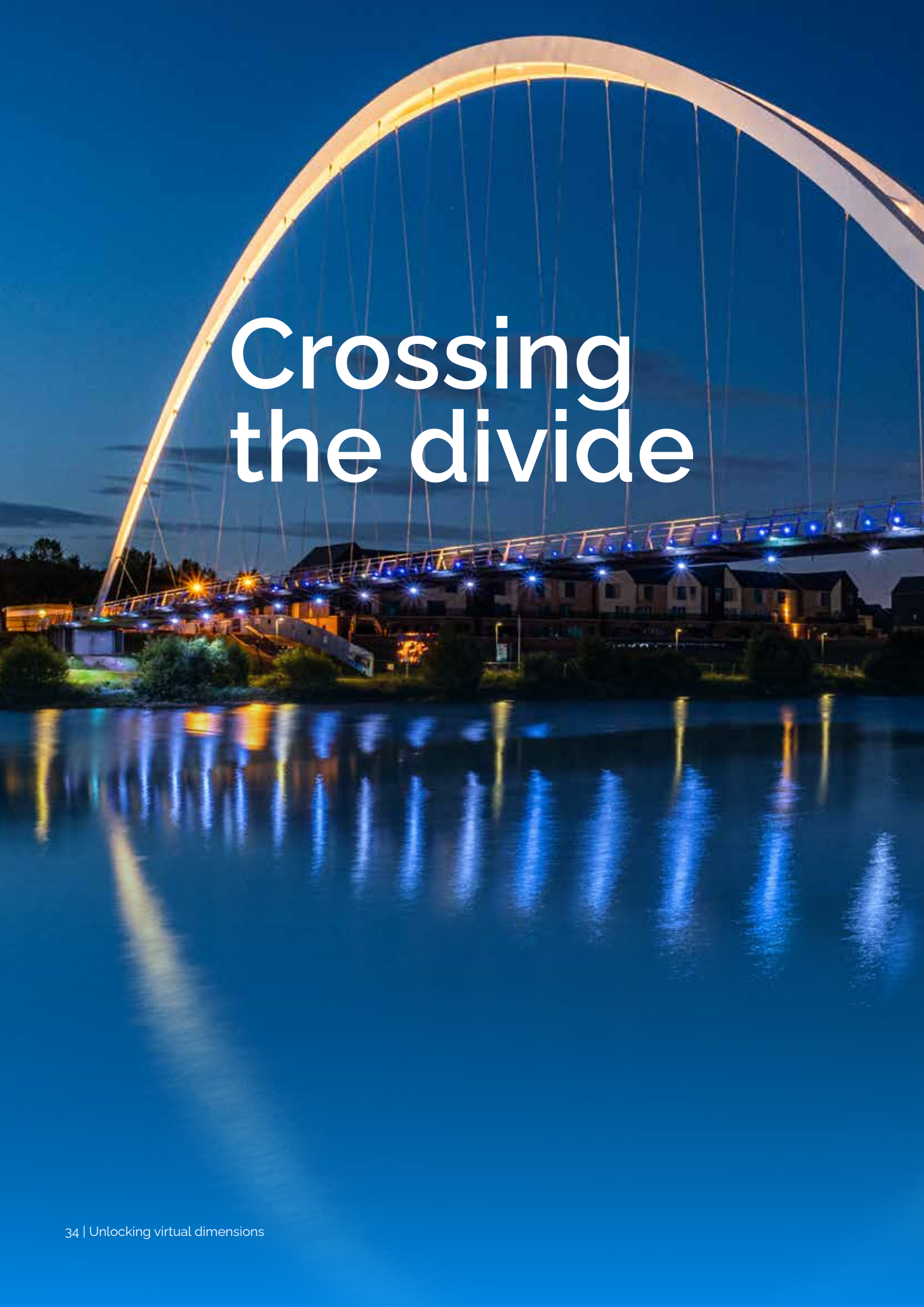
Acting beyond scope 3

In particular, the emergence of industry platform ecosystems[39] offers the opportunity to better understand scope 3[40] carbon emissions, and to allow individual organizations to participate in bigger picture initiatives. They may even help support an understanding of other system of systems dimensions like externalities of value chains - effectively going beyond scope 3. This is a critically important step to understanding the full scope benefit or detriment of decarbonization initiatives. It should be emphasized that we are not advocating a single all-encompassing platform for managing all interconnected consumption and value chains, such an approach would be unfeasible on a number of grounds. But we do foresee platform of platforms architectures emerging where, driven by common and agreed ontologies, it will be possible to exchange insights, calculate true carbon impacts, and explore scenarios for addressing decarbonization challenges.

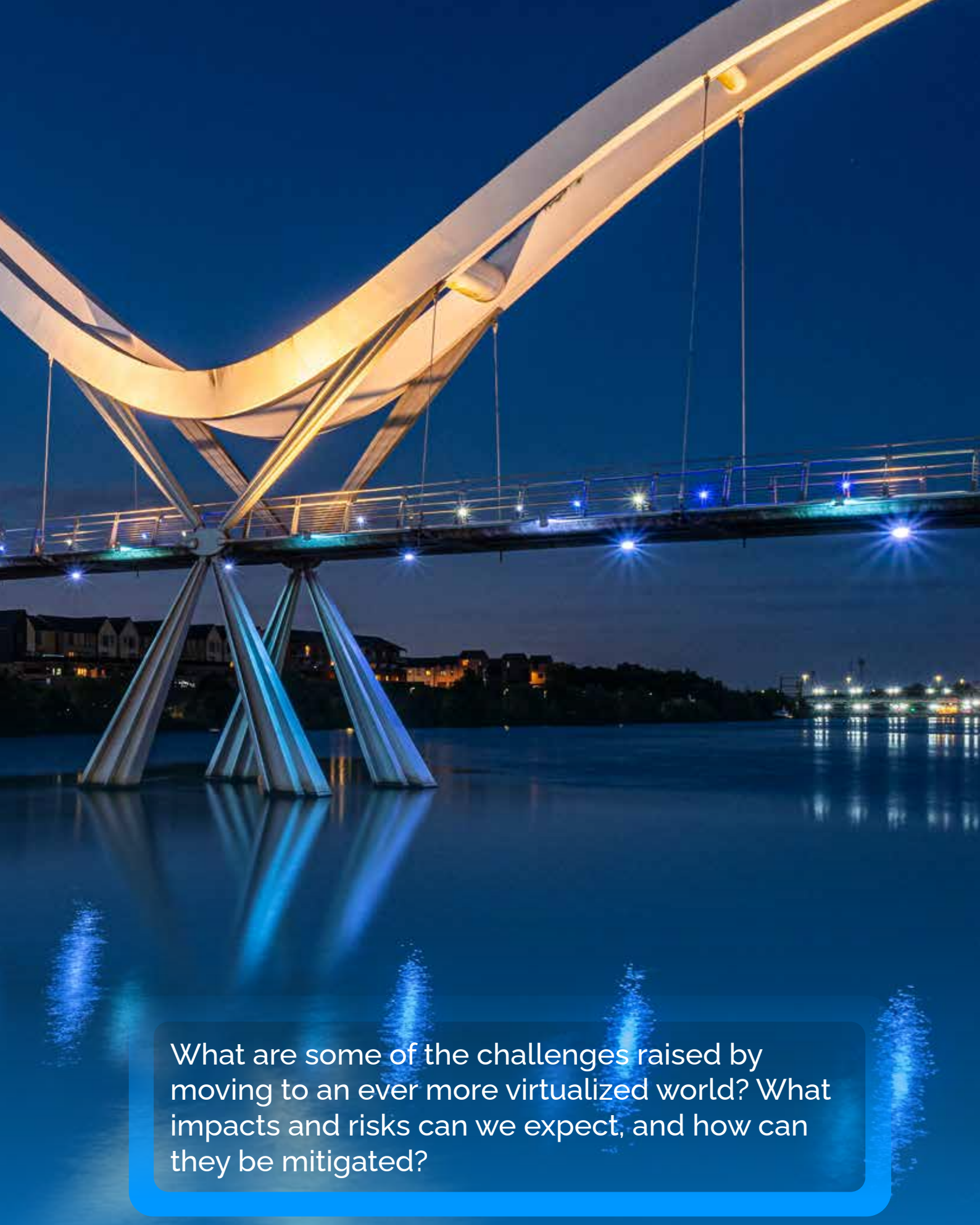
Such collaborative approaches will allow us to better understand where the biggest challenges and opportunities lie. They will help industry players, regulators, and governments to join the dots between otherwise isolated initiatives. We may see new ecosystems emerge in areas as diverse as waste heat trading, obsolete product recycling, externality compensation payments, and total carbon footprint scenario calculation.

Just as happened in the first industrial revolution, we anticipate continual progress in areas such as: the discovery of new materials and catalysts; the execution of work in more efficient virtual ways; the development of new energy efficient technologies like DNA storage and compute[41]; and the growth of clean energy networks. But this time the difference needs to be in the way we enable all these innovations to work together for collective benefit in the war of decarbonization.

39. Refer to chapter Industry platform ecosystems.
40. Scope 3 from the Greenhouse Gas (GHG) Protocol includes indirect greenhouse gas emissions both upstream and downstream of an organization's main operations.
41. atos.net/wp-content/uploads/2021/07/techdays-2021-dna.pdf



Crossing the divide



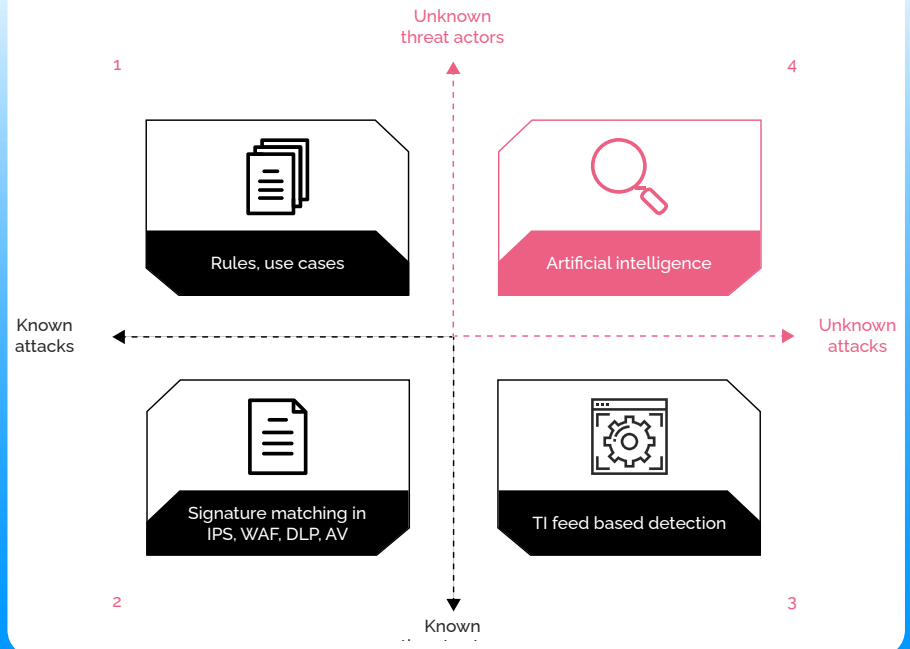
What are some of the challenges raised by moving to an ever more virtualized world? What impacts and risks can we expect, and how can they be mitigated?

The battle of cyber AI

AI will increasingly be used in both cybersecurity attack and defense. Cognitive AI will be an important force multiplier for defenders and should be at the heart of their tactics and strategies.

Recent years have seen a staggering rise in cybercrime, with business email compromise attacks doubling every year, double digit growth in phishing, and ransomware representing more than 10% of breaches. The highest damage is inflicted by highly organized and targeted attacks from unknown threat actors, usually cybercriminals and nation states camouflaging their identity. Employing sophisticated technical and social engineering efforts, often over several months, these attacks increasingly use AI techniques. Such attacks cannot easily be handled by traditional methods, which mostly rely on signatures, rules, threat intelligence and scenario based manual security orchestration automation and response (SOAR). The high success rate of ransomware attacks is an unfortunate demonstration of how today's cybersecurity techniques combined with shortage of cybersecurity professionals, fails to address complex threats.

Figure 10: The threads and cyber protection landscape today



To better cope with the growing variants of AI powered attacks, cybersecurity innovators are themselves turning to AI for cyber protection.

Forward to 2026

We envision that the battle between hostile and protective AI will be at the heart of cybersecurity's future. By 2026, most of the attacks should sit at the top right quadrant of the threat landscape (figure. 10). What's more, the exposure and risks will be much higher, amplified by the perimeter-less world of cloud, edge, and swarm. Billions of smart objects will expand the attack surface of smart cities, industries and homes.

AI will become the de facto technology used by cybercriminals for financially motivated attacks, strategic crime, terrorism, and 5th generation warfare. It will provide attackers with ominous opportunities for critical infrastructure liquidation, massive destabilization of finance, defense, health, or communication systems. There will be surges in cyber destabilization through deepfake based social engineering. The cyber realm will be a major battlefield for hostile nation states; and even terrorism and political assassinations through digital channels may well become a practical reality (e.g., hacking implanted organs or autonomous vehicles).

As the sword evolves, so must the shield. We believe that the evolution of cognitive AI (CAI) which can mimic human thinking for narrow problems and assist decision making for broader problems, can tilt the balance in favor of defenders. CAI has the potential to give us the scale required to successfully defend against advanced cyber threat actors.

A rapid evolution of CAI is expected. Extending the contribution from machine learning (ML) and deep learning, early implementations are expected to start around 2023, with use cases growing rapidly by 2026.

The evolution of AI in cybersecurity today versus 2026 is captured in the table below:

Use of AI in cybersecurity today	Evolution of AI in cybersecurity by 2026
Use of unsupervised learning algorithms; limited use of supervised and deep learning algorithms.	Use of advanced deep learning algorithms becomes cognitive AI.
Lack of breach event repositories limit the use of deep learning and advanced AI to a handful of cybersecurity use cases (e.g., malware, phishing emails).	Frugal AI, able to leverage limited datasets, will fuel CAI development. Deep reinforcement learning will use signals rather than data. Self supervised learning will overcome the need for correct samples. Data sharing frameworks and multiparty computation (MPC) models will create large breach data sets for deep learning algorithms.
AI legal frameworks and ethical frameworks are still at the concept stage.	Mature AI legal and ethical frameworks will be a reality by 2026. Traceable and explainable AI and normativity will be key mechanisms for monitoring AI for ethics and legal compliance.

Leveraging cognitive AI by 2026

Leveraging CAI should tilt the balance in favor of cyber defense and resilience, notably in the following areas:

- **Cognitive threat hunting**

CAI algorithms will mimic the role of threat hunters leading to high fidelity detection and economies of scale, reducing the cybersecurity staffing gap through smaller CAI assisted teams instead of armies of expert hunters.

- **Cognitive security orchestration and response**

CAI will transform SOAR platforms from manual design to autonomous learning for generating attack mitigation response steps. They will leverage edge or swarm devices providing contextual, high-speed and high scale intelligent responses.

- **Cyber threat intelligence (CTI) with federated learning**

CTI will respect data sovereignty requirements by using trusted federation of local threat intelligence sources.

- **Data equity protection**

Data equity[42] principles will enable confident data sharing and unlocking data value. Using CAI to detect malicious changes to data will guarantee data reliability and enable equitable decisions.

- **CAI as virtual CISO (Chief information security officer) companion**

CAI is expected to assist the CISOs for risk management decision making, freeing up time for strategic initiatives.

- **Self-healing systems and cyber resilience**

Ultimately, CAI will enable autonomous self-healing of systems. It will orchestrate rapid breach recovery by assessing and choosing the best options in line with recovery point objectives (RPO) and recovery time objectives (RTO).

Security is a perpetual innovation battle between the sword and the shield. Cyber criminals will continue to leverage AI, but the use of cognitive AI will enable a viable defense. **To maintain an effective defense against organized crime and hostile nation states, organizations must now put AI and cognitive AI on top of their defense tactics and strategies.**

42. atos.net/wp-content/uploads/2021/02/preparing-for-rebound_after-covid-crisis.pdf

Digital resilience: the path toward antifragility

As our world's systems interconnect and digitalize, they become increasingly complex and interdependent. Technology evolves, value flows increase, social media interactions multiply, new ecosystems are established.

As complexity grows, so too does uncertainty. Add to this mix the significant unexpected disruptions that are all too common: market crashes, natural disasters, health crises, and other intrinsic or extrinsic shocks; and we have a recipe for turmoil. The trend is not likely to reverse, so **we must learn to expect the unexpected and live with it**.

The nature of the shocks seems to be evolving as well: in frequency, intensity, and level of disruption. After crises, the operating environment will often be so different from the old normal that companies cannot continue as they did before. Adapting is essential. The aspiration, however, must be not merely to survive, but to thrive.

Powerful research has already been conducted in the fields of **unpredictability, complex decision making and uncertainty**, but the results have not yet been fully utilized by businesses or societies.

A new risk management approach: investing in antifragility

Why was research not fully capitalized upon to solve such critical issues? Probably because the results challenged so-called common wisdom, established beliefs, and mainstream mindsets. Throughout the industrial era, **organizations were structured to maximize short-term efficiency**, and even now, risk management is perceived as a cost; a crisis as something to be avoided; prediction as a skill to be mastered; hyper-optimization as a profitable action; and robustness as the opposite of fragility. However, statements like these no longer hold up to scrutiny.

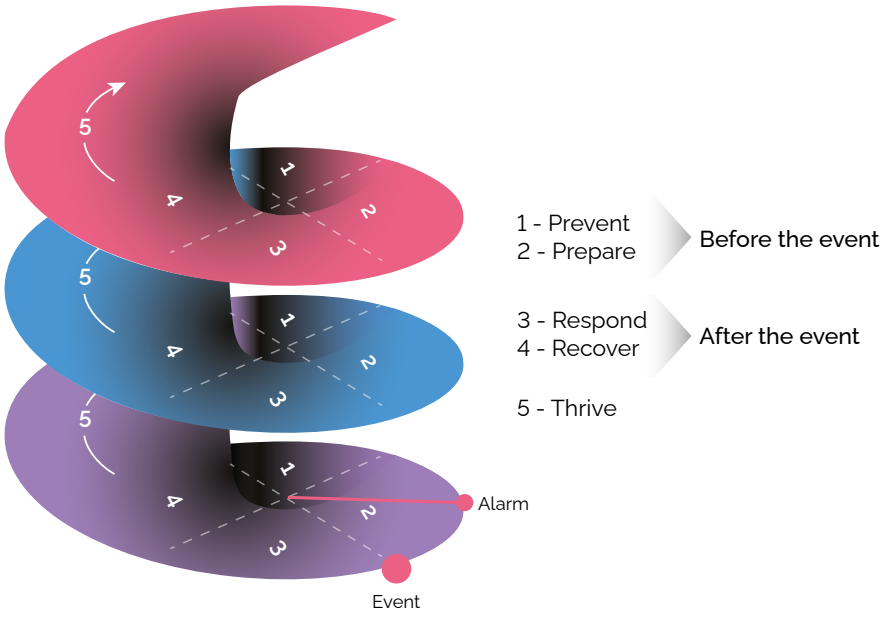
Certainly, when a crisis hits, robustness is better than fragility. Fragile things break under stress, while robust things resist. But robustness can be too inflexible. As the financial analyst Nassim Taleb pointed out, the opposite of fragility is not robustness, it is **antifragility[43]: the ability to gain and prosper from a shock**.

With crises, come opportunities. New markets become accessible, new customer demands require fulfilment, ecosystems change, and the competition landscape is reshuffled. The traditional risk and disaster management cycle comprises four phases: **prevention** and **preparedness** before the event. And **response** and **recovery** afterwards. In figure 11, we propose managing these traditional phases in new ways and extending them into a new, **fifth phase: thriving**.

Organizations that only manage to recover stay in the same plane of resilience maturity.

Organizations that structure themselves to capitalize on disruption, increase their maturity level toward antifragility. They benefit from shocks, grow in crises, and thrive in new environments. With this goal of thriving in mind, risk management becomes a strategic investment for the future.

Figure 11: The path to antifragility



43. Nassim Nicholas Taleb, Antifragility, Random House (US) and Penguin (UK), 2012

Six key levers to antifragile thriving

Best practices in antifragility preparation are emerging. Some originate from pioneer digital players, some from new organizational models, such as decentralized autonomous organizations (DAO). They offer an actionable framework for analysis and action.

1 Define a clear purpose ahead of strategy

To stay on track during crises, enterprises need a guiding purpose. It's what will bind people together and allow strategies and tactics to pivot easily in changing conditions.

2 Develop a people empowerment culture

Part of the DNA of successful antifragile companies is employee adaptability. Empowerment is vital. Creating a culture that embraces change requires adjusting mindsets and skillsets; tapping into a broad diversity of profiles and talents; giving employees the opportunity to become T-shaped and well versed in more than one discipline; and supporting experimentation and occasional failure.

3 Modular connected structures nurturing ecosystem collaboration

Disruptive changes cause ripple effects through large organizations. Modular, loosely coupled organization structures are more resilient than bureaucratic ones, even at the cost of some redundancy. They facilitate the rapid shedding of parts to salvage or evolve the rest. Being part of a wider business ecosystem can also increase resilience. In times of stress, complementarities allow businesses to share employees, data, supply chains, and more.

4 Expand upon the agile way of working

Succeeding in a fast changing world means continuously exploring new business models, testing their feasibility against the market and, if they are viable, ramping them up to scale and starting the next iteration. Using the lean start-up concept in a mature company has proven challenging due to fears of losing market share - ironically, that loss often turns out to be the result of conservatively managed crises.

5 Adopt flexible strategic planning

Strategic flexibility requires agile financial thinking, recognizing that the world is nonlinear. Traditional capital allocation methods are slow. Reacting swiftly in a crisis requires capabilities like flexible portfolio reallocation, divestments, and acquisitions. In crises, normal portfolios can be temporarily unfeasible (lack of supplies, lack of demand). Diverse yet balanced portfolios can keep a company afloat despite disruptions.

6 Use new KPIs to manage volatility

Advanced KPIs are essential for antifragile organizations. Some must be geared to predict disruptions or detect them early. Some must measure fragility and the maturity of antifragility measures. Some must assess the capabilities that support thriving.

AI-based analytics and nowcasting[44] technologies will be of strategic help here. As digital contributes to a more volatile and riskier world, it also brings **new platforms to better predict, collaborate and adapt in real time**. Digital is both part of the problem, and part of the solution.

Adapting the organizational strategy, culture, structure, ways of working, planning and KPIs to become antifragile may become a matter of survival in the highly volatile, boundaryless world of 2026. Best practices may vary by industry but **thriving in the next crises begins with preparing now**.

44. The prediction of present, and very near-term past and future states of economic indicators

The impact of economic models on technology and society

Technology innovation has always tended to be a driving force of economic evolution - acting as a catalyst for efficiency, productivity and hence growth. Digital technologies have proved to be more disruptive than most; but despite all the positive value they offer, they are also a cause of many inequities. This prompts the question: should the entrenched economic models that are driving technology growth be adapted to reflect responsible investment metrics and ensure sustainable and equitable outcomes?

The need for different thinking

In a period spanning just over a century, and bookended by global pandemics, society has been dominated by what has become economic orthodoxy: the pursuit of growth. What we measure and how we measure it has shaped the way we conduct business and assess our individual and collective success. However, as our economic interactions become increasingly digitalized, we seem to be falling into the trap of assuming that it is appropriate to continue using traditional models based on formulas that were devised in bygone societies that operated under very different circumstances. Economic theories that only measure outputs, and not outcomes and impacts, can have significant negative consequences, particularly as we face the stark reality of the impact on our planet of relentless growth in consumption. Gross domestic product (GDP) cannot be the only measure of how successful societies are rated.

Recent and unfolding crises are blowing away some existing economic orthodoxy and many politicians and industry leaders appear to be willing to take the kind of collective action for change that would have seemed impossible only a couple of years ago.

The grand challenges of this world cannot be solved in isolation

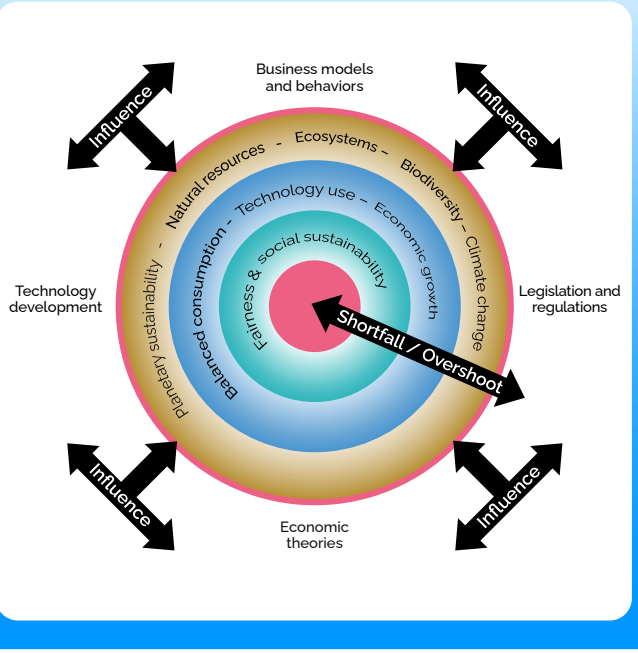
We are now at an inflection point where existing business and economic models no longer meet the needs of humanity. Businesses, governments, and regulators need to take responsibility for the impact of humanity's activities, not just on the planet but on the stability and structure of societies dependent on it. Indeed, sustainability reporting is increasingly concerned with the broader spectrum of ESG (Environment, Social and Governance), we must be open to adopting new economic models that will influence how we fund, design, and deploy the technologies that shape society. However, in general we are lacking the accepted indicators that will help us to visualize and measure the impact of those disruptions. There are several theoretical options that support technology developments which are more harmonious with our planet and less divisive societally. These include the doughnut economics model[45] which focuses on running business and society within planetary boundaries; and the Commons Economy which focuses on the commons and the power of the internet to create self-organizing generative technology infrastructures[46].

Better outcomes for society? Measure what you want to change

At a macro level there's an urgent need to redefine economic success and move away from potentially destructive business models that focus on extraction and consumption, and that tend to reward short-termism.

Changing how we invest in and regulate technology can have a profound impact on the behaviors of the organizations developing and delivering it. For example, through carbon taxes, green energy subsidies, right to repair legislation, and accessibility regulations. Businesses should look to embrace these as opportunities to reshape their value models.

Figure 12: The interplay between economics, technology, business and society



45. doughnuteconomics.org/about-doughnut-economics
46. primer.commonstransition.org/1-short-articles/1-3-what-does-a-p2p-economy-look-like

Changing how technology businesses are funded

We should take time to explore questions such as: how do we support entrepreneurship and invention? Is debt funded market capture good for anyone other than investors? Should nation states be more involved in supporting innovation, or will governments stifle the flexibility required to move fast? Perhaps finance via responsible and sustainable long-term bonds with voting rights could counterbalance short-termism driven by the need to deliver shareholder value.

Who is responsible for change - economists, markets, or governments?

Katharina Pistor, professor at Columbia Law School in New York argues that current law and legal systems around the world only protect the interests of the shareholders. However, investors are rarely accountable for the potential negative impact of their investments, they simply step out when profit is declining or when their investment no longer fits in society. This means that the ultimate financial risks are covered by society itself - as in the case of tax funded bailouts of banks and the fossil fuel industry. We expect regulation to shape markets and if GDP is unsuitable, newer economic theories such as donut economics, can help define more balanced measures of success in a time of reduced consumption and degrowth[47].

Business leaders must focus on new kinds of value creation

Increasingly, institutional investors are looking to capitalize organizations that are sustainable for planet and societies in general. How businesses are structured and operate will impact future funding opportunities. Those that fail to adapt are likely to see a withdrawal of capital and diminishing income streams. We expect collaboration inside and across businesses to be as important to shared value creation as competition has been in the preceding years. As technologists, we can invest in solutions that help us measure and understand impact. We can choose to be socially responsible, inclusive, and equitable. We can build reward structures that support socially responsible behaviors and stop the pursuit of growth in short financial cycles at the mid- and long-term expense of people and planet.

47. degrowth.org/definition-2/

Technology and regulation

The crafting of effective technology-centric regulations requires alignment across many stakeholders to avoid unforeseen consequences and legal loopholes. The process can be made more effective when digital technologies themselves are used to enable collaborative engagements between regulators and regulated organizations.

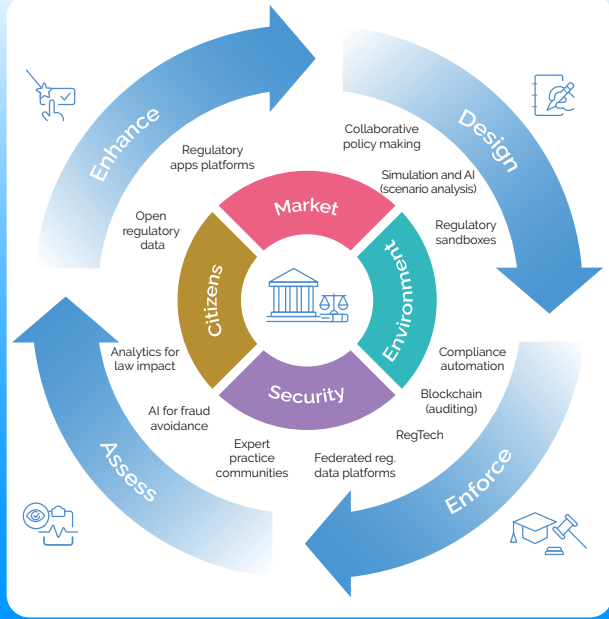
A complex but unavoidable relationship

Historically, the coexistence of technology and regulation has not been easy. Technologists usually see regulators as slow bureaucrats, tied to outdated concepts, and tainted by political ideology. Regulators often view technology champions as opportunists, obsessed with economic success and disconnected from their social responsibility. Crafting good regulations for complex topics is becoming harder, requiring a delicate balance between many stakeholders, and the avoidance of unforeseen consequences and legal loopholes. However, technology regulation is a necessity to avoid unfair business advantages and social inequalities.

By 2026, we will see a global increase in regulatory activity with significant implications on how digital enterprises handle their business. In 2021 we have already seen far-reaching actions in the main regulatory zones of the world: China, with its interventions in every technological dimension; USA, with a more critical approach to its digital champions; and the European Union pushing for socially responsible digital services.
Against this backdrop, organizations must address three important questions:

- How can digital technologies help governments design and enforce better regulations?
- How can digital technologies help companies better comply with regulations?
- How can organizations thrive and even find new opportunities in more regulated environments?

Figure 13: Digitalizing the regulatory lifecycle



Regulation for digital: mapping the battle fronts

From the perspective of **citizens**, existing regulations on privacy, and nascent ones on areas like AI ethics, will evolve to shape Charters of Human Digital Rights. Digital **market** regulations will tackle critical topics like competition and taxation, while coping with complex geopolitical scenarios and the specificities of diverse industrial sectors. **Security** regulations will broaden their scope from lower-level tech standards toward system-wide governance considerations - they will need to become more global to address borderless cyberattacks. Finally, regulation for the **environment** should emerge quickly to provide tools that help fight the climate crisis.

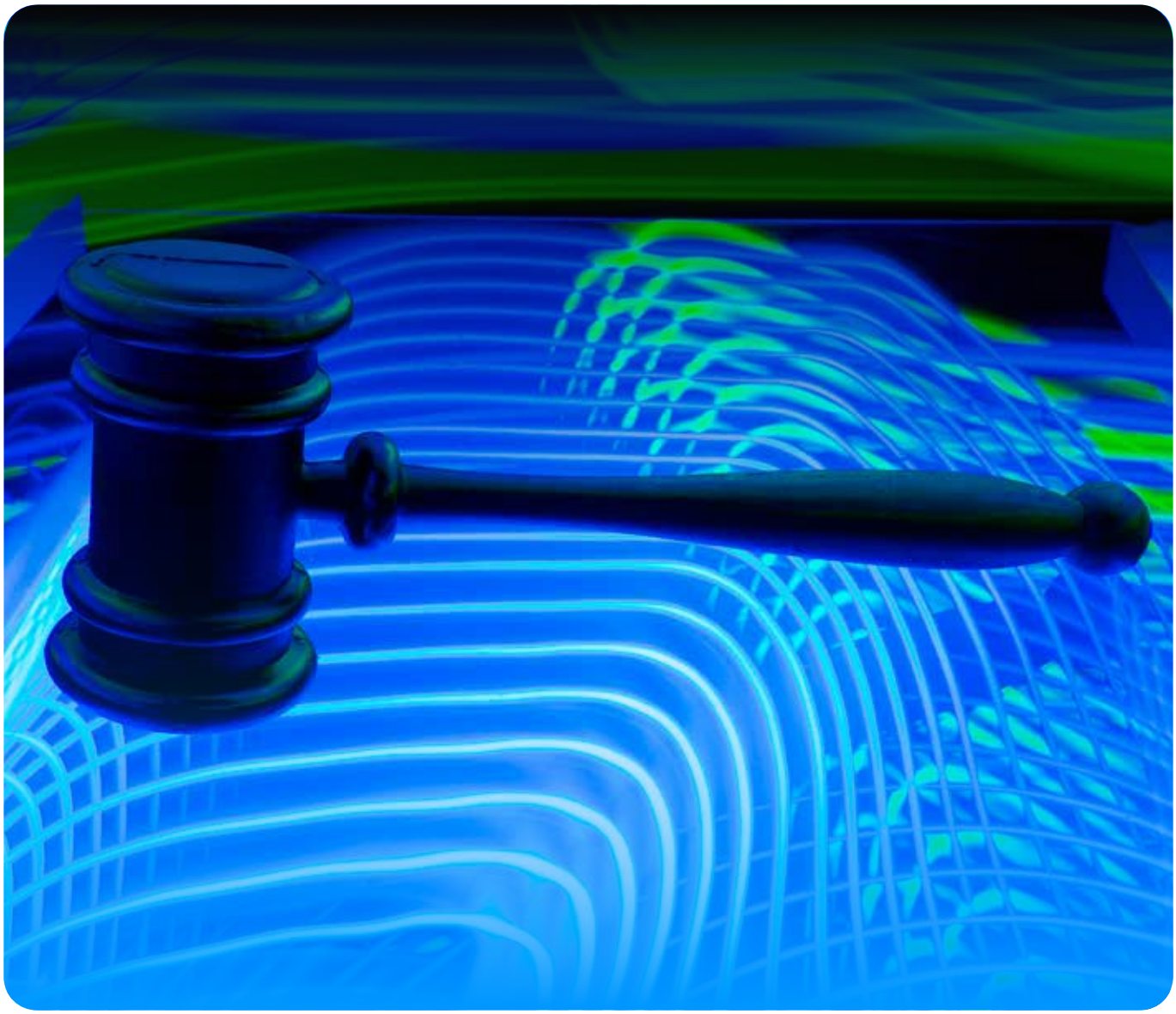
Digital for regulation: using technology for better regulation

If we summarize the regulatory lifecycle as Design-Enforce-Assess-Enhance, there are opportunities for digital technologies to bring significant insight and agility to regulation implementation. At the DESIGN stage, **simulation combined with AI** can help with anticipating negative consequences in complex socio-economical systems. We expect an increased adoption of **regulatory sandboxes**[48] for controlled experimentation across all industry sectors. These will be complemented by **collaboration tools** that ease multi-stakeholder participation for policy definition and testing.

Once in the ENFORCE stage, **automation** becomes key to ensuring high levels of compliance and cost efficiency, extending the concept of **RegTech**[49] beyond its current focus in finance and into other sectors. The impact of automation will reach from low levels (embedded security compliance in IoT) to more meta levels (decarbonization and ESG reporting). Such solutions will be supported by **federated data platforms** building on trust standards that are emerging from digital sovereignty initiatives like **Gaia-X** in the EU.

Expected interplay of developments in technology regulation summarizes the most important areas where intense regulatory activity may be anticipated over the next four to five years.

48. A framework that allows innovators to conduct live experiments in controlled environments under a regulator's supervision.
49. RegTech relates to new technologies developed to help overcome regulatory challenges in financial services.



With regulatory models enriched with more data, **advanced analytics** and **AI** can help detect potential inefficiencies and ASSESS their impact. There is also the potential to ENHANCE the value of regulation with more radical improvements - for example, providing regulation-centered services for policy transparency through **open data** and **application platforms**.

While it is true that regulators need to embrace technology in a deeper way, they have to be highly aware of its limitations. Issues like privacy mishandling, data bias effects in AI, or the potential opaqueness of smart contracts in blockchain-based solutions, may cause bigger problems than the original regulatory challenges being addressed.

Living (and thriving) in a regulated digital world

It is not only regulators that need to change. Most organizations show a reactive (and even, defensive) approach to regulation. In the long term, this only increases business costs, both in adapting to the new legal requirements and indirectly through things like poor public perception in the event of noncompliance.

A proactive and collaborative approach with regulators, sustained by current and new technology, will be beneficial for businesses. It could help with the adaptation of solutions to progressively emerging technology trends (for example, ethics in AI, or those related to decarbonization) and also cope with disruptive legal changes (like the regulatory crackdown in China in 2021[50]). This requires a significant revision of the functions and digital capabilities of legal and compliance departments.

Forecasting the evolution of regulation across the world is hard. But one thing seems certain: in 2026, digital business will be more intensively regulated. That doesn't necessarily need to be bad for business or society. If both regulators and regulated organizations engage collaboratively and take advantage of the potential of digital technologies, the process will be easier, and may even become fertile ground for new social and business opportunities.

50. economist.com/business/what-tech-does-china-want/21803410

Revisiting corporate digital responsibility

New corporate responsibilities in the digital era and beyond

Corporate Digital Responsibility (CDR) is having to progressively change to reflect the evolution of technology and the ways it is increasingly impacting our society.

Value and vulnerability

While digital technologies bring incredible benefit and value, they can also expose new vulnerabilities for individuals, ecosystems, or the natural environment. **How can we ensure that we successfully and sustainably reap the rewards without creating unintended damaging outcomes for society?**

The concept of businesses having social responsibility can be traced back over several centuries, being manifested in initiatives such as the philanthropic provision of schools, hospitals, and homes for the poor. But it is not until the 1950's that the specific principles of Corporate Social Responsibility (CSR) began to be formulated with an early focus on civil rights, pollution, population growth, and the depletion of natural resources.

Fast forward seventy years, and a limited number of core CSR principles have become enshrined in legislation, although in other respects the growing free market economy (particularly in the west) brought a relaxing of government regulation by the state. The focus has shifted to business ethics and CSR as a defined operational response to shareholder or stakeholder pressure. Program frameworks like the EU strategy for CSR and sustainable development goals have promoted CSR to the level of a strategic, albeit voluntary necessity for legitimate value creating corporations.

As digital technologies became the dominant source of business value creation, the concept of Corporate Digital Responsibility (CDR) has emerged as a call for organizations to be held to account for the negative externalities of their digital transformations - and in doing so protect against the vulnerabilities that might result within our society.

A number of attempts have been made to create frameworks for responsible corporate decision making. One example is the **International CDR Manifesto**[51] - its seven core principles are shown in figure 14. The technology driven trends that we anticipate throughout Journey 2026 will stretch and test the limits of how digital responsibility is worked out in the context of these, and possibly other principles.

The next wave of change

Now as we look ahead to 2026, in anticipation of further game changing digitalization and virtualization of our world, we need to ask what more is needed to truly embed digital responsibility at the heart of our value creation principles.

Our overarching vision for 2026 anticipates the unlocking of new virtual dimensions giving rise to a variety of virtual and mixed realities: virtual representations of physical systems and processes; virtual representations of living entities, physical processes, and systems; and also new virtual domains of interaction and exchange. The path forward is full of unknowns - how might our working economy change as we edge toward artificial general intelligence? Who are the stakeholders in transient business opportunities? How do we measure the value of a virtual transaction?

Operating in virtual domains will not only create new ways of living, and conducting business, they will also expose new places for vulnerabilities to form - and will do so at a speed and scale that

Figure 14: Model of vulnerability in the digital age

51. corporatedigitalresponsibility.net

outpaces our ability to regulate in a measured way.
Given the potential negative implications that digital transformations can have on society and the planet, we believe that once again, businesses will need to adopt a form of self-regulation, similar to that already practiced through Environmental, Social and Governance (ESG) commitments.
The ESG framework is already widely recognized by financial stakeholders (and society more broadly) as a critical component of corporate reporting, however, digital domains are still not explicitly covered in its scope.
Heading toward 2026, we believe that companies will need to extend their ESG commitments to explicitly include the impacts of their digital strategies - a new era of ESG digital (ESG-D).

Defining vulnerability

A significant cause of harm through digital change relates to those that cannot make themselves heard or do not have sufficient coping mechanisms to withstand the effects of change. This group includes what we describe as the unintended customer of digital transformation. It includes planet earth, wildlife, young children, the elderly, etc. But it also includes intended customers who suffer unintended consequences, for example: online gambling addiction, cyber bullying, digital identity fraud, and social media induced mental disorders.
In contrast there are those who embrace and become empowered by the use of technologies, yet they can still become vulnerable when unexpected health or life events affect their resilience or capabilities. In that sense we may all succumb to forms of vulnerability in our lifetimes.

A valid approach to ESG-D needs to anticipate and monitor such vulnerabilities, setting in place appropriate mitigating actions when they materialize. Just as we now look to measure and understand the impact of our carbon footprints, we should seek ways of measuring the impact of our digital footprints.

Corporate decision making in 2026 and beyond

To reflect the emerging threats and challenges for society as we accelerate toward new virtual frontiers, we recommend that corporations and organizations undertake a full analysis of the effects and consequences of their digital capabilities, products, and services on their unintended customers. There are clear challenges with fully self-regulated models and so the introduction of standards and encouragement from regulatory bodies will be beneficial in demonstrating compliance - at least initially.
Toward 2026, we advocate an expanded model of ESG-D to become a common reporting standard across all companies and organizations.

Vulnerability refers to the inability of a system, individual or a unit to withstand the effects of stressors.

Social impact of digital

The responsibilities of digital citizens

In the virtual metaverse, both institutions and citizens alike will expect to use digital in a way that strikes a balance between new opportunities brought by technology and evolving societal norms, social responsibilities, and commercial goals.

Digital: the agent of social change

The incredible reach of digital solutions makes it virtually impossible to imagine a world without them. Indeed, one could argue that digital is displacing certain aspects of our human being, including our social interactions, physical contacts, and real experiences.

Amidst a global pandemic, technology has maintained and even created connections between individuals, families, communities, and the workforce. And while the many benefits have been clear, we should nevertheless ask the question:

Do the advantages of digital always outweigh the costs?

There are considerable positives to digital engagement such as raising awareness of global issues, providing access to support networks, and enabling the flow of opinion, compassion, collaboration, and empathy. However, it must be recognized that digital also brings some negatives, with risks from winner takes all monopolies, damaging psychological impacts of the always-on economy of attention, and ultimately the possible rise of a surveillance society. Such trends are self-reinforcing, even self-creating, causing digital solutions to become the shapers of society, sometimes without any regard to the downstream impact.

How can we exploit the benefits of technology without allowing it to create social risk and inequity? As digital platforms change social opinions and transcend our cultures, what are our responsibilities as digital citizens?

Driving social change on a digital platform

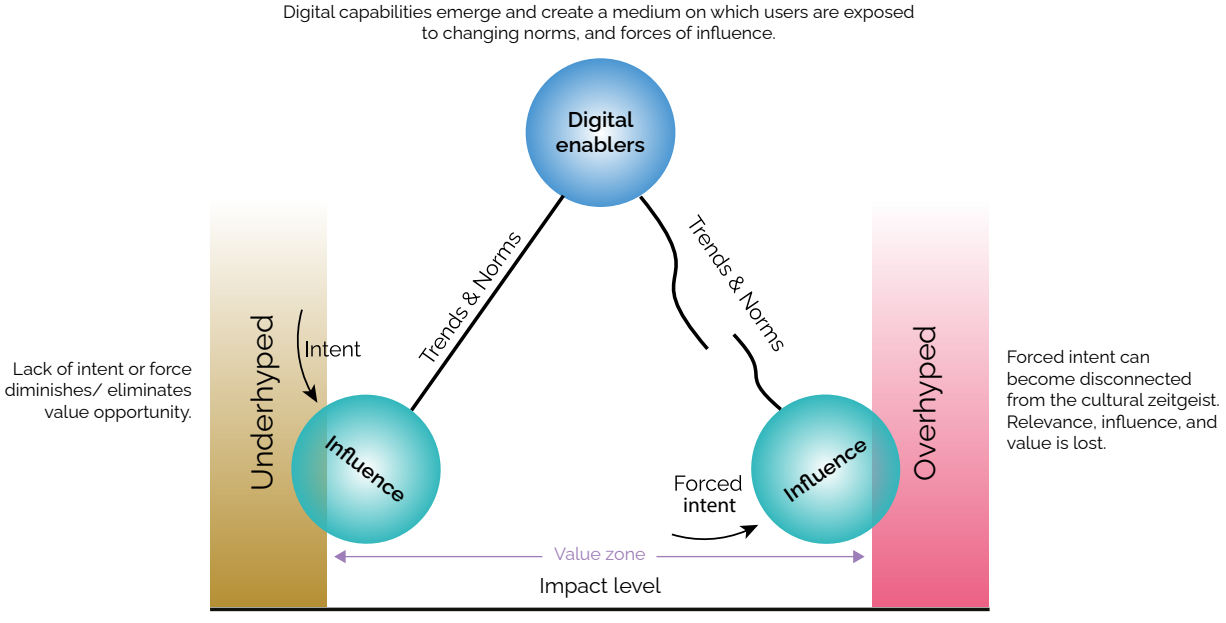
Examples of potential imbalance can be found in the way people, governments and organizations influence each other on the unfettered platform of social media. From vaccines to politics and climate change to celebrity - discussions are no longer strictly based on facts but are heavily shaped and hyped by influencers and the collectively amplified emotions of each platform's echo chambers.

Through digital, anyone with a sufficiently large social presence, be they politicians, individuals, celebrities, or business leaders, can wield influence as never before, manipulating conversations to advance personal, business or political agendas. The constant spotlight on social media deeply impacts our opinions, norms, and values, and through them our social structures.

The dissemination of inaccurate or disingenuous information is rising inexorably. Some commentators argue that within a few years, 50% of consumed information will be false. The progress of deep fakes will make it increasingly difficult to discern truth from fiction.

As technology advances and algorithms and social media business models artificially amplify certain types of messages, we risk disconnecting the digital world even more from reality, and fragmenting society rather than uniting it.

Figure 15: Balancing influence and intent for positive outcomes



Brokering a socio digital balance

Opinions on how and when to apply technology differ enormously along cultural, geographic, age and gender lines — and they seem to constantly shift. Consequently, digital itself is becoming a subjective topic.
In the pursuit of informed decisions, we need to ask ourselves the questions:

- How can we separate manipulation and hype from fact in a way that allows us to broker an appropriate social digital balance?
- How can we leverage the power of social platforms to enable open confrontation of ideas and rally collective support for mutually beneficial initiatives rather than contribute to social polarization?
- How can we shape technology while objectively weighing its advantages and disadvantages, to avoid possible negative side effects?

The impact of technologies becomes more complex and controversial both when they become more intertwined and when subjective opinions come into play — creating a shroud of tech hype that cannot be resolved by one party alone.
To ensure that digital technologies truly deliver the promised benefits, **every stakeholder must balance the intent and influence of technology to make a positive impact without falling outside the value zone**.
As the search continues for solutions to challenges such as unemployment, education, generational challenges, neurodiversity, and socialization, we must look beyond the hype and ensure that digital influence is not abused for short-term gain.

Toward responsible digital citizenship

One part of the answer relies on corporate responsibility, and public regulation. People, governments, organizations, and society must collaborate to balance new social responsibilities with financial and ethical goals.

But the answer must also come from the other side, individual citizens themselves.
With digital, humans are confronted by an always-on, exponential environment that is somewhat unnatural. The extension to virtual metaverses will only tend to exacerbate this challenge. To succeed in mastering the new virtual frontiers, **both institutions and citizens alike will have to use digital in a way that strikes a balance between the new opportunities brought by technology, societal norms, social responsibility, and commercial goals**.
Digital decisions will have to be driven by experience, pragmatism, and balance — rather than by a relentless quest for innovation that may overlook our deeper needs.
Always exploiting digital for maximum impact can create far-reaching problems, even if well-intentioned. If we are not to lose track in virtual worlds, as responsible citizens we will need to stay well-grounded in the real world.

New virtual paradigms

In what ways are new modes of virtual operation, communication, and value exchange redefining the art of possible?

Moment-centric markets

Global commerce expectations and dynamics are evolving as the digital native generations[52] expand their economic influence, assuming more and more decision-making responsibility in their personal and professional lives. Consumers are increasingly calling for products and services that are on trend yet personalized; and on-demand yet sustainable.

Digitally-enabled service providers are creating value propositions that attempt to deliver against and even encourage personalization and sustainability. And while this often leads to improvements in service levels, it also leaves us facing ever increasing levels of overproduction and consequently waste. Fortunately, there is a growing global awareness that resources must be better managed and that our current economic models need to evolve.

Moment-centric markets (MCM) is a new business paradigm that responds to transforming consumer demand and product/service provision. In moment-centric markets, the specific expectations of the consumer are central, and the value chains to fulfil each need are created around them. All value contributors need to be able to make collaborative and consistent data enabled decisions, supported with predictive capabilities, in order to continuously adapt to transient consumer behavior.

In moment-centric markets, the consumer's needs are central and the value chain to fulfilment is created around each individual need.

Creating more intimate buying experiences

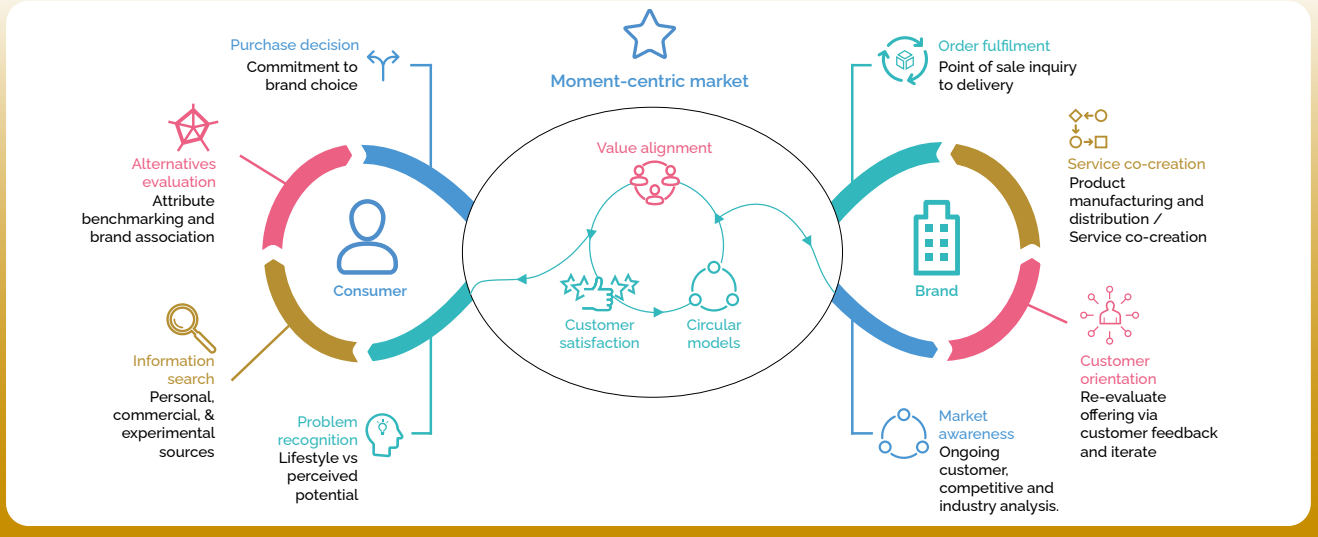
Development of new economic thinking starts with a proper understanding of the dynamic relationship between consumer and retailer. A digital native consumer typically engages in transactions that are cause driven and peer influenced but are also reflective of individual identity. These potentially contradictory expectations can only be effectively managed through insight and analysis of a consumer's buying behaviors, their likes and dislikes, their social motivators, and their current stage in life. This perspective results in momentary markets, that are created when desires arise and evaporate after they are fulfilled or ignored. Those businesses that can satisfy such demands become a new type of brand - ones that recognize traditional brands, but use data-driven platforms, social media and influencers to create a distinct tailored and more intimate buying experience.

Establishing agile brands

To establish themselves as moment-centric market brands, businesses will need to change not just what they produce, but also how they produce it. The what to produce is determined by identifying the needs of their client base and at any given time. This includes an understanding of the current state of demand and also the short-term market dynamics. Traditional market research gives way to immediate feedback loops and influencer predictions.

Generative design[53] principles will become more prevalent as they offer the agility and creativity required to rapidly optimize designs to meet evolving consumer demands. For certain product types, we will see such approaches reinforced through the adoption of large-scale additive manufacturing that will support more sustainable models for on-demand personalization at scale, as well as distributing the production processes nearer to point of consumption.

Figure 16: Interconnected moment-centric market cycles



52. Particularly Gen Z, born between 1995 and 2010.
53. An iterative design process that uses intelligent automation to generate outputs that meet certain requirement constraints.

Sustainable business models

The MCM way of working will offer its participants the opportunity to address their sustainability and financial targets. This is a perfect fit for companies pursuing the triple bottom line of People, Planet and Profit. The business model value for MCM can be described in any combination of the three bottom lines, without compromising its financial validity.

A key aspect to MCM business models is their ability to sustain and appropriately reward all participants across the entire value chain. Where brand is no longer just the underlying product intellectual property, this is not always straightforward. Design, production and distribution moves from a somewhat linear model to a shared, dynamic and iterative model. Circular principles including redesign, reuse and recycle also hold an important place in sustainable MCM business models.
Such complexity can only be effectively managed through digital supply chain management approaches that embrace trusted data exchanges, software enabled smart contracts, and cross enterprise process federation.

Some first practical implementations of the MCM principles can be found in the fashion industry. Start-ups and fashion houses are predicting real buying moments using prescriptive analytics and responding with proactive offers that include made-to-order product lines. The buyer can actively participate by configuring personalized design options built around their own 3D body scan, selecting many more colors, cuts, and styles. The chosen design can then be prototyped in studios or in local micro-production units that offer agile production with zero waste, and delivery in the shortest possible time.

The moment-centric markets approach to consumerism is a powerful response to the growing economic challenges of generation (digital expectations) and ecology (resources and waste). It allows for laser focused demand satisfaction while respecting the limits of what our planet can produce and bear. It needs to be noted though, that the ability to cater to any whim may well cause overall consumption to increase, which can counter some of these effects. Economic (pricing, durability) and psychological stimuli (impulse control, impact awareness, etc) can be examined to limit that effect.

The inner workings and promises of MCMs seem very distant from our current global supply chains, but first steps can be made with relatively small effort by ensuring that service co-creation between consumers and brands drives business model orientation and subsequent supply chain transformation.

Changing the communication game

The business landscape in the communication industry is fundamentally transforming. Hyperscale cloud providers are entering the communication service market, bringing new dimensions of service diversity and extreme performance. At the same time, traditional communication service providers (CSPs) are using cloud technologies to make network resources and the digital services running over them more accessible and automated.

CSPs, hyperscalers, and digital service providers are becoming increasingly intertwined, as they find new ways to collaborate and leverage each other's strengths to unlock maximum business outcome value. At best, this will become a cooperative/competitive relationship. Not only will CSPs, hyperscalers and digital service providers need to review their positioning, but also their customers will need to rethink their partner strategies.

Key trends in communications

Continuous move to edge

In Europe alone there are currently over four hundred thousand cell interconnects[54], and analysts predict this to grow to more than one million by 2026[55]. This is mostly driven by an increase in small cell deployments and is further accelerated by the growth in IoT communication endpoints.

Could Elon Musk's Starlink lead to a surprise checkmate move in the telco industry? By launching 42.000 non-geostationary satellites into low earth orbits, Starlink aims to offer Internet and mobile communications - particularly in rural areas, where established fixed and cellular providers have coverage issues. With new concepts such as laser connected satellite networks, and a cost-efficient launch platform with SpaceX, established SAT providers are being left behind. The move has triggered the emergence of new SAT programs in other organizations incl. Apple. Even though the physical barriers of latency, bandwidth, and user-device power may be currently too high to completely offset cellular and fixed-line technologies, business models like those of Starlink will certainly augment the telco landscape and lead the way to a new Satellite communications paradigm.

The challenges that arise from the continuous move to the edge can be grouped into:

- Heterogeneity and scale of endpoints
- Massive growth of data processed
- Increased cyberattack surfaces involving many different tiers and technologies
- Sustainability and management complexities from increased levels of spatial distribution

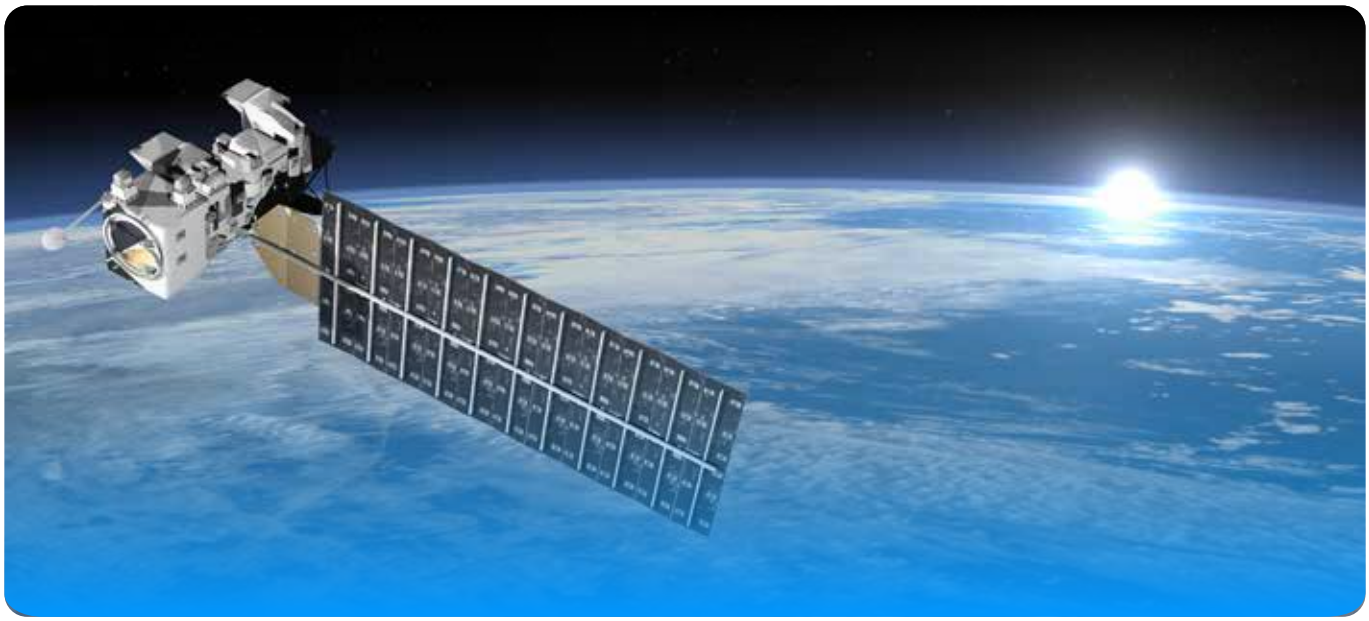
These require a multidimensional data processing and security strategy. There will be a massive impact on application architecture and information strategies as they address value progression, data traceability and control of data authenticity, quality, and ownership.
Moving data intelligence to the edge is an effective solution to dealing with data growth trends. Multitier approaches, that use edge servers as distributed data nodes, are being increasingly applied to improve manageability and security.

Separating infrastructure from communication management is an accelerating global trend for a newly established breed of companies that are focusing on sharing and optimizing the infrastructure by making use of data from CSPs and their own passive infrastructure. This will extend into the active network and edge compute domains until we see a network/compute continuum and a reshaping of the market landscape and roles of CSPs, hyperscalers and digital service providers.

Figure 17: Hyperscalers and telcos are playing out new competing strategies over their position at the edge

54. assets.ey.com/content/dam/ey-sites/ey-com/es_es/news/2021/02/ey-parthenon-and-ewia-report-on-european-mobile-tower-sector-v2.pdf

55. dgtlinfra.com/small-cell-forum-forecast-35-million-2026/



From virtualization to autonomy

Up to now, network virtualization has been focused on the disaggregation of physical network components (appliances) into virtualized network infrastructures (NFVI) and virtual implementations of network functions (NFV) to make more efficient use of compute and storage resources. VNF's have allowed some network services to be automated, but their vertical stack architectures limit their efficiency and scalability for large-scale 5G or edge deployments.
To address this challenge, cloud native network functions (CNFs) are emerging. They use container technology to provide the necessary flexibility and horizontal scalability, as well as reduce equipment and energy costs.

The continued convergence of communication and cloud technologies is forcing CSPs to find a new role in the telecommunications ecosystem, working alongside the cloud and digital service providers, content providers and over the top experience creators.

Their success will rely on the adoption of highly segmented business models within a development ecosystem that produces value added services across a broad range of use cases. Among the most innovative concepts are haptic and intent-based[56] networks, environmental context adaption, and automated policy and network segmentation to simplify onboarding of customers and devices.

Business impact and data economy

With the rise of cloud edge challenges and, in particular, the ongoing battle over data sovereignty, many CSPs have tried to establish a cloud business by building infrastructure capacities that promote security and sovereignty dimensions - yet without significant breakthrough success. In contrast, by leveraging large scale standardization and automation, hyperscalers have maintained their dominance in the cloud services business, while at the same time expanding in the edge cloud and investing in telco technology (for example, the acquisition of Affirmed and Metaswitch by Microsoft). By offering various innovative digital platform technologies and building application frameworks and developer communities, the hyperscalers are increasingly locking customers into their specific cloud ecosystem.

Nevertheless, there is huge motivation to facilitate a more balanced market in the data trading space, one that ensures a secure and regulated exchange and generation of value - not to displace established market structures, but to unleash unexplored opportunities. This will include deploying new digital and cloud based services in a decentralized way through the network, as opposed to just using the network as a transport layer.

The communication industry should be well placed to launch such data platforms, bringing value to the market, and creating new roles and data driven service ecosystems. They will offer end-to-end network enabled platforms with technology landscapes that do not enforce lock-in. Time will tell whether CSPs have the capacity on their own to invest in such platform creation, as well as dealing with the capital costs of network modernization and spectrum licences.

The need for a new communication paradigm

Digitalization of the economy and the explosive growth of data at the edge is accelerating the need for a new communication paradigm, thus drawing new players to the telecommunications market. These newcomers are seeking to leverage the data economy to generate new revenue flows and opportunities. CSPs are well advised to follow the lead of hyperscalers in establishing a broad ecosystem of developers and service partners to navigate the transition.

During the next four years the telecommunication industry will face the greatest disruption since the appearance of smartphones. Network virtualization and data driven technologies are changing the telecommunications market and have lowered the entry barriers for newcomers to the industry, enabling hyperscalers and other cloud providers to offer services that directly compete with or replace traditional telecommunication services.

Customers should make conscious decisions where to place their bets - on the increasingly centralized, pre-integrated cloud ecosystems of the hyperscalers, or the emerging ecosystems of partners that are focusing on deploying sovereign, carbon neutral cloud services over a decentralized, distributed cloud/edge continuum.

56. ***Networking*** technology that is intelligently configured ***according to*** business ***intent*** and specific service requests.

Business ecosystem platforms

Moving from monopoly approach toward federation and co-operation with the right ecosystem of partners

The business platform economy has shown its power over the last decade through the rise of dominant market players such as Uber, Airbnb, Amazon, and Alibaba. Even though its economic principles are well researched and published, only a limited number of businesses have truly succeeded in exploiting them. The natural internet dynamic of "winner takes most" means that platform models tend to prosper through achieving dominant, almost monopolistic, positions. Fair competition, social responsibility and sustainability do not appear to be among their value propositions.

Against this backdrop, we now see the emergence of data-driven **business ecosystems** - a next generation of peer-driven platform thinking. Although this new model is unlikely to usurp that of the current platform monopolies, it has the potential to offer significant complementary routes to value creation: value that can only be sustained when all involved organizations share a mutually beneficial relationship. Each entity must be flexible, adaptable, and cooperative, and will often contribute to the value creation and control of the operating platform that supports the ecosystem.

Setting the scene: monopoly vs value sharing

Business ecosystems deal in **data**. To ensure equity in such data exchanges, the value of each data source and their relative contributions to incremental benefit for the platform need to be understood, acknowledged, and carefully managed. In addition, the constraints of data protection, regulatory compliance, and multiple dimensions of sovereignty have to be respected.

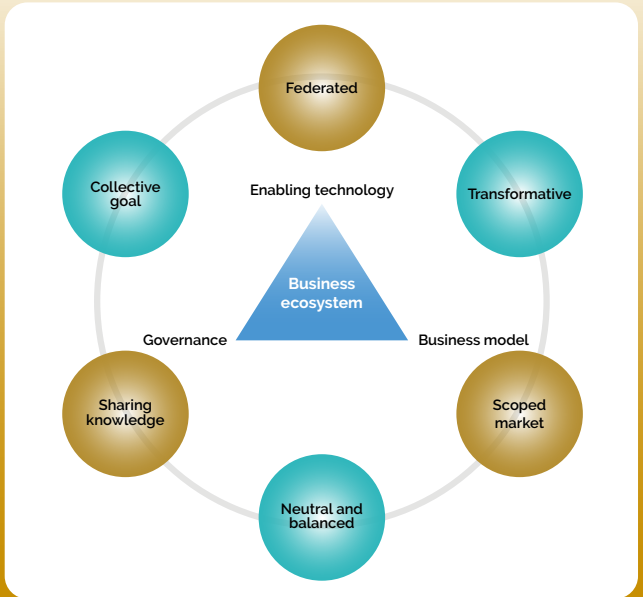
The self-organizing nature of platform enabled business ecosystems means that success will tend to depend upon an appropriate selection of complementary partners, who are able to combine business and technical skills to deliver a **combination of value and scale to players**. Agreement to coinvest, sharing in both cost and risk, will encourage the pursuit of mutually beneficial outcomes and will help avoid constraints in driving the desired multisided network effects.

Governance toward a common goal

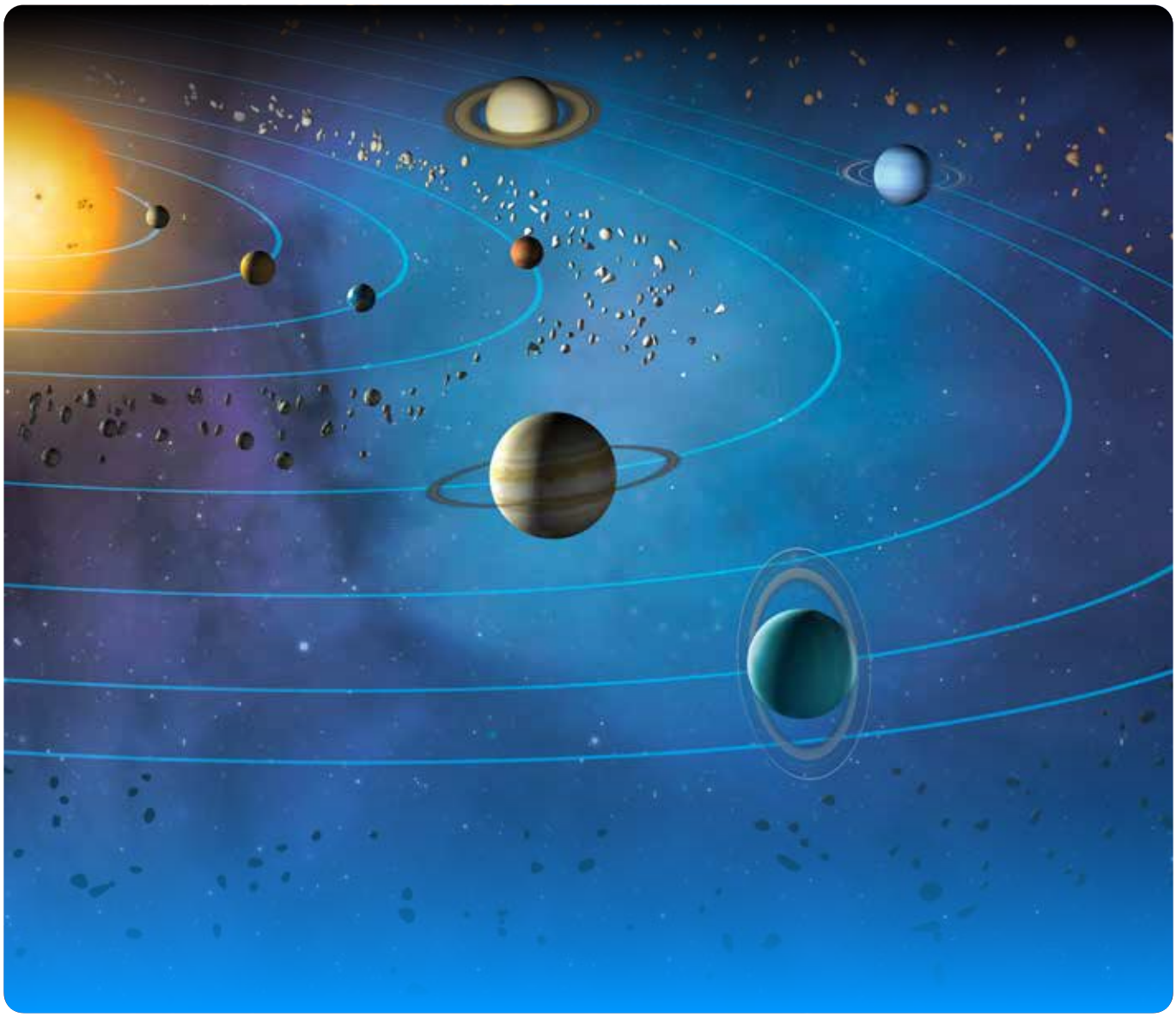
Business ecosystem platforms require enforceable **policies and standards** to ensure that the ongoing interaction between participants remains **trusted, fair, and beneficial. Platform operators** have a special responsibility in this respect. They should be **neutral** regarding the business outcomes of the ecosystem and must bear the responsibility for managing the governance model that will shape its operation and destiny. Governance models must be based on principles of **openness, transparency, accountability, and fairness**, if they are to be trusted by all participants. Even though we are seeing open, decentralized, self-organizing platform ecosystems appearing (e.g. Catena X[57] in the automotive industry), their governance models must still align with, and support, the expected collective outcomes. There should be an appropriate balance between **cooperation and competition** to help avoid conditions where dominant players emerge.

Attempts by large businesses to act as both platform operator and main business stakeholder have quite often led to push back from potential partners. One option for guaranteeing neutrality within an ecosystem is the creation of a new legal entity or joint venture to act as owner of the platform and operate its own business model that supports the growth and evolution ambitions of the collective ecosystem.

Figure 18: Business ecosystems and platforms



57. catena-x.net/en/



Enabling technology

Business ecosystem platforms will tend to share similar **modular and scalable technology components** to those of cloud native applications, but they will often incorporate enhanced security and trust capabilities such as federated identity management, sovereignty, distributed ledgers, and advanced encryption. As the connectivity and bandwidth benefits of 5G networks become increasingly available, federated data sharing models that exploit the value of edge technologies will further enrich platform enabled ecosystems. A powerful example is that of mobility data platforms, which can act as significant lever in the transformation of the transport industry and hence in the wider decarbonization challenge. By 2035 most new cars will be electric, and shared usage models are likely to be commonplace. However, for such outcome led services to be effective, transport providers will have to combine other modalities such as buses, trains, and bicycles. Business ecosystem platforms will help governments, mobility providers, citizens, and other complementary service providers to realize such a vision. In this kind of use case, a primary objective of the business ecosystem platform needs to be to change the mindset and behavior of people.

Ecosystems with a broad scope of diverse participants, data sources and business models may require the interconnection of several digital platforms to support their ambition. Each component platform will serve as an edge component, orchestrated as part of a multisided market by ecosystem federation services - a kind of platform equivalent of the cloud edge continuum. Standardized, structured and industrial frameworks are emerging, both from a technology architecture and data governance perspective, however we anticipate much evolution in this space if truly scalable, sustainable, and value maximizing solutions are to be realized.

Business ecosystem platforms must support mutually beneficial, **collective goals** on behalf of all their participants. They need to be **flexible and adaptive** to remain relevant in the seemingly ever-changing environment of data value, governance, and sovereignty. Many open questions remain, and each ecosystem will have to find its own path, particularly regarding **value creation, service monetization, and business models**, as well as required underlying technology and business transformations.

Redefining communication models

The first two decades of the 21st century have had a transformational impact on communication, with the emergence of social networks and the decentralization of content production and consumption. There are some distinctive trends associated with the new communication models that have emerged.

A new communication paradigm

With universal access to information channels, and little editorial control, there no longer exists a common understanding of what is true. Levels of trust in traditional media are low, and the attempts by governments or social media companies to impose truth are failing. Peoples' opinions are more open than ever, leading to the formation of subcultures and alternate digital realities.

In some cases, political and democratic processes have been severely impacted. The innovative use of social media in the Barack Obama and Brexit campaigns, and the influence of social networks in electoral battles (e.g. between Trump and Biden in 2020) have demonstrated that digital platforms now form part of the main battlegrounds in politics.

New information channels have provided increased visibility and social awareness on matters that may have otherwise been relegated down the political agenda (LGBTQ+, Black Lives Matter, MeToo) and are helping to conform and enforce social change.

On-line gaming and eSports platforms are challenging and surpassing traditional media channels. 26-year-old influencer Ibai Llanos provides commentary and interactive content to his 8.2 million followers for Spanish football and other special or even exclusive events.

Innovation in communication technology, at the core of sociological changes

Technology has made possible our hyper-connected society, in which content production is both decentralized and concentrated. Everyone can be a storyteller and a brand, and content created at almost no cost can be consumed anywhere, at any time.[58]

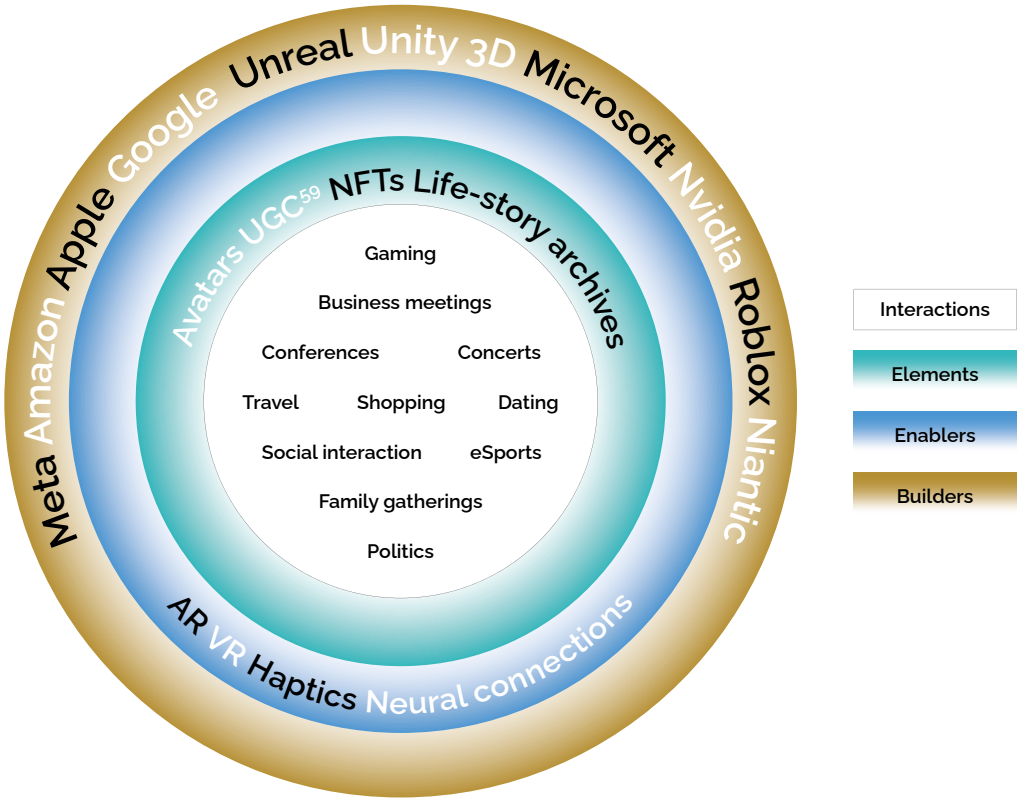
We now communicate using multiple channels that feed off each other, bringing hyper personalized experiences where the virtual and non-virtual are mixed. Advances in video, network and artificial intelligence (AI) technologies enable the generation of more sophisticated content which blurs the boundaries between the physical and the digital world. This not only brings possibilities that were until now part of the science fiction realm, but also makes it more difficult to differentiate truth from fake.

The agents and types of communication have also evolved alongside the technology, opening the door to human to machine and machine to machine communication models. Direct interactions with devices through smart assistants like Alexa or Siri are expanding to facilitate interactions in our daily lives with smart devices - cars, TV and even robo-pets. Machine to person and machine to machine communication models will use AI to enhance and optimize information exchange between parties and automated processes.

The pivotal role of technology has created a strong dependency on it, as exposed in recent events. The pandemic completely transformed the way we think about communication and interaction, with online Christmas dinners, online education and healthcare, and a massive increase in remote working. October 2021 saw a massive outage of Meta, Instagram and WhatsApp - for six hours, billions of users lost their voices, unable to communicate in the way they had become accustomed to. The impact on Meta was a 40 billion dollar drop in market capitalization.

58. marketingcharts.com/charts/us-adults-social-platform-use-by-demographic-group-in-2021/attachment/pew-social-platform-use-by-demographic-apr2021

Figure 19: Anticipated players and trends in the emerging communications metaverse.



Impact beyond social interactions

The transformational trends in society and technology will have a direct impact on companies and business models. We anticipate:

- Increased self-regulation by content hosts, the appearance of fact checkers, and the control of information by governments on certain topics - such as the censorship of content related to vaccines.
- Diminishing influence of traditional media; only real/live events (e.g. a football match or an election) will be truly concurrently viewed by massive audiences, and even then this will be across multiple channels.
- The monetization of content will shift from traditional broadcasting and written media to more intimate on-demand platforms.
- The prevalence of online immersive learning and artificial intelligence platforms for teaching; the growth of remote healthcare; and a profound transformation of traditional on-site working model toward hybrid models.
- Maturation of emotional AI and electrodermal measurement to introduce nuance and nonverbal cues (tone, context, body language) into how we communicate across digital.

Communication models are being redefined by technology through new platforms and services, content generation options, and monetization vehicles. New opportunities and risks will continue to emerge as the boundaries of traditional communication are pushed and transformed, bringing tangible implications to all, from politics, business, and society, to personal relationships and entertainment. Understanding and embracing these trends is necessary to be a relevant actor in the coming decade, no matter what the sector of activity.

With increasing interest and investment in the virtual "metaverse" - we see ever greater possibilities of a world combining digital and physical, where most interaction is only accessible through AR and VR. However, with such environments controlled by the tech giants. there are clear echoes of the dystopian science fiction novel Ready Player One.

59. User Generated Content

Quantum technology

Reshaping the digital landscape

Quantum computing has incredible potential to solve highly complex, calculation intensive problems that are beyond the limits of classical general purpose and high performance computers. As hardware and algorithms continue to evolve, by 2024 we predict an emerging quantum digital ecosystem that will steadily mature across a variety of industry scenarios. By 2026 it is our expectation that we will have begun the transition from quantum simulation to a few real use cases being mature enough for adoption by industry.

The application of quantum computing in industry

There are some common use cases across multiple industries where quantum computing techniques will augment the traditional computing environment. These include optimization centric algorithms like the Quantum Approximate Optimization Algorithm (QAOA)[60] and quantum simulations where the parallel nature of computation can be exploited at scale. However, we anticipate the most significant breakthroughs coming within industry specific applications:

Manufacturing: the increased mathematical processing power of quantum computers will enable manufacturers to model the behaviors of complex molecules and chemical compounds, leading to the formulation of new materials. Research in this area overlaps with that in the chemical and petrochemical industries, where investments are being made in the discovery of new drugs and understanding their interaction with organisms and other substances.
With improved simulation of complex systems, there is large potential for manufacturing design optimization and the elimination of redundant components. Better prediction of material behavior, resilience and lifetime operation under load will help to improve performance and safety of manufactured components.

Financial services: quantum computers are particularly good at risk calculation and optimization - a staple of banking and insurance. Use cases include portfolio risk adjustment, credit exposure estimation, optimal capital allocation, quicker risk and scenario calculations in equity and FX trading, and smart routing and trade matching.
Many financial institutions have started to develop and test quantum algorithms. Their results affirm the importance of using real-life challenges to assess the practical benefits of quantum technologies. Many promising applications have run into unexpected barriers, but a few, like portfolio optimization, have been shown to scale so favorably compared to classical alternatives, that production systems are anticipated in only a few years' time.

Telecommunications: quantum communication is a focus topic for a number of telco providers, particularly the area of establishing quantum internet infrastructure. The integration of quantum capabilities in existing telecom infrastructure and services will enable new services like quantum metrology, clocks, quantum security protocols, and information networks.

Energy and utilities: we see quantum technologies playing an important role in the optimization of smart energy networks. Balancing energy supply, demand, and storage to maximize the use of renewable generation will be an essential ally in the decarbonization of our utility grids. Quantum security solutions can also be expected to serve a role in protecting our critical national infrastructure as decentralized management and control solutions expand the potential cyberattack surface.

Transport and logistics: complex large-scale route optimization, and other scenarios that require solutions to NP-complete[61] problems, are perfect applications for quantum computers. Analysis of traffic flows will address transport congestion and improve safety. Aviation and railway networks will be able to introduce more complex multi-hop journey patterns, reducing overall distance, cost, and emissions.

Defense: this sector is already exploring quantum sensing for underground and underwater surveillance, as well as quantum security solutions - both offensive and defensive.

Healthcare and life sciences: quantum computing, together with artificial intelligence (AI) and high-performance computing (HPC), will offer molecular simulation and drug design for precision and personalized medicine. It will also speed up AI recognition of medical images to help in early disease detection. Innovations in room temperature magnetic resonance imaging (MRI) are also supported by quantum technologies.

60. https://arxiv.org/abs/1411.4028

61. NP-complete is short for nondeterministic polynomial-time complete. These are problems that have a solution that can be verified quickly, but there is no classical computing way to quickly find a solution.

Quantum technology development

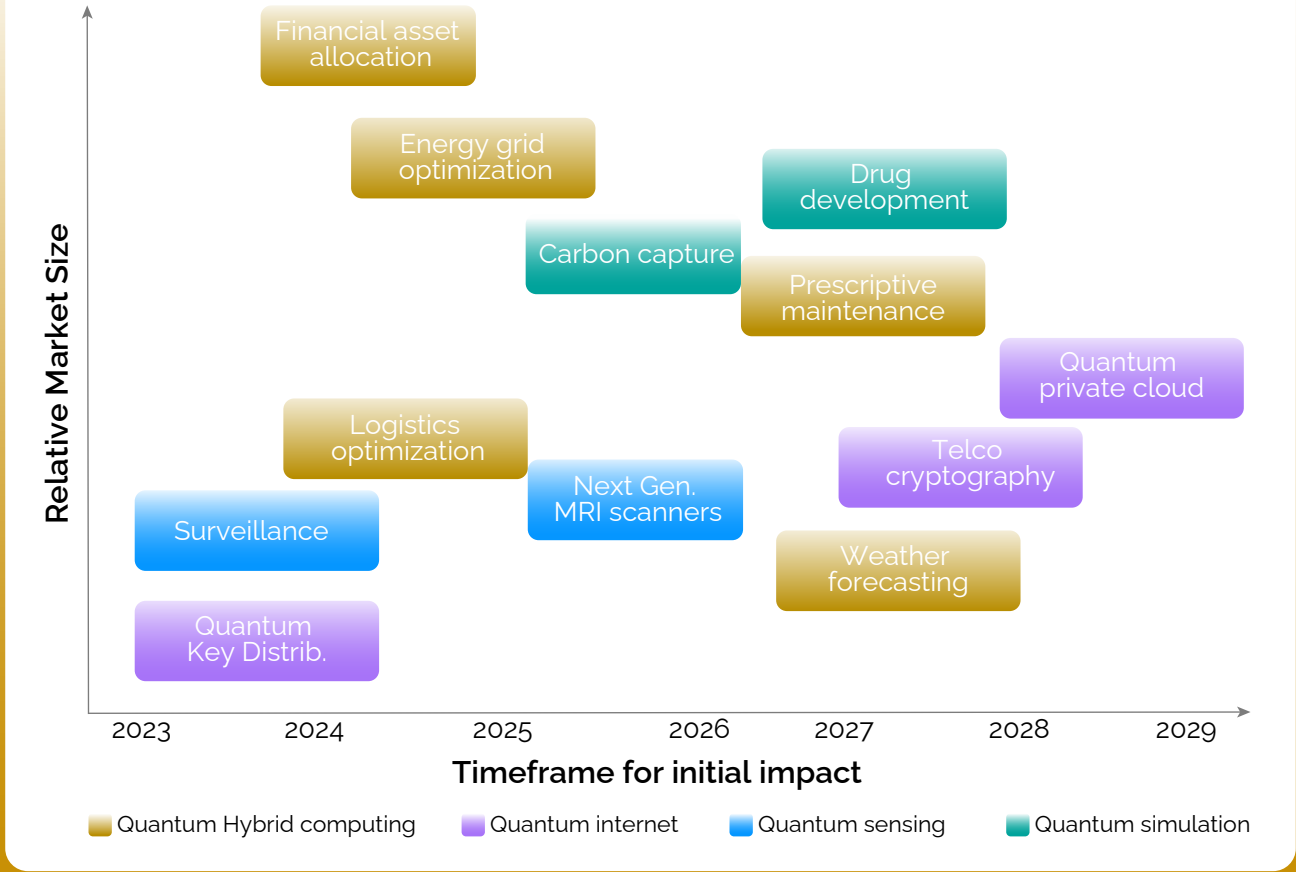
It has been proven that some real industry problems can only be practically solved by quantum computers. Technology breakthroughs will continue, and implementation costs and barriers to adoption will be lowered by developments such as quantum HPC hybrids and the prospect of room temperature machines (two companies have working prototypes that use quantum photonics). Operational machines with 1200+ qubits, and capable of addressing meaningful production workloads, are expected by the end of 2023. While this appears to be only 10 times the size of today's machines, with the exponential nature of quantum computing this is significant, especially for certain applications. Although quantum hardware is not yet mass-produced, there are simulators available, and it is imperative that industries begin to build the skills and quantum algorithms relevant to their challenges now.

New quantum algorithms together with classical computing, machine learning and artificial intelligence, will help to optimize processes, classify and correlate data, and allow the simulation of a variety of complex systems. Practical quantum computing solutions for industry will emerge for a range of currently intractable use cases.

Quantum Key Distribution computing is expected to offer significant leverage in addressing one of the world's current grand challenges: climate change. We expect that it will help discover improved ways to store energy in batteries, build better climate models, and deliver more efficient means of carbon capture and power generation - and do so in a way that is inherently energy efficient.

While it is difficult to predict precise next steps, one thing is certain - quantum technology is set to change the digital landscape forever.

Figure 20: Production quantum initiative market size analysis



The routes to artificial general intelligence

Today's artificial intelligence (AI) achievements are considerable, with AI systems routinely achieving similar or better performance than humans on a range of specific tasks. But current capabilities are considered very narrow and lacking in self-awareness, consciousness, genuine intelligence and intuition. However, the rate of AI evolution is such that it is possible to imagine systems capable of performing almost any intellectual task that a human can - **artificial general intelligence** (AGI). While no one expects AGI to be a reality in 2026, we should look at the progress steps for its disruptive business benefits as well as potential danger areas.

Technological breakthroughs in AGI

The road to AGI is paved with incremental improvements in approaches, algorithms, hardware, and data. Major developments emerging over recent years can be summarized as below:

Deep neural networks span virtually all aspects of machine learning, ranging from machine vision, and paradigms natural-language understanding (NLU), to time-series analysis and reasoning. Recent AI techniques focus on improving overall AI robustness and increasing the AI's generalization capabilities by learning on unlabeled data.

Transformers are deep learning models capable of differentiating significant and insignificant parts of input data through attention. One of the most well-known achievements is OpenAI's GPT-3[62], a very large model able to generate realistic texts, answer general questions, and more. Transformers have been successfully applied to computer vision, where the attention mechanism provides increased model accuracy and reduced computational cost.

Self-supervised learning (SSL) allows for the training of models from large datasets that are infeasible to label by hand. SSL applies to many deep learning scenarios where pretrained models are not available off-the-shelf or are cost prohibitive to create. The ability to continuously learn from raw input in any medium such as text, images, audio, and sensors is critical to AGI systems.

Continual learning and lifelong learning techniques mimic human learning to adapt to new circumstances and environments, while still performing well on prior training data.

Sample-efficient learning aims to replicate humans' ability to learn a task after only being shown how to do it once or twice.

Unsupervised domain adaptation deals with domain shifts. For example, in an outdoor camera network, a significant change in weather or lighting conditions may cause a drop in machine learning (ML) model accuracy. Domain adaptation tackles the issue of transferring to target domains knowledge learnt from different source domains with many annotated training examples.

Reinforcement learning is an approach in which an agent interacts with its environment and learns to take actions which are reinforced by rewards. Desired outcomes get larger rewards than undesired ones. One of the great AGI promises of reinforcement learning is that it provides an explicit answer to why intelligent agents do what they do.

Hybrid AI machines mimic a child's cognitive development. For example, we first learn to distinguish an apple from a banana, then to associate symbols, and progressively complex categories. Finally, we learn the ability to deduce new facts, skills, and knowledge. The goal of hybrid AI machines is to acquire knowledge by discovery, deduction, or instruction.

Last but not least, **advances in hardware** lead to disruptive architecture changes. For example, neuromorphic chips emulating activity spikes in human brains. Other promising routes are photonic computing hardware and quantum computers, that might accelerate AI by several orders of magnitudes.

Ethical considerations

Further development of AI will allow the most intelligent entities to progressively be given the power of decision, become more robust, and directly contribute to their increased intelligence. This will create a feedback loop, fueling cycles of progress and disruption. But we should not forget that AI is a tool; we must maintain an ethical balance between humans and machines. AGI without a moral compass could lead to dangerous results with a devastating impact on humans. It is important that governments understand and regulate the development of AI, and organizations must embrace this important topic when building AI systems.

Business opportunities on the route to AGI

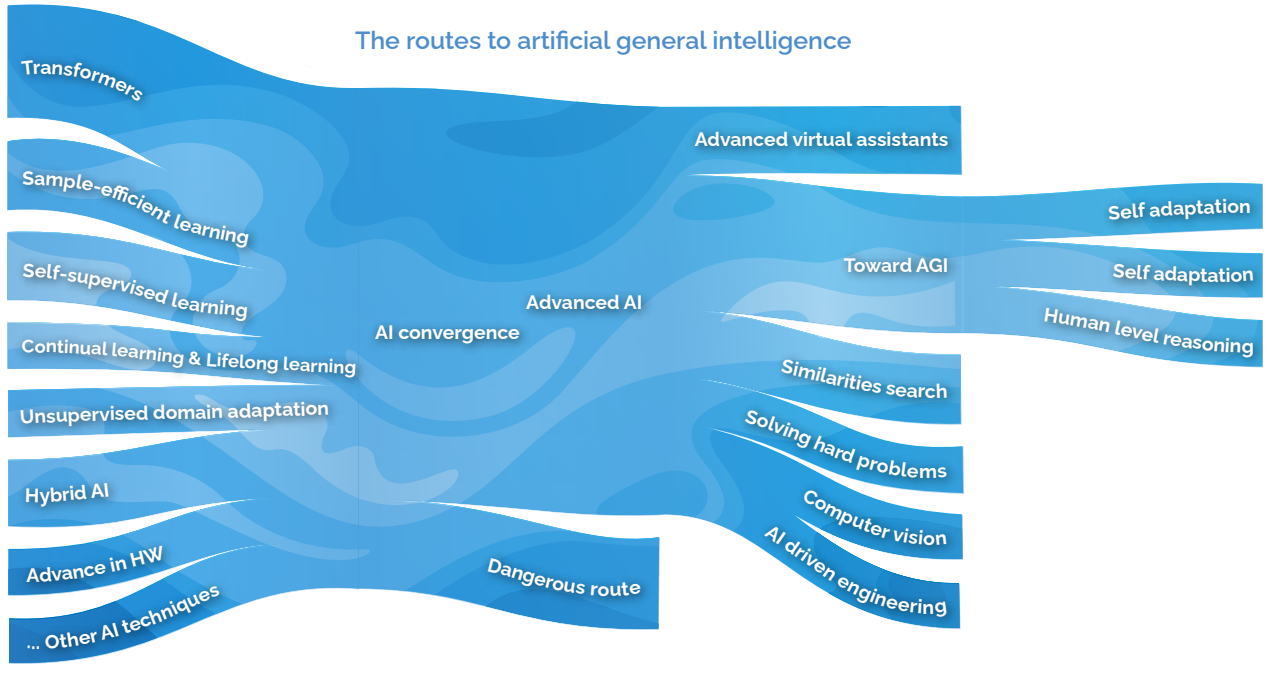
The rate of progress of AI will lead to many new business opportunities. For example, transformer techniques available as cloud services can help the B2B market build their own NLU solutions. Vector similarity searches (one of the key ingredients of Transformers) yield outstanding results for finding similarities between sentences, molecules, geometry, images, codes, 3D shapes, and many more. They can be applied to enterprise

62. https://openai.com/blog/gpt-3-apps/

data such as skills and products for capturing better contextual information about entities.
Advanced virtual assistants will likely be the most visible achievement on the road toward AGI. They will become more and more indistinguishable from human interactions, and support much more complex queries and tasks, managing conversations on various topics, engaging in discussion with humans, and drafting written communications.
We can also expect to see more hard problems, such as computational chemistry, drug design, financial modeling, and optimization being solved by using techniques that are stepping-stones to AGI.

Artificial general intelligence is probably the most divisive idea in AI research. We don't know yet if we are close to achieve AGI or if it even makes sense to try. Nonetheless, technological breakthroughs will continue to happen, with a considerable impact on industry, society, and our personal lives. Anticipating them, and building trust and fairness is the key to widespread acceptance.

Figure 21: The routes to artificial general intelligence



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About the Atos Scientific Community

The Atos Scientific Community crafts the Group's vision for the future of technology in business and anticipates the upcoming trends and technologies that will shape businesses and society in the years ahead.

Its global network comprises more than 170 of the top scientists, engineers, and forward thinkers from across the Group. Together they represent a rich mix of skills, experience, and backgrounds.
Through regular blog posts, white papers, thought leadership reports and above all the biennial Journey publications, the Scientific Community has established Atos as a thought leader and helped its clients safely navigate the challenges of the digital age.

Scientific Community members are creators of change, taking a proactive approach to identify and anticipate game changing technologies. They also play a major part in patent creation and develop a wide variety of cutting-edge proofs of concept. As mentors of the Atos IT Challenge - an annual competition for universities around the world - they help nurture the next generation of digital talent.

Working together with the Atos Expert Community, Atos R&D centers and the Group's external research partners, members of the Scientific Community help bring groundbreaking concepts and services such as quantum computing into the Atos portfolio. They also work on society impacting services such as accessibility and digital inclusion. This ensures that clients enjoy early access to the revolutionary technologies that will transform their businesses.

Follow the Atos Scientific Community on atos.net/scientific-community

Let's continue the conversation!

How will you unlock the potential of virtual dimensions in your business?
How will the growing connection between the physical and virtual worlds stretch the boundaries of your operations as you journey to 2026 and beyond?

The Atos Business Technology & Innovation Center (BTIC) network offers the chance to engage in virtual or physical sessions with Atos Scientific Community members, bringing hands-on experience of the innovations that will help you meet your transformation challenges and grow your business.

Through technology briefings, co-innovation workshops and proofs of concept, you will not only get insights into the latest technology developments and trends, but you will also gain an understanding of what they could do in your industry and for your own organization.

Contact us online or through your Client Executive Partner to organize a workshop.

atos.net/btic

About Atos

Atos is a global leader in digital transformation with 112,000 employees and annual revenue of c. € 11 billion. European number one in cybersecurity, cloud and high performance computing, the Group provides tailored end-to-end solutions for all industries in 71 countries. A pioneer in decarbonization services and products, Atos is committed to a secure and decarbonized digital for its clients. Atos is a SE (Societas Europaea), listed on Euronext Paris and included in the CAC 40 ESG and Next 20 Paris Stock indexes.

The purpose of Atos is to help design the future of the information space. Its expertise and services support the development of knowledge, education and research in a multicultural approach and contribute to the development of scientific and technological excellence. Across the world, the Group enables its customers and employees, and members of societies at large to live, work and develop sustainably, in a safe and secure information space.

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Let's start a discussion together