In collaboration with Accenture

WORLD ECONOMIC FORUM

Navigating the Industrial Metaverse: A Blueprint for Future Innovations

INSIGHT REPORT

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Images: Getty Images, MidJourney

Contents

Foreword

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The metaverse aims to be the future of the internet – a spatial, social internet experience that uses existing and emerging technologies to seamlessly blend physical and digital worlds. With recent developments in generative artificial intelligence (AI), metaverse creation and growth may expand. While media announcements about AI and the metaverse may compete for media attention, they are, in fact, partners in this digital evolution.

In May 2022, the World Economic Forum launched the Defining and Building the Metaverse Initiative, which orchestrates an integrated approach to the development and governance of the metaverse. The initiative is divided into two workstreams: governance, and economic and social value creation. It seeks to build a responsible, equitable, inclusive, diverse and accessible metaverse through discussions with a wide array of stakeholders.

This report continues the World Economic Forum's Defining and Building the Metaverse Initiative. In collaboration with Accenture, previous outputs from this initiative include:

- *Demystifying the Consumer Metaverse*
- *Social Implications of the Metaverse*
- *Interoperability in the Metaverse*
- *Privacy and Safety in the Metaverse*
- *Exploring the Industrial Metaverse: A Roadmap to the Future*

In this report, the economic and social value creation workstream underscores the imperative for global collaboration in forming a shared understanding of the industrial metaverse. Building on the foundations from *Exploring the Industrial Metaverse: A Roadmap to the Future*, a Cambridge collaboration, and extensive analysis across five primary industries (industrial manufacturing, automotive, cities and urban infrastructure, energy and healthcare), this publication aims to provide leaders with a strategic guide. It aims to illuminate pathways for creating and realizing opportunities across the industrial value chain, identifying the areas most impacted, and establishing best practices that encourage innovation and growth, while safeguarding privacy and security.

To build a metaverse that is economically vibrant as well as equitable, accessible and inclusive, attention must be given to human dimensions, equality and sustainability. The report draws on contributions from a diverse global working group of over 150 experts across academia, international organizations, civil society, governments, technology and business sectors.

Executive summary

With the industrial metaverse poised to supercharge the next industrial revolution, leaders must embrace it to stay ahead.

The industrial metaverse, projected to be a $100 billion market globally by 2030, is spearheading operational change by seamlessly incorporating transformative technologies across industrial value chains. This innovation promises participants a blended reality where the physical world becomes unconstrained through its digital counterparts, which offer agility, adaptability and real-time interactivity.

This report emphasizes how the metaverse will propel the next phase of industrial revolution through the convergence of digital twins, a core building block of the industrial metaverse, and three rapidly evolving fields – spatial computing, artificial intelligence (AI), and Web3 and blockchain. It outlines opportunities for leaders, explores how various industries are using these technologies to unlock value and discusses the foundational elements for a collaborative, responsible and economically sustainable next era of the internet. The aim is to assist stakeholders in navigating the complexities and realizing the transformative opportunities of the industrial metaverse.

A selection of this paper's key insights:

- **The metaverse is poised to supercharge the upcoming phase of the industrial revolution.** Leaders are developing and sharpening their strategies to unlock value from the industrial metaverse, using technologies to intelligently merge the digital and physical realms. This fusion aims to enhance experiences, boost engagement and elevate productivity through the creation of new realities.

- **Embracing innovation to withstand a myriad of disruptions.** Leaders are doubling down on innovation to fortify themselves against disruptions stemming from technological shifts, changing consumer preferences and climate change. These technologies promise enhanced data simplicity, transparency, interaction, collaboration and efficiency in business processes.

- **Pioneering new routes for value creation across enterprise functions and industrial value chains.** The industrial metaverse impacts the entire value chain, driving productivity and growth, opening avenues for diverse revenue streams, solving real-world problems digitally and driving greater efficiency. This report explores its impact through a set of themes that showcase significant departures from current approaches to design and engineering, collaboration, manufacturing and operations, facilitating superior decision-making.

- **Competition intensifies as leaders strive to get ahead with real-world implementations already flourishing.** This report analysed over 600 spatial experiences and Web3 initiatives executed by 100 of the largest companies across 10 industries. This included extensive analysis across industrial manufacturing, automotive, cities and urban infrastructure, energy and healthcare.

- **Emerging technologies play a pivotal role in advancing growth and adoption.** Digital twins are a core building block, actively simulating real-world objects, and in combination with AI and quantum computing, these technologies will be crucial for processing the world in more intricate ways. Together, they will efficiently and accurately simulate complex scenarios at greater speed.

- **Players actively adopting these technologies and techniques will succeed and thrive.** Leaders will be faced with the daunting task of navigating a complex, ever-changing landscape but can better prepare themselves by understanding how this impending shift will alter business processes through greater product design, development and operational efficiencies.

- **Cross-industry collaboration is required to build capabilities and ecosystems that will unleash its full potential.** The irrefutable potential notwithstanding, a carefully calibrated approach is required to create meaningful, optimal outcomes for all stakeholders. Key considerations were identified to deliver a responsible, ethical and economically viable industrial metaverse.

Embracing each innovation will accelerate leaders in their mission towards a more sustainable and resilient future. By demystifying the technologies and techniques, routes to value and potential headwinds, this report supports stakeholders in effectively navigating the industrial metaverse and accelerating its adoption in the decade ahead.

Introduction

How the metaverse will propel the next phase of industrial revolution.

The metaverse aims to be a spatial, social internet experience that uses existing and emerging technologies to seamlessly blend physical and digital worlds. It will enable shared, persistent realities, transforming how people interact with information, others and their surroundings.

The metaverse, a vision for the internet's future, combines current online experiences with new spatial dimensions,[1,2] drawing widespread interest for its research, development and investment potential. It promises to revolutionize how people live, work and interact and how enterprises function. AI plays a pivotal role in this shift, capturing public attention as a key force driving the next-generation internet, alongside spatial computing, web3, blockchain and other groundbreaking technologies.

While the consumer metaverse swings between public intrigue and scepticism, the industrial metaverse has gained traction among innovators and early adopters, already delivering tangible value in their operations. This reinforces the shared belief that the industrial sector is among the metaverse's most influential arenas.

Although it would appear that the topic of the metaverse has receded towards the latter half of boardroom discussions, recent announcements from Sony and Siemens at CES, discussions at the World Economic Forum Annual Meeting in Davos and the launch of the Apple Vision Pro have brought the metaverse back into the limelight. These high-profile announcements have rejuvenated interest and investment in metaverse technologies, coupled with a resurgence in Web3, catalysing growth throughout the metaverse ecosystem.

This report discusses the metaverse's crucial role in accelerating the industrial revolution, specifically the industrial metaverse. It clearly outlines opportunities for leaders to harness its value and the key considerations for creating a collaborative, responsible and economically viable next era of the internet for the economy, business and people.[3]

Reinvention as the strategy for success

Accenture's *Reinvention in the age of generative AI* report concluded that for companies to stay ahead of disruption, they must continuously reinvent their businesses and set new performance frontiers for themselves and their industries.

Generative aritificial intelligence (AI) has emerged as a powerful catalyst for reinvention, accelerating organizations' progress towards unprecedented performance levels. According to Accenture's report, technology is the top lever of reinvention for 98% of organizations, with 82% of those organizations identifying generative AI as a key driver of this change.

As companies embark on their reinvention journey, the metaverse will emerge as a critical frontier, where establishing a strong presence in the metaverse will likely become a fundamental requirement.

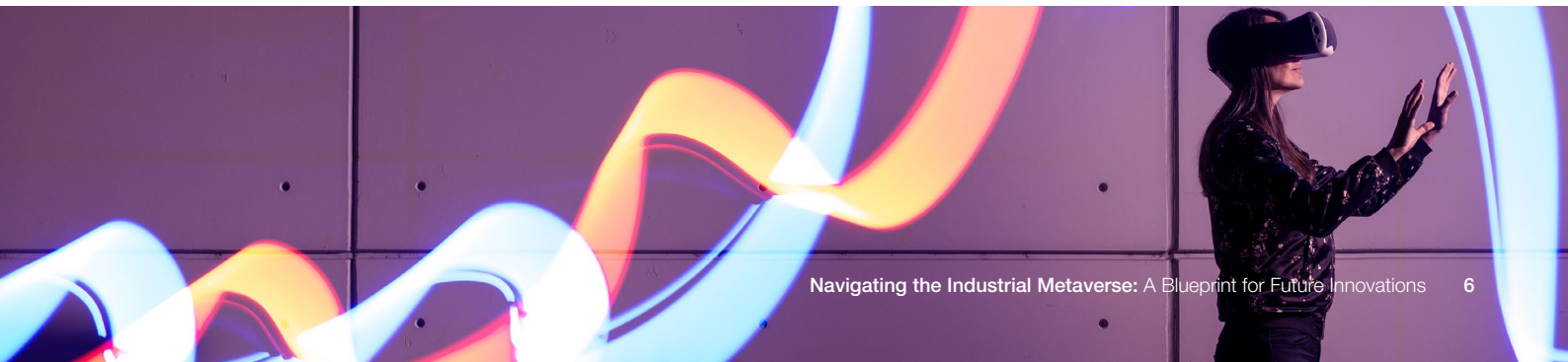
A new era of experience and efficiency

92%

of executives plan to create a competitive advantage for their organizations by leveraging spatial computing.[4]

Undoubtedly, the metaverse offers substantial opportunities across industries through new forms of experience and ownership possibilities, and there are three evolutions within the internet that will impact this revolution, creating value in new realities:

- **Spatial experiences** – an emerging version of virtual environments that provides a sense of space and belonging, seamlessly blending the physical and digital worlds. These experiences are enabled by spatial computing, otherwise known as extended reality (XR). This encompasses a suite of technologies, including augmented reality (AR), mixed reality (MR) and virtual reality (VR).
- **Digital ownership** – a shared infrastructure that is distributed to enhance trust and security, enabled by Web3 and blockchain.
- **Generative AI** – accelerating and reducing barriers to entry of content development, enabled by artificial intelligence and machine learning (ML) tools.



The metaverse: consumer, enterprise and industrial

The emergence of a new spatial computing medium, and the applications that will take advantage of its capabilities to pierce the physical-digital divide, is imminent. The metaverse has struggled under the weight of ever-expanding definitions and expectations, but the value in the technology behind it has never been in doubt. Although often represented as a single all-encompassing digital world, the metaverse can be viewed as three distinct sectors: consumer, enterprise and industrial. The pace at which each of these sectors will evolve is uncertain, but all analyses project rapid growth for the industrial metaverse and its enabling technologies within the next decade.

The **consumer metaverse** focuses primarily on the social, entertainment and educational experiences of individuals. Leveraging capabilities like interactive product launches, immersive settings and tokenized experiences unlocks new avenues to boost brand engagement, purchase experience and customer loyalty. The earlier report, *Demystifying the Consumer Metaverse*, provides further insight into consumer-facing metaverse applications, routes to value and how industry players can realize the economic opportunity through traditional and entirely new business models.

The **enterprise metaverse** virtualizes working engagement, learning, communication and collaboration across distances, forming new ways of working. Instead of mundane instructional videos, employees can practise and apply skills in a real-time immersive setting alongside others. This applies to everything from learning culture and core values during employee onboarding to practising complex, high-risk and hazardous scenarios in a safer virtual space.

FIGURE 1 **Opportunities across enterprise functions**

The **industrial metaverse** focuses on how digital information and AI are used to optimize interactions between people, physical goods, production assets, places, processes, supply chains, operations, field services and equipment, and industrial environments. Immersive technologies enable bidirectional knowledge flow between the physical and virtual worlds. This can transform analyses of past activities and future predictions at strategic and operational levels across manufacturing, industries, government functions or processes where the link between the physical and virtual is important. The goal is to bring software agility to the physical world's complexity while enabling remote collaboration.

FIGURE 2 | **Opportunities across industrial value chains**

Opportunities across industrial value chains

Industrial metaverse for **design and engineering**

is narrowing the gap between designers, engineers and customers by allowing them to collaborate and co-create during early design stages, helping shorten design cycles.

Industrial metaverse for **production and operations**

is enabling new methods for upskilling the workforce, contextualizing data, simulating experiences and promoting collaboration like never before, regardless of physical locations.

Industrial metaverse for **supply chain**

is building distributed, trusted and secure supply chains that provide end-to-end visibility, helping de-risk and reduce costs throughout.

$22 billion

Estimated size of the immersive collaboration market by 2030, representing 35% of the total market.[5]

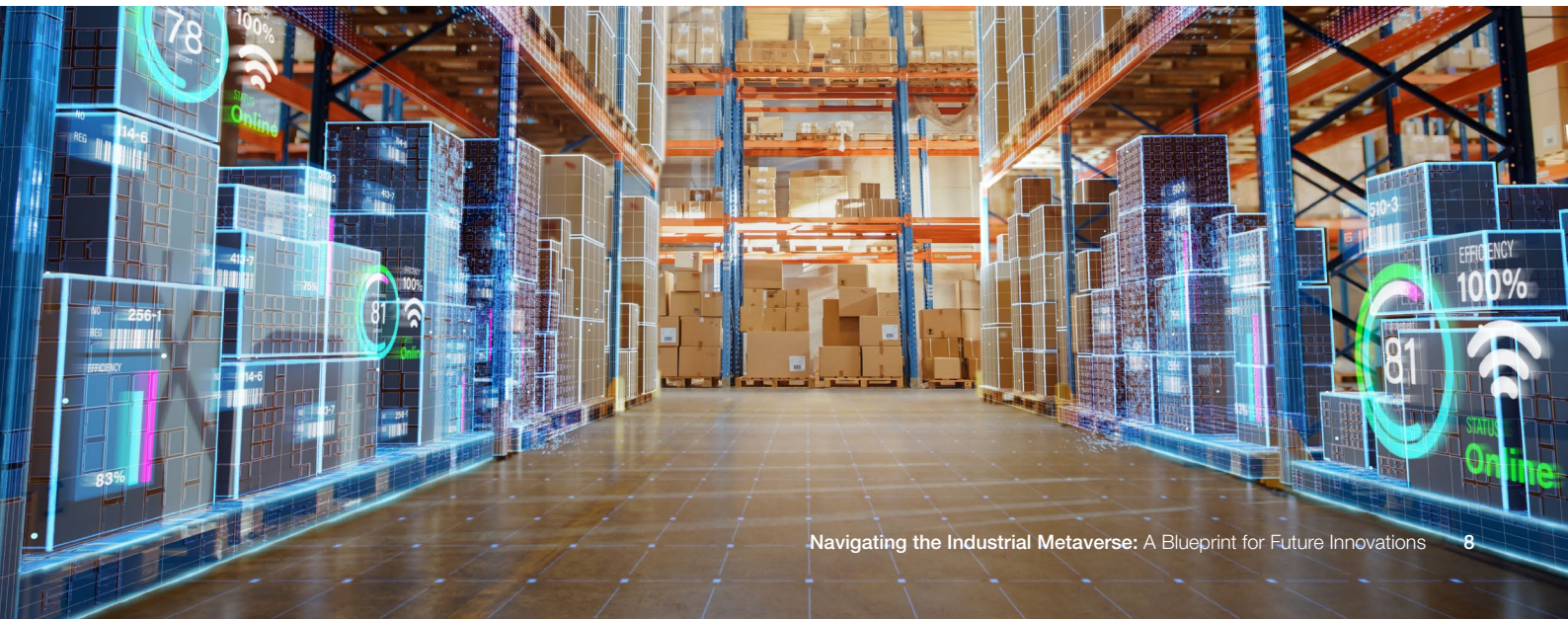
Although real-life applications of the consumer metaverse are still developing, the industrial metaverse is ahead on the adoption curve, aligned with actual problems and business imperatives and driven by on-the-ground implementation.

Amazon Robotics exemplifies this by building digital twins of its warehouses. Through the implementation of NVIDIA Omniverse, digital twins have been used to run simulations to optimize warehouse design, train intelligent robot assistance, and better configure human and robot workstations.

Mercedes-Benz is empowering its factory employees – from frontline workers and plant managers to process engineers[5] – to drive process innovation through data insights even as it takes the next step to digitize its production process using NVIDIA Omniverse to design and plan manufacturing assembly facilities.

Helsinki launched a 3D digital twin of its urban environment (Helsinki 3D) with the purpose of simulation, visualization and analysis for urban planning. The resource efficiencies enabled by industrial metaverse solutions help boost business competitiveness while continually driving progress towards sustainability, resilience, decarbonization and dematerialization goals.

The enterprise metaverse also plays a vital role in helping organizations accelerate operations, boost collaboration and streamline everyday processes. While this report will predominately focus on the applications of the industrial metaverse, from a wider enterprise perspective, the metaverse will also fundamentally change how businesses operate, impacting talent attraction, learning and collaboration methods, and how transactions and processes are conducted across functions. These are all implications for the industrial sector to consider and, therefore will also be explored in part within this report.



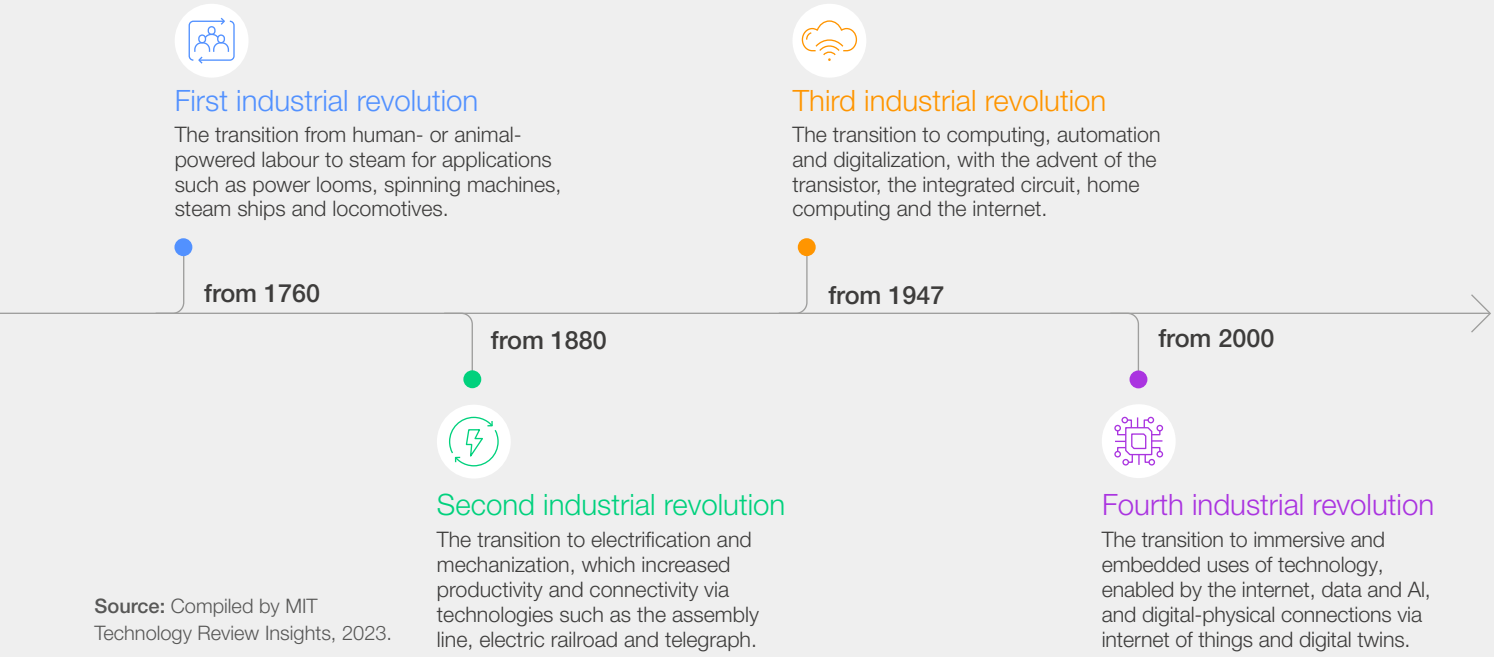
The industrial metaverse

Sparked by new technologies and changing customer behaviour, the world is entering an industrial renaissance. Immersive virtualization now facilitates collaborative learning, building and innovation unbound by geography, demographics or physical limitations.

Amid recovery from the COVID-19 pandemic, a series of technological, macroeconomic, societal and business-to-business (B2B) customer trends are accelerating and converging to create new challenges and opportunities for growth in the industrial sector. Industrial companies cannot simply focus on a return to the pre-pandemic normal. The scale of ambition needs to be much higher, shifting gears to enter a new phase of accelerated growth.

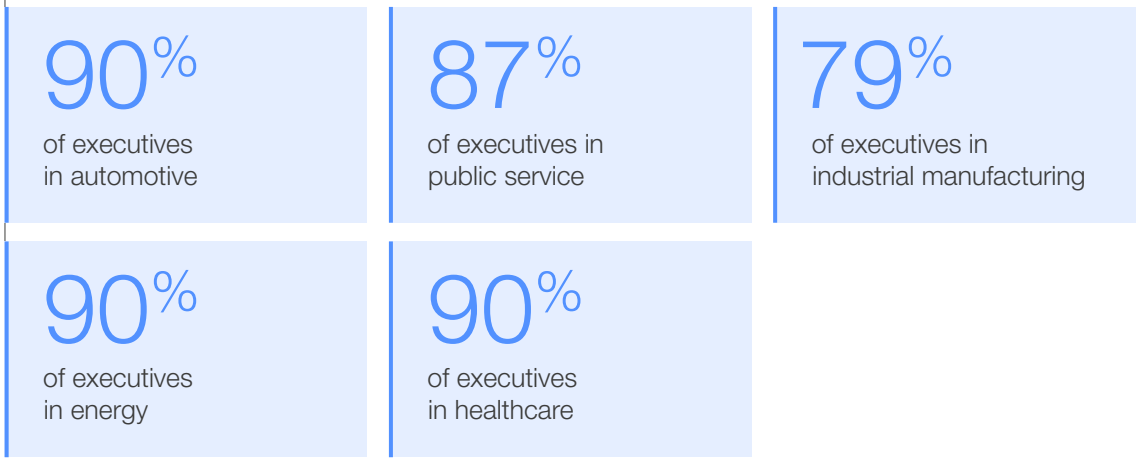
The metaverse helps companies fuel growth by meeting evolving B2B expectations. It also helps companies reimagine connected products, build intelligent operations, prioritize sustainability, and blend technology with talent and new ways of working. By combining these technologies uniquely, companies in the industrial sector are creating distinct business value.

FIGURE 3 **Timeline of industrial revolutions**



Source: Compiled by MIT Technology Review Insights, 2023.

FIGURE 4 **Executives believe primary metaverse technologies are already inspiring their organization's vision or long-term strategy**



Source: Accenture Technology Vision 2023

Analysis shows a significant uptick in industrial metaverse activations since 2018, recording a compound annual growth rate (CAGR) of 47% over the 5 years since then.

The industrial metaverse, which mirrors and simulates real machines, factories, cities, transport networks and other highly complex systems in the digital world, as described by MIT and Siemens, will offer to its participants fully immersive, real-time, interactive, persistent, and synchronous representations and simulations of the real world. This will empower industries, from automotive to healthcare, to solve extraordinarily complex real-world problems digitally.[6]

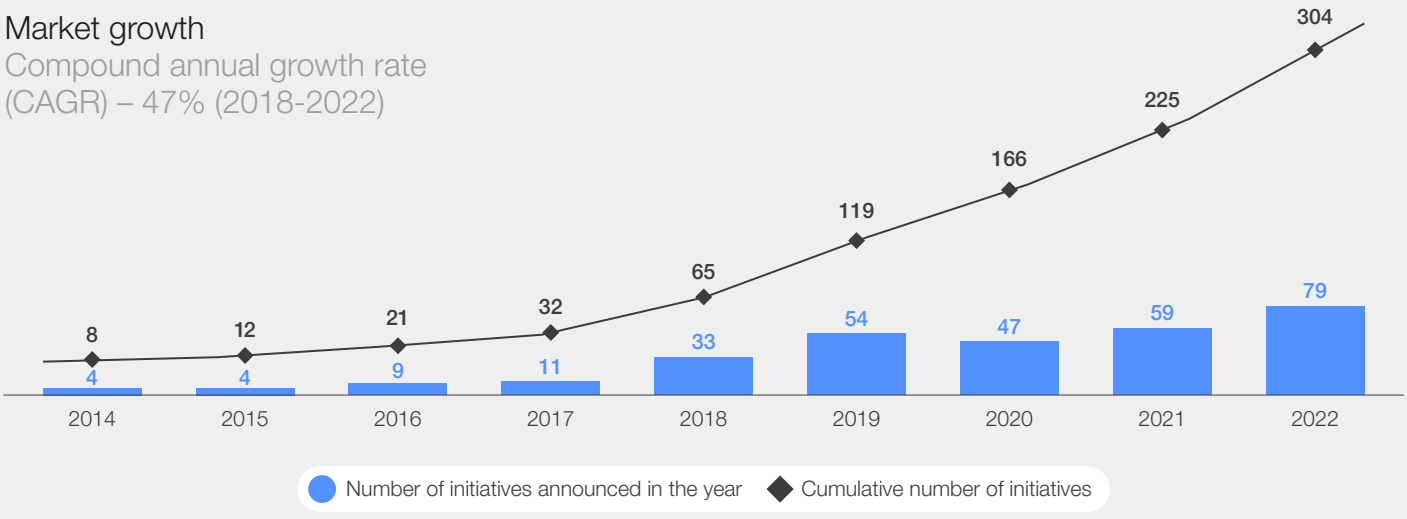
The industrial metaverse is no longer just a concept, taking shape with real-world implementations. Analysis of over 600 spatial experiences and Web3 initiatives, which were executed by 100 of the largest companies across 10 industries (see Figure 5), revealed automotive, energy, software and platforms, and aerospace and defence currently lead the way in industrial metaverse investment and activity.

Activations across the industrial metaverse have risen steadily since 2014, but after hype outpaced technological maturity, some companies have developed a degree of hesitancy towards activating and announcing new capabilities in 2023. This decline is in part due to the rise of generative AI; there is an assumption among many that its emergence has caused the metaverse to retreat into the background. The reality, however, is that the metaverse is alive and well.

From an investor relations perspective, generative AI may have taken centre stage, but the development of the industrial metaverse continues at a fast pace, with real-world implementations happening across a diverse set of industries. This is evident by the sheer volume of initiatives analysed within this report, and it seems that AI will in fact be a crucial building block for the industrial metaverse, and the broader metaverse in general.

> **[The metaverse is] immersive, making users feel as if they're in a real environment; collaborative in real time; open enough for different applications to seamlessly interact; and trusted by the individuals and businesses that participate**
>
> Annika Hauptvogel, Head of Technology and Innovation Management, Siemens

FIGURE 5 **Industrial and enterprise metaverse activations over the years**



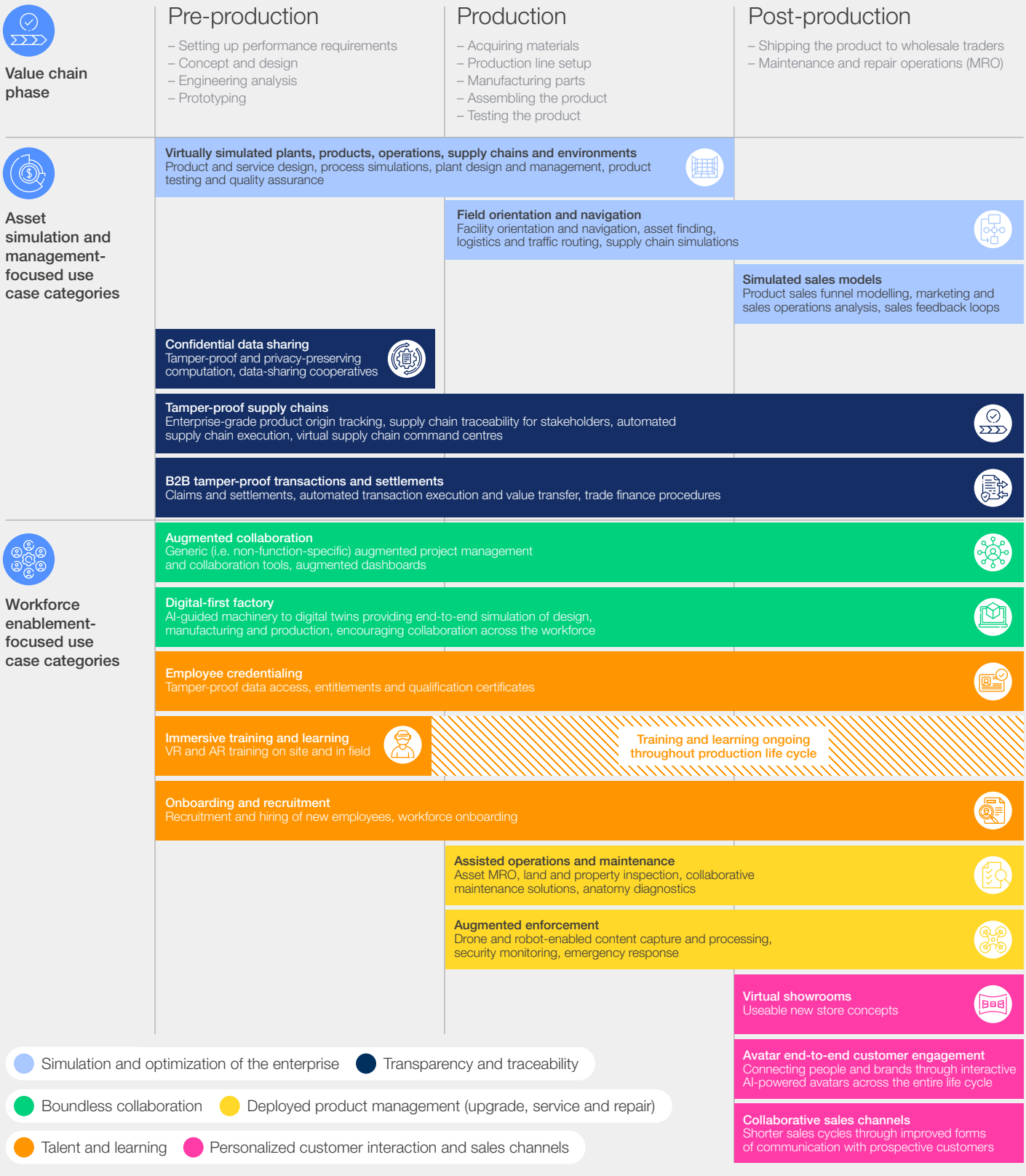
Note: Refers to enterprise and industrial metaverse initiative announcements made by leading 100 companies across 10 industries: Aerospace and defence, automotive, banking, energy, health, industrial, insurance, retail, travel, software and platforms.

Source: Accenture

Opportunities across the industrial value chain

Industrial metaverse applications can be clustered along the product life cycle into pre-production, production and post-production. All these use cases represent a concrete way to generate impact and value for companies both in terms of operations and business models, supporting the shared community belief that industry is among the most relevant fields of impact of the metaverse.

FIGURE 6 **Industrial and enterprise use cases across the value chain**

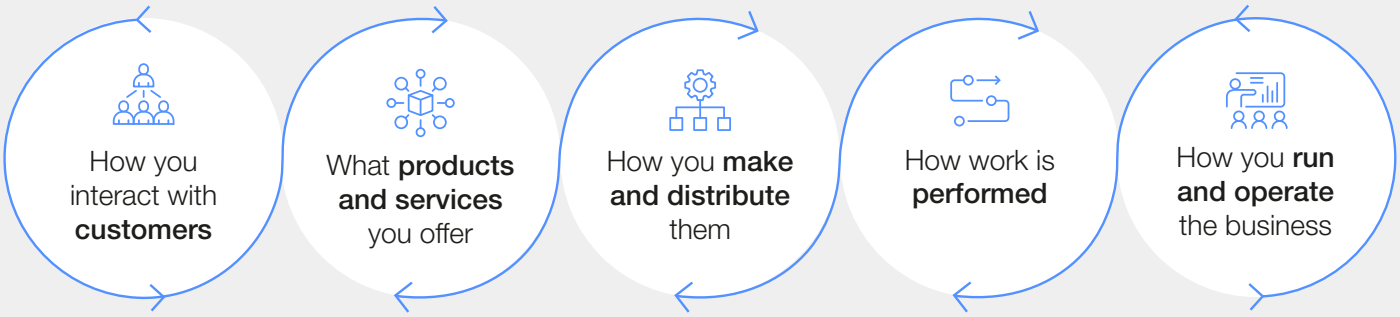


Source: Accenture; World Economic Forum, *Exploring the Industrial Metaverse: A Roadmap to the Future*, 2023.

Technologies accelerating a new industrial revolution

Powered by a converging stack of innovative technologies, the metaverse is impacting every part of an organization – from customer experiences and products to employee experiences and enterprise operations (see Figure 7). Organizations building the industrial metaverse agree it relies on existing and developing foundational technologies as the fabric: digital twins, spatial computing (XR/AR/MR/VR), blockchain and Web3 and AI/generative AI. Robotics, internet of things (IoT), and cloud and edge computing also play a vital role, acting together as the building blocks of the industrial metaverse.

FIGURE 7 **The metaverse is transforming all aspects of business**



Digital twins as a core building block of the industrial metaverse

In advanced industries, almost 75% of companies have already adopted digital-twin technologies that have achieved at least medium levels of complexity.[7]

The concept of digital twins is at the core of the industrial and enterprise metaverse – a virtual model designed to accurately reflect real-world environments and objects.

A digital twin integrates all the data about physical environments and objects across their entire life cycle. In the future, the industrial and enterprise metaverse will ultimately be an aggregation of dozens of interconnected digital twins replicating everything from physical assets (like products, shop floors and office buildings) to people (such as customers and employees) to core business processes and supply chains. Industrial players will be able to create digital twins to run live simulations of real-world physical objects and infrastructure – from factories to power grids to car tyres. Workers can detect incidents pre-emptively and run risk-free experiments. Today, the use of digital twin technologies can be seen in the development of 85% of the world's electric vehicles (EVs) or powering breakthrough prototypes, such as the world's first solar aircraft and new biomaterials.[8]

BOX 1 **What is a digital twin?**

A digital twin refers to a virtual replica or representation of a physical object, process, system, or entity in the digital world. It is created by collecting and integrating various data sources from computer-aided design (CAD) data, sensors, simulations, and other sources to create a real-time digital counterpart. The digital twin is designed to mirror the physical entity, allowing for monitoring, analysis, and prediction of its behaviour and performance.

> **The industrial metaverse will not just help us fix things when they break, it will be a place where engineers, workers, anybody, can experiment and test improvements. AI bots will tour digital twins 24/7 on their own and come up with innovative ideas to make things better.**
>
> Roland Busch, Chief Executive Officer, Siemens[9]

> Industry experts foresee AI as a significant enabler of the industrial metaverse, with its potential to elevate other enabling technologies to new heights.[10]

A new spatial medium is emerging as generative AI takes centre stage

Generative AI is a transformative force that is accelerating the speed to market of metaverse design and content development, helping to reshape new realities. Generative AI tools will upend digital labour by creating more efficient workflows, helping stakeholders in the industrial sector quickly draft immersive experiences, dramatically shortening input gathering and initial review.

Several leading companies such as PepsiCo, Tesla and BMW are using AI infrastructure for digital twins of factories and supply chains to generate synthetic data that can then be used to train AI/ML models. This is helping accelerate data-driven decision-making, analyse and improve performance, and provide predictive maintenance. In some cases, it is even facilitating real time virtual or 3D collaboration across geographies.

BOX 2

Factory of the future

Mars is combining AI with digital twins to simulate operations in over 100 of their manufacturing facilities globally. By combining AI with digital twins and IoT, Mars can use real-time data to predict and optimize production while monitoring equipment performance. These systems have enabled the introduction of robotics to increase the precision of product manufacturing and offset labour challenges.

96%

of executives believe AI agent ecosystems represent a significant opportunity for their organization.[11]

Generative AI's "build" capability will expand over time to automatically create the 3D asset, environment, sound and animation outputs guided by human-driven craft expertise. Generative AI's recent popularity has increased demand for better experiences.

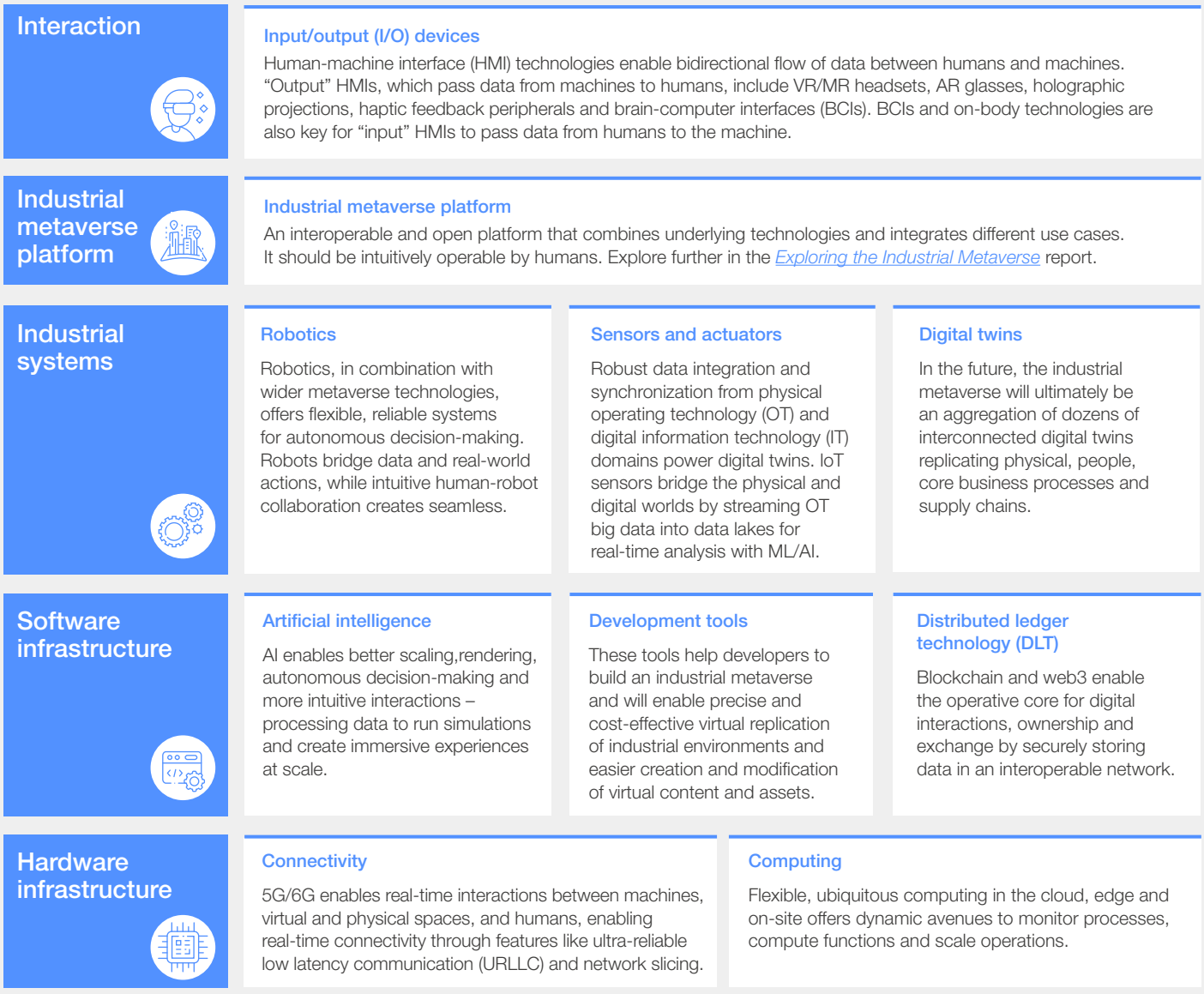
The creation of virtual embodied agents – AI-driven chatbots in humanoid-presenting avatars that draw, talk and gesture the way people do – will increase the demand for augmented and virtual reality experience layers tailored to an organization's needs.

According to a recent study by Accenture, generative AI has enormous economic potential. An additional $10.3 trillion in economic value could be created by 2038 when organizations adopt generative AI responsibly at scale, in ways that place people and innovation first and foremost.[12]

Additional enabling technologies

In addition to digital twins and generative AI, which form its core components, the industrial metaverse is powered by a multi-layered technology stack, beginning with hardware infrastructure encompassing connectivity and computing. The software infrastructure layer incorporates AI, development tools and distributed ledger technologies like blockchain, dependent on the underlying hardware. Industrial systems further include robotics, diverse sensors and actuators (IoT), laying the groundwork for an industrial metaverse platform. Atop these layers, the interaction layer, featuring input/output (XR) devices, serves as the user interface.

FIGURE 8 **Underlying technologies and capabilities of the industrial metaverse**



Source: Accenture; World Economic Forum, *Exploring the Industrial Metaverse: A Roadmap to the Future*, 2023.

IoT sensors stream OT big data into data lakes for real-time analysis with ML/AI. This processed data runs simulations, providing both possible scenarios and historical insights, overlays operational digital twins, and combines with IT data for actionable insights. Generative AI will add an experiential layer here as it can create 3D assets, avatars and components for virtual worlds that will lead to immersive experiences at scale.

Robots bridge data and real-world actions, while intuitive human-robot collaboration creates seamless teamwork.

BOX 3 | Autonomous robots at industrial sites

Frans, Telia's industrial robodog, is a mobile robot for diverse industries. It collects and analyses data, performs 3D modelling, gas and thermal imaging, monitors progress, detects hazards and aids in tasks. It operates in hazardous environments and creates 3D models for a metaverse, enabling remote collaboration.[13]

Real-time interactions enabled by 5G/6G are required for critical applications such as robotics and remote operations, requiring the stability and reliability of the wireless network, while 5G/6G and edge computing will help enhance productivity, human interaction and virtual collaboration in digital-first settings.

XR has transformative potential in the industrial sector, providing various benefits such as improved efficiency, enhanced safety, and more effective training and design processes. XR experiences are enjoyed by humans with human-machine interface (HMI) technologies. "Output" HMIs include VR/MR headsets, AR glasses, holographic projections, haptic feedback peripherals and brain-computer interfaces (BCIs). BCIs and on-body technologies are also key for "input" HMIs to pass data from humans to the machine.

Digital twins form the creative core, whereas blockchain and Web3 enable the operative core for digital interactions, ownership and exchange. Blockchain can provide safe and secure storehouses for digital twins and knowledge. Synchronized nodes ensure consistent virtual world experiences. Smart contracts enable real-time transactions, providing legal, transparent and compliant trusted data exchange. Non-fungible tokens (NFTs) prove existence, authenticity and ownership of metaverse assets, enabling trading of digital twins and value creation throughout the asset life cycle.

Building infrastructure that ensures interoperability is an essential building block to realizing the potential and future development of the metaverse in its entirety – and in the case of the industrial metaverse, where various technologies, tools and processes will be used, interoperability will ensure that data can flow freely and accurately between different components of the metaverse ecosystem. This will facilitate efficient collaboration, data exchange and decision-making across disparate systems, ultimately enhancing productivity, innovation and competitiveness within industrial operations. Moreover, interoperability will foster open standards and ecosystems, encouraging the development of diverse and interconnected solutions that can address complex industrial challenges effectively.

Together, these foundational technologies and capabilities can help derive significant value from the metaverse for the industrial sector.

Catalysing business growth through the convergence of these emerging technologies

43%

of organizations plan to increase investments in new technologies to improve efficiency to manage through changes/disruptions in the business environment.[14]

Metaverse technologies are innovating processes for consumers, the workforce and enterprise, helping to accelerate the evolution of the internet in experience and infrastructure. The world is also entering a point of convergence, with huge opportunities lying at the confluence of these technologies which will help to realize the full potential of the industrial metaverse. For example, generative AI can accelerate the uptake of spatial learning experiences by making them more intuitive, conversational and context-aware. Similarly, spatial computing can help generative AI assume a digital identity to embody its potential in an immersive, engaging and lifelike manner with humanoids and virtual avatars.

Early signs of industrial players combining these technologies together are already evident, multiplying their impact and value creation. Companies that prioritize one over the other, such as moving investments away from spatial computing, Web3 and blockchain in favour of generative AI, risk losing out on the powerful value creation that their synergies have to offer in the long term.

BOX 4

Virtual integration for real-world efficiencies

NVIDIA Omniverse and NVIDIA AI gave BMW the chance to simulate the 31 factories in their production network. All the elements of the complete factory model, including the associates, robots, buildings and assembly parts, can be simulated to support a wide range of AI-enabled use cases such as virtual factory planning, autonomous robots, predictive maintenance and big data analytics. These new innovations will reduce planning times, improve flexibility and precision, and, in the end, produce 30% more efficient planning processes.[15]

Over time, the convergence of these technologies will create a seamless interface between the real and digital worlds, and the impact they could create is much larger than the sum of their parts. Companies stand to witness a multiplier effect if they can harness the combinations well.

Metaverse inherently human by design

95%

of executives believe making technology more human will massively expand the opportunities of every industry.[16]

Human by design is a pivotal shift in the relationship between humans and technology. Designing technology to enhance rather than alter human qualities fosters greater productivity, connectivity and accessibility. This approach not only addresses concerns about technology's impact on people's lives but also unlocks greater potential for innovation and value creation across industries. Through intuitive design and human-like intelligence, technology becomes more accessible, making it easier for individuals to interact with and benefit from it.

As technology becomes more human-centred, it has the potential to revolutionize various aspects of life, from work to healthcare, and to empower individuals to contribute to the digital revolution in unprecedented ways. Ultimately, embracing human by design philosophy ensures that technology serves humanity's needs and aspirations, paving the way for a more inclusive and empowered digital future.

The industrial metaverse is providing companies with new ways to immerse, experience and collaborate across the industrial value chain:

- **Immerse**: more natural and intuitive ways to interact with data across the value chain with the ability to immerse in digital twins for better contextualization (e.g. size/scale), allowing people to sense contextualized data rather than having to attempt to make sense of the data itself.
- **Experience**: ability to simulate near-realistic situations to develop soft skills and technical skills (e.g. emergency preparedness), virtual prototypes and 3D worlds to experience solutions prior to the build phase, to learn by trying rather than learning to try.
- **Collaborate**: closer to real-life engagements with people and assets that allow those involved to collaborate virtually and more effectively, unbound by geography or physical limitations, accelerating the entire product life cycle.

Part 1

Industrial metaverse: why leaders should act now

The metaverse offers an opportunity to unlock the power of the next industrial revolution.

1.1 Start of the next industrial revolution

Overall, the metaverse is estimated to be valued at around $900 billion by 2030, with virtual experiences accounting for nearly two-thirds of that number.[17] The industrial metaverse, already influencing design and operation from products to entire cities, is predicted to hit $100 billion in global revenues by 2030, surpassing the combined value of the consumer metaverse ($50 billion) and the enterprise metaverse ($30 billion).[18]

FIGURE 9 **Industrial metaverse: why now?**

$100 billion
global industrial metaverse market by 2030

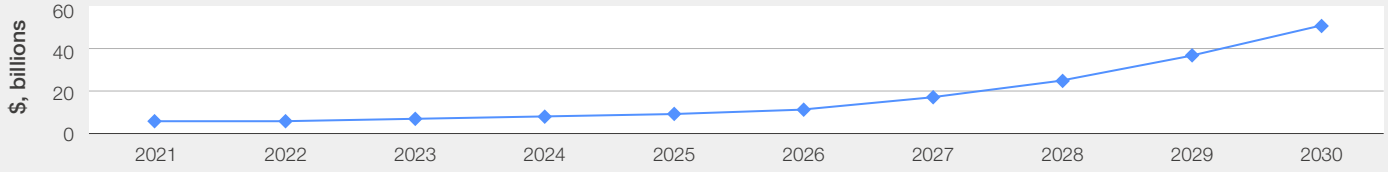
$183 billion
global digital twin market by 2031

92%
of US manufacturing executives in a 2023 survey claim to be experimenting with metaverse use cases, with each exploring as many as six use cases on average

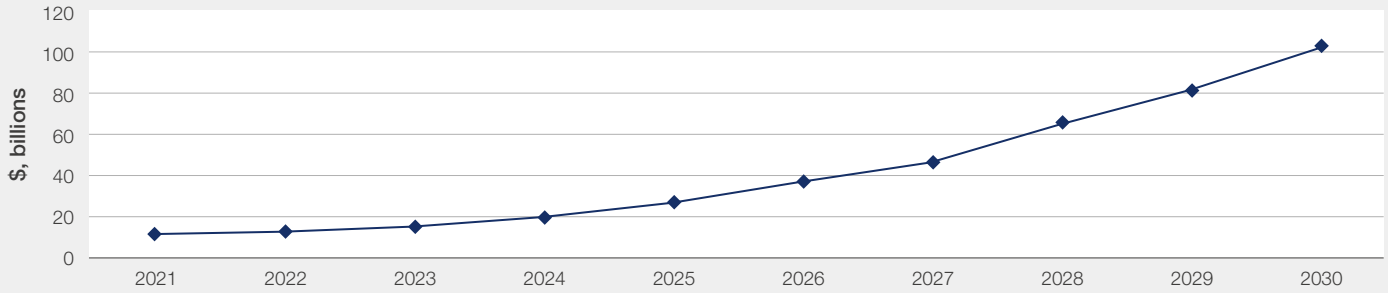
Sources: Lawton, George, "Why the industrial metaverse will eclipse the consumer one", *VentureBeat*, 23 December 2022, https://venturebeat.com/virtual/why-the-industrial-metaverse-will-eclipse-the-consumer-one/; "The emergent industrial metaverse", *MIT Technology Review Insights in partnership with Siemens*, 29 March 2023, https://www.technologyreview.com/2023/03/29/1070355/the-emergent-industrial-metaverse/; "Exploring the industrial metaverse", *Deloitte*, 2023, https://www2.deloitte.com/us/en/insights/industry/manufacturing/industrial-metaverse-applications-smart-factory.html.

FIGURE 10 **Global metaverse revenue projections**

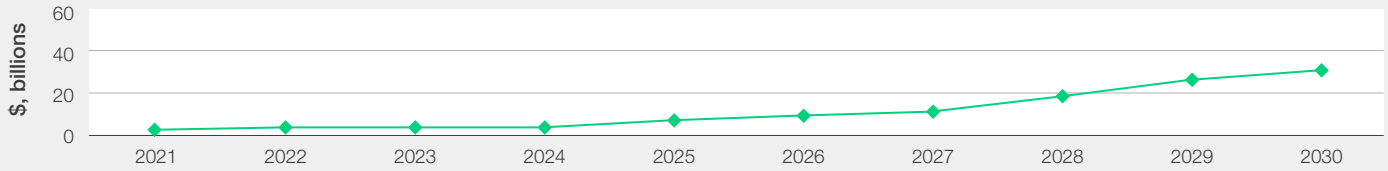
Consumer metaverse Virtual space revenue (world markets)



Industrial metaverse Digital twin and simulation and industrial XR revenue (world markets)



Enterprise metaverse Immersive collaboration and related cloud revenue (world markets)



Source: ABI Research.

FIGURE 11 | **Global metaverse market size estimates by industry**

Automotive	Healthcare	Energy	Industrial manufacturing
Value in 2022: $2.2 billion	Value in 2022: $4.92 billion	Value in 2022: $6 billion	Value in 2021: $12.9 billion
Value in 2032: $27.2 billion	Value in 2029: $75.8 billion	Value in 2031: $80 billion	Value in 2031: $24.4 billion
CAGR: 28.6%	**CAGR: 47.8%**	**CAGR: 33.4%**	**CAGR: 7.3%**

Sources: "Metaverse in Automotive Market", *Allied Market Research*, September 2023, https://www.alliedmarketresearch.com/metaverse-in-automotive-market-A107609; "Metaverse in Healthcare Market: High Investments and Technological Advancements to drive global market growth", *Maximize Market Research*, 2022, https://www.maximizemarketresearch.com/market-report/metaverse-in-healthcare-market/213965/; "Global Investment in Energy Metaverse Estimated to Grow to Nearly $80 Billion in 2031", *Guidehouse Insights*, 27 July 2023, https://guidehouseinsights.com/news-and-views/global-investment-in-energy-metaverse-estimated-to-grow-to-nearly-$80-billion-in-2031; "Metaverse in Manufacturing Market 2022", *Market Statsville*, December 2022, https://www.marketstatsville.com/metaverse-in-manufacturing-market.

1.2 New industrial world where the metaverse plays a pivotal role

The industrial metaverse is already helping industries foster growth, while ensuring net positive environmental outcomes in increasingly competitive economies, by helping to:

- Compress transformation cycles
- Attract, engage and retain the workforce
- Build transparent and sustainable supply chains
- Curb the waste menace, protect the environment
- Transform the customer interaction experience

Compress transformation cycles

Today's executives face an unprecedentedly complex and dynamic business landscape. Technology, consumer preferences and climate change are driving massive structural shifts in how the world operates. Accenture's *Total Enterprise Reinvention* research shows a 200% rise in the Global Disruption Index – a composite measure that covers economic, social, geopolitical, climate, consumer and technology disruption – between 2017 and 2020, compared to only 4% between 2011 and 2016. The exponential rate at which industrial systems are becoming complex, coupled with the nonlinear growth in global disruptions influencing corporate trajectories, makes it imperative for businesses to expedite their transformation cycles.

Compressed cycles require faster, better learning and coordination across the enterprise. That's where the industrial metaverse comes in, transforming each business process into a virtual being in which every element can be studied and understood individually or collectively, and its impact analysed at speed. This optimizes the decision-making process for employees and provides a 360-degree view to the C-suite to make tough decisions – it fast-tracks informed, data-driven operational decisions, rapidly boosting efficiency and productivity.

The metaverse makes it easier for the C-suite to identify performance improvements and assess their impact more rapidly and accurately. Immersive XR and digital twin learning help globally-dispersed employees collaborate, test solutions live and find better solutions faster at scale. At the same time, digital twin control towers facilitate seamless collaboration between managers, operators, leadership and ecosystem players.

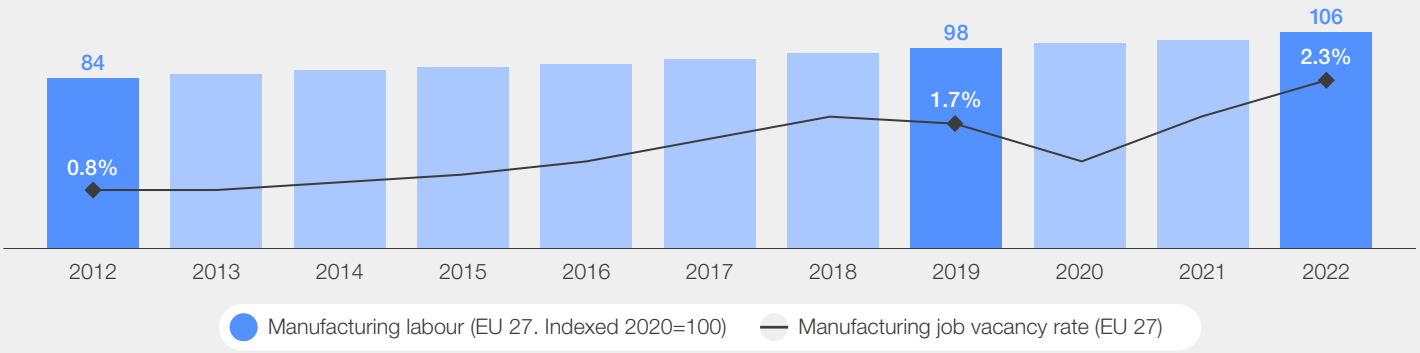
BOX 5 **Early adopters already generating significant value**

Operational efficiency		
Monitoring operations and making real-time decisions – from anywhere – reducing the time it takes to establish and run capital projects with immersive environments.	Workers equipped with augmented reality experienced a 30% reduction in issue resolution time.[19]	Shell uses AR helmets to provide field workers with remote over-the shoulder supervision by operation experts across the world. Each helmet comes with a built-in computer that is voice-controlled and equipped with a 7-inch display and a camera, allowing expert technicians to see through the eyes of a worker.

Attract, engage and retain the workforce

Skills shortages resulting from ageing populations have already started to become a burden for industrial growth in many nations across the world.[20] Talent shortage is becoming more acute than ever, with a staggering 77% of employers worldwide struggling to find the skilled professionals they required in 2023. This represents a notable increase of 2 percentage points compared to the previous year (2022) and more than double the challenge faced in 2015 when only 38% reported difficulty in sourcing talent.[21] As a result, the manufacturing industry is experiencing an uncommon labour situation. Consider the European Union (EU), where job vacancy and labour cost rates are at an all-time high, signalling serious recruitment and retention difficulties. At the same time, labour costs in manufacturing are also at record highs (see Figure 12).

FIGURE 12 **EU's labour vacancy rate**



Note: Job vacancy rate = number of job vacancies/ (number of occupied posts + number of job vacancies) x 100

Source: Eurostat Labour Market Database, extracted 19 August 2023.

COVID-19 popularized web conferencing and remote work. Full remote work isn't universally suitable, with some workers feeling detached; but studies show 13% remote productivity gains and 70% morale boosts.[22] The metaverse can bridge these gaps as interactions become fully immersive and intuitive, offering a new frontier for employers to attract, engage and retain the workforce in ways that bridge the physical and digital divide in a hybrid work environment. Talent fairs organized in immersive spaces can attract diverse talent irrespective of geographical boundaries.

Moreover, the recruitment process becomes more inclusive with avatar interactions eliminating common issues arising from unconscious bias. Virtual onboarding can help new recruits from all over the world to connect with company ethos and culture more effectively. Virtual offices in the metaverse can spur global collaboration, transcending the constraints of physical locations. They empower employees to seamlessly connect and collaborate, and foster collective growth unfettered by geographical boundaries or spatial limitations.

The story of Mars' "Factory of the Future" shows how leading companies are taking action, using AI, cloud, edge computing and digital twins to transform and modernize their global manufacturing operations.

In addition, the metaverse provides a unique platform for immersive training experiences that could help upskill talent quickly.[23] Training involving hazardous assets, machines and situations can be carried out without putting health and safety at risk, alleviating safety and time-to-proficiency concerns of workers.

BOX 6 **Early adopters already generating significant value**

Development of future workforce

Onboarding and training team members from around the globe in a personalized fashion; simulating potentially hazardous situations without the need to be on-site.

Training using extended reality has resulted in a 20% boost in productivity across newly trained employees.

Davita reimagined their employee training by building a virtual to scale model of their dialysis machine, allowing workers to experience the machine using a VR headset. It has allowed trainees to build muscle memory of movements required to string the machine, leading to greater learning retention.

Build transparent, traceable and sustainable supply chain

In recent years, supply chains have faced multiple disruptions in the form of climate crises, geopolitical issues and economic instability. Some of these challenges continue to test the transparency, flexibility and resilience of supply chains. Businesses with deep visibility into each component of their supply chain can leverage those insights to make more strategic decisions during disruption. These advantages create opportunities to build adaptable manufacturing processes, which in turn have the potential to support mass customization of products, providing more tailored services to end-consumers.

Metaverse, Web3 and blockchain technologies are advancing efforts towards sustainable supply chains. Blockchain, for instance, enables the recording of every transaction or movement of goods on an immutable and transparent ledger. This ensures that every participant in the supply chain can trace the origin and journey of products, providing visibility throughout the entire supply chain process. Similarly, with spatial computing, companies can move their command centres and control towers to virtual spaces, enhancing collaboration and reducing the need for physical interventions.

BOX 7

Early adopters already generating significant value

Manage complex supply chains

Multi-party data sharing powered by blockchain will enable a real time visibility engine and collaboration platform for end-to-end management to address volatile customer demand, and frequent supply disruptions.

Transparent and traceable supply chains increase predictability, which has shown to increase productivity by 20% across a workforce.

SAP has added blockchain technology to its supply chain traceability platform to aid its stakeholders in the agricultural industry, facilitating greater visibility for their products and boosting confidence in food safety. The platform allows the stakeholders to trace ingredients and products, enter requests and offerings, and verify and execute transactions in convenient and trusted ways.

Curb the waste menace and protect the environment

Reports suggest that 2.12 billion tonnes of waste are dumped worldwide every year.[24] An estimated 92 million tonnes of textiles waste[25] and 350 million metric tonnes of plastic waste is generated annually.[26] In the sustainable mobility market, 17.6 gigawatt hours (GWh) of lithium-ion batteries reached end of life by 2021, potentially growing to 140 GWh by 2035.[27]

The metaverse can facilitate virtual fabrications and simulations, enabling companies to experiment with different product options digitally, resulting in more efficient use of materials and a decrease in physical waste. Moreover, the metaverse as a platform can support on-demand and customized production models, allowing companies to manage demand and supply more efficiently and sustainably, without compromising on speed and scale.

The design, simulation, stress testing and operation of plants can eliminate material and time wastage associated with testing large capital projects before commissioning them at scale. Validating the whole process virtually before projects get commissioned brings companies very close to a zero-loss launch. In an earlier publication, readers can delve deeper into the approaches and considerations required to enable a sustainable metaverse (*Social Implications of the Metaverse*).

BOX 8 **Early adopters already generating significant value**

Drive sustainability across supply chains		
Advancing towards sustainability and net-zero targets through increased transparency, traceability and visibility of product flows, driving improvements across the supply chain, and enabling ethical sourcing, secure tracking and resource-efficient production.	According to Boston Consulting Group (BCG), retailers who streamline operations and improve their inventory management practices could improve margins by $500-700 million.[28]	Ford has used digital ledgers to record and store information on a blockchain. Through tokenization, they can improve the traceability of their supply chain and track whether environmental or ethical concerns exist in the refineries and mines where EV battery supplies are sourced.

Transform the customer interaction experience

The ultimate objective of every business is to retain existing customers and attract new ones. With the industrial metaverse, businesses can significantly transform customer interaction experiences with innovative solutions for collaboration, communication and operational efficiency. Businesses can use the metaverse to help customers configure and visualize customized product options before placing orders. This ensures that the final product meets specific requirements, reducing the likelihood of errors.

Moreover, companies can make better and more informed product design and market decisions even before launch with more refined insights gained from immersive environments. In B2B environments, conducting virtual inspections of facilities, machinery or infrastructure can be especially useful for audits and compliance checks, saving time and resources compared to physical visits.

BOX 9 **Early adopters already generating significant value**

New products and services	Improving offerings through new and enhanced customer insights, enabling customization and configuration in innovative ways, delivering entirely new concepts, and driving net-new growth opportunities.	BCG found that personalizing customer offerings through metaverse technologies could improve margins by $200-400 million due to improved store traffic and customer loyalty.[29]	Maserati wanted to design a new interactive configuration experience for clients coming into showrooms. A virtual car configurator was built to provide customers the optionality to customize their vehicles online, before they entered a showroom.
Customer experience	Enhancing customer interactions with products and services through immersive experiences, enabling new engagement methods, customization, sales and service channels.		

Part 2

Unlocking the value in the industrial metaverse

Unlock immediate value with the industrial metaverse. Companies that prepare now are more likely to succeed in the future.

2.1 Shifting gears for growth across the industrial landscape

The industrial metaverse is delivering immediate value to organizations today in terms of financial benefits, increased sustainability and improved efficiency, through process optimizations, scenario modelling, digital analysis, AI-enabled predictions and more. It is creating opportunities for increased revenue growth, as well as reduced operational costs – from traditional improvements across the industrial value chain to improvements that are entirely unprecedented. The diversity of initiatives across industries proves there is growing interest and traction for its various use cases.

Exploring routes to value creation in the industrial metaverse

Industrial manufacturing

Automotive

Energy

Healthcare

Cities and urban infrastructure

Click to skip to the relevant section

Industrial manufacturing

Click to skip to the relevant section

The metaverse can provide powerful simulations for manufacturing: designing, simulating and testing production lines and processes; offering capabilities such as virtual prototyping, AI-generated synthetic data, safe worker training, robotics integration, digital twin creation, real-time data integration and physics-based simulations; and using AI and machine learning for industrial automation.

Factory of the future

Siemens integrated automation, AI and IoT to develop autonomous factories that create highly efficient, adaptable and sustainable production flows with the goal of enabling real-time data-driven decision-making, predictive maintenance and seamless connections between machines and processes.

Impact across the value chain

Procurement	Product design	Manufacturing	Marketing	Financial services
Responsibly sources the raw materials used to build products	Design products and variants like construction and mining equipment, engines, turbines and diesel electric locomotives	Develop and manufacture high productivity equipment. Remanufacturing services	Effective sales, advertising and marketing programs. Sales and product support	Financing services for customers and dealers. Equipment-related loans and leases
Industrial metaverse				
Immersive supply chain network map Virtual supplier audits Marketplace and sourcing platforms Simulation of supply chain scenarios Risk assessment and mitigation	Product modelling Virtual prototyping and design reviews User testing and feedback Materials and texture visualization Design simulation and rapid iteration	Equipment monitoring and control Facilities digital twin Maintenance planning Logistics and transportation optimization Quality control and inspection Manufacturing process simulation	Metaverse experience centers Virtual campaign testing Virtual product launches Consumer insights and analytics Interactive product demonstration Market research and testing	Virtual financial ecosystem Trade finance documentation Risk assessment and modelling Assent and equipment financing Real-time finance data visualization Smart contracts
Enterprise metaverse				
Virtual supplier engagement and onboarding	Augmented workstation Cross-functional collaboration	Asset and industrial maintenance Collaborative problem- solving Resource planning	Sales enablement sessions 360-degree educational video view Virtual trade shows and conferences	Collaborative financial planning Virtual events, townhalls
Augmented collaboration				
Mixed reality onboarding and training				

Automotive

Click to skip to the relevant section

The metaverse can digitalize every phase of the automotive product life cycle. Advanced simulations help to optimize vehicle performance, as well as develop and test vehicle design by mimicking real-life driving conditions, leading to the development and testing of autonomous vehicles. Prototyping through simulations, XR and AI facilitate the sustainable operation of automotive manufacturing facilities and processes, while also creating compelling virtual showroom experiences for an improved customer experience.

Software-defined vehicles

Renault, in partnership with Google, developed software defined vehicles – a revolutionary approach to position software as the focal point of a vehicle, bringing rise to predictive maintenance, monitoring and new revenue streams with upgrades and subscriptions.

Impact across the value chain

Design, style and engineering	Raw material procurement	Manufacturing	Logistics and distribution	Sales and aftermarket services
Aligning vehicle design and prototyping with ESG* goals	Procurement of parts from OEMs** and suppliers	Develop and manufacture sustainable vehicles	Transport of the vehicles to retail outlets	Effective sales, advertising and marketing programmes. Sales and after-sales support
Industrial metaverse				
Design and prototype vehicles and components in virtual environments Digital twins of manufacturing facilities Virtual car clinics Innovation labs	Supplier engagement Supply chain traceability Cross-border vendor and partner management	Virtual control tower Digital factory layout design Quality assurance based on digital twin Remote simulation and optimization of factory operations	3D visualizations to monitor and optimize the entire supply chain Blockchain-based “track and trace”	Augmented store layout Remote assistance Virtual driving experience
Enterprise metaverse				
Virtual concept discussions	Secure and tamper-proof data inflow	Real-time workforce updates Employee safety	Virtual partner and vendor engagement	Sales enablement sessions

Augmented collaboration

Connected worker operations

Onboarding and training

Virtual events

* Environmental, social and governance

** Original equipment manufacturer

Energy

Click to skip to the relevant section

The metaverse can help energy companies simulate and plan energy infrastructure, from power plants to distribution networks, reducing energy waste and providing resilient systems. Digital twins assist with remote monitoring and predictive maintenance to improve the efficiency of operations and reduce the need for physical on-site visits. The use of spatial computing facilitates virtual training environments, reducing high-risk on-site training for nuclear power plants. Blockchain has a powerful role to play in tracking green energy sources from origin to consumption, making it easier to measure sustainability progress.

Upstream digital transformation through connected workers

Petrofac is using diverse worker and asset sensors, location tracking, Microsoft's IoT Hub, Azure cloud and IoT edge tech to improve connections between workers and physical assets. This innovative system deploys wearable headsets to digitalize on-site instructions, autonomously recording and documenting data, leading to streamlined operations.

Impact across the value chain

Exploration and appraisal	Development	Refining and warehousing	Storing and transport	Trade and retail services
Finding commercially viable hydrocarbons trapped underneath the Earth's surface	Going after hydrocarbons through continuous drilling wells and facility construction	Convert crude oil into marketable products and storage	Transport to the depot by tank truck, train, pipeline or ship	Marketing activities of oil products and services, low-carbon fuels and new energies for mobility
Industrial metaverse				
Visualize 3D models of reservoirs Visualize and analyse seismic data in 3D Discover natural resources more effectively Detailed simulations of reservoir behaviour over time	Simulate drilling operations to optimize well placement Remote inspections and maintenance Digital twins of oil rigs and wells Real-time environment impact analysis	Remote surveillance and assistance Digital twin of the distillation facilities and processes Predictive maintenance and analysis of warehouse operations Virtual inspections	Virtual product tracking Supply chain traceability Simulate the environmental impact of energy storage and transport activities Smart contracts and invoice generation Virtual audits and inspections for regulatory compliance	Virtual experience centres Virtual platforms where energy producers, consumers and traders can engage in virtual energy trading Blockchain for secure, transparent and automated billing and payment processes
Enterprise metaverse				
Integrate data from various sources for unified enterprise decisions	Develop realistic training simulations, emergency response and safety drills	Secure and tamper-proof data inflow	Virtual partner and vendor engagement New vendor onboarding Process education	Virtual events, townhalls Virtual energy trade shows and conferences C-suite interactions, engagement sessions with retailers
Employee safety and well-being training				
Enable geographically dispersed stakeholders to engage virtually				
Connected and safe worker operations				
Onboarding and training of workers				

Healthcare

Click to skip to the relevant section

By providing health professionals with enhanced tools, support and visibility, the metaverse and Web3 technologies are helping biopharmaceutical and medtech companies solve manufacturing and device problems, bolster R&D and improve operations. Digital twins, blockchain and AI are enabling more resilient supply chains through actionable insights, while providing patients and healthcare professionals with more personalized experiences.

Blockchain-based eZTracker

Zuellig Pharma, a pharmaceutical distributor in Asia, has developed a blockchain-based platform to verify the authenticity of products, bringing greater transparency and trust across the pharmaceutical ecosystem.

Impact across the value chain

Pre-clinical Research	Clinical trials	Product development	Manufacturing and distribution	Sales and marketing
Market and competitive intelligence, preclinical studies, drug research	Patient recruitment, protocol development, clinical trial and data management	Drug development, quality testing and analysis	Demand planning, procurement management, packaging, distribution and logistics support	Market access and HEOR*, patient support and access programs, medication services, product support
Industrial metaverse				
Virtual laboratories to design and test new drug compounds Digital twin of R&D labs Virtual prototype simulation of experiments Product behaviour assessment and pattern analysis	Visualize clinical trial process, biostatistics and statistical programming Patient interaction with their own data and treatment plans	Virtual factories to co-develop, test and analyse new drugs Test new drug composition and likely reactions via simulations Visualize and simulate the effects of repurposed drugs Immersive equipment testing environment	Digital twin of facilities and sites Augmented warehouse management Immersive supply chain network map Tamper-proof logistics and supply chain automation and management Virtual site visits	Educational sessions for front-end staff 3D visualization of drug development life cycle for sales and marketing staff Virtual support for distributors and retailers
Enterprise metaverse				
Biological and chemical data visualization for researchers Cross-border virtual research and ideation	Virtual patient onboarding Blockchain-powered, tamper-proof data access and management across organization units	Train researchers and clinicians in various aspects of drug development Augmented worker operations	Partner and vendor engagement in virtual spaces Simulate regulatory inspections and audits	Experience centres for sales and delivery representatives Virtual events for sales and front-end staff

Collaborative workspaces for stakeholders to co-create solutions

Onboarding and training of researchers, data scientists, front-end and other staff

Protocol and regulatory framework simulations

* Health economics and outcomes research

Cities and urban infrastructure

Click to skip to the relevant section

The metaverse can accelerate planning and designing of large-scale construction projects, besides ensuring their efficient operation and monitoring. It can help reduce costs through data integration and predictive maintenance, collaboratively plan urban environments and infrastructure, and optimize strategies for traffic, energy and waste management via simulation. Simulation capabilities can also enable sustainable solutions, augment transport infrastructure, facilitate real-time tracking of people and assets, and create immersive virtual tours for smart cities.

Connected communities and infrastructure

NEOM, a large-scale futuristic development initiative in Saudi Arabia, establishing technologically advanced cities through smart infrastructure and the creation of new economic sectors and industries. Through the integration of smart sensors within its urban infrastructure, using digital twins and AI for data collection and analysis. These insights will play a pivotal role in enhancing municipal electronic systems, proactively maintaining infrastructure and offering real-time recommendations for sustainable improvements.

Impact across the value chain

Planning and visioning	Infrastructure and connectivity	Data management and analysis	Smart services and applications	Regulatory framework and governance
Plan an interactive virtual version of a futuristic smart city	Build essential smart city infrastructure (i.e. IoT, communication networks, data centres)	Data storage and management systems to handle data generated by sensors and devices	Develop and deploy smart city services and applications based on data and insights gathered	Establish a regulatory framework that supports the smart city's development
Industrial metaverse				
Interactive 3D city modelling Virtual overlay of prospective city, zoning and land use information Scenario testing and simulations	Digital twin of construction process Virtual representation of data networks, IoT devices and digital services Simulate and test the connectivity infrastructure	Data analytics platforms Virtual data visualization Digital twin to optimize city services and operations Virtual command centres	Metaverse applications that mirror real-world smart city services: – Smart traffic management – Waste management solutions – Predictive policing – Emergency response systems – Smart lighting and building management systems	Tamper-proof data management Cybersecurity enablement Visualize and assess regulatory impacts Virtual compliance audits
Enterprise metaverse				
Virtual collaboration with city officials, urban planners, technology experts and community representatives	Virtual project management Employee safety	Collaborative data exploration Explore data sets in a 3D virtual space and derive insights	Virtual partner and vendor engagement	Collaborate with public and private sector partners and create a governance structure Virtual governance layer, including virtual town hall meetings, digital city council sessions, etc.

Augmented dashboards and reporting tools

Mixed reality onboarding and training

Virtual events

FIGURE 13 | **Use cases for the industrial and enterprise metaverse across wider industries**

Select the tabs to discover more

- Scientific research
- Aviation
- Aerospace
- Media and entertainment
- Retail and consumer packaged goods

The metaverse can facilitate scientific research by offering the ability to: simulate fluid and particle dynamics, analyse complex scientific data, create visualizations of scientific experiments, enable interdisciplinary collaboration among researchers, develop predictive AI models, facilitate data integration across systems and handle heavy workloads on cloud-based graphics processing unit (GPU)-accelerated computing servers.

Good Chemistry has used AI and quantum algorithms in the cloud to run chemical simulations that are more accurate and 1,000 times faster than the current industry standard.

FIGURE 13 | **Use cases for the industrial and enterprise metaverse across wider industries**

Select the tabs to discover more

- Scientific research
- **Aviation**
- Aerospace
- Media and entertainment
- Retail and consumer packaged goods

The metaverse can create impact for aviation companies in many ways, such as using XR to simulate air traffic scenarios, test new procedures and train air traffic controllers – thereby enhancing safety and efficiency. Collaborative design and maintenance can be made more effective for a globally dispersed workforce. Conducting pre-production tests in virtual environments reduces the risk of damaging expensive production aircraft and using AR headsets for guided installations helps increase operational efficiency.

Airbus is using MR to design passenger cabins, thereby improving the speed of R&D by 80%. They are also using AR to provide information to operators on the manufacturing floor.

FIGURE 13 | **Use cases for the industrial and enterprise metaverse across wider industries**

Select the tabs to discover more

- Scientific research
- Aviation
- **Aerospace**
- Media and entertainment
- Retail and consumer packaged goods

VR has the potential to connect terrestrial and orbital workers in immersive virtual environments, unlocking the collaborative capabilities of low-orbit R&D. Using the metaverse to train astronauts allows teams to practice and refine their skills in low-risk environments.

Onyx by J.P. Morgan tested the world's first bank-led tokenized value transfer in space, executed via smart contracts on a blockchain network established between satellites called Spacebridge that orbit the Earth. The solution increases the speed of receiving intraday funding, reducing operating costs by 56%.

FIGURE 13 | **Use cases for the industrial and enterprise metaverse across wider industries**

Select the tabs to discover more

- Scientific research
- Aviation
- Aerospace
- **Media and entertainment**
- Retail and consumer packaged goods

The metaverse can help speed up content creation through real-time, cross-team collaboration across application suites for complex 3D scenes, providing a centralized repository for assets and projects. This enables photo-realistic 3D rendering of environments, generative AI for ideation, 3D avatar representation for immersive virtual experiences using the proposed standard USD file format for seamless data exchange.

The Walt Disney Company is using spatial computing, digital twins, AI and IoT to enhance the filmmaking process in their StudioLAB, as well as in wider design, advertising and gaming, leading to $30,000 in savings per production.

FIGURE 13 | **Use cases for the industrial and enterprise metaverse across wider industries**

Select the tabs to discover more

- Scientific research
- Aviation
- Aerospace
- Media and entertainment
- Retail and consumer packaged goods

The metaverse can transform the operations of retail and consumer packaged goods companies with applications such as paperless signing of logistics documents for supply chain efficiency and digital twins for creating autonomous stores. It can also help streamline inventory management by using blockchain-based stock-keeping unit (SKU) tracking, integrate blockchain platforms for "farm to fork" food traceability, and use AR/VR headsets to optimize restocking strategies, simulate floor plans and develop product demos.

Amazon has collaborated with NVIDIA Omniverse to build full-scale digital twins of their warehouses to optimize warehouse design and better train robot assistants. The implementation of sophisticated robot systems has yielded operating cost savings of 20%.

Pioneering new routes for value creation

To help leaders understand and break down the opportunities, the following themes represent notable shifts from today's approaches to design, collaboration, manufacturing and operations, helping realize net-new value through higher operational efficiency, process improvements, increased safety and collaboration, enhanced decision-making and much more.

FIGURE 14 **Paths to unlocking economic value across enterprise functions and industrial value chains**

1 Talent and learning

Themes

Immersive technologies, in combination with AI and digital twins, are revolutionizing the training and learning experience, boosting both knowledge retention and productivity. In industry, metaverse and AI redefine the approach to upskilling, making for safer and more cost-effective approaches to train talent. Building personalized, experiential, interactive and engaging environments for better recall, competency and overall workforce performance.

Select value drivers

Simulated SKU and augmented experiences for accelerated skills development and worker safety

2 Boundless collaboration

Themes

The metaverse is transforming workforce collaboration. Offering shared virtual spaces for teams across the organization to communicate, simulate and remotely execute solutions seamlessly, to deliver easier and faster joint innovation and ventures. Enhancing the product design, development and engineering process, through the metaverse's ability to minimize barriers and enable interaction and collaboration across geographies, time zones and languages.

Select value drivers

– Collaborative design and development

– Visualized situation evaluation and remote assistance

3 Transparency and traceability

Themes

Enterprises that reshape how they share their data and information with customers, partners and stakeholders will develop the closest relationships, enabling them to thrive in a competitive environment. Supply chain transparency and traceability, trade and transaction, and visibility of product flows are enhanced through tokenization and distributed ledger technologies (DLT), enabling ethical sourcing, secure tracking and improved operational efficiency.

Select value drivers

– Supply chain resiliency

– Transport, logistics management

4 Simulation and optimization of the enterprise

Themes

In partnership with digital twins, AI is helping to enable the simulation and optimization of internal processes across the enterprise, combining smart manufacturing, resilient and transparent supply chains, shared services and more to form a virtual enterprise (all operations) that combines previous, current and future datasets for better simulation and anticipation.

Select value drivers

– Simulated plants, products and operations

– Field orientation and navigation

5 Deployed product management (upgrade, service and repair)

Themes

Physical products will have digital twin counterparts capable of simulating their real-world capabilities, unlocking new avenues to experience, measure and analyze products, places and services. This two-way relationship between the physical product and its digital twin has enabled organizations to rethink how they develop and post-manage products with remote maintenance and upgrades in mind.

Select value drivers

– Remote support, service and upgrades

– Predictive maintenance and asset management

6 Personalized customer interaction and sales channels

Themes

The metaverse offers a new way to engage with customers. Challenging fundamental assumptions about what the experience of industrial companies will look like in the future. Immersing customers in products, services and other offerings, completely altering the customer experience, creating new ways to engage, new levels of customization and configuration, and new forms of sales and service channels.

Select value drivers

– Personalized interaction and configuration

– Remote customer care

Note: the impact on business processes (value chain) will be covered in one or more of the themes.
Refer to *Social Implications of the Metaverse* for more detail on the metaverse's impact on business processes.

Click to skip to the relevant section

2.2 Talent and learning

The metaverse and AI both provide net-new approaches to upskilling the workforce in safer, more cost-effective environments, while building personalized and engaging toolsets. Immersive, experiential learning and interactive training boost knowledge retention, competency and performance in real-life situations. "Hands-on" learning has been shown to more than double knowledge retention, with experiential methods three times more effective than traditional textbook-based learning.[30]

FIGURE 15 **Unlocking value through metaverse technologies**

~41%
faster resource ramp-up through use of breakdown tool and VR training

~33%
higher learning retention with VR compared to video

~23%
reduction in onboarding time of new employees

Sources: Accenture, "Learning in the Metaverse: HR will be the champions of this new way of work", *Strivr*, 2022, https://www.strivr.com/blog/learning-in-the-metaverse-this-new-way-of-work/.

XR can revolutionize soft skills training by immersing people in stressful and unfamiliar environments for better mental, physical and emotional preparation. FundamentalVR, a VR platform for surgical training, introduced Haptx Gloves to simulate the touch and feel associated with surgical operations, making it possible for students and surgeons to practice surgical techniques before moving onto a cadaver or patient.

BOX 10 **Caseworker training reimagined**

San Diego County needed to improve their process for determining eligibility for social benefits by reducing the case worker error rate. By using Avenues VRL, caseworkers were trained in a simulated environment, allowing them to experience the mental and emotional stress related to making social support decisions.

Source: Accenture

Impact:

- 40% reduction in training time
- 31% reduction in employee turnover
- 75% reduction in training costs
- Approximately 70% of trainees reported improved observation, inquiry and interpretation skills
- 90% of trainees indicated better preparation for their job and tasks

Digital twin simulations provide enhanced access to nuanced, real-world learning in complex areas. For instance, in the medical field, immersive 3D content allows students and surgeons to access a comprehensive range of learning opportunities.

XR and spatial design, paired with advanced learning theory and data insights, provide workforces and students with an optimized learning experience. Platforms such as Talespin and Strivr offer collaborative tools, content and insights that help accelerate learning, upskilling and real-time feedback, boosting workforce confidence by nearly 300%.[31] There is massive room for improvement – an Accenture study found that 90% of executives believe their existing training models need to become more effective and efficient, while 94% of workers would stay longer at a company if it invested in their career development.[32]

Immersive environments streamline recruitment and onboarding through realistic workplace scenario simulations, assessments and training. The ability to deliver seamless remote operations helps industries address challenges such as skills and labour shortages, pandemic-driven hybrid working, and the cost and safety implications of mobilizing people within complex industrial environments. Deploying remote operations significantly improves operational efficiency across design, manufacturing and production, driven by the ability to quickly upskill workers to take on more valuable tasks.

BOX 11

Field training

Honeywell launched a new version of its Immersive Field Simulator (IFS) offering, a mixed reality-based training tool that incorporates a digital twin of physical plant operations. The IFS, enables simulation of onsite environments, enabling operators to meet specific training requirements in a flexible and convenient manner.

Remote training opportunities stimulate greater collaboration and learning among teams and functions globally. This drives a greater quality of output for industrial companies in terms of the products and services they offer, while realizing operational savings and achieving improved worker output and satisfaction. All of this will be explored further in the section on boundless collaboration.

BOX 12

VR training centre

Saudi Aramco in partnership with PaleBlue developed immersive learning for their employees, simulating inspection processes and electrical and chemical field maintenance. Using VR, employees were trained in a gamified manner, creating an engaging and interactive corporate training program.

Blockchain and decentralized digital identity will help establish a reliable and standardized system for verifying employees' credentials and qualifications and storing that data in a way that prevents unauthorized modifications or tampering.

BOX 13

Technical training and credentialing

CEL Electric tapped into Credivera's capabilities to issue verifiable credentials for their workforce, effectively steering clear of recruitment fraud that costs employers $600 billion annually. CEL also uses Credivera's technology solutions to verify its workforce certifications and employee health before they enter a work site.

Tamper-proof data access ensures authenticity and integrity of information for verification purposes, entitlements and qualification certificates, allowing employees access to specific resources and responsibilities.[33,34] In addition, this capability helps organizations to instantaneously assess employees' training performance and provide feedback. This has given rise to verifiable credentials in the workforce, and the capacity to verify a worker's certifications and health before accessing a work site. For further details on workforce credentialing, refer to the World Economic Forum's recent report *Reimagining Digital ID*.

CASE STUDY 1

HoloLens 2 for manufacturing

Industry:
Pharmaceuticals

Novo Nordisk partnered with Microsoft to bring HoloLens 2 to their manufacturing facilities and provide augmented 3D instructions and guidance to onboard and train shop floor employees. The HoloLens 2 has been used to overlay physical surroundings with an interactive virtual layer, creating an MR that workers use to operate machinery, make mechanical adjustments and handle highly regulated compounds on the manufacturing floor. Connected workers have access to real-time support and assistance, resulting in greater operational efficiency, improved production and higher quality of output.

Value proposition

The partnership between Novo Nordisk and Microsoft has enabled real-time field training, reducing human error, increasing worker safety and expediting employee onboarding. The platform enabled Novo Nordisk to collect and analyse real-time data to improve manufacturing floor operations, instantaneously supporting workers with operational adjustments through AR guides and reassuring management and regulators that drug quality is maintained throughout the production process while driving greater operational efficiencies and cost savings across the production process, from machinery to worker interaction.

Impact

~30% reduction in manager oversight using MR guides, improving worker effectiveness.

75% decrease in rework, leading to annual savings of $13,680 per worker.

80% savings in consumable costs associated with instructions and training using MR.

Sources: "HoloLens 2 helps Novo Nordisk employees see work in new ways", *Microsoft*, 27 June 2022, https://news.microsoft.com/europe/features/hololens-2-helps-novo-nordisk-employees-see-work-in-new-ways/; "The Total Economic Impact of Mixed Reality using Microsoft HoloLens 2", *Forrester Consulting*, November 2021, https://tools.totaleconomicimpact.com/go/microsoft/HoloLens2/.

2.3 Boundless collaboration

New manufacturing projects are going digital first, powered by AI, cloud and edge computing and shared virtual spaces to create one digital thread. From AI-guided machinery to digital twins providing end-to-end simulation of design, manufacturing and production, these technologies foster collaboration with the human workforce and are set to revolutionize the future of factory operations.

FIGURE 16 **Unlocking value through metaverse technologies**

~90%
reduction in travel across XR enabled teams

~60%
increase in task efficiency by on-site workers using MR

~40%
improvement in mechanical service time by linking on-site mechanics with remote experts through AR

Sources: "Using VR to Unlock the Power of Remote Collaboration", *Harvard Business Review*, 2020, https://hbr.org/sponsored/2020/10/using-vr-to-unlock-the-power-of-remote-collaboration2/, "The Total Economic Impact of Mixed Reality using Microsoft HoloLens 2", *Forrester Consulting*, November 2021, https://tools.totaleconomicimpact.com/go/microsoft/HoloLens2/, "Finding the Business Value in Augmented Reality", *Boston Consulting Group*, 2 October 2023, https://www.bcg.com/publications/2023/finding-the-business-value-in-ar.

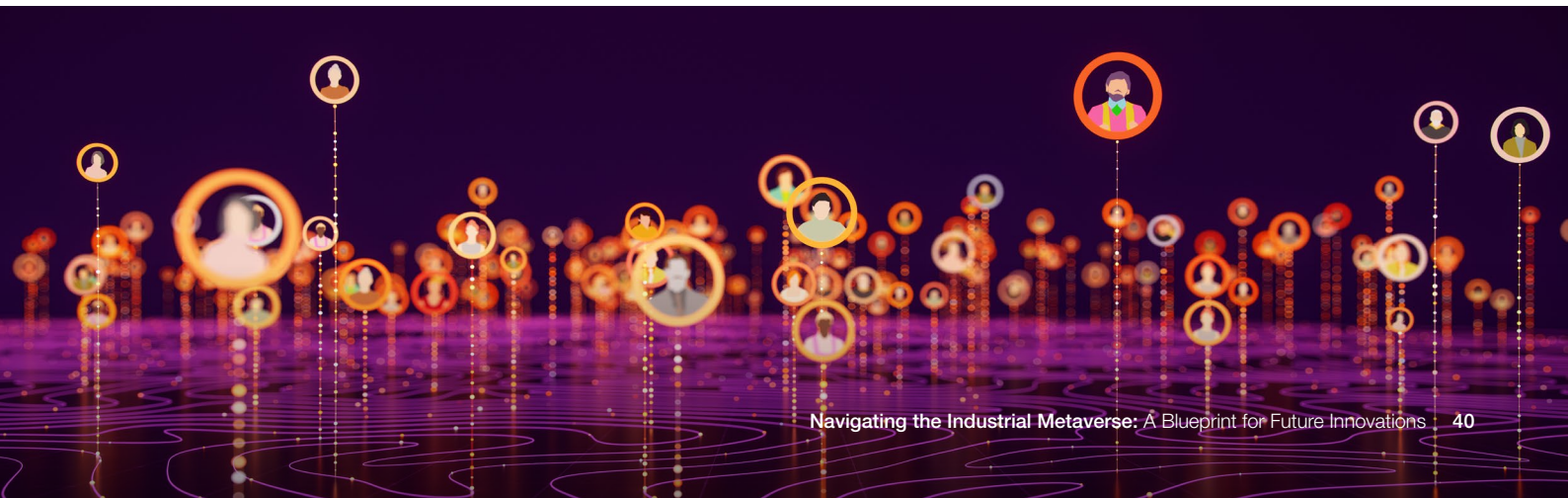
> **In the future, factories will be much more connected, relying on a mix of technologies, from artificial intelligence, data platforms and edge devices to the cloud, robotics and sensors.**
>
> Goetz Erhardt, Europe Lead, Digital Engineering and Manufacturing, Accenture

Augmenting the collaboration process enables enterprises to enhance situational awareness and improve task execution towards breaking organizational silos and boosting productivity of cross-functional teams. Enhanced project management tools provide real-time data overlays and visual instructions for better information sharing and communication, speeding up decision-making processes across teams.

BOX 14 **Augmented for surgical success**

Accenture, Skye Group and CHRISTUS Health Excellence and Innovation Center have enabled surgeons to use Microsoft HoloLens 2 to overlay models, X-rays and CT scans over the patient, increasing operational efficiency by eliminating the need to step away from the patient and view diagnostic images, ensuring a sterile environment is maintained.

Creating digital twins on platforms like Nvidia Omniverse – used for building and operating industrial metaverse applications – provides an interaction layer for virtual collaboration. Identity and access management domains enable stakeholders to collaborate on specific segments of an industrial application, aiding in training, planning, designing and engineering of products and services through the simulation of various scenarios.



BOX 15 | **Collaborative design**

Eclipse Automation is integrating Dassault SolidWorks with Nvidia Omniverse and MS Teams to facilitate a more collaborative design and review process with clients. This has enabled customers to interact with products during solutioning, preventing costly design changes in later development stages.

Additionally, it has empowered automotive, consumer packaged goods and architecture industries, among others, to deliver digital-first factories, streamline operations of warehouses and entire production lines to the designing, planning, operating and monitoring of large-scale sites in real time, as seen in recent collaborations with BMW, PepsiCo and architectural firm Woods Bagot. As advancements in AI start to hit the factory floor, the industrial manufacturing process could change and evolve further. Conversational systems such as OpenAI's ChatGPT are likely to be integrated into robotics, enabling more sophisticated, emotionally intelligent machines and enhancing collaboration through faster decision-making.

BOX 16 | **Virtual prototyping**

BMW is using Holo-Light solutions to accelerate the R&D of new products by using AR to visualize their 3D CAD models. The AR solution enables engineers to collaborate in a physical space by simultaneously interacting with the 3D model, allowing them to adjust the design in real time. This technology facilitates collaboration from across locations, where changes are saved remotely as opposed to alterations being shared to a physical object.

The use of augmented and virtual reality, in combination with robotics, creates spaces, experiences and workflows that make for more flexible, productive and enjoyable working environments while reducing costs and improving quality of work. This can be particularly useful when it is not possible or practical to physically visit a location or engage in a particular activity in the real world. It brings employees together in simulated virtual spaces where they can work safely, remotely and in real time.

CASE STUDY 2

Upstream digital transformation through connected workers

Industry:
Energy

Petrofac developed the oil and gas industry's first (and one-of-a-kind) connected construction solution. For this, it used a variety of worker and asset sensors and location trackers as well as Microsoft's IoT Hub, Azure cloud platform and IoT edge technology. The implemented solution uses wearable headsets to digitize instructions in the engineer's field of view while simultaneously capturing and documenting data in an autonomous fashion.

Value proposition

The solution has boosted workforce safety, construction site performance and profitability by improving knowledge transfer and upskilling. The time to make decisions came down significantly as the solution reduced the need for coordination between onshore and offshore resources. Troubleshooting incidents saw improvements as SMEs could better guide engineers through repairs.

Impact

~200% improvement in workers' operational efficiency

~3,000-hour reduction in worker backlog

~15% reduction in maintenance spend by embedding virtual collaboration into maintenance processes

Sources: "Connected Workers Deliver Ultra-Efficient Maintenance", *Petrofac*, https://www.petrofac.com/services/our-work/asset-maintenance-uk-bp/; "Digital collaboration for a connected manufacturing workforce", *McKinsey & Company*, 5 May 2020, https://www.mckinsey.com/capabilities/operations/our-insights/digital-collaboration-for-a-connected-manufacturing-workforce.

2.4 Transparency and traceability

Unique identifiers generated from data and stored on a distributed ledger ensure all participants of a system have access to the same information in real time, providing greater transparency. This increased transparency with operational stakeholders results in a virtuous cycle where everyone reciprocates with trust and collaboration. To achieve these collaborative relationships, enterprises must rethink their data strategies and improve product traceability across their industrial ecosystem.

FIGURE 17 **Unlocking value through metaverse technologies**

~70%
elimination data duplication due to fewer silos and reduced data fragmentation

~50%
increase in back-office efficiency through automated reconciliation processes

~15%
reduction in inventory

Source: Accenture

BOX 17 **Automated transactions**

Saudi Aramco has deployed blockchain at its oil fields and refineries to improve performance and reconcile smart contracts, which are secure, self-executing digital contracts that automatically execute all or parts of an agreement with a vendor once certain conditions have been fulfilled.

Industrial companies will need to explore confidential data-sharing solutions that preserve people's privacy even as information travels across the ecosystem. This is achieved by a unique identifier generated from the data content on a blockchain that ensures consistency throughout network nodes. These unique identifiers, called hashes, facilitate traceability, while a set of network-agreed rules validates data transactions. The industries predominantly deploying this use include aerospace, banking and healthcare.

BOX 18 **Blockchain-enabled health records**

Anthem Blue Cross is using blockchain technology to enhance encryption of patient data and control data access and sharing. By implementing blockchain, Anthem aims to provide patients with more control over their health information while ensuring its security. The technology allows efficient and secure data exchange between healthcare providers, leading to improved patient care coordination and streamlined administrative processes.

A recent survey by logistics group Freightos revealed that 96% of supply chain professionals plan to use AI technology, although only 14% have already adopted it.[35]

Multinational companies are revolutionizing supply chain management in the face of global challenges, seeing collaborative opportunities as strategic, not purely operational. Organizations are using AI to navigate their intricate supply chains to forecast demand, manage risks and automate trade with suppliers. Companies like Unilever, Siemens and Maersk are at the forefront, employing AI to negotiate contracts, analyse customs declarations and discover new suppliers in alignment with their strategic objectives.

The adoption of blockchain within supply chain and data governance architectures empowers organizations to reliably track records in a tamper-proof single source of truth, as well as assuring them that raw materials are being sourced ethically and sustainably. Tamper-proof supply chains help to enable enterprise-grade product and data tracking, ensuring traceability, transactability, value security and fidelity for stakeholders and end-customers. This is achieved through blockchain-based smart contracts and dispute-resolution protocols, which ensure that the product or data being shared on the supply chain remains safe and secure.

Enterprises across industries have begun adopting control towers, enabling greater resiliency across the supply chain by utilizing 3D models, AI/ML, IoT, cloud and blockchain. This facilitates end-to-end visibility through 3D interactive dashboards and supports new ways of working, such as predictive modelling and autonomous execution. With AI, bottlenecks are proactively identified and prescribed solutions, creating a more automated way to track resources.

BOX 19 | **Blockchain enabled data-sharing marketplace**

95%

of global executives agree that data transparency is becoming a competitive differentiator for their organizations because it enables people to act with confidence.[36]

Catena-X is a multi-party data-sharing ecosystem for automakers that aims to enhance traceability, efficiency and interoperability across the industry. The data-sharing marketplace is enabled through distributed ledger technology (DLT), using smart contracts to automate transactions between suppliers and customers. Using these capabilities are a consortium of 10 German corporations such as BMW, Mercedes-Benz, Schaeffler and auto part suppliers. Catena-X has delivered improved supply chain visibility, enhanced quality control, reduced maintenance costs and better inventory management for its partners, leading to improved vehicle production time and lower CO_2 emissions.

Blockchain-based smart contracts and dispute resolution protocols ensure the product or data being shared on the supply chain remains safe and secure. Advanced supply chain control towers have led to a reduction of 3-5% in logistical costs, improved labour efficiency by up to 20%, and optimized capital efficiency by reducing inventory up to 15%.[37] Building a transparent, resilient and traceable supply chain has enabled oil and gas providers to capture these benefits by closing data gaps and developing operating models to optimize decision-making. Multi-party systems used in supply chains have integrated operations by centralizing information in interactive 3D dashboards, leading to:

- Fewer silos and reduced data fragmentation, eliminating up to 70% of data duplication
- Improved line of sight to upstream and downstream risks and opportunities, resulting in three times more top-line growth than previously recorded
- Automated reconciliation processes, optimizing back-office efficiency by up to 50%.

Source: Accenture

CASE STUDY 3

Blockchain-based eZTracker

Industry: Pharmaceuticals

According to the World Health Organization, one in 10 medical products in developing countries are substandard or counterfeit. Zuellig Pharma, one of Asia's largest pharmaceutical distributors, launched a blockchain-based platform, eZTracker, to verify transactions and share data across stakeholders. The platform uses an immutable ledger, bringing trust and transparency to the supply chain. Using a mobile app, a QR code is scanned to authenticate the product and detail the manufacturing, transport, storage and distribution. This application is part of a broader blockchain-based vaccine management system, called eZVax, that helps governments and healthcare providers manage all aspects of vaccine distribution and administration.

Value proposition

eZTracker has empowered customers to validate the safety and legitimacy of their aesthetic products, boosting transparency and traceability for healthcare practitioners, patients and distributors. In addition to reassuring users, the API enables automated ordering and replenishing, improving stock allocation. The increased traceability has helped establish a robust data management platform, which has been further leveraged to identify how, when and which products are sold strengthening the forecasting process.

Impact

~$20 million is saved by resilient and trusted supply chains due to improved control and decision-making

~30% increase in planning efficiency due to end-to-end supply chain visibility

~120% improvement in delivery accuracy due to comprehensive and reliable

Sources: "Zuellig Pharma launches blockchain-based eztracker in Thailand to help consumers verify authorised aesthetics products in seconds", *Zuellig Pharma*, 15 February 2020, https://www.zuelligpharma.com/b/zuellig-pharma-launches-blockchain-based-eztracker-in-thailand-to-help-consumers-verify-authorised-aesthetics-products-in-seconds; Accenture.

2.5 Simulation and optimization of the enterprise

Transparent value chains enable sustainable, resource-efficient production, while digital twins and immersive experiences support rapid design and development of everything from buildings and vehicles to wider products and services. Early-stage simulation facilitates efficient, cost-effective design by allowing design and engineering teams to quickly pivot and make decisions faster. The metaverse can also support early-stage product development, yielding more efficient, collaborative design.

FIGURE 18 **Unlocking value through metaverse technologies**

~78%
detection of planning mistakes due to virtual simulations and analytics, saving budget and time

~70%
lower design costs

~56%
reduced time to production through visualization of real-world products that can be analysed and refined before actual production

Source: Accenture, "NVIDIA BMW Blend Reality Virtual Worlds to Demonstrate Factory of the Future", *NVIDIA*, 13 April 2021, https://blogs.nvidia.com/blog/2021/04/13/nvidia-bmw-factory-future/.

Digital twins in combination with generative AI are transforming factory planning by accurately simulating complex operational scenarios to simplify decision-making processes, significantly reducing costs and increasing efficiency. Large global manufacturers such as Siemens, Hyundai Motor, Airbus and BMW are using these capabilities to deliver immersive, multidimensional and traceable digital twins which unlock new value pools across product life cycles.

BOX 20 **Future of air traffic management operations**

Airbus is developing a simulation environment called USim to understand and build a safe and sustainable unmanned traffic management (UTM) framework for the future of airspace. USim generates a digital twin of UTM elements, enabling testing of services and interoperability without real-world consequences. ML simulations allow for efficient testing and identification of failure scenarios, helping researchers explore complex UTM challenges while generating data to craft UTM industry standards.

> **By using the visualization capabilities of Siemens Plant Simulation, our customers get a clearer grasp of the packaging process so they can understand what happens when failures occur, which parameters have been specified, and how the constraints have been defined.**
>
> Tobias Hetzer, Deputy Head, Project Engineering LoeschPack, Altendorf[38]

Outdated recruitment and high clinical trial dropout rates pose challenges for the pharmaceuticals industry. To address these concerns, a study called Virtual Imaging Clinical Trial for Regulatory Evaluation (VICTRE) was conducted to compare a simulated clinical trial with digital twins with a clinical trial with real patients. The results were consistent, indicating viability to accelerate R&D using the technology.

Complex decision-making processes can be handled by simulations representing real systems, with 2D/3D visualization improving understanding and communication. Key outcomes include:

- Generative site planning and layout optimization simulations
- Plant simulations and discrete-event simulations to optimize production logistics and material flow
- Process simulations for production flow and human-centred design.

BOX 21

Urban planning and design through digital twins

In an effort to curb flash flooding, Singapore developed a digital twin of their country which combines aerial imagery with street-level data to provide decision-makers with a highly detailed 3D representation used to improve urban planning and design.[39]

Robotics and the metaverse will help companies use simulation, automation and autonomous operations. These elements will reduce operating costs, address skill gaps, increase agility and enable digital design validation before capital deployment. Factories, warehouses and fulfilment centres are using simulation to better configure human and robot workstations to improve employee ergonomics and gain significant operational efficiencies.

BOX 22

3D car configurator with NVIDIA Omniverse cloud

WPP has been using NVIDIA Omniverse to unify Denza's complex design and marketing pipeline.[40] By using the Omniverse platform and generative AI, WPP has been able to build digital twins of Denza vehicles and photorealistic backdrops that can be quickly rendered and customized. This enables WPP to quickly produce marketing campaigns through simulation, on behalf of Denza.

Similarly, operational efficiencies and cost reductions are being realized using digital twins to simulate sales models, decide on optimal pricing, create marketing campaigns and optimize delivery routes, while boosting revenues through more tailored presentation methods to customers.

CASE STUDY 4

Factory of the future

Industry:
Automotive

BMW created a digital version of its upcoming electric vehicle facility in Hungary that allows for full-scale testing in a sandbox environment and identifying and solving potential issues – whether it's floor layouts or the assembly process. NVIDIA Omniverse, digital twins, virtual reality and AI are leveraged to optimize multibillion-dollar factory layouts prior to committing the capital expenditure.

Value proposition

BMW is treating digital twins as a blueprint for its own future operations as they save time and costs, and dramatically reduce wastage by detecting flaws, reviewing floor layouts and validating the assembly process before a physical build. The consequent optimization of manufacturing facilities results in faster production, improved time to market and greater sustainability.

Impact

~30% more efficient planning processes due to reduced planning times, improved flexibility and better precision

~10% improvement in safety and sustainability through digital twin planning

~40% improvement in final product quality

Sources: "NVIDIA BMW Blend Reality Virtual Worlds to Demonstrate Factory of the Future", *NVIDIA*, 13 April 2021, https://blogs.nvidia.com/blog/2021/04/13/nvidia-bmw-factory-future/; "Digital Twin: Benefits, use cases, challenges, and opportunities", *Science Direct*, March 2023, https://www.sciencedirect.com/science/article/pii/S277266222300005X.

2.6 Deployed product management (upgrade, service and repair)

IoT devices are being used readily across industrial settings due to their ability to collect real-time data and insights. They enable real-time digital twin performance mimicry, instantaneous remote monitoring, simulation and physical object updates. An estimated 75 billion IoT sensors are expected to be deployed globally by 2025, while the global IOT market is predicted to grow from $478 billion in 2022 to $2.5 trillion by 2029 (26.4% CAGR[41]). Data and insights collected through these devices help drive strategic decision-making and boost operational efficiencies by identifying redundancies, changes in performance and synergistic opportunities. Bringing rise to opportunities around predictive maintenance, where real-time monitoring systems predict failure for pre-emptive corrective action.

FIGURE 19 **Unlocking value through metaverse technologies**

~75%
fewer mechanical breakdowns through predictive maintenance capabilities

~30%
reduction in maintenance costs, and higher operating lifespan for machines

~45%
reduction in downtime enabled through predictive maintenance resulting in approximately 25% increase in production

Source: "Operations & Maintenance Best Practices", *US Department of Energy*, August 2010, https://www1.eere.energy.gov/femp/pdfs/OM_5.pdf.

XR can support field repairs by augmenting technicians' field of view with mechanical guidance. Led by the automotive sector, 42% of automotive companies have either already deployed or plan to deploy XR technologies in their service operations.[42] Conversely, VR-operated robotics interact with a collaborative automation system to enable remote service. This mitigates risk by ensuring technicians remain in a safe and controlled environment, and reduces costs.

Advances in large language models (LLMs), cloud, edge computing and IoT have led to significant adoption of predictive maintenance; it is estimated to expand to $21.2 billion by 2027, growing at a 26.1% CAGR.[43] Combined with visualization and scenario simulation via digital twins and XR, more integrated, immersive platforms are emerging for industrial applications. The precipitated impact of failure or maintenance downtime on an industrial ecosystem can be measured through a system-wide digital twin.

BOX 23 | **Digital twins to improve jet engine efficiency**

Rolls-Royce's Intelligent Engine Platform, which uses digital twins and AI to monitor the performance of their airline engines and charts maintenance schedules based on predictive maintenance, uses insights pulled from advanced data analysis.[44] The platform suggests avenues to optimize performance by using data on how the pilot is flying the plane and how the aircraft is operated, saving Rolls-Royce over 200 million kilograms in CO_2 emissions since 2014.

Industrial predictive maintenance improves machine lifespans by identifying needs pre-emptively, with maintenance dashboards showing:

- 25-30% reduced maintenance costs[45]
- 70-75% fewer mechanical breakdowns[46]
- 35-45% less overall downtime[47]
- 20-25% higher production.[48]

As the Nokia/EY report notes, overlaying metaverse technologies makes predictive maintenance even more actionable when visualized through facility or machine digital twins.[49]

By adding facility planning capabilities to digital twins, companies can assess repair needs, plan factory rearrangement and simulate the optimal way to minimize downtime during repair windows.

Siemens Energy engaged NVIDIA to help deploy power plant digital twins with real-time data visualization in a physically accurate ML Omniverse twin.[50] The resulting insights accurately modelled and predicted maintenance needs, reducing mechanical failures and facility shutdowns.

As corporations and consumers shift their perception of value from hardware to software, industries have put greater focus on implementing software-based features that enable greater efficiency across entire value chains. More integrated products bring rise to digital features that can be remotely upgraded, extending applications beyond consumer products and factories to use cases for urban infrastructure. An example of this is Saudi Arabia's NEOM, where IoT, cloud, digital twins and AI are being used to plan and execute its developments, and are intended to improve operations by analysing traffic and consumer data.

CASE STUDY 5

Software-defined vehicles

Industry: Automotive

Renault's software-defined vehicles place software as the driver of hardware performance through the power of digital twins and AI to collect the vehicle's operational data, analyse the inputs and generate outputs to upgrade vehicle performance. In partnership with Google and Qualcomm, sensors have been distributed across vehicles to collect and depict data in a centralized digital twin. Using AI, upgrades are suggested, tested in the digital twin and deployed.

Value proposition

Software-Defined Vehicles open the possibility of automobiles evolving during their lifespan. Collecting and analysing performance data facilitates safety, connectivity, navigational and sustainability enhancements, resulting in an improved driver experience. The feedback of data to Renault can be used to improve future iterations of vehicles, leading to a constant feedback loop across the value chain. Real-time detection of defaults and inefficiencies enables predictive maintenance of vehicle parts and opens the possibility of integrated supply chains, which automate part ordering and service scheduling.

Impact

$150 million of additional original equipment manufacturer (OEM) revenue created as new revenue streams such as upgrades and subscriptions become unlocked

~50% reduction in downtime

~40% increase in machine life

~40% savings using predictive maintenance compared to reactive maintenance

Sources: Renault Group, *All about Software Defined Vehicle*, 24 April 2023, https://www.renaultgroup.com/en/news-on-air/news/all-about-software-defined-vehicle/.

2.7 Personalized customer interaction and sales channels

Customers have so far interacted with digital storefronts via screens, using experiences built for individuals. The metaverse will fundamentally alter such conventional norms in the future. Presenting products and services to customers in an immersive environment revamps their experience, creating new ways to engage, new levels of customization and configuration, and new forms of sales and service channels.

FIGURE 20 **Unlocking value through metaverse technologies**

~240%

increase in brand loyalty, reducing churn and improving the rate of returning customers

~60%

improvement in conversion of leads to customers, leading to more sales

~48%

of retailers are ready to implement AR in their shopping experience, as 56% of consumers indicate that AR gives them more confidence about the quality of a product

Sources: "Our Results", *ByondXR*, 2023, https://www.byondxr.com/; "How Augmented Reality Can — and Can't — Help Your Brand, *Harvard Business Review*, 29 March 2022, https://hbr.org/2022/03/how-augmented-reality-can-and-cant-help-your-brand.

Already, the metaverse and Web3 are taking customer interactions deeper to fuse the physical world with digital experiences. XR, digital twins and Web3 will reinvent enterprise-client interactions – from virtual showrooms for seamless customer experience to collaborative sales channels through immersive virtual platforms, and the simulation and optimization of product build and configuration in collaboration with the customer.

BOX 24 **Reinventing the car shopping experience**

To make car shopping easier and more personalized, Smart, in collaboration with Accenture Song, launched a fully digital buying experience for its new electric car lines.[51] A new approach to car customization was taken through the implementation of a direct sales model, where the customer chooses the journey and, based on the data, suggests relevant personalization options/configurations.

Fiat is showing how user self-driven discovery can help with sales conversion. Typically, when people are buying a car they are able to test drive one model, but then have to look at a different model or a bunch of advertising pamphlets to see the customization options. They don't necessarily get to drive the exact car they want to buy. Fiat built the Fiat Metaverse Store to challenge this paradigm. Within the virtual store, users are able to customize their car model with all the various body types, colors, interiors, and infotainment options. Users can then take the car out on a virtual test drive to experience what it would be like and see the features up close. Throughout the experience they are accompanied by "Product Genius" – a connection to a live expert who can answer any questions.

When immersed in their shopping experience, customers have greater clarity, leading to a better understanding of their own desires. This creates opportunities for more tailored offerings, which can result in up to five times more service revenue. Harvard Business Review (HBR) outlined three methods in which the customer experience can be altered by the metaverse:[52]

1. Creating new ways to discover and explore products
2. Fusing physical and virtual product experiences in a meaningful way
3. Connecting people and brands through interactive AI-powered avatars that offer human-like versatility; serving the full customer life cycle with on-demand support.

In the not-too-distant future, AI will develop the ability to connect people and brands through interactive AI-powered avatars that offer versatility similar to that of a human, serving the full customer life cycle with on-demand support, further tailoring offerings, and altering the entire customer experience. For further insight into AI-powered avatars and the value of digital entities, refer to the *Metaverse Identity: Defining the Self in a Blended Reality* report.

BOX 25 Real-time ray tracing in human-eye resolution

Announced at SIGGRAPH2023, NVIDIA and Varjo XR-3 are helping unlock high-fidelity photorealism and real-time ray tracing capabilities in human-eye resolution in MR for true 3D visualization.[53] This will create new opportunities for brands to showcase their products and services, providing XR developers and users access to leading XR capabilities. Car designers are among the first users to realize the benefits. In partnership with leading car manufacturer General Motors, Varjo (in collaboration with NVIDIA) showcased how this advancement in MR visualization allows the design team at the carmaker to experience their design assets with ultimate realism, reduces friction and increases iteration speeds.

Using VR and MR, AI chatbot avatars can be trained on the core data of an industrial company, whether it is an industrial manufacturer, a military contractor for aircraft or a heavy machinery maker. These avatars can provide end-to-end customer engagement. For instance, an avatar could answer customer questions and conduct purchase negotiations like a salesperson, handle simulation and training, and even take on the role of customer care with the ability to speak any language. In theory, an AI chatbot avatar could be assigned to a customer and cross-trained on the company's product and client needs or data, emerging as a one-stop virtual assistant servicing the full customer life cycle.

Automotive has been an early adopter of XR for sales processes. Dealers using these technologies have seen sales conversion rates of more than 90%. From a retail perspective, ByondXR found 400% higher customer engagement when using immersive technologies to augment the shopping experience.[54]

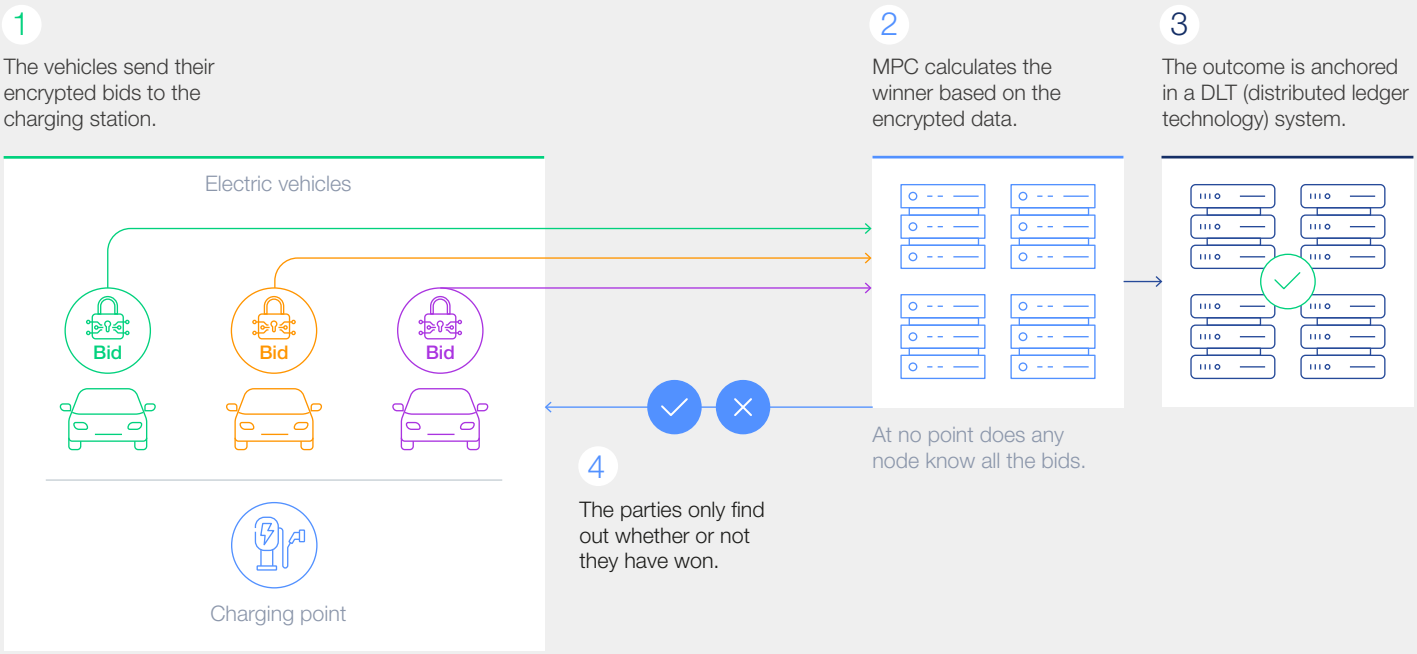
Kellogg's VR grocery tracked eye movements to optimally reposition products, increasing sales by 18%.[55] As Web3 continues to develop, enterprises will find unique ways to enhance the customer experience. For instance, a 2022 Deloitte survey found that 30% of customers are more likely to gravitate towards brands offering NFT loyalty programmes.[56]

BOX 26 Economy of things at the convergence of AI, web3 and blockchain

Using the power of Web3 to increase customer integration with products provides unique opportunities to drive greater efficiency. Bosch has spearheaded the development of the economy of things (EoT) by using tokenomics, AI and DLT to create a smart network between automobiles and charging stations, which facilitate automated negotiations based on a series of parameters set by the driver. For example, the driver can set an electricity price cap and a minimum charge level (e.g. staying above 20%). The solution does the rest, leaving the driver to relax while the Bosch smart network proactively plans a driver's route by analysing charging network pricing and availability, comparing it with the parameters set by the driver and automatically negotiating and identifying the most economical charging options. The customer experiences the most tailored route option, which enables greater efficiency. Bosch EoT is powered by:

1. DLT
2. Tokenomics and tokenization
3. Self-sovereign identity (SSI)
4. Multi-party computation (MPC)
5. Artificial intelligence (AI)

FIGURE 21 | **Economy of things at the convergence of AI, web3 and blockchain**



Source: "Cars that negotiate with charging stations", *Bosch*, https://www.bosch.com/stories/dlt-cars-that-negotiate-with-charging-stations/.

Industrial companies effectively using Web3 and the metaverse to acquire customers through value-based experiences and interactions are likely to capture the most market share.

CASE STUDY 6

Virtual showroom

Industry:
Automotive

SEAT created a virtual showroom offering immersive experiences for its customers, where they can customize, analyse and appreciate every detail of the car. Accessible from every device, the platform revitalized SEAT's customer base, as people got the power to customize their vehicles and save their preferences in an online account. When a customer is ready to speak to a sales adviser, they can start a showcase remotely. The sales adviser takes them through the physical car in an interactive session while ensuring that the customer's privacy is maintained.

Value proposition

Through this platform, SEAT has been able to generate customizable customer experiences and track customer preferences, which are then used at the point of sale. Sales advisers now have access to knowledge and information about a customer as soon as they enter the dealership. This helps the advisers build a stronger rapport with the customer and interact with them on a more value-driven level.

Impact

2-fold increase in customer screentime, leading to over 1 million carsales

6 months to realize return on the investment

~10% increase in SEAT website traffic

Sources: "SEAT launches the first hyper-realistic virtual showroom", *Accenture*, 2021, https://www.accenture.com/es-es/case-studies/automotive/seat.

Summarizing leading value plays across industry sectors

Click to skip to the relevant section

Industrial manufacturing

Talent and learning

Train and educate factory workers to learn manufacturing processes and equipment usage in a safe and controlled environment.

Boundless collaboration

Shared virtual workspace allows engineers and designers to collaborate on ideation and prototyping of products.

Transparency and traceability

Real-time integration of data across engineering, manufacturing and services to improve process efficiency and inventory use.

Simulation and optimization of the enterprise

AI and ML can be used to generate synthetic data for cost-effective robot training and process automation scenarios.

Simulation of physics, particles and material behaviour under different conditions to better inform production processes.

Create digital twins of manufacturing plants and robot equipment to monitor performance and validate solutions.

Deployed product management

Monitor factories through IoT, collecting data that provides insights to better predict maintenance and improve service engineer scheduling.

Personalized customer interaction and sales channels

Demonstrating products and functionality through XR and digital twins to industrial clients. Enabling visibility throughout the product life cycle, for better understanding of the final output and allowing for earlier iteration and intervention of the product design to meet the client's needs more effectively.

Automotive

Talent and learning

Train automotive manufacturing facility workers on the intricacies of a vehicle's build, reducing instances of the worker cross-referencing instructions.

Boundless collaboration

Design, plan, build and commission new EV plants and gigafactories.

Allow designers, engineers and stakeholders to collaborate in real time with photo-realistic 3D design visualizations.

Transparency and traceability

Design safe and sustainable production processes with reduced energy consumption and waste generation.

Simulation and optimization of the enterprise

Concept generation, product design, prototype simulation and usability testing of vehicle designs.

Train and test autonomous driving systems using AI and ML capabilities to improve safety and reliability.

Deployed product management

Deploy "over the air" updates to vehicles, enabling cars to be upgraded with new software capabilities remotely.

Personalized customer interaction and sales channels

Improve customer experience by creating realistic virtual showrooms and building car configurators, allowing them to customize their cars online before even entering a showroom.

Energy

Talent and learning

Train technical engineers using virtual reality within digital twins of in-field machinery, leading to lower risk and greater learning retention versus video.

Boundless collaboration

Allow onshore and offshore engineers to collaborate in real time through AR instruction/guidance.

Transparency and traceability

Using blockchain and smart contracts to automate data capture and validation, creating a transparent data environment for all stakeholders.

Simulation and optimization of the enterprise

Oil can be extracted from wells quickly and safely through scenario-based simulation and testing of different drilling options prior to actual drilling.

Deployed product management

Monitor machinery through IoT, collecting data that provide insights to better predict maintenance and improving service engineer scheduling.

Personalized customer interaction and sales channels

EV drivers have a more integrated experience between their vehicles and charging stations and better route planning by identifying the most appropriate charging station based on the driver's requirements.

Summarizing leading value plays across industry sectors (continued)

Click to skip to the relevant section

Healthcare

Talent and learning

XR to train healthcare practitioners in medical and surgical procedures.

Boundless collaboration

Enable multiple stakeholders to view the same diagnostic images in real time during surgery through augmented overlay.

Transparency and traceability

Validate the source of medicines through traceable and transparent supply chains, ensuring the quality is maintained throughout.

Simulation and optimization of the enterprise

Digital twins have the capability to simulate and plan intricate surgical tasks, allowing surgeons to have greater accuracy and confidence in the operating room.

Deployed product management

Connected devices within a hospital setting facilitate remote monitoring of performance, enabling greater identification of when failure may occur. This ensures patients have the right medical care when needed.

Personalized customer interaction and sales channels

Medical sales representatives have greater opportunities to meet with healthcare professionals and showcase the capabilities of new products in 3D virtual environments.

Cities and urban infrastructure

Talent and learning

Immerse public service workers in unfamiliar environments to simulate stress and emotional reactions involved in difficult decision-making.

Boundless collaboration

Perform design and engineering using a highly collaborative workspace, enabling cross-domain synergies.

Enhance urban infrastructure planning by enabling collaborative design.

Photo-realistic renderings allow for accurate visualizations and collaboration with key decision-makers.

Transparency and traceability

Enable city-scale, real-time tracking of people and assets from IoT sensors and cameras.

Integrate and visualize real-time data via multiple IoT assets throughout a project's operational lifetime operational lifetime.

Simulation and optimization of the enterprise

Simulate energy transmission and waste management scenarios to meet sustainability targets.

Analyse and simulate data of climate patterns and natural disasters for effective emergency response planning.

Simulate traffic and crowd movement to optimize transport and road infrastructure.

Simulate complex construction scenarios to identify roadblocks and resolve them through virtual rehearsals to de-risk project schedules.

Deployed product management

Use IoT and digital twins to create full-scale smart cities that enable administrations to repurpose unused land identified through analytics.

Personalized customer interaction and sales channels

Design virtual tours to provide immersive and interactive experiences for virtual visitors.

Part 3

A look into the future of the industrial metaverse

As the industrial sector enters a new era, the future of each industry will change dramatically.

3.1 Markets leading the way in industrial and enterprise applications

As the industrial sector stands poised for the next phase of growth, enterprises around the world are embracing the opportunities that the metaverse promises in interesting ways. A total of 634 metaverse announcements made by over 100 large companies across the globe were analysed to better understand the landscape; which parts of the world are investing in metaverse, which sectors are seeing the most activity and in what areas, what is the outlook for the industrial metaverse and so on.

Analysis shows that the growth markets – a region comprising Asia, Latin America, the Middle East and Africa – are most active in industrial and enterprise metaverse applications, with 37% of total activations, compared with 36% and 27% for North America and Europe respectively.

FIGURE 22 **Leading use cases implemented by large companies as a percentage of total use cases analysed in the industrial and enterprise metaverse**

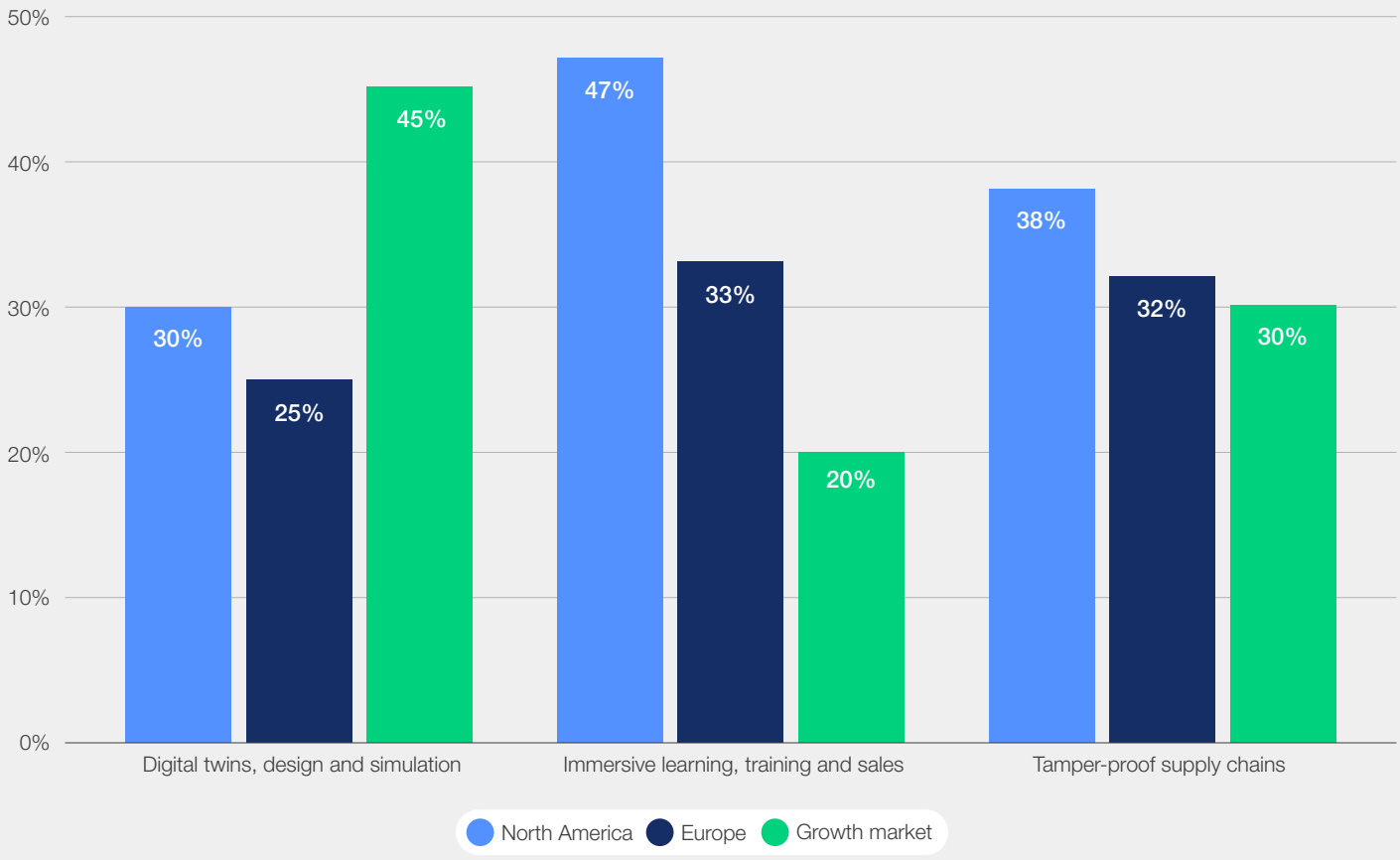
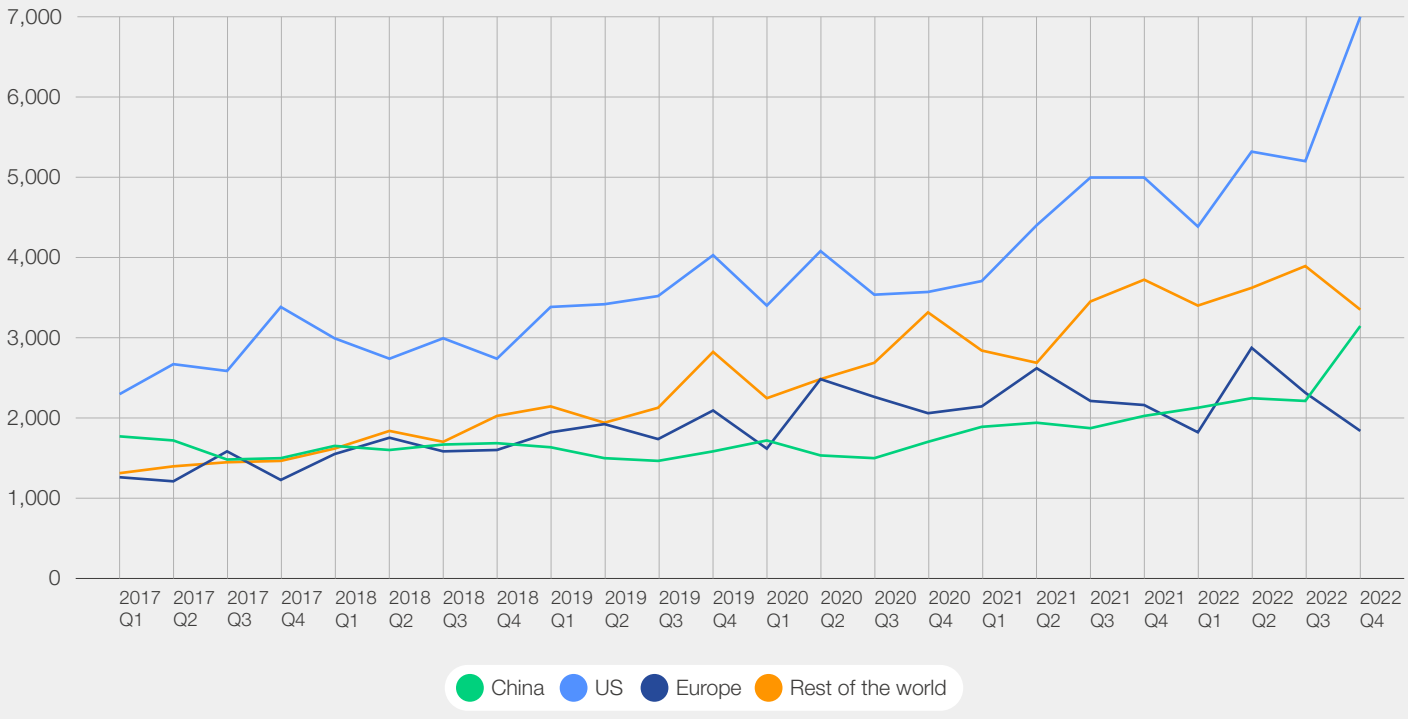


TABLE 1 | **Industrial and enterprise metaverse activations across region**

North America	Citigroup used the Sigma digital twin from Future Facilities to improve their New York City data centre's efficiency, finding potential savings of $290,000 annually.	Phillips 66 Humber Refinery introduced a VR training suite capable of recreating a life-size, life-like refinery environment. To date, several thousand staff and contractors have been inducted in what has become one of the world's most intensively used VR training facilities.	Boeing commissioned a blockchain-based platform, Simba, to build a fully integrated supply chain solution capable of tracking F/A-18 wing parts from sub-tier suppliers. SIMBA's blockchain-based solution aggregates this segmented data, creating an immutable, transparent supply chain platform for an F/A-18 wing part.
Europe	Eni is using digital twins to construct virtual versions of its wells in challenging operational conditions and to simulate the effect of decisions in a safe environment.	The DHL Group uses extended reality and artificial intelligence in the US and Chile for employee training programs and to optimize customer service. DHL Supply Chain, the contract logistics specialist, has seen average productivity increases of 15% in trials of augmented reality technology in warehouses.	The BMW Group initiated the PartChain project to ensure seamless traceability of components "at the push of a button" and to provide immediate data transparency in complex supply chains for all partners involved going forward.
Growth markets	China Communications Construction (CCC) used digital twin platform Bentley OpenRoads to model a 68km road corridor with 30 to 40 bridges and a budget of approximately $7 billion. Post-construction, the operator uses the same model for traffic simulation in case of road widening requirements.	Toyota Material Handling (TMH) has partnered with a Toronto-based VR company (VR Vision) to provide VR learning resources that will supplement existing training programs for onboarding service technicians and other professionals.	Alibaba's cross-border e-commerce platform Kaola, uses blockchain for traceability. The shopping platform uses Ant Financials blockchain technology to record logistics details, customs clearance and product registration.

Leading companies innovating with metaverse use cases are also actively filing patents to establish their long-term competitive advantage. The US has maintained its dominant position in global patents pertaining to the metaverse. Large US-based software and platform companies including Meta, Microsoft, Intel and Apple are among the top 20 metaverse patent applicants. Companies headquartered in Asia, however, especially China, continue to file the highest number of patents, particularly in enterprise simulation and digital twins.

FIGURE 23 | **Number of patents filed across metaverse categories by filing location per 1 million patents – Q1 2017 to Q4 2022**



Source: Accenture research analyses on LexisNexis patent data, 41 millions of patents analysed from January 2017 to December 2022.

TABLE 2

The dominance of Chinese companies in patent filing for enterprise simulations and digital twins – Q4 2022

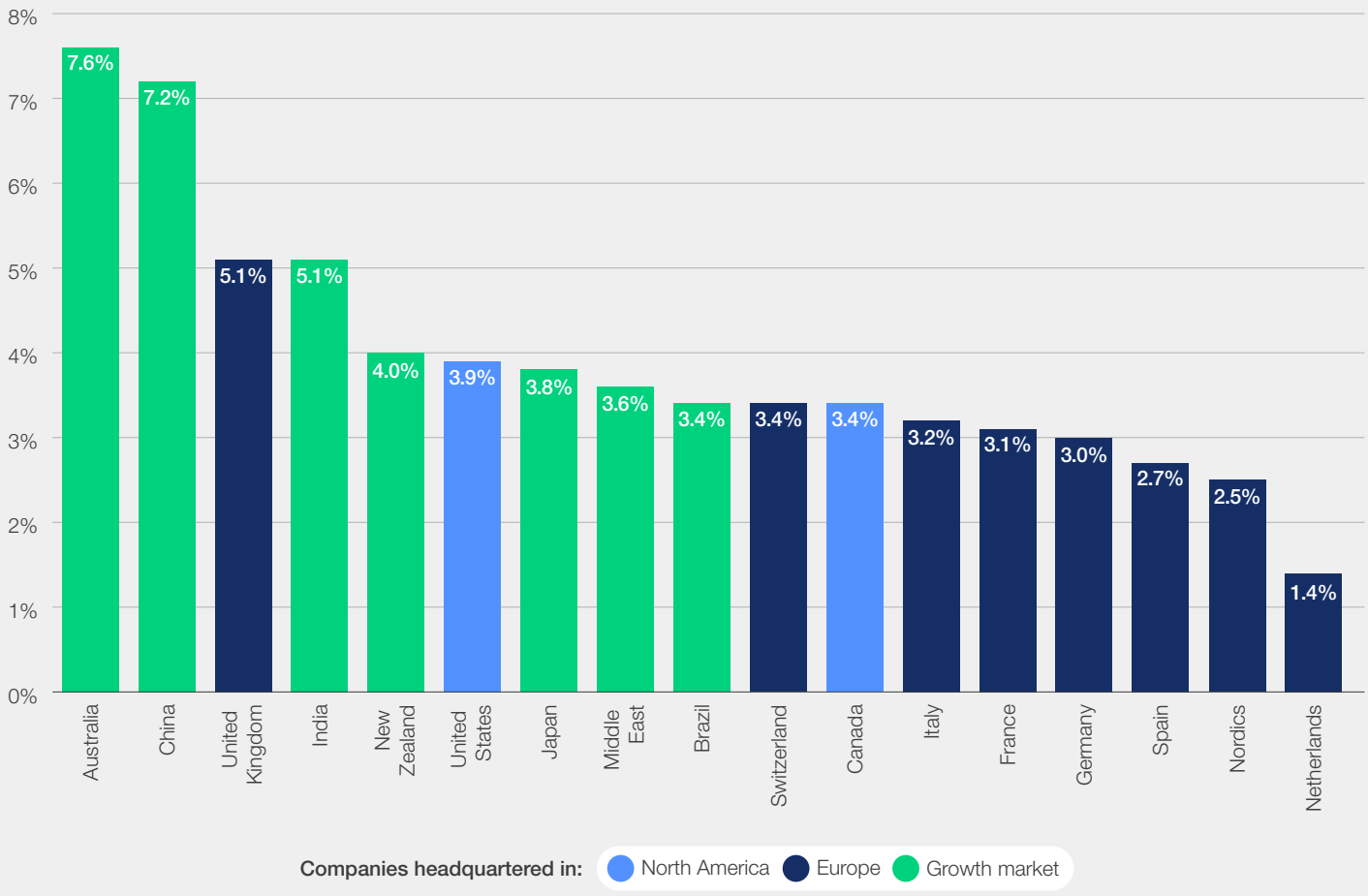
1	State Grid	6	China Shipbuilding Group
2	China Southern Power	7	Tencent
3	Siemens	8	Baidu
4	CASC	9	CETC
5	AVIC	10	General Electric

Adoption of the metaverse is in line with the positive outlook of senior executives regarding revenue opportunities from the technology. According to the Accenture Business Trends Survey conducted in May 2022, respondents from companies with some form of strategy regarding the metaverse believe that in the next three years, 4.2% of their revenue will come from new products, services or business models relating to the metaverse, representing a value of $1 trillion.

Analysis shows that companies in growth markets are more optimistic about the potential of the metaverse compared to counterparts in North America and Europe. Companies in growth markets expect upwards of 5.6% of revenue in 2025 relating to the metaverse, compared to 3.8% and 3.4% in North America and Europe, respectively. Seven of the top 10 countries that express optimism about revenues from metaverse opportunities are also from growth markets, including Australia and China, where the expected percentage of revenue from the metaverse (7.6% and 7.2% respectively) is almost double that of North America and Europe.

FIGURE 24

Executives across growth markets expect metaverse initiatives to drive a higher share of revenues in the next three years

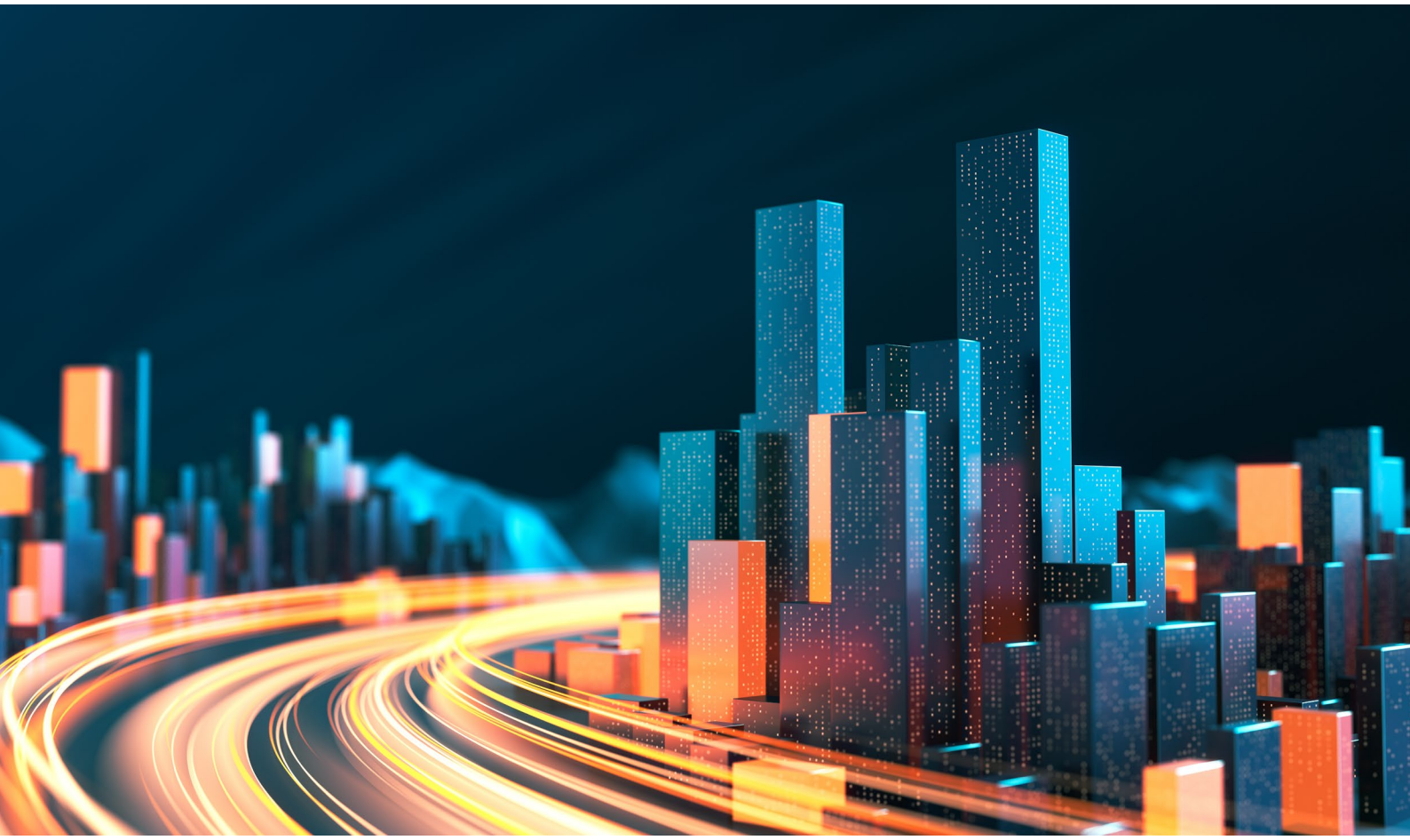


Note: Median revenues executives expect from new products, services or business models related to the metaverse in 2025.

3.2 The role of governments in metaverse growth

Governments, too, are actively fostering the metaverse. For example, the European Commission has reported that as part of their metaverse strategy, "the EU will connect virtual world developers with industry users, invest in the uptake and scale-up of new technologies, and give people the tools and the skills to safely and confidently use virtual worlds."[57] Similarly, China's *Three-Year Action Plan* targets industrial metaverse development, emphasizing advanced technologies, a thriving 3D interactive ecosystem and comprehensive support.

The Middle East, particularly the United Arab Emirates, stands out for its robust government backing of metaverse adoption. The Dubai Metaverse Strategy anticipates 40,000 jobs and a $4 billion boost to the economy by 2030. It is a strategy that has already been successful in showcasing tangible results, as it has attracted more than 1,000 blockchain and metaverse companies to the area so far.



3.3 Start-ups in the industrial metaverse ecosystem

Companies like Forma Vision, Cosmos Tech and Worlds are using a combination of these technologies to improve collaboration, simulate complex scenarios and automate supply chains.

Many customers seek hyper-personalized, convenient and effective processes, bringing rise to new engagement models that utilize spatial computing, AI, Web3 and blockchain. BehaVR uses VR as an innovative and immersive way to tackle behavioural conditions such as anxiety and depression, creating a safe, creative and non-invasive method of treating mental health disorders, which demonstrates that immersing patients in a virtual environment can lead to better health outcomes than traditional allopathic medicine.

Exploring the emerging companies with the potential to disrupt the industrial sector in 2024 and beyond, a total of 800 global metaverse start-ups and scale-ups were analysed. Meet 32 (non-exhaustive) of the most promising start-ups to watch globally within the industrial sector.

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

- Talent and learning
- Boundless collaboration
- Transparency and traceability
- Simulation and optimization of the enterprise
- Deployed product management
- Personalized customer interaction and sales channels

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

Talent and learning

Apogee Tech
Industrial automation systems developer intended to improve safety and operational efficiency of factories.

M3dics
Anatomical reconstruction platform designed to offer 3D anatomical modelling for pre-operative planning.

SkyHive
Labour market intelligence platform developer designed to reskill enterprise workforces and communities.

Strivr
Immersive learning platform designed to elevate the way people and organizations train, learn and perform.

Talespin
Virtual learning platform developer designed to power knowledge transfer and skill alignment.

Boundless collaboration

Transparency and traceability

Simulation and optimization of the enterprise

Deployed product management

Personalized customer interaction and sales channels

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

Talent and learning

Boundless collaboration

Cintoo
Cloud management platform designed to bridge the gap between reality capture and digital twins.

CoderBlock
Developer of a digital metaverse platform designed to facilitate remote collaborations between individuals.

Forma Vision
Developer of a holographic meeting platform designed to offer face-to-face remote meeting experiences.

Hyperverse International
Developer of a virtual content management platform designed to help enterprises conduct events in VR.

Imverse
Developer of 3D hologram software designed to provide personalized and interactive experiences.

InVision Medical VR
Developer of VR technology being used to improve communication across the healthcare industry.

Touchcast
Enterprise metaverse company improving people's lives through the power of immersive experiences.

Tsunami XR
Cloud collaboration platform designed to serve globally distributed teams.

Vantari VR
Developer of VR platforms designed for procedural training for hospitals, universities and medical device companies.

Transparency and traceability

Simulation and optimization of the enterprise

Deployed product management

Personalized customer interaction and sales channels

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

Talent and learning

Boundless collaboration

Transparency and traceability

Agorus

Developer of custom residential construction technology architecture software designed to change how the world builds and accelerate construction.

Courtyyard.io

Provider of digital asset conversion services intended to securely tokenize physical assets into non-fungible tokens.

MBD Financials

Developer of a cross-chain photorealistic metaverse platform designed to create a financial ecosystem.

Worlds

Developer of an AI industrial metaverse platform for measuring, improving and building artificial intelligence-based automation into the ground floor operations of supply chain companies.

Simulation and optimization of the enterprise

Deployed product management

Personalized customer interaction and sales channels

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

Talent and learning

Boundless collaboration

Transparency and traceability

Simulation and optimization of the enterprise

3Vjia technology
Developer of a 3D interior design platform intended for the home manufacturing industry.

Alleantia
Developer of industrial IoT platform intended to help with and accelerate any industrial digital transformation.

Cosmo Tech
Developer of global software designed to make optimal business decisions in the most complex environments.

Duality Robotics
Robotics simulation tools for industrial applications.

Good Chemistry
Cloud computing technology designed to predict chemical properties at breakthrough scale and speed.

Narnia Labs
AI-based software intended to provide operational optimization recommendations using synthetic data.

Virtonomy
Provider of data-driven studies focused on virtual patients intended to shorten the time taken for medical products to reach the market.

Deployed product management

Personalized customer interaction and sales channels

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

Talent and learning

Boundless collaboration

Transparency and traceability

Simulation and optimization of the enterprise

Deployed product management

DataMesh

Developer of an enterprise metaverse platform based on digital twin and XR technology designed for manufacturing enterprises.

Ketos

Actionable water analytics technology designed to measure, manage and forecast water quality and efficiency.

Rooom

Developer of an online presentation platform designed to provide 3D product view.

Uino

Developer of smart visual management platform and applications specializing in digital twin visualization.

Personalized customer interaction and sales channels

FIGURE 25 | **Industrial and enterprise metaverse start-up segment map**

Select the tabs to discover more

Talent and learning

Boundless collaboration

Transparency and traceability

Simulation and optimization of the enterprise

Deployed product management

Personalized customer interaction and sales channels

Ameria

Developer of an all-in-one software platform designed to offer integrated gesture control in public spaces.

Behavr

Developer of virtual reality therapeutics designed for mental and behavioral health.

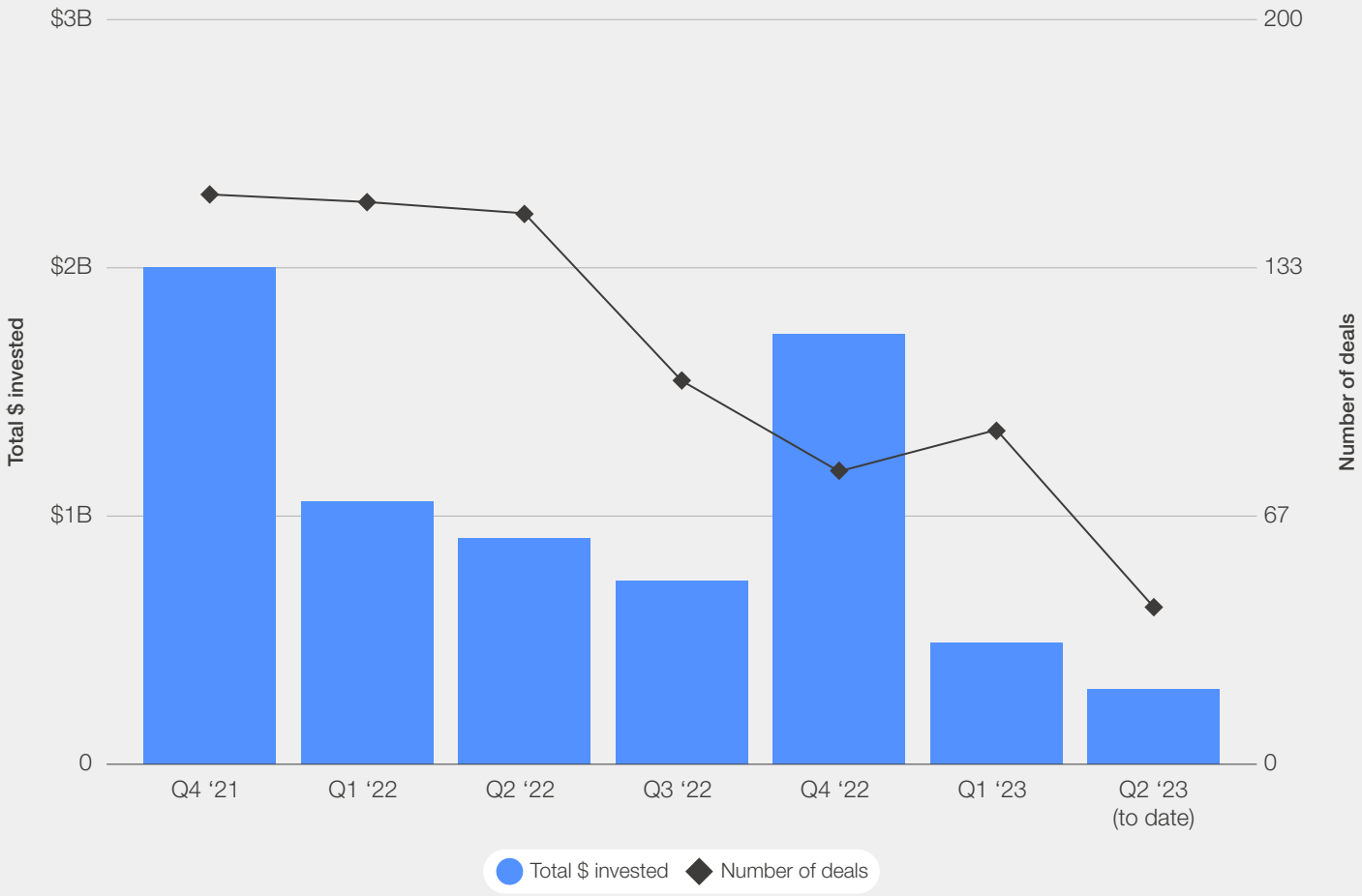
Magnopus

Operator of a content-focused technology company intended to design and build XR experiences.

3.4 Investment landscape

The current funding landscape looks very different to a couple of years prior, both in dollar value and deal flow. Based on recent economic conditions, investor appetite for start-ups in the metaverse has fallen precipitously. From the fourth quarter of 2021 to the first quarter of 2023, investment dollars fell by 77%. In the first two quarters of 2023, metaverse start-ups received a meagre $284 million in investment, with a total of 46 deals being finalized.[58]

FIGURE 26 **Funding to venture capital-backed start-ups in the metaverse**



Source: Metinko, Chris, "Metaverse Investing Has Slowed. Can Apple Save It?", *Crunchbase*, 15 June 2023, https://news.crunchbase.com/ai-robotics/metaverse-investment-data-aapl/.

With this shift, a flight to quality has emerged in the venture capital (VC) space as companies such as GoStudent have raised nearly $700 million to capture the potential of the VR- and AI-enhanced tutoring market.[59] Organizations with unwavering investment towards metaverse enablement, however, will be best positioned to integrate the novel concepts, business models and ideas from emerging voices when the appetite for immersive technologies and experiences returns.

Even as VCs shift their investment focus, major players such as Meta, Apple and Microsoft continue to invest capital and make strides towards new spatial experiences. The release of the Meta Quest 3 and Apple Vision Pro, along with Microsoft Copilot integration with HoloLens 2, indicates a steadfast approach by major corporations to advance spatial computing and the future of work and commerce through new immersive technologies and experiences.

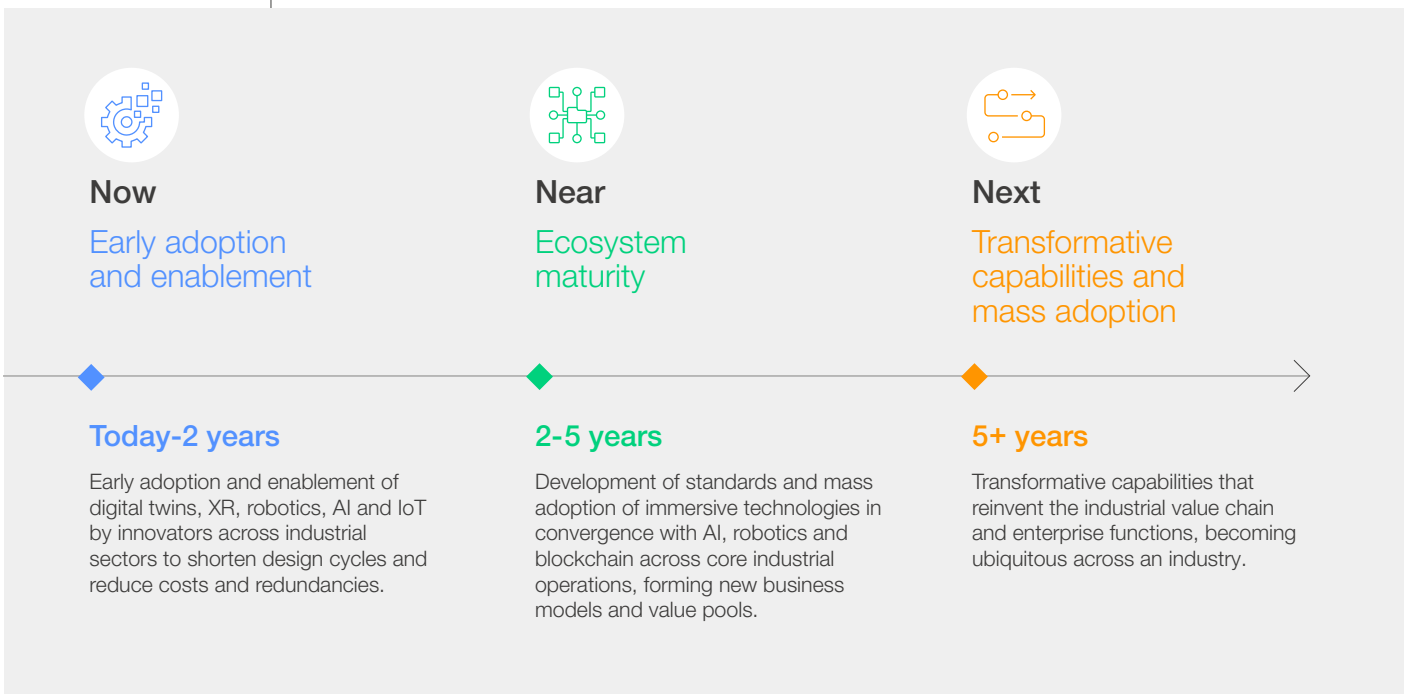
> **Today marks the beginning of a new era for computing … Just as the Mac introduced us to personal computing, and iPhone introduced us to mobile computing, Apple Vision Pro introduces us to spatial computing.**
>
> Tim Cook, Chief Executive Officer, Apple

3.5 Future value horizons in the industrial metaverse

As the industrial sector enters a new era in which spatial experiences, digital twins, Web3 and blockchain and AI take centre stage, the future of each industry will change dramatically as opportunities to drive greater design and operational efficiencies emerge. Leaders will be faced with the daunting task of navigating a complex ever-changing landscape but can better prepare themselves by understanding how this impending shift will alter business processes. Figure 27 projects the evolution of the industrial metaverse over the next five years and beyond.

Each industry will derive unique benefits from its metaverse journey based on where it starts, what it wants to achieve, and the barriers it faces as it strives to achieve these goals. This report will now delve a little deeper into how the industrial metaverse could help transform processes and business models in the five industries identified earlier as having made a head start in adopting metaverse technologies and techniques.

FIGURE 27 **Projected horizons of metaverse growth and adoption in the industrial sector**



Future of industries

Industrial manufacturing

Automotive

Energy

Healthcare

Cities and urban infrastructure

Click to skip to the relevant section

Future of industrial manufacturing

Click to skip to the relevant section

97%

of industrial manufacturing executives agree the convergence of digital and physical worlds over the next decade will transform their industry.

The metaverse has the potential to revolutionize manufacturing. Over the next two years or so, technology will reach a stage where it will be possible to seamlessly integrate equipment, processes and workers through IoT, AI and XR, thereby linking the physical with the digital in the manufacturing setting. Using machine learning, digital twins can simulate the manufacturing process, and with regular cross-functional collaboration, can inform efforts to improve output. Simulation will also enable more sophisticated equipment monitoring and asset maintenance, and will help in predicting malfunctions. With this information, human capital can be better scheduled and deployed to fix these malfunctions and reduce downtime.

Looking ahead, it is likely that the world will see a rise in immersive technologies throughout the operations of manufacturing companies. AI can help increase the speed and accuracy of quality control of finished products. Blockchain can increase supply chain transparency and traceability, allowing manufacturers to better analyse and optimize logistics, inventory management and distribution. The adoption of blockchain will also enable smart contracts: agreements between suppliers and distributors can be automatically notarized, invoiced and executed as transactions move to a shared immutable ledger. This integration of blockchain into the supply chain brings enhanced transparency and traceability to manufacturers, helping them on their journey towards their sustainability goals.

A day in a new reality: smart shop floors

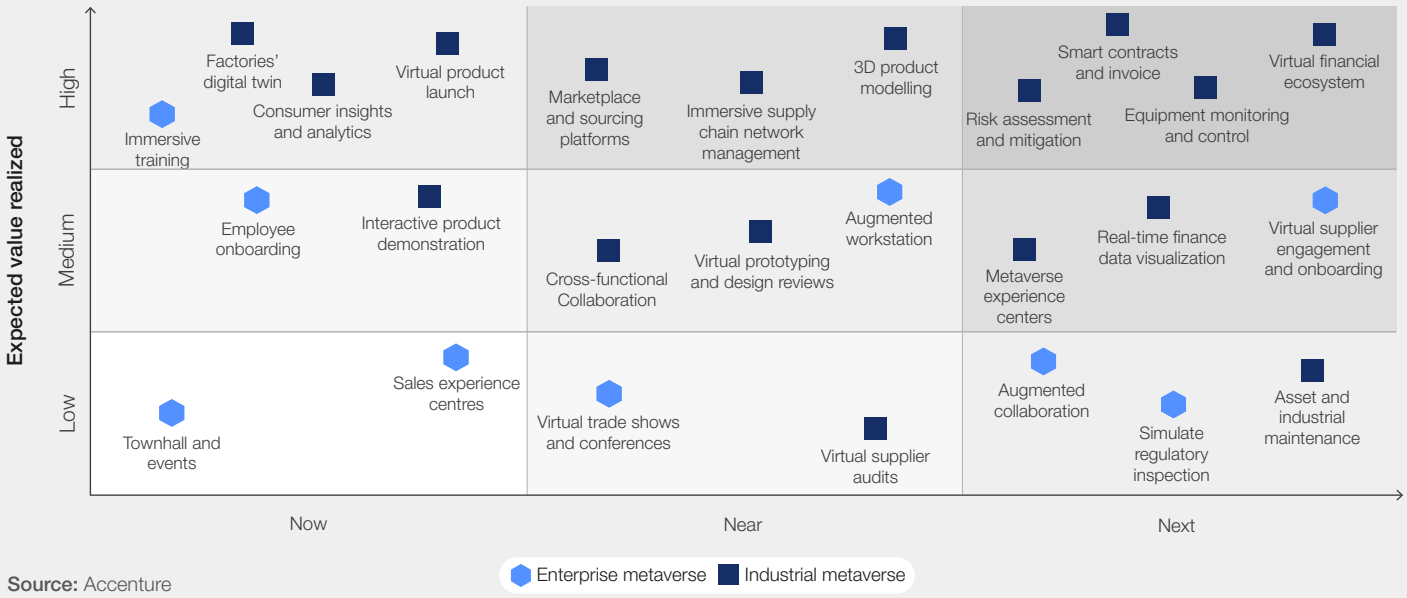
It's 2030. Abhishek, a mechanical engineer at a manufacturing plant, enters the facility and puts on his MR headset that instantly outlines his tasks for the day.

His MR visor displays a high priority job: preventing the imminent failure of a mission-critical assembly line robot. The catch? Abhishek has never fixed this type of robot before. Undeterred, Abhishek begins his examination, and his MR headset scans the robot, retrieving its serial number and model from the factory's inventory system.

Using this information and matching it with predicted failure data, Abhishek asks, "Where is the issue located and what needs to be done?"

In response, the virtual assistant displays detailed schematics, highlighting the exact component that needs replacement. Abhishek gets a notification that the replacement part arrived two days ago and is located in the northwest corner of the facility's storage unit. After retrieving the piece, Abhishek requests the virtual assistant for step-by-step instructions to carry out the repair. With helpful visualizations, the virtual assistant guides Abhishek, ensuring a successful outcome. It automatically closes the work order upon completion.

FIGURE 28 **Industrial manufacturing market compass**



Source: Accenture

Future of automotive

Click to skip to the relevant section

70%

of automotive business executives are planning to integrate the metaverse in their organizational activities.[60]

As automakers look to innovate in a low-margin environment, they will need to simultaneously streamline operations while becoming more adaptable to consumer needs. To achieve this, manufacturers are leveraging robotics, XR, digital twins and IoT to improve design, manufacturing and delivery of both vehicles and services.

In the next two to three years, the R&D processes will become technologically centric, as engineers leverage virtual spaces to feel the presence of the vehicle throughout the design process. After vehicle delivery, the digital twin will become the heart of its performance as IoT sensors collect real-time data. Simulations using the digital twin can monitor performance and intelligently diagnose mechanical malfunctions, bringing rise to predictive maintenance and thereby reducing customer unknowns and improving mechanic scheduling. Head-mounted displays, combined with AI, will close the mechanical skills gap and enable owners to make minor repairs on their own.

In five plus years, VR training programs can simulate complex repair procedures, allowing mechanics to practice and enhance their skills in a safe and controlled environment. This can help bridge the skills gap in the industry. Data-driven insights via Web3 and blockchain will help sales representatives understand customer preferences instantaneously, helping them to create a more personalized buying experience.

A day in a new reality: perfectly personalized

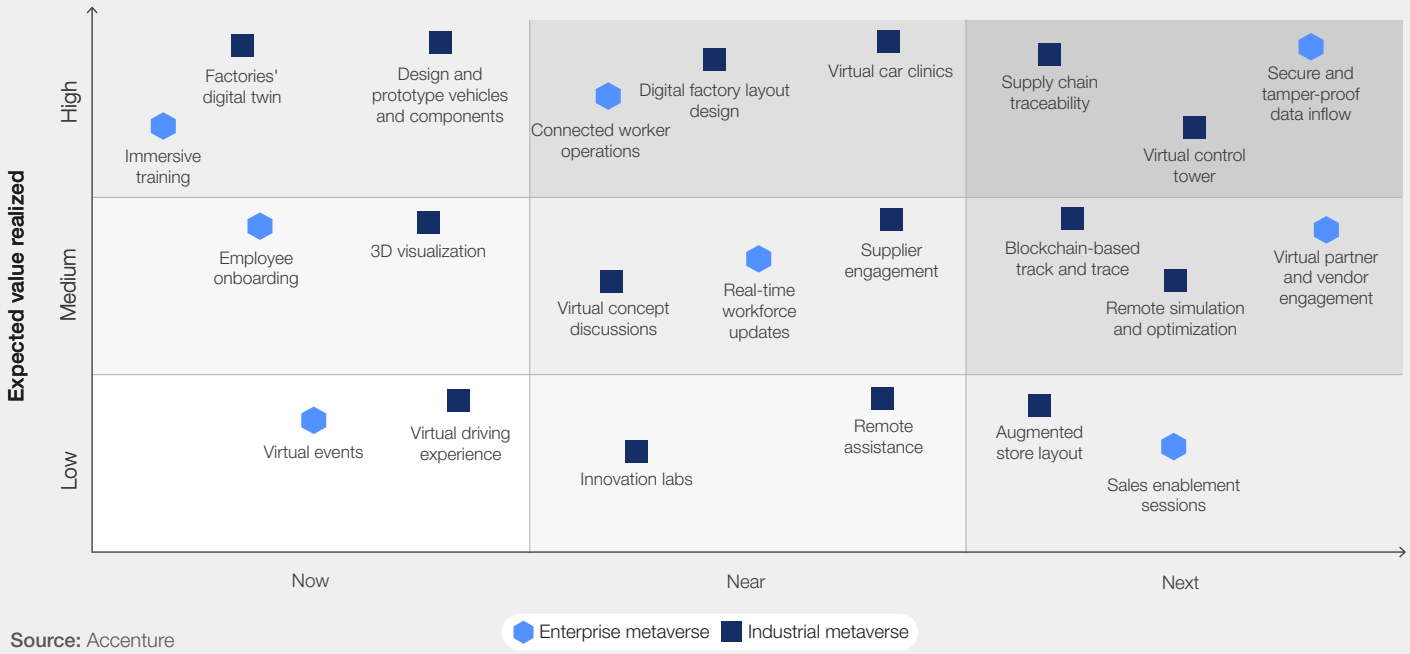
Victor Stephenson has owned his autonomous electric car for seven years, enjoying all the remote updates that customize the vehicle's features to match his preferences. All these preferences are saved in an online database and linked to Victor's digital ID.

Now, Victor is looking for a new car. He sits down in his comfy haptic chair, slips on his virtual reality headset and logs into the automaker's sales platform with his digital ID. A sales representative appears immediately, armed with all the details about Victor's dream car in terms of design, performance and safety.

Together, they dive into a lineup of the latest vehicle models, all tailored to Victor's unique tastes. They even take a virtual test drive, where Victor gets to experience the car's capabilities, comfort and features as if he were behind the wheel. Impressed, he seals the deal with a secure biometric confirmation on his digital wallet.

A couple of weeks later, Victor's new car arrives. As he settles into the driver's seat, he can't help but notice that everything is perfectly customized to his liking. He takes the car out for a spin, marvelling at his personalized vehicle and the excellent sales experience.

FIGURE 29 **Automotive market compass**



Source: Accenture

Future of energy

Click to skip to the relevant section

Emerging technologies will play a major role in the energy industry as it diversifies into renewables, hydrogen and biofuels in the face of challenges such as skilled labour shortage, lack of interoperability between different platforms and systems, physical risks to field employees, and the need for regulatory adherence across geographies.

In the next two years, energy players will enhance their use of technologies such as IoT and AI across several processes. For example, field equipment (such as wind turbines) can be remotely monitored using IoT sensors, data that can then be fed into an AI-powered digital twin. Automated predictive analytics can be used to identify equipment malfunctions before they become critical, resulting in improved worker safety and downtime. Virtual training in realistic immersive environments can help workers prepare for field deployment by practicing technical repairs, equipment operation and safety habits. Emerging shared virtual spaces could lead to improved ecosystem-wide collaboration, bringing together suppliers, partners, colleagues and other stakeholders to analyse interoperable data, leading to more informed and mutually beneficial decision-making. The move to a sustainable net-zero future is being accelerated by Web3 and blockchain as energy companies leverage interoperable networks to build transparent, tamper-proof supply chains to ethically source raw materials.

Over the next five plus years, tokenization can make carbon credits transferable in immutable marketplaces. This can help increase traceability, reduce fraud, and automate the life cycle of an offset, including registration, data collection, verification and retirement. Smart contracts open the possibility of automated contracts, invoicing and payments as companies increase collaboration with external stakeholders.

99%

of energy executives agree that emerging technologies will help their organizations remain resilient on the global stage by accelerating reinvention.

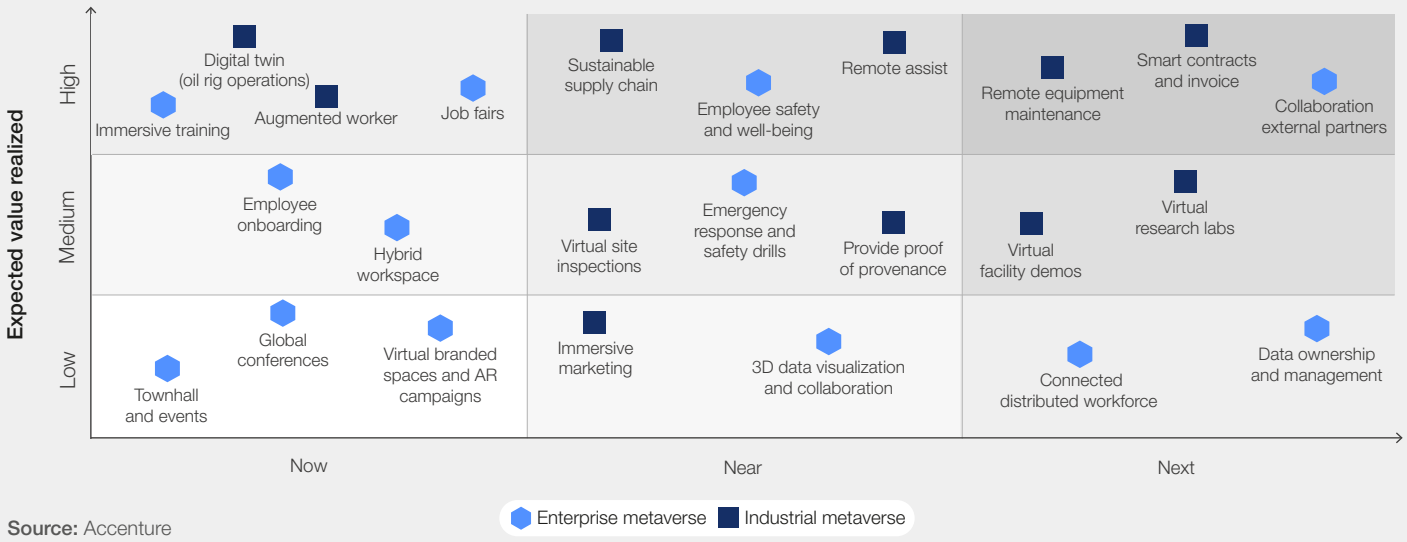
A day in a new reality: ready renewables

Mia Turner is the newest solar installation technician at a renewable energy company. She begins her onboarding by linking her digital wallet – which holds her digital ID, certifications and credentials – to the training platform. The platform analyses Mia's credentials and creates a personalized training program tailored to fill any knowledge gaps she may have.

With her VR headset on, Mia embarks on her training journey. A virtual instructor guides her through customized course content, providing step-by-step instructions in a digital twin environment that perfectly replicates real-world conditions. The best part? After Mia gives her consent, the training program tracks her progress and offers real-time feedback on her technique.

After completing the training program, Mia feels confident and well-prepared for her first day at the solar farm. The virtual environment not only equipped her with practical skills but also deepened her understanding of the renewable energy landscape. As Mia steps onto the physical solar farm, armed with the knowledge gained from her immersive VR training, she is ready to contribute to a greener future.

FIGURE 30 **Energy market compass**



Source: Accenture

Future of healthcare

Click to skip to the relevant section

89%

of biopharma executives believe that programming the physical environment will emerge as a competitive differentiation.[61]

The metaverse can speed up the evolution of both healthcare services and R&D in pharma and medical technology. It can help companies find unique ways to accelerate the development and distribution of products in the highly-regulated healthcare environment, while bringing treatment options to patients in a human-centric manner.

Over the next two to three years, it will become commonplace for healthcare organizations to use immersive technologies and AI to simulate chemical and physical reactions for early-stage drug development. XR-enabled improvements to remote care will improve patient retention in clinical trials across geographies by eliminating the need for travel. Spatial computing can improve collaboration between pharmaceutical companies and healthcare practitioners (HCPs), closing the technical gap and bringing demonstrations directly to the HCPs who administer treatment.

Over the next five years the metaverse will facilitate faster, better and more holistic treatments via the convergence of digital and real-world operational environments. Virtual onboarding will walk the patient through the treatment journey even before it begins, addressing the patient's questions, concerns and uncertainties and enhancing patient experience and treatment compliance. Integrating VR to gamify treatments for children can foster an unprecedented level of comfort in paediatric care. Blockchain and quantum computing will facilitate an interconnected healthcare ecosystem, expediting identification and recruitment of appropriate clinical trial participants by harnessing traceable patient data.

A day in a new reality: surgical precision

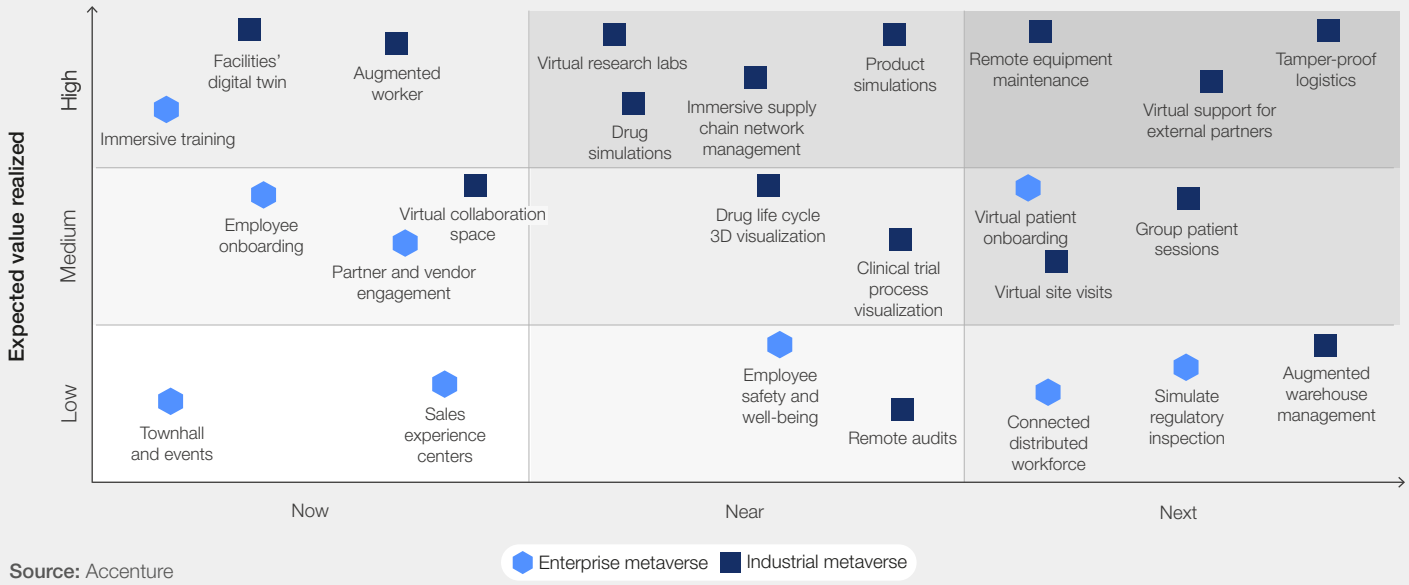
Wendy Miller, a surgeon, has just finished reviewing her patient's CT scan and, as she takes off her MR headset, she contemplates the highly intricate surgery that lies ahead. Her goal is to remove a tumour from the patient's liver. However, Dr Miller has already dissected the diagnostic data by magnifying and rotating 3D models, gaining a thorough understanding of the tumour's proximity to vital organs.

After planning the surgery, she downloads the patient's data into her practice module. She puts on her haptic gloves and MR headset, and she is instantly transported into a simulated operating room with her patient on the operating table.

Dr Miller begins practising the exact movements she would make during the surgery. With haptic feedback, she can feel the resistance and texture of the tissues. The training platform throws unexpected challenges her way, boosting her technical skills and mental preparedness.

On the day of the surgery, Dr Miller enters the operating room, puts on her MR headset and views her surgical plan overlaid on her patient. It's exactly what she trained for in the weeks leading up to the surgery. This instils a sense of calmness in her, knowing that she's fully prepared to perform the operation with surgical precision.

FIGURE 31 **Healthcare market compass**



Source: Accenture

Future of cities and urban infrastructure

Click to skip to the relevant section

94%

of public service executives agree that digital identity is becoming a strategic business imperative.[62]

IoT sensors, data analytics and AI play a major role in the running of smart cities, which could be the solution to today's global challenges of population growth, traffic congestion, environmental issues and housing shortages.

In the near term, architects will be able to integrate CAD models into 3D VR environments for a more immersive design and sales experience. Virtual representations can help construction teams plan each step of the building process and can be used for employee training as well.

In the next five years, as cities and urban infrastructure become better integrated with citizens and information flows seamlessly between stakeholders to deliver tailored experiences, the data generated can be stored on hybrid blockchains (tamper-proof data platforms). This will enable interoperable networks that allow public servants to provide more efficient public services like transport and emergency services.

Smart sensors deployed along waterways, in buildings and on roads will collect data that rolls up to a digital twin of each piece of municipal infrastructure, facilitating real-time monitoring in virtual command centres and simulation to identify issues before they occur. Municipal digital twins and simulation will allow city planners to play with new concepts before implementing them, resulting in less wasteful spending and better allocation of human capital.

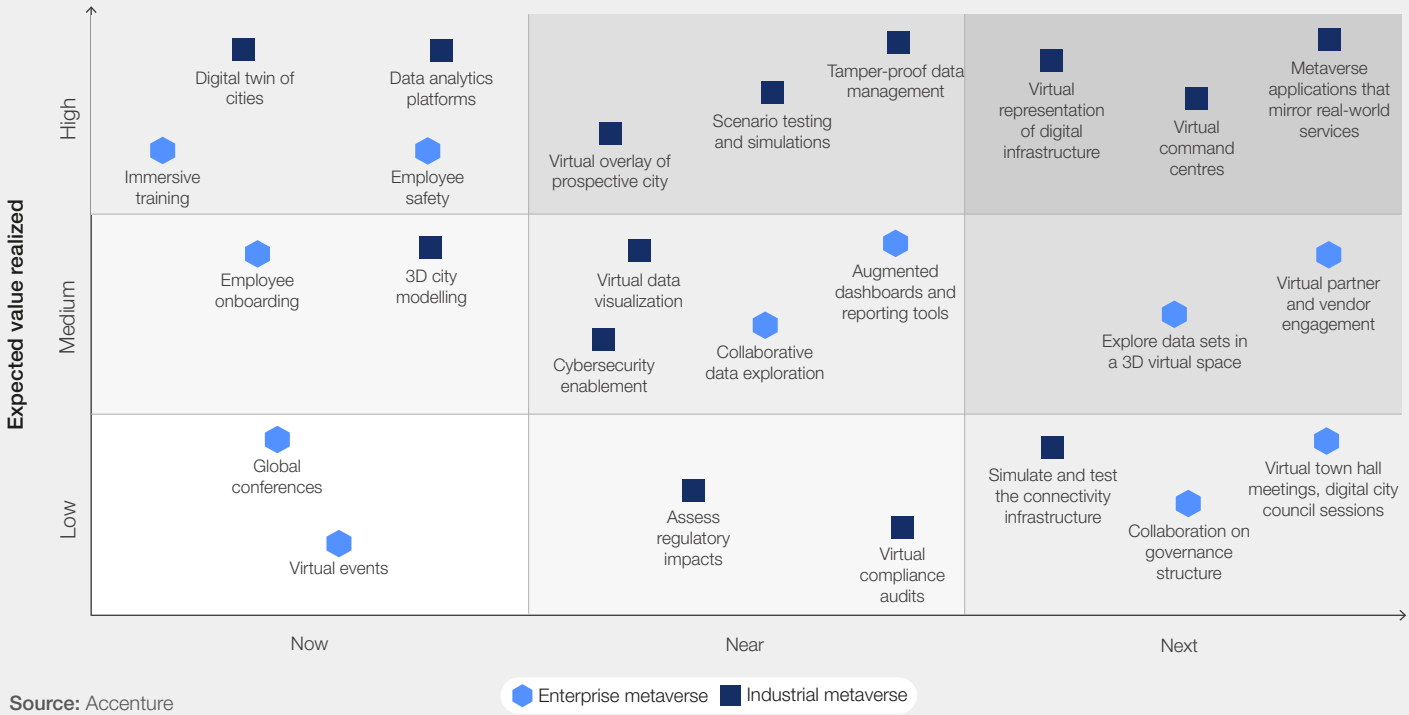
A day in our new reality: realizing an architect's vision

Akira Yamamoto, a renowned architect, is designing a new skyscraper that will redefine the Tokyo skyline. Akira immerses herself in a VR workstation at her design studio, visualizing the digital twin of her creation. The virtual environment allows Akira and her team to perceive the scale and proportions of the building in ways traditional blueprints could never capture. She walks through the floors, assessing sightlines and viewing the skyscraper from various perspectives.

After some final adjustments, she takes her team to the construction site. Using AR, she compares the construction progress to her designs, ensuring every detail matches her vision. She walks the construction team through the next steps, showing them how the building will come to life.

Equipped with sensors, the building provides real-time data on its responsiveness to weather conditions. This aids building inspectors and city councillors in their evaluations and approval decisions, ensuring safety and efficiency.

FIGURE 32 **Cities and urban infrastructure market compass**



Source: Accenture

3.6 The role of emerging technologies in advancing the industrial metaverse

Generative AI and quantum computing offer unprecedented possibilities for the industrial and enterprise sectors when combined with digital twins, spatial computing, Web3 and blockchain-powered secured exchange. The combination of AI and quantum is critical in developing more intricate ways of computing the world. Together, they work to simulate complex scenarios efficiently and accurately, and will play a central role in accelerating the industrial adoption of the metaverse.

Generative AI can bring significant productivity gains across business operations due to its ability to scale in ways humans cannot. Quantum computing offers fast and precise solutions to complex problems, enabling simulations across a wide array of scenarios and business functions. Quantum sensors accurately collect detailed data, enabling functions like quantum navigation, which is being implemented by Airbus.[63]

In healthcare, generative AI and quantum computing are revolutionizing drug development. Digital twins are being used in combination with generative AI and quantum to simulate molecules interacting with each other, significantly reducing the time, cost and failure rate of drug development by nearly 90%.[64]

Select examples (non-exhaustive) have been identified to showcase how the convergence of emerging technologies, now and in the future, can help to accelerate the techniques and capabilities of the industrial metaverse.

FIGURE 33 **Examples of emerging technologies advancing the industrial metaverse**

Generative AI and the industrial metaverse

Virtually simulated plants, products, operations, supply chains and environments

In life sciences, the integration of generative AI into design and testing will increase accuracy and precision and help streamline R&D operations.

Tamper-proof supply chains

Cloud-based collaborative data infrastructures and single-source-of-truth solutions will simplify the management of highly connected systems. For instance, in smart city solutions, generative AI can aggregate data from diverse urban systems and their complex supply chains like transport, energy and waste management and enhance city planning and services.

Field orientation, navigation and learning

Generative AI will enable contextually aware, AI-driven traffic routing and supply management across the entire value chain.

Quantum computing and the industrial metaverse

Virtually simulated plants, products, operations, supply chains and environments

Digital twins can be resource-intensive, and quantum computing's immense processing power can significantly accelerate the simulation process, enabling real-time analysis of intricate industrial systems.

Tamper-proof supply chains

Quantum technologies can help create unforgeable cryptographic signatures, ensuring the authenticity of products and components and making it impossible to alter records.

Field orientation, navigation and learning

Quantum-powered algorithms can analyse real-time traffic, weather and delivery schedules to chart the most efficient routes for fleets. This will not only reduce operational costs but also minimize carbon footprint.

Part 4

Realizing the full potential of the industrial metaverse

The potential of the industrial metaverse notwithstanding, a carefully calibrated approach is required to create meaningful, optimal outcomes for all stakeholders.

Four key considerations were identified to deliver a responsible, ethical and economically viable industrial metaverse.

4.1 Creating a future-ready workforce

In the next five years, 23% of global jobs will witness transformation, forcing workers to adapt their skills to market demand.[65]

From remote work to virtual meetings to automation, the COVID-19 pandemic put the global labour market on a path of continuous reinvention. The rapid digitalization of workplaces and adoption of new ways of working make it incumbent on organizations to visualize how roles will evolve in the future and act accordingly.[66]

To develop a skills transition road map for new and redesigned job roles, industrial organizations need to understand the talent they have and the talent they will require. For instance, companies in the electric vehicle space will inevitably need workers in large numbers for installation and maintenance of charging stations. Spatial experiences enable boundless knowledge transfer at scale, while blockchain will notarize and validate the credentialization of trained workers through secured gateways. Workers in industrial settings will have visual guides and digital assistants, which will make them efficient and improve outputs. Knowledge generated from technologies such as digital twins, big data and AI must be made accessible through XR's immersive simulations, learning and collaboration. This elevates workforce and ecosystem partnership and learning, delivering value across operations and enterprises.

When the digital natives of today join the workforce of tomorrow, it is safe to assume that they will be at ease interacting with emerging technologies like generative AI, spatial computing, Web3 and blockchain. Therefore, companies must ensure access to training is democratized, allowing experienced engineers and technicians to impart "uncodified knowledge" to new entrants from remote locations.

Even as technology becomes an inseparable part of workers' lives, it is imperative for organizations to find a balance between using the capabilities and preserving their critical thinking skills. This can be done by training workers in problem-solving and analytical reasoning with an aim to boost higher-order thinking.

Workforce transitions will not be uniform across industries or roles. For example, it is projected that in the next five years, there will be more jobs in science and advanced technology and fewer jobs in customer service and office administration.[67] To that end, companies need to build an agile workforce by investing in skills mapping and imparting hard and soft skills to their people. Workspace modifications will be required to maximize technological benefit, improve output and accommodate worker needs, especially for roles that will become augmented through spatial computing, AI and blockchain.

In preparing for enterprise reinvention, businesses will need to take human-centric approaches in the deployment of new technologies. Businesses will need to prepare for a shift where an organization's most valuable employees become not those on the front line, but those calibrating technological guidelines. The impact on the new responsibilities, roles and functions of human workers will require deep attention throughout this shift.

BOX 27 Upskilling in automotive and healthcare sector

BMW is tapping the metaverse to enhance efficiencies in building electric cars, showcasing how virtual reality can streamline complex manufacturing processes.[68] At the same time, VirtualiSurg's VR software, a metaverse application, is being used at Paris' Georges Pompidou European Hospital for professional medical training. [69]

The practical application of VR in industries as diverse as automotive manufacturing and health care indicates growing confidence in the metaverse's role in professional development.

The economic aspect is also crucial. Affordable VR headsets, for example, can democratize advanced training, simplifying upskilling across industries.

With high-quality educators leading virtual training sessions, a blend of traditional and futuristic approaches to education and skill acquisition is on the cards – where human expertise is augmented by the capabilities of metaverse technologies.

4.2 Building towards a more sustainable future

With data driving immersive, intelligent experiences, initiating a "green software" movement to help build the world's industrial environments in the metaverse is critical.

From an environmental standpoint, not bounded by the physical world, the industrial metaverse has the potential to unlock significant benefits. Acting as a bridge between physical and virtual worlds, digital twins can represent everything from manufacturing plants and skyscrapers to cars and urban infrastructure, boosting efficiency and reducing waste. Smart sensors, AI/ML and XR can bring down energy consumption meaningfully while virtual, immersive environments can help create more collaborative workspaces.

Companies must, however, be mindful of the fact that running metaverse applications can be a double-edged sword – blockchain, AR/VR and cloud computing require vast processing power, which can increase their carbon footprint, albeit while alleviating emissions in other functions and domains. The effect on energy consumption, and by extension carbon emissions, could be significantly greater – a company's approach to data centre efficiency and power sources will need to be considered when forming a long-term vision for their industrial metaverse strategy. Against this backdrop, organizations will need to integrate sustainable IT practices, optimize server farms and virtual environments for energy efficiency, and explore renewable energy sources. The metaverse offers a unique platform for experimenting with sustainable practices; however, proactive measures like green software engineering and cloud optimization are crucial to mitigating potential emissions.[70]

Readers can delve deeper into approaches to building a sustainable metaverse across the value chain, environmental challenges of metaverse technologies, and the role core industrial metaverse technologies such as digital twins will play in accelerating sustainability, from smart building to car prototyping and more, in an earlier publication, *Social Implications of the Metaverse*.

TABLE 3 **Metaverse sustainability**

Sustainable manufacturing in the industrial metaverse	Green software practices	Strategic decarbonization and environmental, social and governance (ESG) practices
Digital twins can boost efficiency and sustainability. This concept is transforming sustainable manufacturing by facilitating virtual simulations that inform real-world processes, reducing resource waste and optimizing product life cycle.[71]	Organizations are recognizing the need for green software, which emphasizes efficient use of resources throughout their life cycle – from development to maintenance. This involves adopting practices such as code optimization and energy benchmarking, and considering the energy demands of AI-based applications from the outset.[72,73]	With the information and communication technologies (ICT) sector accounting for a significant portion of global emissions, there's an urgent need to widen the scope of sustainable IT. The vast amounts of data required for the metaverse raise sustainability concerns. Solutions like dynamic resource allocation, green hosting and the use of renewable energy sources are being explored to address these challenges.[74]

4.3 Enhancing safety and security

Companies must overcome digital safety challenges to ensure virtual environments do not compromise the well-being of the industrial workforce. Spatial tools collect vast arrays of data that, when used correctly, can identify and address online harms, help combat harmful content and enable companies to invest in talent to support platform integrity.

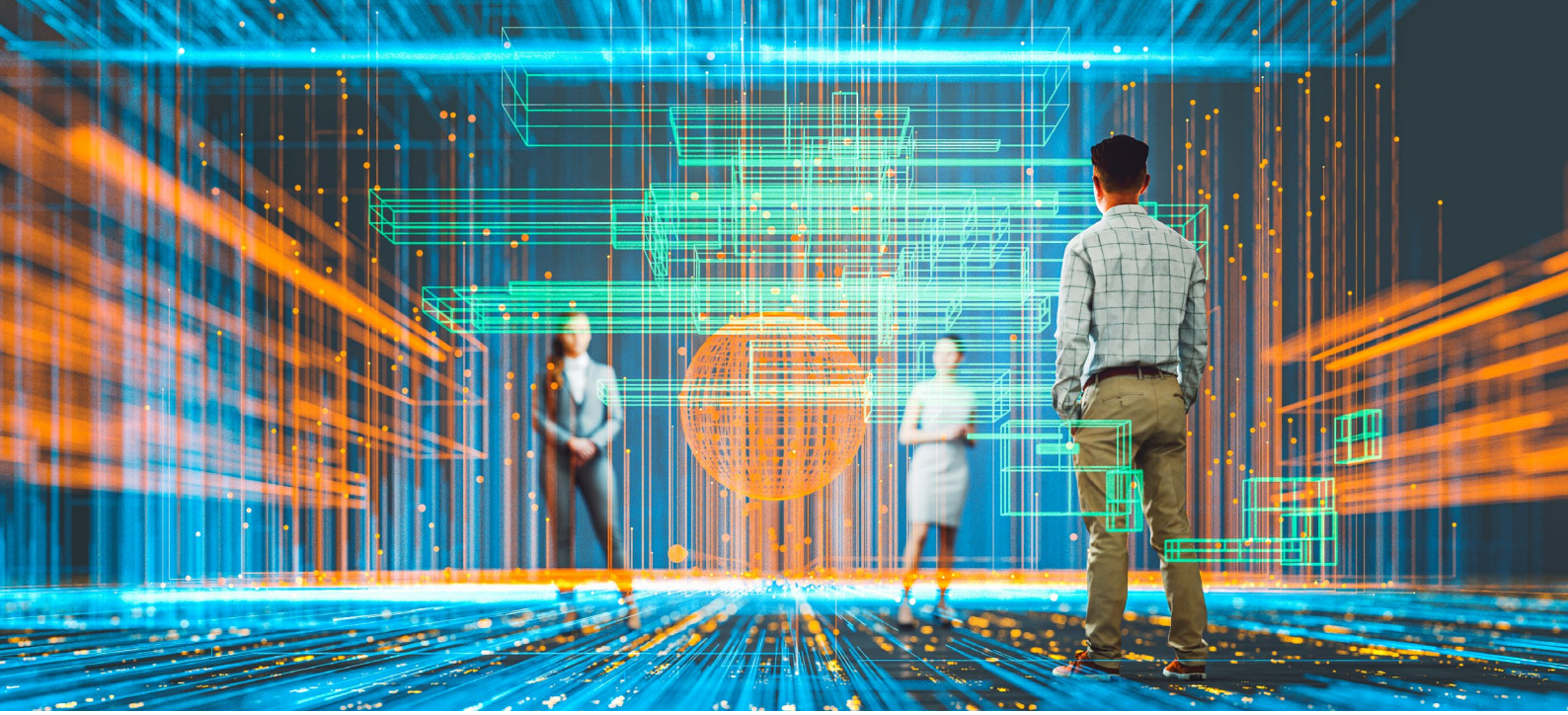
BOX 28 Identity management and trust in the metaverse

Digital identity[75] is a cornerstone of the metaverse experience. Unlike today's internet, where digital identities are often siloed with specific platforms or companies, the metaverse envisions a scenario where users have portable identities, complete with their data and history. While this portability is desirable, it also raises significant security concerns as it may expose stakeholders to fraud.[76] Blockchain-based credential services and multi-factor authentication can be used to enhance trust in metaverse identities. Stakeholder involvement is paramount to shape digital identity governance and to monitor for impersonation and fraud.

As generative AI integrates into more intelligent metaverse environments, safety and security have become paramount. For instance, an engineer could ask an AI assistant to recommend safe handling practices for hazardous materials within the digital twin of a manufacturing plant. If the AI pulls unsafe information from outdated data sources, it could suggest dangerous practices. Companies need safeguards to ensure that language models are appropriately updated, and they provide accurate, up-to-date recommendations aligned to proper protocols. A multifaceted approach involving cybersecurity of industrial metaverse platforms, assets and users is required.

BOX 29 Building trust in persistent digital worlds

The metaverse is designed to be persistent, meaning activities continue even when users are not actively engaged. This persistent nature requires rethinking digital services, monitoring and controls. Technologies like blockchain and AI can automate identity authentication and asset management, boosting trust. Independent audits of smart contracts and infrastructure are recommended to ensure the integrity of the virtual environment. Cloudflare emphasizes that trust begins with transparency.[77] It is essential to openly communicate both successes and failures, own up to mistakes, and be accountable to the same rules and laws that govern everyone else.



4.4 The road ahead

In the burgeoning field of the industrial metaverse, a concerted focus on infrastructure and connectivity is likely to be a fundamental requirement. The emergence of digital twins is revolutionizing real-time monitoring and simulation, allowing for an unprecedented synthesis of virtual and physical systems. The deployment of 5G/6G and edge computing is crucial to enabling the high-speed, low-latency transfer of data that industrial applications demand.

BOX 30 A blueprint for industrial metaverse

Adoption across industries will vary in need and velocity, with sectors like automotive, aerospace, energy and pharmaceuticals at the forefront. Currently, companies are experimenting with VR for safety training and mixed reality for showrooms but face challenges with integration, data interpretation and high costs. A lack of clear vision, strategy or governance for the industrial metaverse are potential barriers to consider. [78]

Additional considerations:

- Market drivers – economic, social, environmental, political and legal factors for responsible growth
- Technologies – edge connectivity, AI, blockchain, etc.
- Managing resources – financial, organizational, human
- Identifying use cases – review the product life cycle and develop a comprehensive road map

Interoperable standards are the linchpin for seamless system and platform integration, while robust cybersecurity measures are mandated to safeguard the metaverse's sensitive industrial data. Central to this evolution is cultivating a skilled workforce – architects of this new realm – equipped to navigate, enhance and secure the metaverse's value potential. Further exploration of future developments of these technologies, resource requirements and more can be found in *Exploring the Industrial Metaverse: A Roadmap to the Future*.

BOX 31 XR for enterprise

Nokia demonstrated that XR is an emerging ally for enterprise use cases in the industrial segment.[79] It requires the integration of VR, AR, MR, 5G/6G, IoT, cloud, edge computing and AI in technology stacks. The roadmap ahead involves innovating infrastructure with new hardware and software to meet the demand of industry 4.0 and transform the operation of facilities and plants.

4.5 Leading drivers for growth and adoption of the industrial metaverse

Seven areas (non-exhaustive) were identified as top prerequisites for growth and mass adoption of the industrial metaverse.

TABLE 4 **Prerequisites for growth and mass adoption of the industrial metaverse**

Skilled workforce	A **skilled workforce** is crucial for the industrial metaverse as both need to work in tandem to succeed. At present, industries are facing several challenges on the workforce front: – Talent shortage – High training costs – Resistance to change – Succession planning complexities
Hardware, infrastructure and computing power	**Hardware, infrastructure and computing power**, including cutting-edge advancements in quantum computing, are crucial drivers for the industrial metaverse as they form the backbone of immersive technologies, connectivity and data processing. Currently, there are several challenges in this area: – High implementation and computing costs – Rapid technological obsolescence – Complexity of quantum algorithms – Challenges in scaling and maintaining reliable systems
Regulatory framework	A well-defined **regulatory framework** encourages innovation and provides a structured environment for the responsible development and deployment of metaverse technologies in industrial settings. Frameworks for metaverse tools and applications will also have to be designed and built. Yet it also carries risks such as: – Stifled innovation – High compliance costs – Slow adoption – Global standardization challenges Realizing the promise of the industrial metaverse will require cross-industry collaborations on standards and infrastructure.
Cybersecurity	**Cybersecurity** is a significant risk for the industrial metaverse due to the potential for data breaches, system vulnerabilities, insider threats and the increasing sophistication of cyberattacks, which could compromise operations and sensitive information.
Efficient supply chain	An **efficient supply chain** is crucial for the industrial metaverse as it ensures timely deployment, cost efficiencies, scalability and global collaboration, providing a competitive edge and fostering innovation. Supply chain risks in the industrial metaverse include material shortages, dependency on specific suppliers, global disruptions, increased resource demand, technological obsolescence, quality issues, cost fluctuations and intellectual property concerns.
AI	As disclosed throughout the report, **AI** is a crucial building block of the industrial metaverse, whether it's automation or predictive analytics. It drives efficiency, innovation and adaptive processes, transforming industrial operations by integrating intelligent systems that optimize productivity and response to dynamic conditions.
Digital twins	**Digital twins** have evolved into indispensable business assets for forward-thinking companies and stand as a foundational element in the burgeoning industrial metaverse. Positioned to emerge as indispensable instruments for streamlining processes and enhancing decision-making in every industry, the upcoming iteration of digital twins is poised to be characterized by photorealistic representations, physics-based simulations, AI-enabled and seamless integration within metaverse ecosystems. These strategic investments not only lay the groundwork and pave the way for a more immersive enterprise but also herald a transformative era, reshaping the operational landscape of organizations across every industry and unleashing the untapped potential of data and AI.

4.6 Progressing towards a safer, more sustainable and innovative future

The metaverse is not one single strategy or technology but a continued evolution of connected experiences. Each innovation will add value to an organization's investment in a sustainable and resilient future. No matter where a company is in its metaverse journey, it will quickly unlock the value and benefits of these new technologies. Every company's journey will be unique; nevertheless, leaders should keep three key rules in mind:

1. Be creative but keep it simple. Explore experiences to inspire creativity but prioritize those that add value by tying initiatives to strategic objectives. Go back to the basics and build upwards with creativity at the core.

2. Start small and focused. Start with use cases that can be easily measured to demonstrate value to your organization and gain executive sponsorship to move ahead.

3. Engage with early building blocks. Target areas quickly yet thoughtfully. Early engagement engenders long-term trust and delivers a competitive edge.

Conclusion

The emergence of the industrial metaverse heralds the dawn of the next industrial revolution. Powered by a range of innovative technologies, from digital twins to spatial computing, AI and Web3, it is poised to reshape global economies, redefine business landscapes and transform people's experiences worldwide, akin to the transformative impact of the internet.

This digital evolution presents a vast array of opportunities for leaders. By leveraging the industrial metaverse, enterprises can revolutionize their operations, from streamlined product design to enhanced operational efficiencies across the value chain. Virtual sensors, autonomous logistics, collaborative robotics and supply chain optimizations are just a glimpse of its potential applications.

As the world navigates an increasingly complex and dynamic environment marked by supply chain disruptions, demographic shifts and digital advancements, the pressure on industry players to serve and deliver has never been higher, and so understanding how this imminent shift will reshape business processes and embracing industrial metaverse technologies and techniques is crucial. It offers a pathway for leaders to navigate challenges, drive economic growth and foster innovation.

It is important to note that, alongside its promise, the industrial metaverse brings challenges such as safety, security, regulatory compliance and infrastructure requirements. Collaborative efforts among stakeholders are imperative to address these issues and to unlock the full potential of this transformative technology.

Looking ahead, the industrial metaverse will continue to evolve, becoming an interconnected 3D ecosystem that shapes industries and human experiences. Enterprises must prioritize designing seamless and user-friendly human experiences to fully harness its potential.

To lead in this era of technological innovation, executives must reassess their stance on fundamental technologies driving the industrial metaverse. By embracing these advancements early on, businesses can position themselves at the forefront of the digital revolution, shaping industries and impacting lives for decades to come.

Contributors

This report is a combined effort based on numerous interviews, discussions, workshops and research. The opinions expressed herein do not necessarily reflect the views of the individuals or organizations involved in the project or listed below. Sincere thanks are extended to those who contributed their insights via interviews and workshops, as well as those not captured below.

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