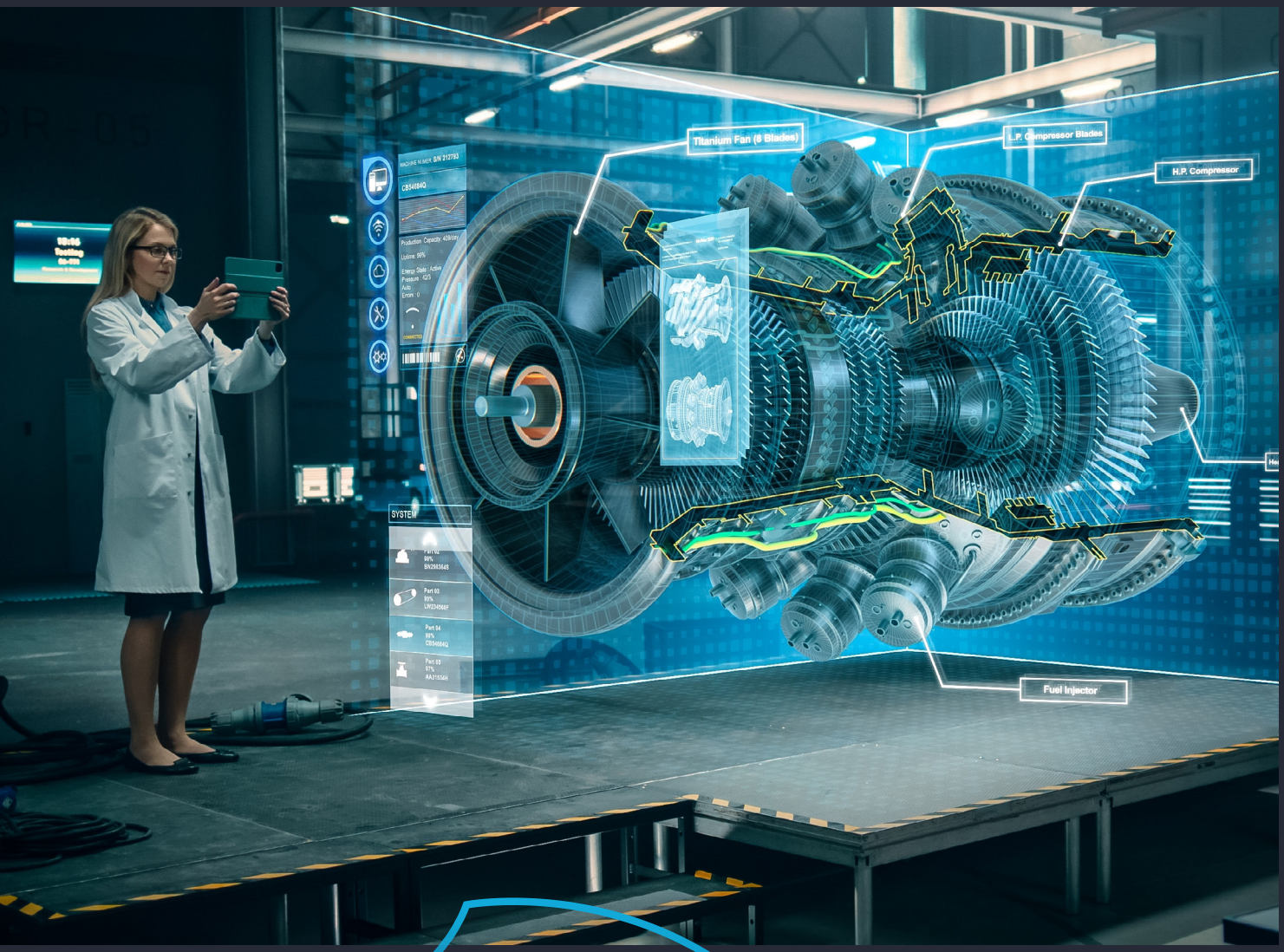


Navigating the new industrial digital landscape.

A pragmatic perspective for CXOs and digital transformation practitioners.

Capgemini

Foreword

Intelligence is meeting experience: the physical and digital convergence, powered by agentic and physical artificial intelligence, is redefining the industrial digital landscape - serving people better and improving the efficiency of industrial processes at scale.

Alexandre Embry
CTIO
Head of the Capgemini AI Robotics & Experiences Lab

The Challenges

Industrial companies are increasingly under immense pressure, from external economic and geo-political stresses, as well as significant internal financial and operational challenges. If businesses are to manage these pressures, they need to improve their operational efficiency. They must reduce product development time, accelerate innovation integration cycles, and optimize production costs, while maintaining quality and enhancing supply chain resilience.

Moreover, they also need to achieve a step-change in sustainable transformation over the next 5-10 years, by focusing on sustainable product design, carbon neutrality, and circularity principles. Finally, in the context of a global talent war, they must rethink their employee experience, modernize their operations and improve recruitment attractiveness, particularly for the younger generation.

The Solution

To address these imperatives, a key path is to accelerate, converge and scale-up ongoing digital transformation streams, such as data and AI-driven strategy, digital continuity, IIoT (the Industrial Internet of Things) or software centricity, while also leveraging cutting-edge technologies. This will achieve the needed transformation, with efficiency, seamless integration and accuracy benefits. Key to this achievement is the Industrial Metaverse, which is both an approach and a technology convergence platform, with a unique ability to converge physical and digital, and significantly, do so at scale.

The benefits are comprehensive:

- **Greater Operational Efficiencies:** This convergence enables companies to improve their ability to collaborate, design, simulate, operate, optimize and automate industrial processes. It impacts product design and operations' efficiency, by generating quantifiable cost savings, boosting automation, reducing time to market and improving quality.
- **Improved Employee Experience:** Through role and process redesign, reduced job risk, enhanced on-site safety, improved training and learning - including reducing by 50% the time spent - industrial roles become more attractive to scarce talent.
- **Positive Impact on Sustainability:** The implementation of an industrial metaverse approach decreases the need for physical assets, minimizes waste, optimizes energy and resources, and supports substantial reductions in CO2 emissions - up to a 50% reduction in some industries such as automotive.

Collectively, the benefits outlined demonstrate why an industrial metaverse approach is clearly an appropriate solution, able to tackle the major issues, and aligning business, people and planetary objectives.

How?

From a technical perspective, the industrial metaverse has been born from the convergence of a breadth of legacy tech and more importantly emerging game-changing technologies. Inspired by Industry 4.0 ignited 10 years ago, the current landscape of industrial digital transformation includes key transformation streams such as Digital

Continuity, IIoT, IT/OT convergence or Data/AI-driven operations that improve process efficiency, and result in the major achievement - the Digital Twin. When merged with emerging technologies, such as natural, immersive and AI-driven interfaces, edge-AI, smart advisors and agentic systems, this gives rise to the full and powerful concept of industrial metaverse that pushes the boundaries of what's possible in industrial operations.

This progressive transformation needs to be achieved step by step.

One of the first foundations is our concept of Internet of Digital Twins that brings a first layer of advanced experiences: collaboration, visualization and interaction.

Then, by assessing data, mobilizing an ontological approach positioned as a core model, and injecting more intelligence, the virtual environment becomes more cognitive, more understanding of what is happening in the real world, and able to anticipate, predict and advise.

As a consequence, the virtual layer becomes autonomous, the system develops self-healing capabilities and can autonomously optimize processes in real time. This is achieved by deploying autonomous AI-agents that mirror the human organization, capable of interacting with each other, with humans, machines, robots, and able to react and act autonomously in the real world.

This might be perceived as a long journey to travel, but adopting a structured and incremental approach, at the enterprise level, enables value to be delivered quickly at each step of the deployment process, whether addressing greenfield or brownfield transformation projects. The value is achieved at speed, as the Industrial Metaverse roadmap does not reinvent but is a continuation of existing initiatives, adaptable to different starting points and digital maturity levels, and relying on existing and mature technologies. There is minimal operational disruption because it is layered on top of existing systems without needing a complete overhaul, providing that organizations have or can build robust foundations and adopt a structured end-to-end approach.

Capgemini plays a critical role in enabling this convergence and realizing subsequent benefits. As your business and digital transformation partner, we bring our core business and technology expertise, proven methodologies and a broad ecosystem of specialist partners to successfully design, build and deploy a high-value Industrial Metaverse, at scale.

Capgemini Intelligent Industry and Industrial Metaverse

With its Intelligent Industry value proposition, Capgemini is positioned today as a major strategic partner for industrial companies. With a range of services that is unique on the market, and the cross-disciplinary skills of over 70,000 engineers, IT/OT architects, data science experts and consultants, Capgemini supports its clients' business and digital transformations, end to end. Intelligent Products & Systems, Intelligent Operations, Intelligent Support and services, it's across the entire lifecycle that use cases can generate value.

Faced with a particularly intense global context, all our clients today have to tackle major challenges and accelerate their digital transformation and the mobilization of the best technologies at scale, starting with the dazzling maturation of artificial intelligence. However, the technical and organizational complexity of such transformations must be mastered, sequenced and orchestrated. The value of these transformations must also be made available to everyone in the form of an attractive, relevant experience.

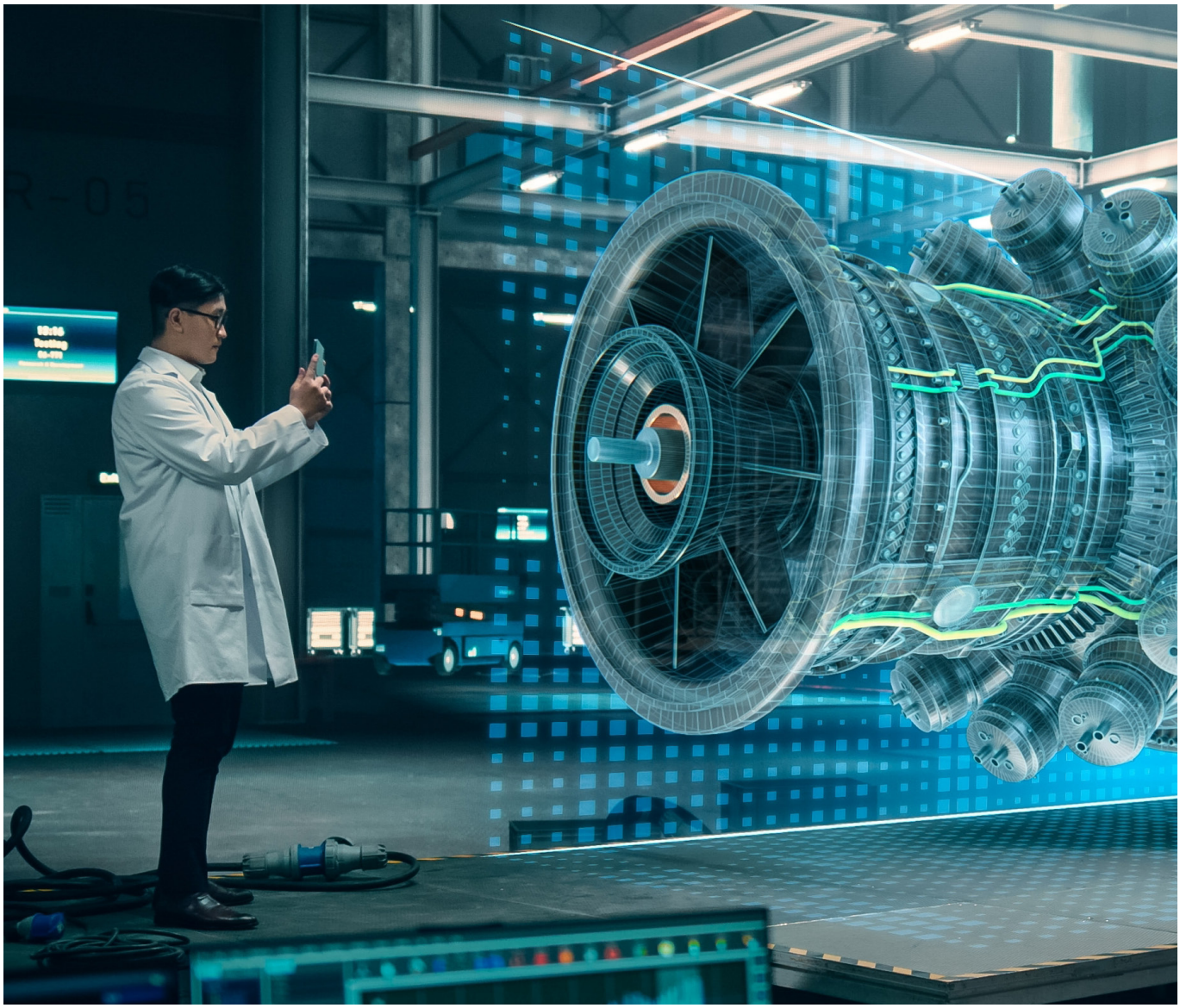
This is where the concept of the Industrial Metaverse comes into its own. Both a transformational approach (iterative and value-oriented) and a platform for technological and experiential convergence, we see the Industrial Metaverse as the new path to scale that will enable Intelligent Industry to reinvent itself.

This report defines the why, the what and the how. Let's hope it will be useful to all in opening the way to a world where Intelligence meets Experience.

Pierre Bagnon et Olivier Saignes
Capgemini Intelligent Industry Accelerator

Your guide to implementing the Industrial Metaverse: Gain a competitive edge and become a pioneer

This report offers valuable insights into the evolution and benefits of the industrial metaverse. It has been specifically written for CXOs and leaders in R&D, data, engineering, and innovation in many industrial sectors. The information and insights from use cases will benefit leaders in digital transformation, across various management functions. We take a pragmatic approach to the implementation of the industrial metaverse and decode the apparent mysteries behind the concept. The application of an industrial metaverse approach will generate a competitive advantage for these pioneers, whether in supply chain, manufacturing and retail, as we believe that the industrial metaverse will undoubtedly develop from a 'buzzword' and 'science fiction' to an essential component of industrial processes.



Introduction

It's 4:30 in the afternoon, and John is standing in the heart of a sprawling factory. But this isn't just any factory – it's one that doesn't exist yet. Well, not in the physical world at least. John slips on his VR headset, and with a few quick adjustments, he is transported into a high-fidelity digital twin of the proposed manufacturing site.

The factory is bustling with activity, a stark contrast to the empty plot of land that exists in reality. The purpose of his virtual visit today is to perform a safety inspection. In the past, this would have required blueprints, 3D models, and countless meetings. As he navigates the virtual corridors, he encounters a large industrial press. In a physical factory, this machine would be incredibly dangerous to operate without proper safety protocols in place. Here, however, John observes its function up close, analyzes its output, and even simulates various failure scenarios to ensure the safety measures are foolproof.

He moves towards the assembly line, where robotic arms meticulously perform tasks. One of the arms pauses abruptly – a pre-programmed fault to test the response protocols. John pulls up a holographic interface, diagnoses the issue, and initiates a virtual repair. This exercise allows him to fine-tune maintenance procedures long before the first bolt is ever tightened in the physical world. He removes his headset and returns to the physical world. The sun is setting over the empty lot where the factory will one day stand.

Ready or not…

The industrial metaverse (IM) has been a dream for decades, always just out of reach due to technological limitations. One by one, those challenges have been solved. Recent advancements in AI, connectivity, and an increase in processing power now make it possible to connect the digital and the physical worlds. Real-time 3D (RT3D) technology now allows for real-time simulations and virtual prototyping that drastically reduce time-to-market and costs.

A new dimension of information

We've entered the next step of digital transformation. Information is moving from 2D devices like smartphones to 3D immersive experiences. Since 3D information capturing closely resembles how humans capture and understand information, this shift will redefine how companies operate.

These new connections between the digital and the physical will lead to digital twins of entire production lines where you'll be able to simulate, test, and optimize processes with no physical risk. Envision collaborative, virtual environments where teams from around the globe can interact in real-time, enhancing productivity and innovation. These capabilities are no longer a dream, but are now being adopted by pioneers across industries.

As we delve into the core of this playbook, we invite you to envision the potential of the industrial metaverse in the heart of your business operations.

What's inside

08 **Why is the Metaverse a disruptor for industries?**

11 **What is the Industrial Metaverse?**

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Companies are facing tough challenges

The Industrial Metaverse is bringing a new route to scaling the physical-digital convergence. Organizations are adopting the industrial metaverse to boost efficiency, strengthen supply chains, personalize customer experiences, and enhance sustainability, as well as achieving significant cost savings and productivity gains.

Organizations today are facing a range of tough challenges in keeping up with industry trends. Sustainability is becoming more important, with growing pressure from customers and regulators to reduce environmental impacts. While companies want to go green, the cost of making those changes can be hard to manage. At the same time, customers are expecting more personalized, high-quality products, which puts extra strain on resources. To make things harder, the cost of ownership, materials, and energy is rising, making it tough for businesses to stay competitive. Balancing these demands while remaining profitable is a constant struggle in today's fast-paced world.

Our research shows that organizations are looking to industrial metaverse solutions to address the various challenges with which they are facing.

Extent to which organizations agree that the below are the key drivers of their digital twin investments

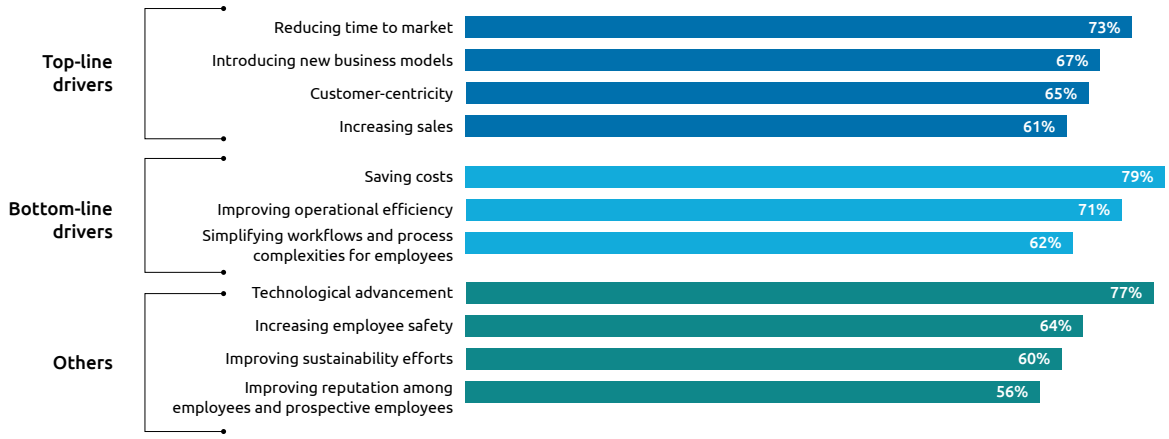


Figure 1: *Digital twin investments are driven by top and bottom lines as well as safety, sustainability and brand reputation*

Source: *Capgemini Research Institute:, Digital Twins: adding intelligence to the real world 2022 , N=1000 organizations*

Organizations are investing in industrial metaverse technologies to address challenges like sustainability, rising costs, and customer expectations, as these technologies offer potential benefits that align with their needs.

Industrial Metaverse reduces operational inefficiencies and costs

Traditional methods of monitoring and managing operations can be inefficient, leading to increased costs and downtime.

By providing real-time insights and simulations, the IM enables businesses to optimize processes, allocate resources more efficiently, and reduce downtime. This leads to cost savings and improved productivity.

A report from Capgemini Research Institute shows that organizations have realized a 13% decrease in costs, across the various use cases of the industrial metaverse[1].

BMW has introduced a Digital Vehicle File that creates a digital twin for each vehicle, tracking its entire lifecycle. This file includes detailed information about every component, maintenance history, and upgrades made throughout the car's life. This comprehensive record aids in better maintenance and recycling processes. Furthermore, BMW is creating a virtual factory for its new plant in Debrecen, Hungary. This digital twin allows real-time simulations of the manufacturing process, optimizing layouts and logistics before physical construction begins. The platform provides improved collaboration between teams across different locations, significantly reducing planning time with 30% and costs with 20%[2].

The Industrial Metaverse is an all-in one solution

Industrial Metaverse helps build resilient supply chain

As we saw in 2020 with the Covid-19 pandemic, and now with the wars in Ukraine and the Middle East, escalating geopolitical tensions pose a risk to business operations and supply chains. Across earnings calls and corporate filings, chief executives of S&P 500 companies referred to the word "geopolitics" around 12,000 times in 2023, three times as many as in 2021[3] . This shows growing concerns about geopolitical risks.

Global supply chains are increasingly complex and prone to disruptions, affecting production schedules and inventory management. The IM enables better visibility and collaboration across the supply chain. Companies can use digital twins to simulate supply chain scenarios, optimize logistics, and respond proactively to disruptions. One notable organization to do so is Airbus UTM. This division of Airbus is focused on developing the infrastructure necessary for future air mobility, including the safe operation of delivery drones. Their industrial metaverse technology allows them to model, simulate, and scale various scenarios for critical stakeholders such as drone pilots and regulators. This capability helps in identifying potential risks early, thereby minimizing disruptions in their supply chain operations[4].

Industrial Metaverse meets increasing customer expectations

Meeting customer demands for personalized products and experiences can be challenging with traditional manufacturing processes. The Industrial Metaverse allows for greater customization and flexibility in production. Virtual environments enable customers to visualize and configure products to their specifications before they are manufactured.

In a Capgemini survey Total Immersion: How Immersive Experiences and the Metaverse Benefit Customer Experience and Operations among 8000 consumers, 77% answered that they believe that immersive experiences will significantly change their interaction with people brands and services. And 78% of shoppers prefer immersive interactive experiences over video[5].

Camille Fournet, a luxury leather goods brand founded in 1945, has recently enhanced its customer experience through an interactive 3D product configurator developed in collaboration with SmartPixels. This innovative tool allows customers to customize watch straps and other leather goods in a highly immersive and photorealistic manner. This resulted in 66% more user engagement and 5-fold increase in conversion[6].

Industrial Metaverse augments employee experience by improving safety, allowing collaborative ways of working and supplementing training

Industries face challenges in maintaining their workforce with turn over rates higher than 20%[7]. This level of turnover disrupts operations, due to insufficient personnel and knowledge leakage. Furthermore, training employees, especially for complex tasks or hazardous environments, can be costly and risky.

The IM provides workers with better training tools and on-the-job support through smart AI assistants. These AI tools can also save and share important knowledge, so expertise isn't lost when employees move on. By making factories more engaging and exciting places to work, the Industrial Metaverse helps attract new talent and keep operations running strongly.

Industrial metaverse technology can also increase employee safety by supporting remote operations and removing the need for direct human involvement in physically dangerous work situations.

The Industrial Metaverse can bring threefold value

Through its digital twin Echo, Equinor, an international energy company, has been able to achieve a reduction of up to 50% of offshore man hours at its Johan Sverdrup oil field, reducing employee exposure to risks[7] .

There's also a significant gap in formal training provided by companies: 59% of employees report having no workplace training, with most of their skills being self-taught. Additionally, 33% of U.S. workers find their company-provided training ineffective[8]. To address this gap, 3D-based training programs within the IM provide immersive, risk-free environments for employees to learn and practice their skills. Carl's JR. uses an AR app for self-paced learning and uses real time 3D visualizations to simulate audit inspections. This resulted in a 73% reduction in training costs for the franchisees and a doubled amount of platinum audit scores[9].

Industrial Metaverse technologies are enabling a sustainable future

There is increasing pressure on companies to reduce their environmental footprint and improve sustainability.

The IM can help organizations understand and quantify the impact of their past decisions, as well as compare various scenarios that can help forecast the outcome of different decisions. As such, they can help reduce waste, increase efficiencies, propose interventions, and possibly automate change, helping organizations and societies become more sustainable as they become more digital. Heineken created a virtual brewery. The simulation showed approximately 70% of energy use was linked to the generation of heating and cooling necessary for the brewing process. By optimizing and monitoring these cooling and heating systems through an end-to-end program, 15-20% energy saving at each site, and an average CO2 reduction of 50% at each site were realized[10].

The environmental impact of the Industrial Metaverse is a critical consideration as it heavily relies on energy-intensive technologies. However, research from Capgemini Research Institute The Eco-Digital Era™ research shows that over the next five years, digital technologies are anticipated to make a net reduction in emissions because their reductions outweigh the associated carbon footprint.

The Industrial Metaverse is a convergence of technology

Industrial Metaverse is both an approach and a technology convergence platform that bridges physical & digital environments, to better collaborate, design, simulate, operate, optimize, and automate industrial processes. This bridge is established through the convergence of simulation experience and intelligence technology.

The Industrial Metaverse is an exciting new approach, emerging as the next logical step from three previously siloed initiatives: Industrial Digital Transformation, Data-Driven Transformation, and Experience Transformation. Historically, each of these transformations has operated independently, creating separate pathways for industrial advancement. However, their lack of integration has had significant challenges, particularly in scaling these innovations effectively across industries.

Challenges in scaling separated initiatives

The disconnection between these initiatives has led to barriers in scalability. For instance, Industrial Digital Transformation initiatives, which aim to create streamlined, tech-enabled industrial processes, have struggled to achieve their full potential at scale, due to a lack of integration with data insights and adaptive user experiences.

Similarly, Data-Driven Transformation, while powerful in providing data management and data science capabilities, has primarily been the domain of hyper-specialists. As a result, these insights have not been fully leveraged by broader business teams or operational staff, limiting their impact in practical, day-to-day industrial contexts.

Experience Transformation has introduced engaging, often immersive technologies, enhancing how users interact with industrial environments. However, without integration of real-time intelligence and data insights, these experiences can sometimes feel disconnected or lacking in functional value. This shortfall has contributed to skepticism around metaverse concepts, as the experiences can be seen as gimmicky, rather than impactful.

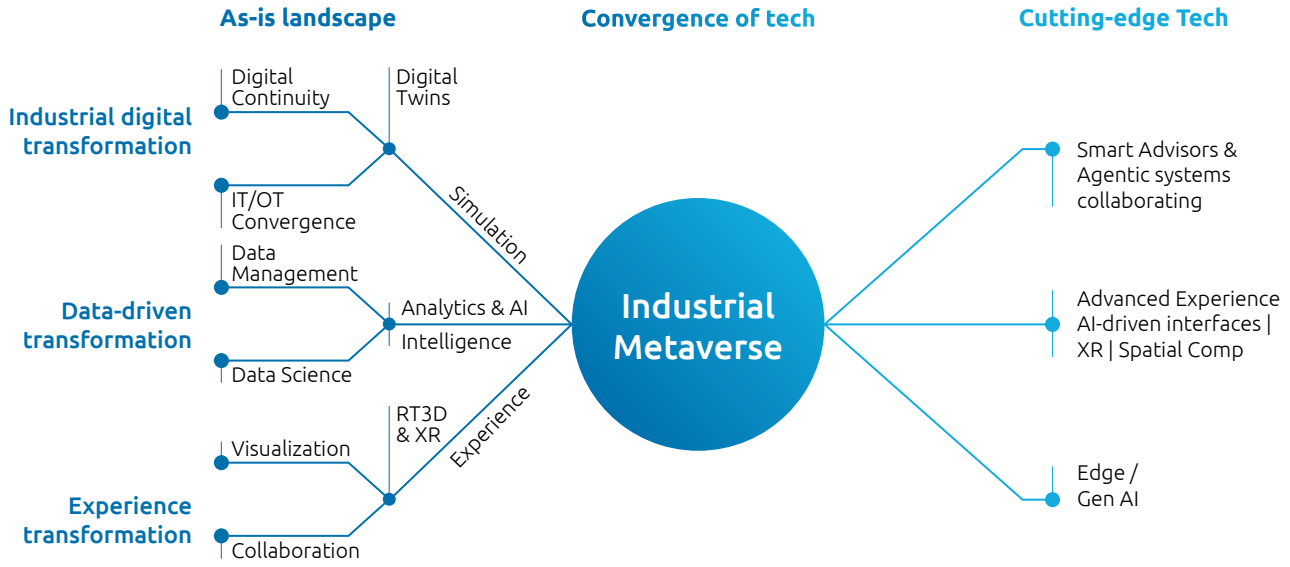


Figure 2: *Industrial Metaverse is a result of earlier transformations resulting in a convergence of tech and an approach to a new way of working*

The new path for improved industrial performance at scale

Why convergence is now possible and powerful

Today, rapid improvements in technology are making it possible to bring these three areas together, creating a unified platform that delivers impact at a new scale.

As both an approach and a technology convergence platform, the Industrial Metaverse bridges physical & digital environments to better collaborate, design, simulate, operate, optimize, automate industrial process. This bridge is built through the convergence of experience and intelligence, creating a digital framework that mirrors and interacts with the physical world.

At Capgemini, we view the Industrial Metaverse as a dual concept: It is both an approach and the result of that approach.

As an approach: It systematically improves collaboration across different industrial disciplines; for example, bridging product design, systems engineering, and manufacturing teams. The goal here is seamless coordination that leads to improved processes and efficiency.

As a result: There is a whole new way of working. This includes smart automation, optimized operations and even immersive experiences that make designing and managing complex systems much easier and more effective.

The role of cutting-edge technologies in the Industrial Metaverse

The convergence of technologies gives rise to new cutting-edge technologies, which are driving a new way of working.

Emerging tools like AI-driven interfaces and spatial computing are making it easier for users to interact with complex industrial environments.

Edge AI, by processing data closer to the source, reduces latency and enables real-time decision-making on the factory floor.

Smart advisors and agentic systems work together to automate tasks and provide intelligent guidance, making industrial processes more efficient and adaptable.

These advancements offer industries a level of responsiveness and insight that traditional systems cannot match.

In the IM, these technologies converge to create a seamless blend of intelligence and experience.

Rather than reinventing the wheel, this approach builds on the latest innovations in simulation, analytics, and immersive experiences. The result is a powerful, scalable approach that allows organizations to significantly improve performance – at scale.

The Industrial Metaverse is a pillar of Intelligent Industry

The Intelligent Industry is one of the three core Strategic Playfields in Capgemini's Services Portfolio, focused on the lifecycle and value chain of our clients. It consists of:

1. **Intelligent Product and Systems** – Engineering of hardware, software, and systems.
2. **Intelligent Operations** – Optimizing production and operational processes.
3. **Intelligent Support and Services** – Providing final user services and support.

We believe the Industrial Metaverse can help transform the entire Intelligent Industry value chain, driving value across these three pillars. Through digital twins, real-time data, and immersive technologies, the IM enables use cases tailored to specific industries - from product engineering to operational optimization and user support.

The Industrial Metaverse is a strategic enabler, offering immense potential to create industry-specific value and enhance business operations across the value chain.

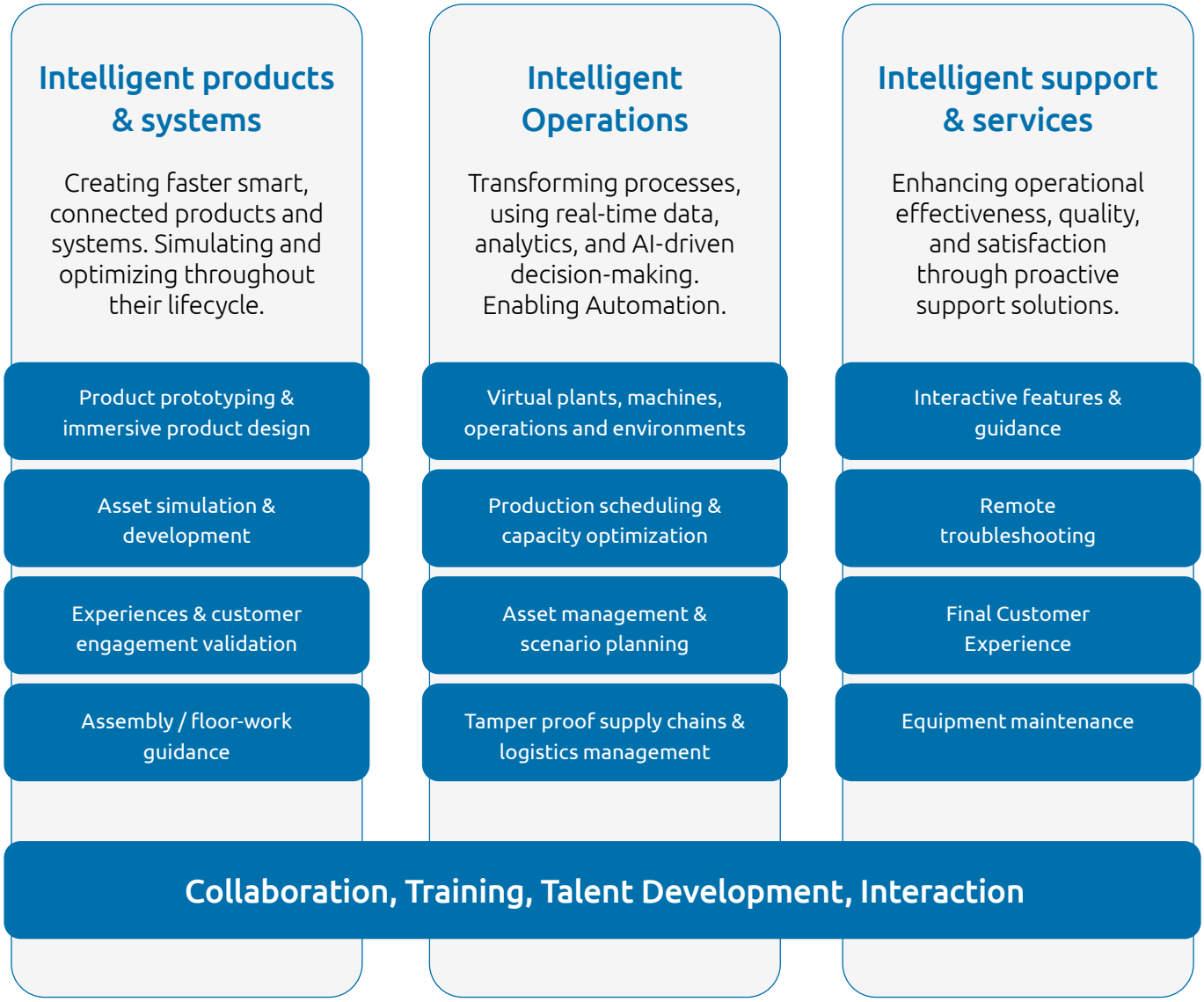


Figure 3: *Use cases for the Industrial Metaverse illustrated with the intelligent industry pillars*

The Industrial Metaverse is built on a combination of technologies

Four dynamic layers converge to define a new vision and a new definition of the Industrial Metaverse at scale. Here, they are represented in this very high-level technical architecture perspective.

Digital foundations layer

This foundational layer is the backbone of the Industrial Metaverse. Without it, there is no possibility for scale-up. It is the result of previous industrial digital transformation efforts, including:

- Connectivity and secure network, to support data harvesting and circulation.
- Infrastructures (edge and cloud), both to compute and manage data aggregation and storage. Scalability and security are key.
- Industrial IoT: the "twinization" and the connection of all equipment (robots, AGV, warehouse…), products and parts (PLM Digital Twins), operators, and all the OT & IT applications (MES, SCADA…) that are involved in industrial processes. Norms and standards ensure consistency and large interoperability.
- Data management: tools, platforms and process that allow businesses to organize, qualify, treat and expose hot or cold data, depending upon the needs.

This foundational layer is the aggregation of all the digital twins of an industrial company. Those Digital Twins can be 1D, 2D, 3D, 4D, etc. The roles of those digital twins are different if we consider Requirements DT, As Designed DT, As built DT, As Operated DT, or As Maintained Digital Twins.

Semantic integration layer

The integration layer responds to the need to transform the aggregation of digital twins of the foundational layer into an accurate representation of industrial processes.

Therefore, we are talking here about an "Internet of Digital Twins", able to describe semantically all the relationships, roles and interactions between all the Digital twins involved in industrial processes, set-up to reach the expected result (in terms of rhythm, of quality, of traceability…). This integration layer is based on complete industrial ontologies (that have to be adapted to the accurate reality of each industrial company).

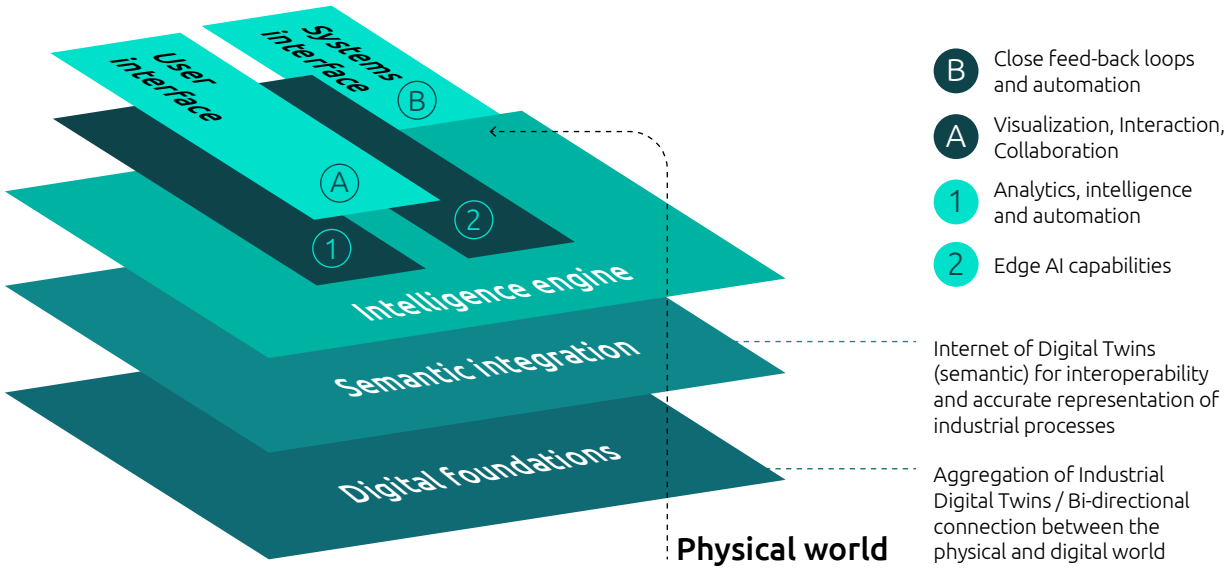


Figure 4: *Use cases for the industrial metaverse*

The Industrial Metaverse is built on a combination of technologies

Intelligence engine layer

This intelligence layer brings the metaverse's intelligence to life, transforming the internet of digital twins into intelligence and value, through use cases development and at scale deployment. This layer has two main components:

1. **Data science and analytics:** Here, data is consumed using AI, gen AI and machine learning algorithms to create insights, and relevant information aggregation, to drive smart decision-making and automation. From accelerated product design, to predictive maintenance alerts, to automated quality control processes, it is the value creation engine.

   Simulation software can provide real-time models, allowing engineers, operators or plant managers to test scenarios or troubleshoot without disrupting actual operations. This is also where AI agent system can operate. (See our specific focus on the following pages).

2. **Edge AI:** Using edge and cloud computing, this sub-layer brings AI to the edge to fuel, in real time, the Industrial Metaverse's intelligence. When needed, this is where 3D models, simulations, and augmented reality overlays are generated. This is also where dynamic close feedback loops can be ignited for the entire ecosystem.

User and systems interface layer

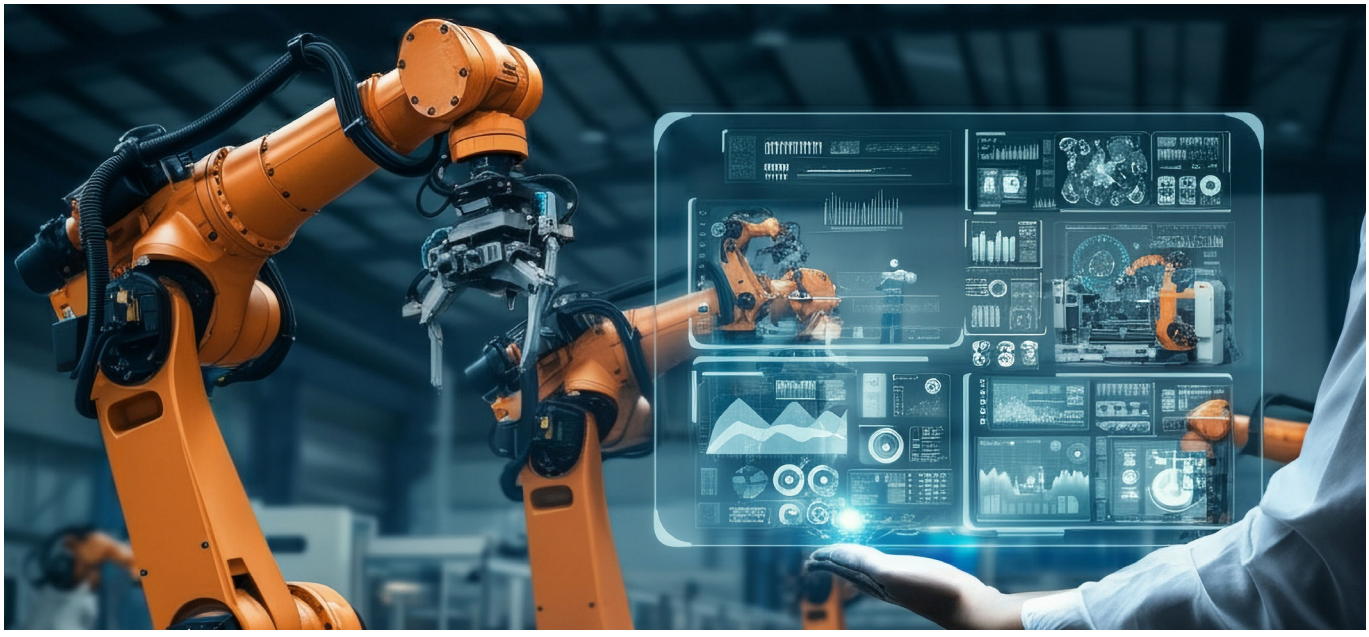
This last layer is a double interaction layer:

A. The user interface layer creates an interactive experience where people connect with the metaverse and where all the Intelligence generated by the other layers meet Experience.

Depending on the objective, data visualization, supervision and hypervision systems, xR, RT3D, spatial computing, immersivity, natural language, and voice to voice interaction, all are mobilized to provide users with the most relevant interaction with industrial operations. Humans, machines and AI are collaborating seamlessly to create value.

B: The systems interface is where the feedback loops to the systems and therefore to the physical world are managed. Depending on the level of criticality, the choice to keep (or not) the human in the decision making process is a key question. But for a lot of non-value tasks, this interface is a new path for automation that allows partial or complete self-adapting, self-healing, autonomous operations.

Beyond these four layers, the rapid development of systemic approaches to AI agent deployment offers extraordinary prospects for acceleration and is truly a new frontier for the industrial metaverse.



AI agents bring autonomy to the Industrial Metaverse

As the Industrial Metaverse develops, new cutting-edge trends are emerging at lightning speed, such as AI agents. They are becoming increasingly important in helping industries automate processes and make decisions in real-time. By using technologies like Knowledge Distillation and Vision Language Models, companies will be able to optimize and guide you in improving productivity.

Intelligence engine layer

As the Industrial Metaverse evolves, integrating advanced technologies, and as such the role of AI Agents becomes increasingly important.

An AI agent can be described as a software entity wrapped around an AI model, using its outputs as inputs to perform actions based on predefined rules.

With this ability to execute tasks, they serve as the operational backbone, making decisions and enabling real-time automation across various industrial applications.

We now explore how AI agents function within the Industrial Metaverse and why they are essential for driving efficiency and productivity.

The benefits of Agents applied to the Industrial Metaverse

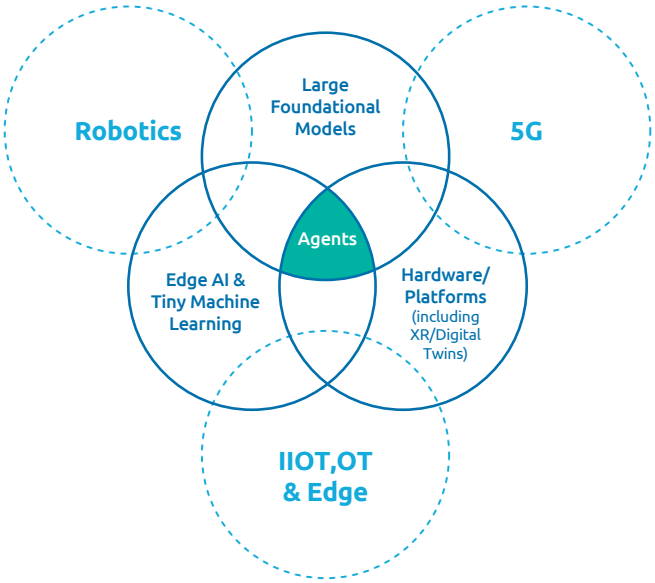
The production process structures the types of agents to implement and how they coordinate together. As a consequence, agentic systems can address the challenges related to the specific process they were designed to support:

- How to shorten production lead times?
- How to design and operate a sustainable production chain with minimal footprint?
- How to optimize logistical flows?
- How to design optimal facilities for people and product flow?
- How to develop new assembly methods?
- How to develop next-gen facilities faster?
- How to save time in customer installation processes?

The different types of Agents

Agents can vary significantly in their visibility and interaction with humans, as well as their level of automation complexity as follows:

- **Specialists/small context agents:** Operate in the background, performing specific, isolated tasks with minimal human interaction, often unnoticed but crucial for efficiency.
- **Context-aware agents:** Manage and execute multiple workflows within their respective contexts.
- **Collaborative agents:** Work alongside human operators in extended reality (XR) environments
- **Simulation agents:** Integrate with factory-level simulations, using data-driven insights to improve real-world operations.



AI agents bring autonomy to the Industrial Metaverse

Deployment of AI agents

These agents leverage the power of Edge AI, which allows them to operate on local devices, and are often refined through knowledge distillation, ensuring they are efficient even in resource-constrained environments.

Edge AI integration

AI agents operate at the edge of the network, processing data where it is generated. This localization reduces latency, enhances real-time decision-making, and minimizes the need for constant cloud communication. By processing data locally, AI agents reduce the computational load on central systems, which is critical in environments where power efficiency is a top priority.

Knowledge distillation

As shown in figure x, AI agents utilize small models that have been distilled from larger, more complex versions. Training data from industrial systems, including machine hierarchies, blueprints, and real-time performance metrics, serves as the input for training AI models.

A large, powerful teacher model (e.g., GPT-4o) trains a smaller, efficient student model (e.g., Llama 3.1) using knowledge distillation. This process ensures the student model learns to replicate the teacher's accuracy while requiring fewer resources.

The student model generates actionable insights. Knowledge distillation allows these models to maintain high performance while being lightweight and suitable for deployment on edge devices.

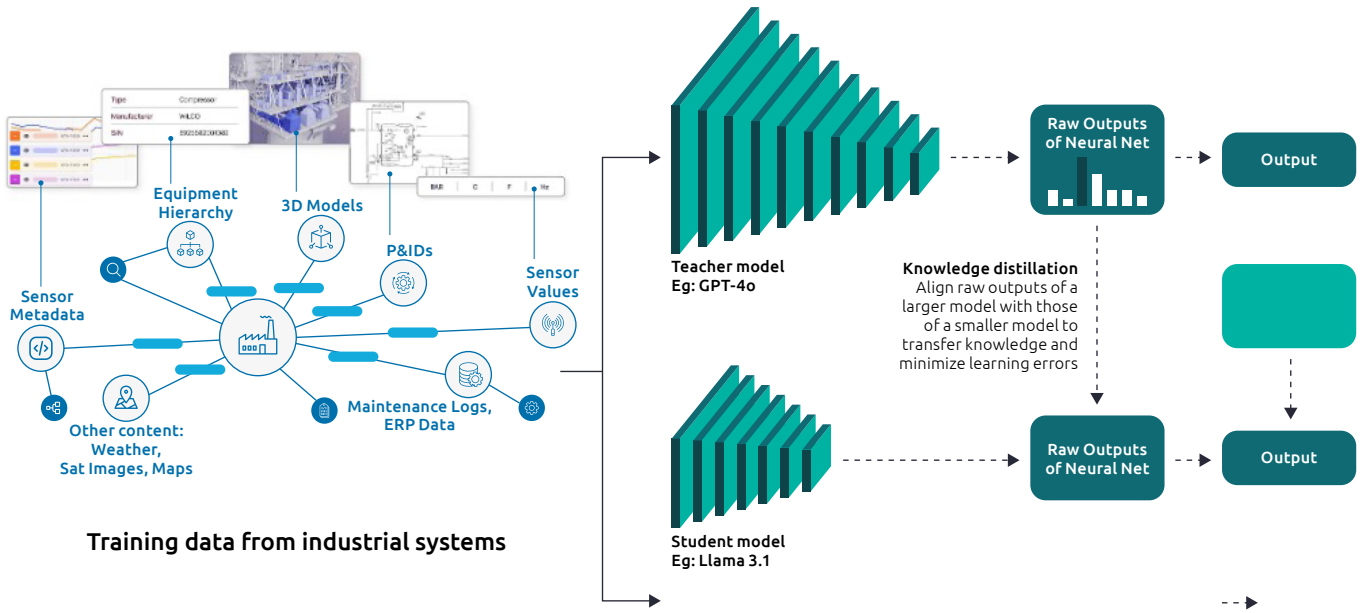


Figure X: *Knowledge Distillation moves intelligence on the Edge*

AI agents bring autonomy to the Industrial Metaverse

Vision Language Models

Vision Language Models (VLMs) are central to advancing AI capabilities in the Industrial Metaverse, as illustrated in figure X. General-purpose models, such as GPT-4 or Claude, offer broad capabilities but are often costly, resource-intensive, and dependent on third-party cloud infrastructure, making them less suited for specialized industrial needs.

Specialized VLMs, like Florence-2, ViLA, and Qwen-VL, address these limitations by combining efficiency, scalability, and task-specific flexibility. They enable AI agents to process visual data (e.g., images, video feeds) alongside textual information (e.g., descriptions, operational logs), allowing them to interpret situations through natural language processing. By integrating visual and textual data, VLMs support contextual decision-making, allowing AI agents to automate complex processes and adapt to dynamic industrial environments.

Multi agents collaboration

In this situation, agents do not operate in isolation. They work together, forming agentic systems that collaborate to achieve more complex objectives. For example:

- **Master Agent:** Consolidates knowledge of the entire factory's operations, supervises the status of operations, and assigns tasks to other agents.
- **Assembly Agent:** Monitors the assembly table and detects anomalies, reporting them from the Quality Agent, enhancing process accuracy.
- **Quality Agent:** Programs a streamlined inspection process according to the information received by the Assembly Agent, identifies patterns and addresses recurring quality issues.

Timeline

Agents will first be introduced as micro-automations, with Digital Process Automation (DPA) workflows as the initial area of adoption. These agents will autonomously make decisions and take actions, such as eliminating false positives or enhancing the precision and efficiency of industrial processes.

By 2027, widespread use of process orchestration will enable dynamic work management, as well as seamless coordination between humans and AI agents. This end-to-end orchestration marks a significant step toward fully integrated AI and physical automation.

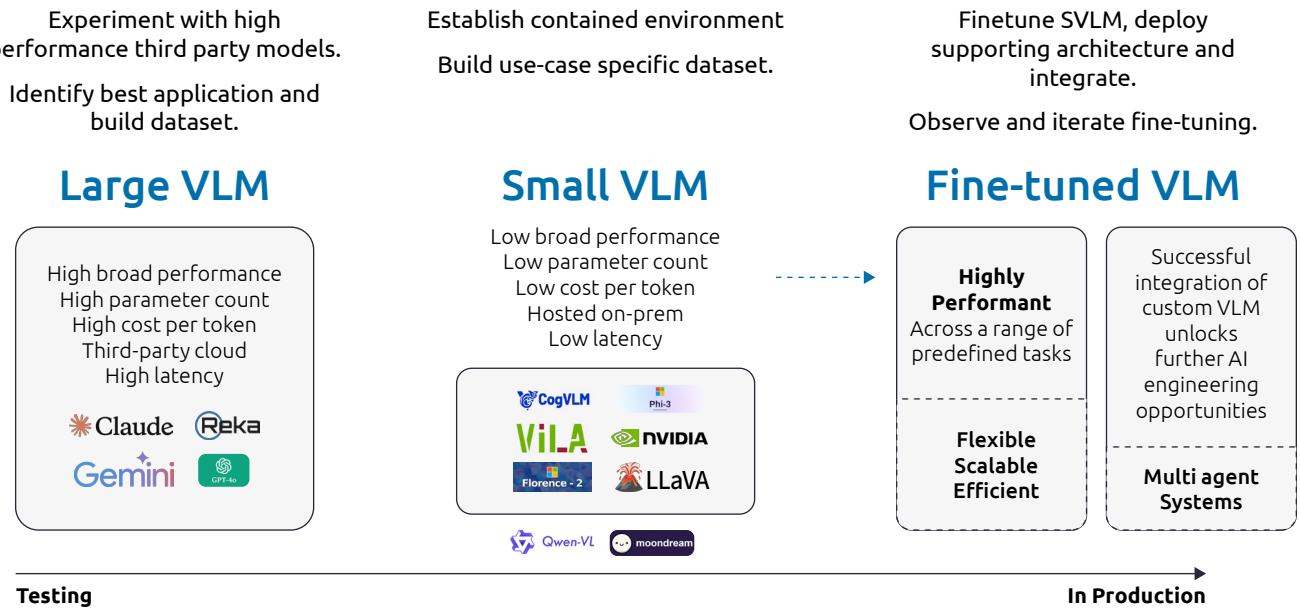


Figure X: *Applying Vision Language Models on the Edge*

Setting up Industrial Metaverse applications

Industrial metaverse use cases rely on the general technical architecture presented in Figure X. The specific components and the maturity of them within the four layers depend on the use case. To show how different technology components come together for specific solutions, let's have a look at a few high-level use cases:

The technology architecture of product prototyping and immersive product design

Product prototyping & immersive product design

Characteristics

Products fully designed and tested in an immersive environment

Value added

- Faster time to market
- Reduced physical prototyping costs

Technology-stack

- Advanced simulation software
- High resolution product data

During the design and development of new products, digital twins can be used to improve product design and reduce time to market and can also maintain engineering-manufacturing continuity.

Designers from Ford design cars in their immersive vehicle environment lab using a Microsoft HoloLens and controller. This setup allows for immersive 3D sketching and review of new concepts. Due to real-time modifications and assessments, without the need for physical prototypes, Ford has decreased the design time of a car from weeks to hours.

The technology architecture of assembly/ floor guidance

Workers can use Augmented Reality (AR) or Virtual Reality (VR) for real-time assembly and floor guidance. This gives them step-by-step instructions and safety alerts right in their view, improving accuracy and speed. Remote experts can also assist live, making the process more efficient.

Assembly/floor guidance

Characteristics

Real time instructions from the computer or remote assistance

Value added

- Proactive error prevention
- Faster assembly

Technology-stack

- e.IOT devices
- Cloud computing and connectivity

Siemens and Michelin utilize AR and AI for floor and assembly guidance with a mobile app developed by Squint. The system allows operators to capture and digitize their expertise by simply recording a video of any procedure, which Squint instantly converts into an AR-based step-by-step guide. By pointing their smartphone at a machine, users can access interactive instructions, including navigation prompts, video tutorials, and digital notes. Squint also enables operators to ask questions and get instant answers based on company documents.

Its real-time monitoring feature allows administrators to analyze data and make informed decisions to optimize efficiency and productivity across the organization.

Setting up Industrial Metaverse applications

The technological architecture of tamper-proof supply chains and logistics management

The Industrial Metaverse provides simulation of supply and demand networks, allowing organizations to improve performance, resilience, and sustainability for augmented customer centricity.

Tamper proof supply chains & logistics management

Characteristics
- Extended enterprise
- Enable portfolio rotation

Value added
- Market and demand driven supply chain
- Dynamic network configuration

Technology-stack
- Blockchain and smart contracts
- AI and machine learning

As described in our report on digital twins, CRI report Digital Twins - Capgemini, Philip Morris International (PMI) uses Industrial Metaverse Technology for its global manufacturing footprint. This allows the company to assess the impact of changes in product portfolio, market regulations, and even business disruption. The solution allows PMI to run forward-looking optimization scenarios considering manufacturing costs, import/export duty, and transportation costs across the network. The company has consequently reduced the use of spreadsheet simulations by 90% and was able to decrease the time required for scenario evaluation from weeks to hours.

The technological architecture of final customer experience

Retailers like Walmart are making shopping more fun and convenient by blending the physical and virtual worlds through IM technologies.

For example, customers can buy products that exist in both real life and in virtual spaces, like in the mobile game House Flip, where virtual items match products sold in Walmart stores.

Final Customer Experience

Characteristics
- Immersive product interaction
- Intelligent real-time support

Value added
- Unique brand experience
- Increased engagement

Technology-stack
- 5G connectivity
- Conversational AI
- Immersive digital marketplaces

Walmart has also launched Walmart Realm, a gamified shopping platform where users can explore different themed environments, interact with products, and enjoy a more entertaining way to shop. To help customers feel confident in their purchases, Walmart offers AR features that let people virtually try on clothes, makeup, and accessories before they buy.

Setting up Industrial Metaverse applications

The technological architecture of collaboration, training, talent development, interaction

McDonald's is revolutionizing its staff training in the quick-service restaurant industry by implementing VR.

Collaboration, training, talent development, interaction

Characteristics

- Personalized learning paths and coaching
- Immersive scenario based

Value added

- Accelerated talent development
- Injury prevention

Technology-stack

- 3d simulation software
- LMS & 360 content

In McDonald's VR training, employees face situations like handling an upset customer, where they must make quick decisions and receive immediate feedback. Initially focused on customer hospitality to drive sales, the training has expanded to include essential topics like personal protective equipment and drive-through operations in response to the COVID-19 pandemic.

The content reflects actual store environments, helping employees better understand their roles. The benefits of this VR training are significant. Research shows that it can be up to four times faster than traditional methods and lead to a remarkable 275% increase in trainees' confidence in their skills.

The immersive nature of 3D technology reduces distractions, enabling employees to fully engage with their training. Furthermore, by integrating VR with learning management systems, McDonald's can effectively track employee progress and validate achievements with certificates of completion.

As we have seen earlier in this report, Industrial Metaverse (IM) is a both a convergence of technologies and transformation areas and a path to structure global industrial transformation. As such, building a company IM is a journey, that must be prepared for and managed.

Building the Industrial Metaverse is a journey

The Industrial Metaverse takes shape across three stages: Building the Internet of Digital Twins, creating a Cognitive Metaverse, and developing an Autonomous Metaverse. Key challenges include gaps in vision, governance, infrastructure, and innovation culture. A structured roadmap - assessing maturity, creating scalable frameworks, and fostering adoption - enables organizations to gradually realize the benefits.

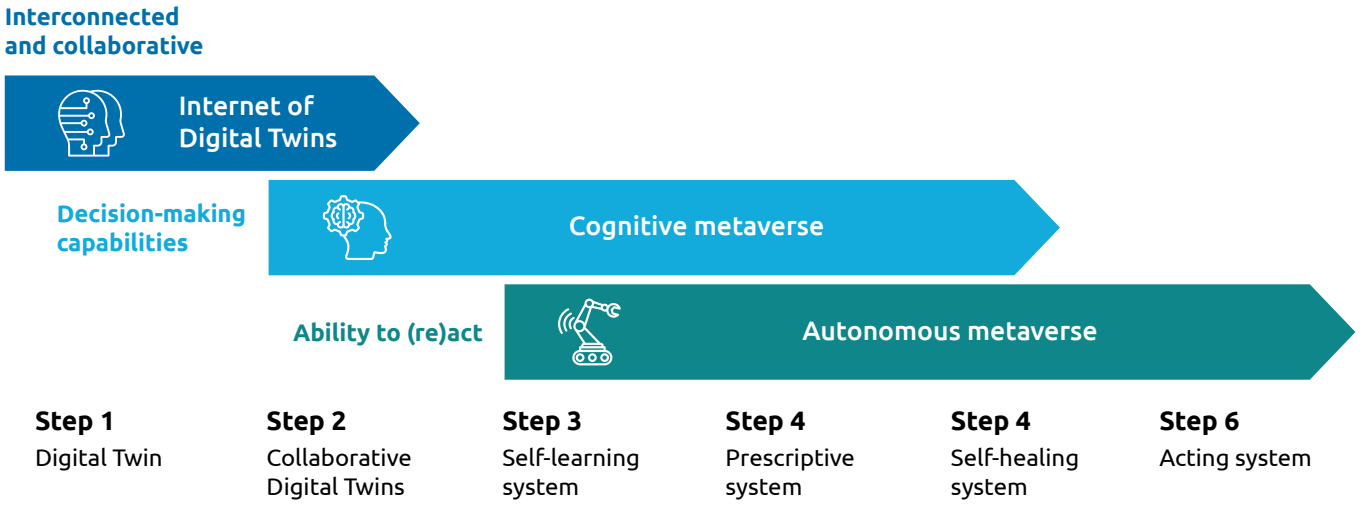


Figure X: *Industrial metaverse journey framework*

Moving towards an IM is a gradual process, and unique to each organization. The path depends on the specific industry and how advanced a company is in its digital transformation journey.

What we offer here is a general framework that outlines six key steps, grouped into three major phases.

Building the Internet of Digital Twins

The first stage centers on the creation of digital twins - virtual replicas of physical objects or processes - made possible through the convergence of IT/OT and IIoT platforms. At this stage, companies use technologies like visualization, collaboration, and interaction tools.

A key challenge here is ensuring that different digital twin projects can work together. This is where the semantic data layer (also known as the "integration layer," "Unified data exchange layer," or "systemic ontological approach") plays a crucial role. It manages the complexity of systems and facilitates effective communication across various platforms, including data (cold, hot, and real-time) and analytics platforms. This interoperability is fundamental to the concept of the Internet of Digital Twins.

Building the Industrial Metaverse is a journey

Creating a Cognitive Metaverse

The next phase is about making the system smarter by industrializing (move to scale) the mobilization of AI and data-driven insights. Here, AI agents are pivotal in making intelligent decisions, predicting scenarios, and offering actionable insights, thus industrializing the value of data and AI. This contrasts with earlier methods that relied on manual approaches.

This system begins to offer 'personal advisors' that offer real-time guidance using AI. Knowledge sharing also becomes important, as companies work to capture and reuse valuable information.

Developing an Autonomous Metaverse

In the final phase, the goal is to create a self-sustaining system that can run processes and make improvements on its own. In this level, companies can deploy autonomous agents, AI-driven systems that interact with humans, machines, and each other to optimize results and continuously improve outcomes in real time.

The journey to autonomy doesn't have to be completed all at once. Even halfway through, with cognitive twins or self-healing capabilities, companies can start to see real benefits. By gradually building up these capabilities, you can achieve meaningful autonomy step by step, getting value from each stage without waiting for a full system to be in place.

The path to a scaled version is not without challenges

However, the path to deploying industrial metaverse is not without challenges. We have identified the following three major areas that are slowing industrial metaverse deployment.

1. **Overcoming a lack of strong vision, management support and well-balanced governance**
   A lack of management support, coupled with operational problems, is, in some instances, causing digital twin implementation to fail. Statistics from the CRI Report Why most digital transformation efforts fail - and how to avoid this - Capgemini illustrate the challenges.

   • Even though 55% of organizations consider digital twins a strategic part of their digital transformation, around half of them (42%) lack a clear vision as to how to deploy them.

   • While 59% of organizations claim to have drawn up a long-term (five years or more) roadmap to develop a digital twin system, about half of organizations (43%) report a lack of managerial commitment to digital twin initiatives and 49% face the challenge of a lack of investment in the concept.

   • The reported lack of strong governance also leads to inefficient program management: At one-third of the organizations surveyed, digital twin governance has not been formalized or is completely lacking.

2. **Deployment and integration of a secure technology and data landscape**
   Organizations face a range of technological challenges that limit the potential of digital twins within specific contexts. Digital twins must integrate with numerous systems, including legacy systems, requiring extensive API integration, connectivity, and data collection capabilities.

   However, many organizations struggle with inadequate internal digital infrastructure; 67% report that insufficient cloud deployment and API integration are major obstacles.

   Furthermore, the lack of a robust, scalable, and flexible IT infrastructure complicates the integration of metaverse technologies, while gaps in data management practices, such as data quality, governance, and security, weaken the foundation needed for success.

The Industrial Metaverse journey

3. The lack of a culture that supports internal and external innovation

In nearly 40% of organizations, immersive initiatives are still considered one-off projects, rather than one link in a chain of continuous improvement. A probable reason for the lack of scaling is the absence of strong central governance. We found that two in three organizations have decentralized governance, with each business unit framing and governing its own initiatives. So, even if pilot projects are found to be successful, scaling them across the enterprise or in other locations could run into several function-specific challenges.

Large organizations find themselves dealing with hundreds or even thousands of suppliers. To work with these suppliers and other partners in a more efficient manner, collaboration platforms are essential.

However fewer than half have deployed such a platform for collaborative use with their partners (even though, on average, this is projected to increase to 58% within the next three years).

A structured approach to accelerate implementation

To tackle these challenges and get started with the IM, adopting a structured enterprise architecture level approach is essential. This should be seen as a natural progression of existing efforts. It can adapt to different starting points and varying levels of digital maturity, ensuring that each initiative builds on existing links and is further propelled by IM concepts. The roadmap to the Industrial Metaverse contains three phases that result in scaled IM benefits.

Phase 1: Bridging the gap

This begins with laying robust foundations that will serve as cornerstones for your future IM. By assessing the maturity of current initiatives and identifying opportunities, organizations can develop a metaverse vision that seamlessly integrates with established operations in engineering, supply chain, and manufacturing.

From here, organizations can create a portfolio of use cases aligned with a global strategy that prioritizes high-value projects. This is an incremental process, building "brick-by-brick" along a structured timeline allowing organizations to refine, adapt, and ensure scalability for all future.

Phase 2: Architecting for scalability

In this phase, we focus on creating a tailored framework that enables seamless technological advancements and lays a scalable foundation. This should be developed with a strong alignment of selected domains, architecture, and technology with a long-term strategy, ensuring a robust foundation that can scale effectively. Collaborating with a network of tech partners will allow organizations to innovate continuously, while rapid integration of capabilities like gen AI and AI agents will accelerate the capability to deploy solutions at scale.

Phase 3: Rolling out the Industrial Metaverse

In the third phase, these capabilities will be expanded across the organization, while structured program management ensures that deployment stays on track. Comprehensive training and change management programs will drive adoption and support employees in adapting to these new capabilities. By prioritizing a test-and-learn approach within a well-supported framework, you can continue to build and scale additional functionalities at a pace that matches the organization's growth.

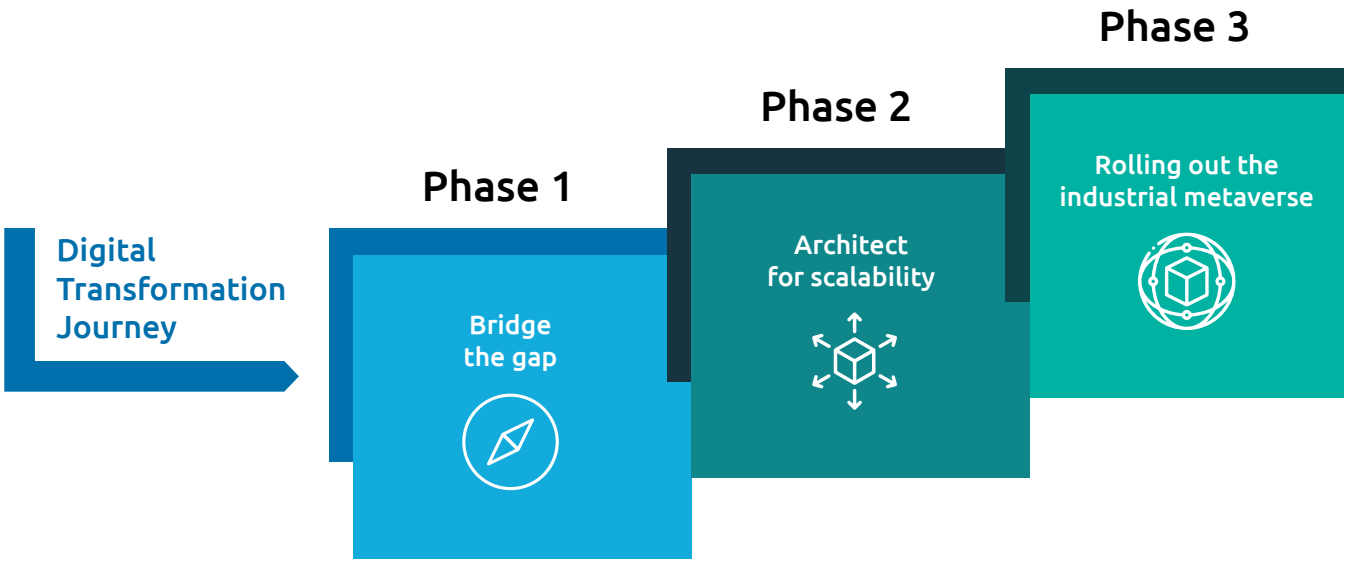
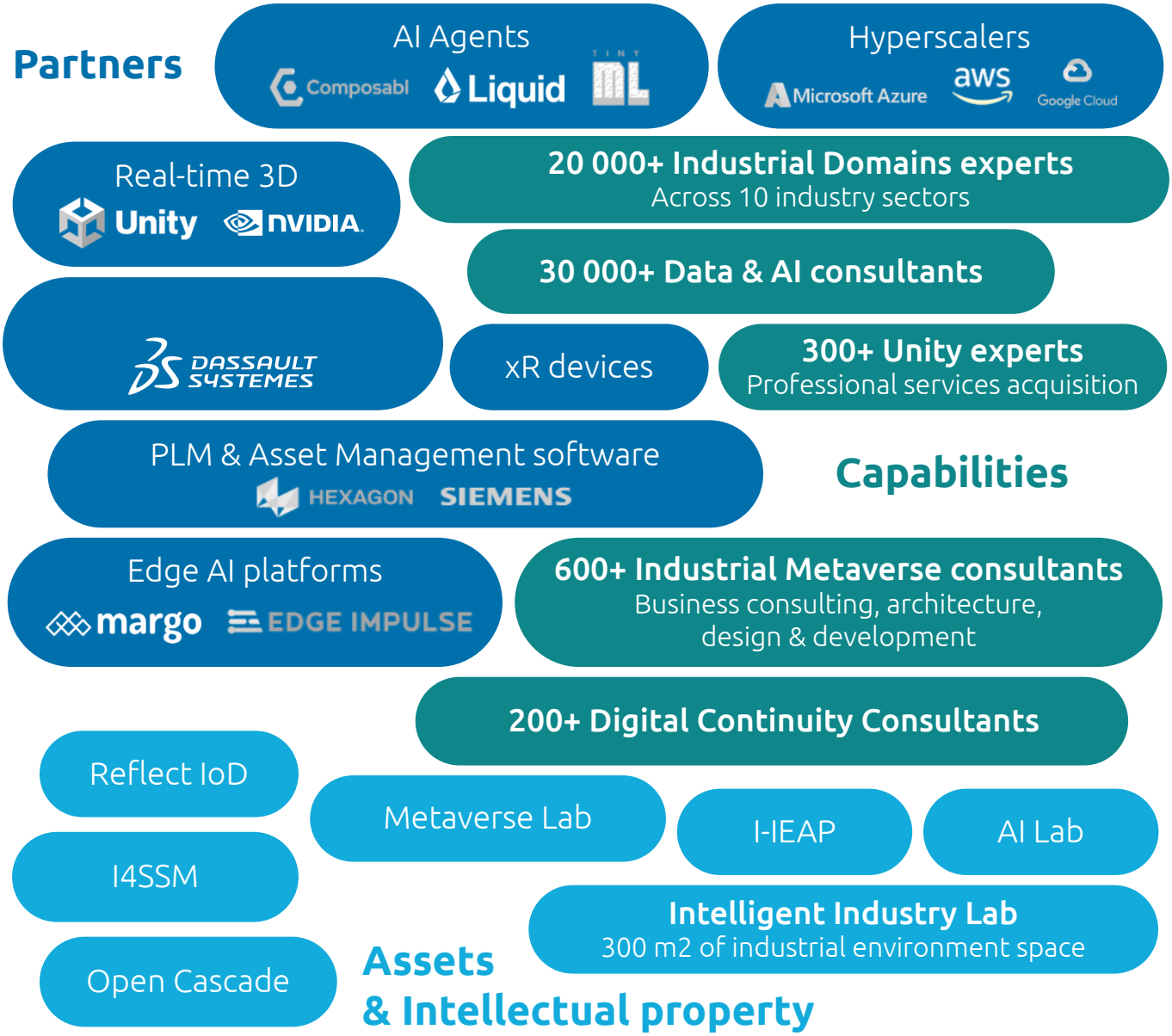


Figure X: *A strategic approach for accelerating the implementation of an industrial metaverse*

Why Capgemini is the best partner for your Industrial Metaverse journey

The pace of technological change today is astonishing and navigating these changes isn't easy. It takes careful thought to choose the right technologies and to build a sustainable ecosystem of solutions and partners that make sense, both technically and financially. Capgemini has assembled a powerful set of tools and expertise to support you on your IM journey.

Through partnerships with top industry players, proprietary assets, and intellectual property, we provide a roadmap that's both efficient and scalable. We are not just a technology partner; our end-to-end Intelligent Industry capabilities are key to transforming your IM goals into success. Our teams bring the human expertise necessary to ensure that your metaverse transformation aligns seamlessly with your broader business strategy.



Conclusion

The Industrial Metaverse offers a transformative path forward for organizations looking to scale up their operations, optimize resources, and adapt to the complexities of a modern, interconnected world.

By the convergence of intelligence and experience, the IM empowers businesses to unlock new levels of efficiency, strengthen supply chains, create tailored customer experiences, and embrace sustainable practices, all while driving measurable cost savings and productivity gains.

This transformation isn't about starting from scratch; it's about building on what already exists. By integrating advanced technologies like digital twins, real-time data, and AI-powered agents, organizations can tailor their journey to their specific industry needs and digital maturity. The flexibility of the industrial metaverse allows for gradual, purpose-driven adoption, making it accessible whether a company is just beginning its digital transformation, or is already highly advanced.

As the industrial metaverse evolves, emerging technologies such as AI agents and automated spatial computing are accelerating progress. These innovations are enabling businesses to automate processes, make data-driven decisions in real time, and improve overall productivity. However, realizing the full potential of the IM requires a structured approach. Adopting a clear framework that adapts to an organization's starting point ensures that each step builds on existing capabilities while leveraging the latest technology advancements.

The industrial metaverse is not a distant vision; it's a practical, scalable approach to reimagining how industries operate. By embracing it with intention and aligning it with business goals, organizations can transform their value chains, unlocking opportunities that were once unimaginable.

Are you curious to see what opportunities the Industrial Metaverse provides for your organization?
Do you want to know how to start your journey in the industrial metaverse?

Contact us below to get started.

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Read more of our point of view

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Sources

1. Capgemini Research Institute: 'Digital Twins: Adding intelligence to the real world, 2022. https://www.capgemini.com/insights/research-library/digital-twins/

2. Case study | BMW enjoys 'vast efficiency' of digital twin factories, 2022. https://www.placenorthwest.co.uk/case-study-bmw-enjoys-vast-efficiency-of-digital-twin-factories/

3. Bloomberg: The global economy enters an era of upheaval, September 18, 2023. https://supplychaindigital.com/articles/digital-twins-bring-resilience-visibility-and-savings-to-su

4. Airbus: Unmanned traffic management, 2024. https://www.airbus.com/en/innovation/future-aircraft-operations/airbus-unmanned-traffic-management

5. Capgemini Research Institute: Total Immersion, 2022. https://www.capgemini.com/insights/research-library/immersive-experiences/

6. Unity: Solutions in retail, 2023. https://unity.com/solutions/retail

7. Forbes: Key HR statistics. https://www.forbes.com/advisor/business/hr-statistics-trends/

8. Equinor: Digital Twins, 2024. https://www.equinor.com/energy/digital-twin

9. Forbes: Training Wanted: 41% of employees to walk out on employers In 2024, 2024. https://www.forbes.com/sites/rachelwells/2023/12/06/training-wanted-41-of-employees-to-walk-out-on-employers-in-2024/

10. Unity: Case studies, 2022. https://unity.com/resources/carls-jr-digital-twin

11. Capgemini Research Institute: The Eco-digital Era, 2023. https://www.capgemini.com/insights/research-library/the-new-digital-economy-research/

12. Heineken: Decarbonization program at breweries and malt houses, 2024. https://www.theheinekencompany.com/newsroom/heineken-selects-siemens-for-multi-phase-decarbonization-program-at-breweries-and-malt-houses/

13. Ford: Building in the automotive sandbox, 2023. https://corporate.ford.com/articles/products/building-in-the-automotive-sandbox.html

14. SCMR: Squint named start-up award winner, 2024 https://www.scmr.com/article/squint-named-nextgen-supply-chain-conference-start-up-award-winner

15. Walmart: Walmart reveals plan for increased immersive commercial experiences, 2024. https://corporate.walmart.com/news/2024/10/09/walmart-reveals-plan-for-scaling-artificial-intelligence-generative-ai-augmented-reality-and-immersive-commerce-experiences

16. Forbes, ' The Metaverse And Digital Transformation at Mcdonald', 2022. https://www.forbes.com/sites/bernardmarr/2022/06/22/the-metaverse-and-digital-transformation-at-mcdonalds/

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Capgemini is a global business and technology transformation partner, helping organizations to accelerate their dual transition to a digital and sustainable world, while creating tangible impact for enterprises and society. It is a responsible and diverse group of 340,000 team members in more than 50 countries. With its strong over 55-year heritage, Capgemini is trusted by its clients to unlock the value of technology to address the entire breadth of their business needs. It delivers end-to-end services and solutions leveraging strengths from strategy and design to engineering, all fueled by its market leading capabilities in AI, generative AI, cloud and data, combined with its deep industry expertise and partner ecosystem. The Group reported 2024 global revenues of €22.1 billion.

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