451 Research
Discovery Report

October 2024

Industrial Metaverse Research Study

Technology

Commissioned by SIEMENS

S&P Global
Market Intelligence

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Executive summary

This is one of two reports analyzing the results of the custom Industrial Metaverse Research Study. These reports examine the characteristics and best practices of industrial metaverse Leaders while contrasting these with the approaches of Challengers and Explorers. This report focuses on the technology perspective of the industrial metaverse, while an accompanying report focuses on business trends.

The Industrial Metaverse Research Study provides a comprehensive analysis of the industrial metaverse landscape. The study aggregates insights from 907 decision-makers involved in the industrial metaverse, encompassing business and technical perspectives, use-case adoption, technical characteristics and impact, major external forces, internal challenges to adoption, perceptions of metaverse vendors and strategic recommendations.

Introduction

The industrial metaverse is captivating organizations globally, as awe-inspiring demos in digital worlds are quickly transforming into initial practical use cases in the physical world. Not all elements of the industrial metaverse concept are fully in place, technically evolved and adopted, but the linking of physical objects and their digital twins with synchronous and real-time data sharing is rapidly progressing. The power to digitally monitor, manage, optimize and predict physical products and processes is a significant value creator for industrial organizations adopting metaverse technologies.

Definition

Industrial metaverse: A shared, immersive, persistent, physics-based digital space where humans and machines interact with one another, and with data, enhancing the physical world as much as replacing it.

While the industrial metaverse as a fully realized concept is still emerging, many metaverse technologies and use cases are already demonstrating several of its key characteristics. The technologies enabling it are highly developed and still improving. Metaverse use cases are currently deployed in production environments, and organizations rely on them for critical industrial operations and processes — even if they may not always be referred to as industrial metaverse.

At the core is the digital twin, which facilitates digital and physical interactions among people, machines, data and information. A digital twin is a comprehensive virtual representation of a physical asset, product, process or space. It allows for the simulation of design alterations, "what if" usage scenarios and changes in environmental conditions as a means to test potential modifications without the costly trial and error of uninformed physical interventions.

> **"The company's digitalization strategy prioritizes the development of a digital twin, which brings the most value in terms of planning efficiency, quality, troubleshooting and proactive maintenance."**
>
> **VP of IT workplace, automotive**
> 50,000+ employees, Europe

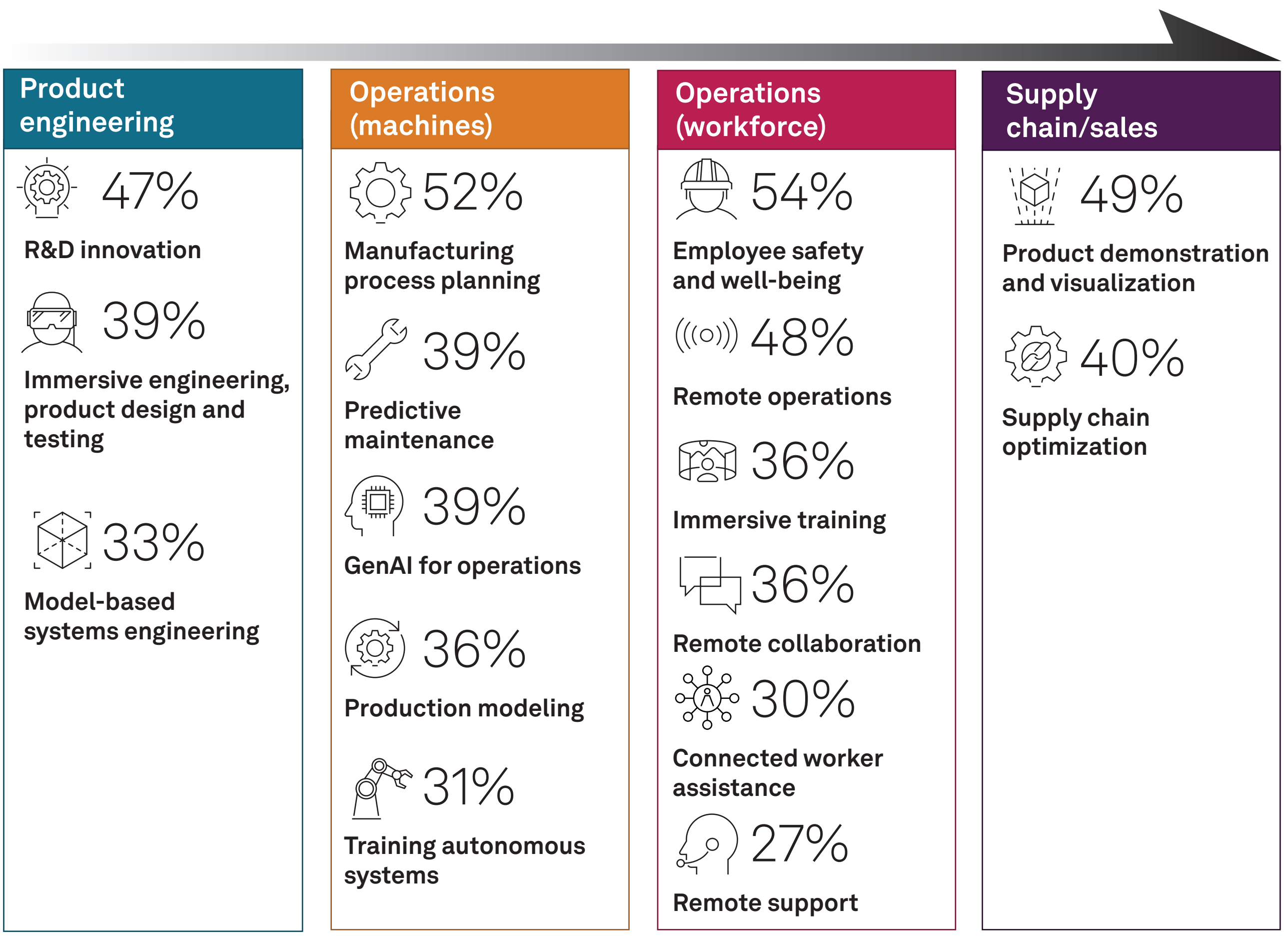
The industrial metaverse provides a space to collaborate, experience and interact with a comprehensive digital twin. While immersive technologies such as extended reality (augmented and virtual reality) enhance this experience, traditional desktop and mobile devices also facilitate many interactions. Furthermore, the industrial metaverse is being enabled and shaped by foundational technologies such as industrial IoT, cloud and edge computing, blockchain and AI/ML (including generative AI).

The business case for industrial metaverse

With long-standing and emerging technologies in place and maturing, the business case for industrial metaverse is gaining momentum with use cases driving significant impact in production environments today. Initial high-impact industrial metaverse use cases include manufacturing process planning to reduce material costs and cycle times, as well as R&D innovation to improve time to market and new product introduction and development rates. These applications are already driving measurable financial impact on the top and bottom line for early adopters.

> "We look for successful use cases in other industries to argue for the adoption of new technologies and make the implementation process more cost-efficient. Our successful use cases have resulted in improved maintenance efficiency, upskilling of staff and higher employee satisfaction, especially among younger colleagues."
>
> **Head of digitalization**
> Utilities/electricity distribution
> 5,000-9,000 employees, Europe

Figure 1: Industrial metaverse use cases across the industrial value chain



Q. What is the current stage for the following industrial metaverse use cases at your organization?
Base: Actively using in multiple projects/locations or in a single project/location. (n=907).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

The number and variety of industrial metaverse use cases are quickly expanding, driven by the significant impact and technical considerations they entail. This research study benchmarks and analyzes the top 16 industrial metaverse use cases identified by survey respondents (see Figure 1), focusing on their adoption, impact and technology.

Metaverse adoption is rapidly segmenting markets

The recognition of significant financial gains and business outcomes from industrial metaverse applications is not universal as adoption is quickly expanding past initial schisms of "haves" versus "have-nots" and into multifaceted market segmentation. Overall, more than four in five respondents (81%) are using, piloting or planning to adopt industrial metaverse technologies, while the remaining 19% either have no plans or plans that are more than three years out.

Among adopters, nearly one-fifth are identified as industrial metaverse Leaders. These organizations are actively rolling out use cases at scale within a matured digital transformation strategy that is delivering significant financial and business impact.

Leaders

Nearly one-fifth (19%) of metaverse adopters are Leaders; they have deployed several use cases at scale and achieved enterprise-wide digital maturity.

Two additional groupings — Challengers and Explorers — sit close behind but have not yet achieved integrated, enterprise-wide digitalization. Their efforts are often uncoordinated and departmental, lacking a cohesive strategy across the organization. However, shortcuts to bypass common hurdles to metaverse adoption are opening through technology innovation and vendor maturity. These developments present a "second-mover advantage," providing a path to avoid excess expenditure of capital, time and other resources that first movers may have succumbed to.

Rounding out the market segmentation is a large swath identified as Observers — those that are still operating exclusively in pilots, proofs of concept or not at all. Yet many are on the cusp of initiating a transformation that could significantly impact their organization and gain self-perpetuating momentum, as has happened with other adopters.

The Industrial Metaverse Research Study delves into these shifting market maturities, showing how an organization's position influences its perceptions and actions. The study offers insights for both business- and technology-minded stakeholders, along with actionable strategic recommendations that can be applied to their own organizations' metaverse strategies.

Industrial metaverse segmentation

The survey data revealed noticeable variances regarding the number and scale of deployed metaverse use cases, as well as the maturity of organizations' digital transformation. These differences underpin the four metaverse adoption categories, which are analyzed throughout the paper and described in Figure 2.

Figure 2: Maturity characteristics

	Leaders	Challengers	Explorers	Observers
Sample size (n)	171 (19% of total)	300 (33%)	101 (11%)	335 (37%)
Number of metaverse use cases active in single and/or multiple sites/projects	10+	8-9	1-7	0
Digital transformation maturity	Enterprise-wide: **100%**	Enterprise-wide: **17%** Departmental: **72%** Piloting/proofs of concept : **10%**	Enterprise-wide: **40%** Departmental: **48%** Piloting/proofs of concept: **13%**	Enterprise-wide: **26%** Departmental: **37%** Piloting/proofs of concept: **23%** Consideration: **12%** No strategy: **2%**

Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

Organizations with a centralized, enterprise-wide digital transformation strategy achieve far greater success than those operating in a decentralized and departmental manner. These organizations benefit from ongoing and structured support from C-level executives, management board and steering committees. These metaverse Leaders have incubated a culture that embraces new technologies and democratizes best practices for adoption. Their initiatives are managed and optimized by formal digital teams, and they have successfully deployed and scaled several metaverse use cases.

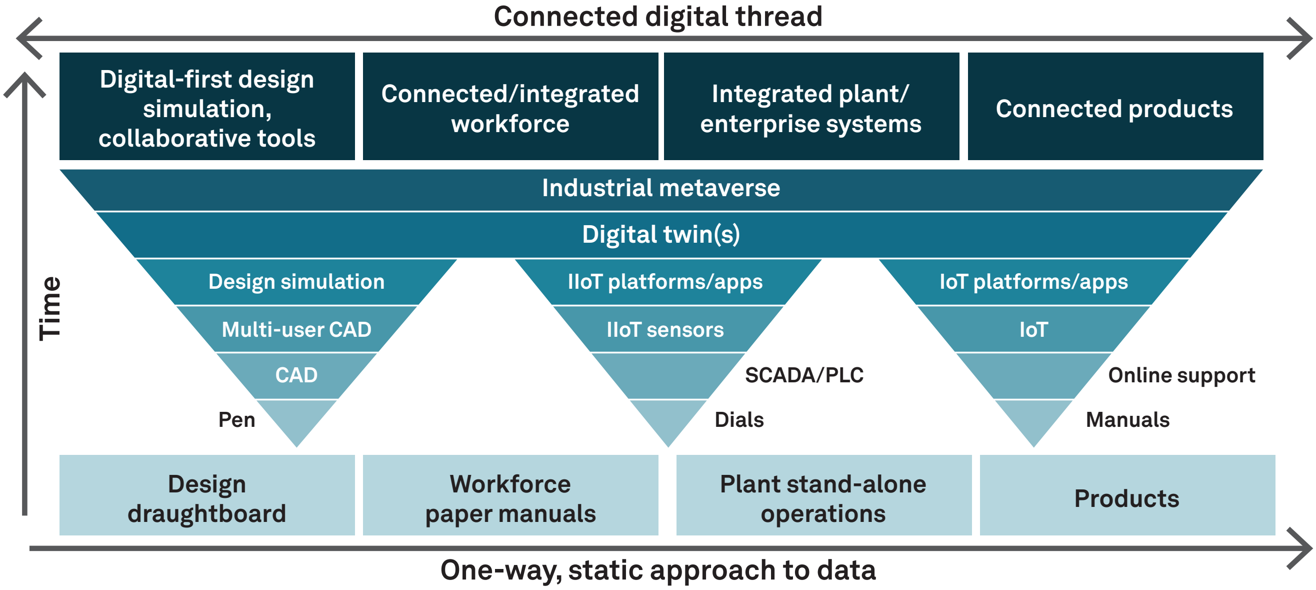
The large pack of Challengers is not far behind the Leaders in terms of the number of metaverse use cases deployed. However, the maturity of Challengers' digital transformation is far more nascent and often even trails that of companies with fewer metaverse use cases (Explorers, Observers). As with other digital projects in industrial settings, many organizations have highly siloed efforts, where each department, region or site may pursue its own efforts, forming a fragmented installed base of digital projects.

However, metaverse maturity doesn't equal digital maturity; organizations with more established digital programs may not have implemented industrial metaverse at scale, or vice versa. In fact, a relatively high share of Explorers and Observers show a level of enterprise-wide and departmental digital transformation comparable to many Leaders. These segments also report usage of key technologies critical to digital transformation — i.e., AI/ML, IIoT, cloud, etc. — at similar rates to those of Leaders.

The evolution: From IIoT to digital twin to industrial metaverse

The industrial metaverse should be viewed as an evolution of the digital transformation of industrial systems. It represents the potential to integrate data and the workforce into a unified, real-time digital system. The digital twin is a key building block that provides a reliable source of "engineering truth" to multiple use cases and applications, accurately reflecting, for instance, the state of plants and processes and the features of new designs and products.

Figure 3: Evolution to industrial metaverse



Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

Industrial applications have constantly adopted new technology, in many cases integrating the new alongside legacy systems. In the past decade, industrial IoT has transformed isolated physical plants and factories into digitally connected webs of assets. This development has occurred alongside the digital transformation of product design and products themselves. These elements combine in a digital thread through industrial metaverse applications, providing access to a single engineering source of truth, rather than a segmented picture in which each stage — design, manufacturing and shipped product — represents a one-way handover from silo to silo.

Historically, industrial software and systems such as CAD, IIoT, applications and connected products were point solutions for sets of sensors and processes, often leading to disparate digital silos replacing physical ones. This digital patchwork is evolving into a more integrated setup, combining richer unified data and digital twins. These, in turn, become part of a larger, system-wide digital twin and a digital-first life cycle. The workforce interacts in real time with these digital twins and one another.

This integration is at the core of the industrial metaverse, where engineering precision is linked to the physical reality of the plant, leading to a more unified system for greater efficiency. In time, this will form the basis for a "system of systems" — or an "internet of twins" — as supply chain integration and cross-company collaboration increases. Industrial metaverse Leaders — organizations that have implemented enterprise-wide digital transformation and deployed 10 or more metaverse use cases — embody this ongoing shift toward a system-of-systems view.

Digital twin integration:

"It was the idea when the use case was implemented, to standardize that globally, because until today, we would have not hundreds, would have thousands of different digital twins. And with this centralization and standardization, we want to reach, roughly, for each and every different division, five to six digital twins, not more — this is currently our aim. I know that we can't tackle everything there, but at least we get the majority of 90% and be covered. This will be already helpful, and this is our goal for 2028."

VP of IT workplace
Global automotive supplier
10,000+ employees, Europe

Key findings: Technology trends

1. **Broad adoption of high-impact use cases:** Specific industrial metaverse use cases, such as R&D innovation, manufacturing process planning, predictive maintenance, remote operations, and employee safety and well-being, show high adoption rates, indicating their immediate and significant value, as well as applicability in multiple locations.

2. **Emergent use cases drive impact but with limited scale:** Use cases such as model-based systems engineering, immersive engineering, training autonomous systems, connected worker assistance, immersive training and remote collaboration are in the emergent stage with notable activity in single locations and proofs of concept (PoCs), suggesting they are foundational for future integration.

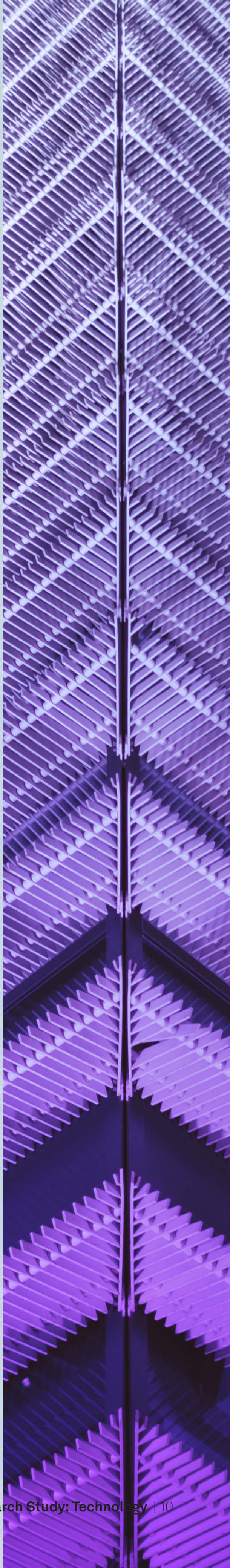
3. **Digital twin integration is crucial:** Higher levels of digital twin integration correlate with more active engagement in industrial metaverse applications. This integration is crucial for creating a unified data environment that enhances the accuracy and efficiency of both legacy and new applications.

4. **Key attributes for industrial metaverse applications:** Advanced industrial metaverse applications feature high synchronicity (constant communication with multiple users) and extensive data sharing. These attributes are essential for effective collaboration and decision-making in industrial operations. They are being adopted, deemed worthy of investment, and identified as improvements required for constant compute and bandwidth capability.

5. **Potential for evolution in low-integration use cases:** Use cases with currently lower levels of data sharing and synchronicity, such as immersive engineering and production modeling, are still valuable because they create foundational designs for digital twins. These use cases are expected to evolve and become more integrated over time.

6. **Interoperability and skills shortages are major challenges:** The lack of interoperability and common standards, along with the complexity of integration and a shortage of skilled personnel, are significant barriers to industrial metaverse adoption. Addressing these issues through standardized tools, training programs and robust security measures is essential for successful implementation.

7. **Businesses have clear expectations for their partners:** Businesses see strong competencies in AI/ML, interoperability and technological innovation as crucial when selecting partners. Effective partnerships with vendors that offer these capabilities provide seamless integration with existing systems, support continuous technological advancements and help build robust ecosystems for accelerated adoption and scaling of metaverse applications.



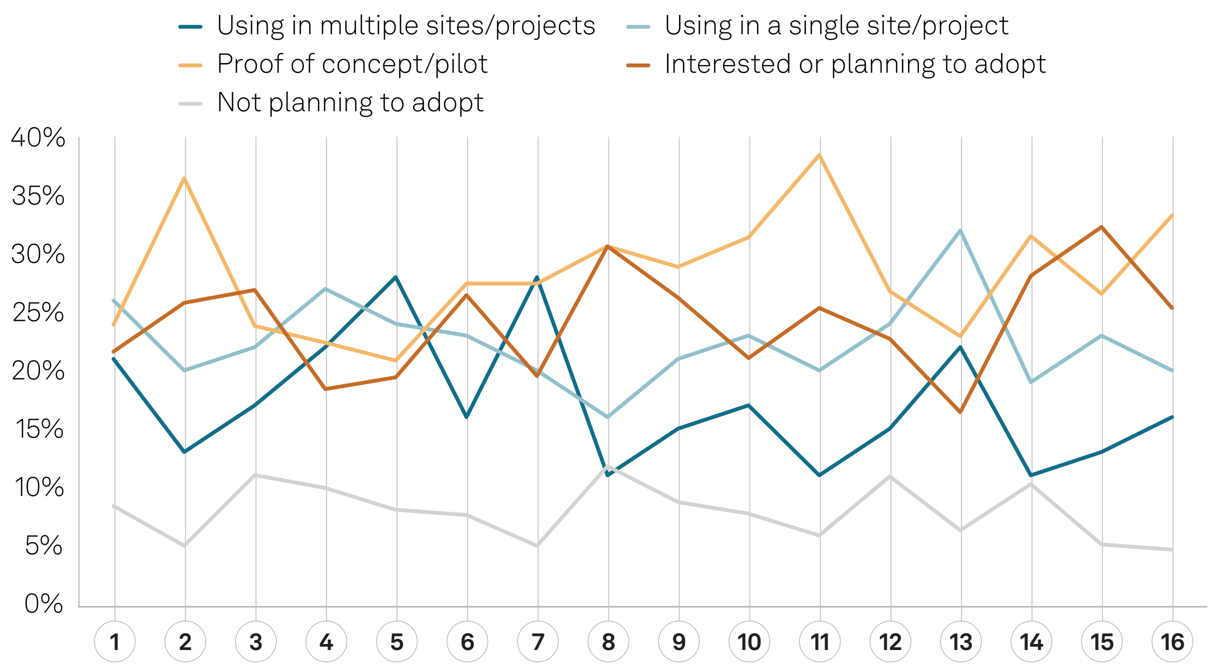
Tech trends in the industrial metaverse: Use cases, technology, impact and challenges

The industrial metaverse is rapidly evolving, driven by transformative use cases and foundational technologies. Key applications are enhancing operational efficiencies, workforce capabilities and customer interactions. Critical technological advancements include digital twin integration, real-time interaction capabilities and improvements in cloud streaming accessibility. The analysis of current adoption patterns, further technological convergence, and challenges such as interoperability and skill shortages reveal how these innovations are reshaping industrial practices and strategies.

Current trends in use case adoption

A comprehensive view of industrial metaverse use cases along the industrial value chain — composed of both product and service life cycles — reveals various adoption peaks and pits among the 16 industrial use cases analyzed. This result examines the range of use cases that, once fully integrated, could be considered a full industrial metaverse ecosystem. Over time, all use cases would be fully implemented and active in multiple locations. However, it is important to remember that this is an emerging field, with constant and incremental improvements. Different business needs, appetites for change and the technical maturity of the systems involved create a complex landscape. The drive is, as ever, to improve industrial processes rather than to create an industrial metaverse for its own sake. Leaders report higher levels of adoption of overall use cases and are heading toward full implementation across multiple locations, but there is still a lot to be done to reach that goal.

Figure 4: Adoption stages of industrial metaverse use cases across the value chain



1 R&D innovation
2 Model-based systems engineering
3 Immersive engineering, product design and testing
4 Product demonstration and visualization
5 Manufacturing process planning
6 Predictive maintenance
7 Remote operations
8 Remote support/telepresence
9 Production modeling
10 Supply chain optimization
11 Training autonomous systems
12 Generative AI for operations
13 Employee safety and well-being
14 Connected worker assistance
15 Immersive training
16 Remote collaboration

Q. What is the current deployment stage for the following industrial metaverse use cases at your organization?
Base: All respondents (n=907).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

Notably, several use cases exhibit relatively high adoption, with significant deployment across both multiple and single locations, indicating greater maturity (see Figure 4). For example, R&D innovation and manufacturing process planning each see more than 20% adoption in both multiple and single locations, while predictive maintenance, remote operations, and employee safety and well-being also show strong adoption figures.

Other use cases present a more diverse and dynamic picture. Supply chain optimization and immersive engineering/product design and testing are used extensively by some, limited to single locations for others, and in PoC stages for many. These technologies are on their way to becoming more pervasive but have not yet achieved widespread, consistent adoption.

Furthermore, several use cases are emerging with significant activity in single locations and PoCs. Model-based engineering and training autonomous systems, for instance, show high engagement in PoC stages (each 36%-38%), with substantial single-location use. Connected worker assistance, immersive training and remote collaboration reflect a growing trend toward enhancing workforce productivity and collaboration through advanced technologies, each with notable single-location and PoC activity.

Overall, the adoption landscape reveals a spectrum of readiness and implementation stages for industrial metaverse use cases. While some technologies are broadly adopted and integrated into multiple locations, others are still being tested and refined, indicating ongoing efforts to fully integrate these innovations into industrial operations. This variability in adoption is further highlighted when examining how Leaders, Challengers and Explorers differ in their approaches to implementing these use cases.

In some cases, there are considerable gaps in the adoption of a use case between Leaders, Challengers and Explorers. For example, Leaders reported much stronger adoption of generative AI for operations (80%) and remote support (62%) compared to Explorers (28% and 9%, respectively).

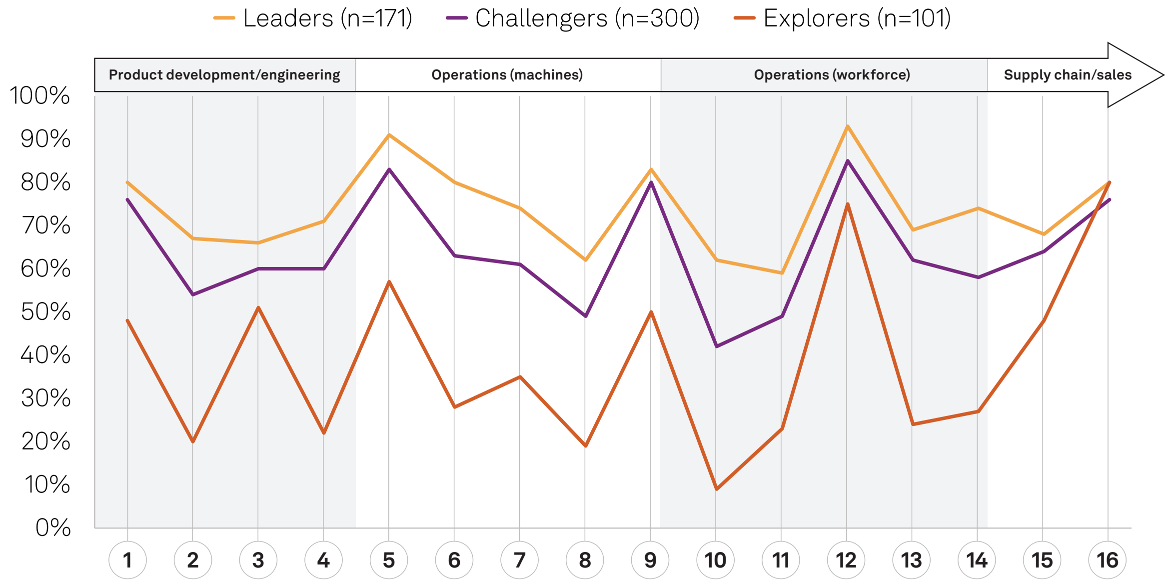
At the same time, several use cases had broad adoption among all active metaverse users, with adoption rates exceeding 50% across the board. Notably, the gaps were minimal or even zero for employee safety and well-being (Leaders, 93%; Explorers, 75%) and product demonstration and visualization (Leaders, 80%; Explorers, 80%).

Product demonstration and visualization

"We've changed and created a process with the metaverse to allow them to see our new product lines in the metaverse, to be able to build it out within a technical space of a showroom or a bedroom or a living room."

Global director of technology
Consumer goods
500-999 employees, North America

Figure 5: Use case adoption among Leaders, Challengers, Explorers



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7 Predictive maintenance
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10 Remote support
11 Connected worker sassistance
12 Employee safety and well-being
13 Remote collaboration
14 Immersive training
15 Supply chain optimization
16 Product demonstration and visualization

Q. What is the current deployment stage for the following industrial metaverse use cases at your organization?
Base: All respondents.
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

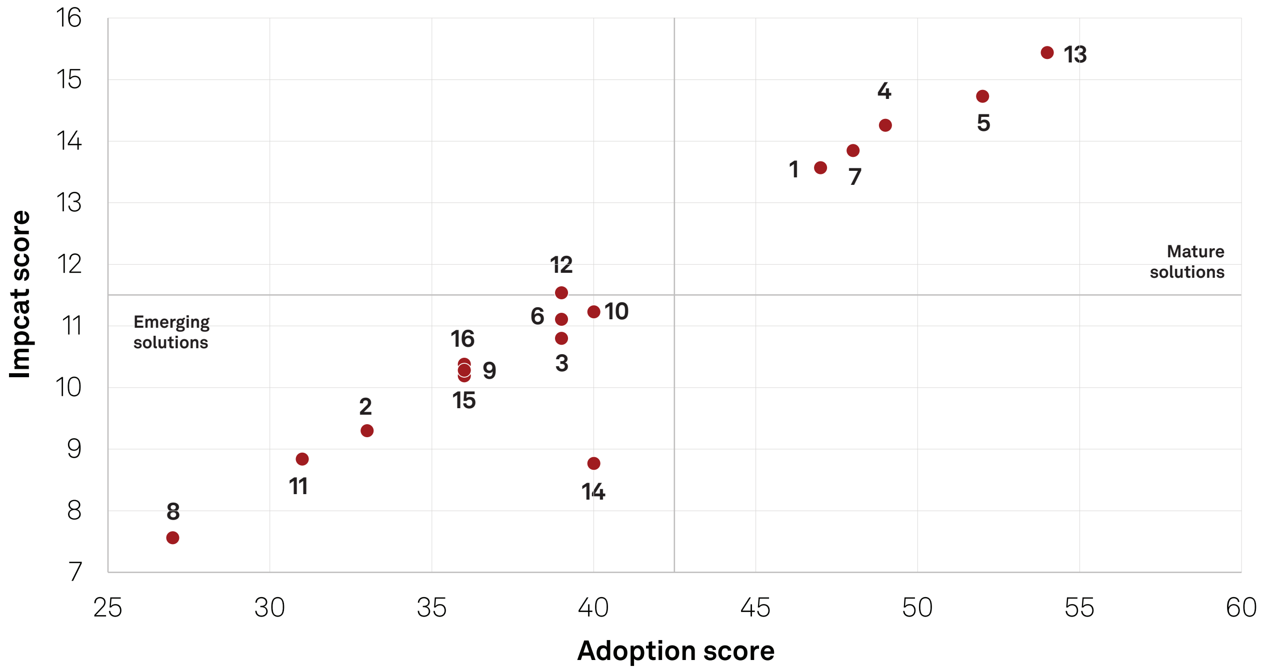
Measuring impact

To accurately represent how industrial metaverse use cases create value for business operations (e.g., improving product quality) and financial results (e.g., increasing revenue, reducing operational costs), 451 Research created an index of adoption and impact based on:

- **Adoption**: We calculated adoption scores by combining the percentages of respondents who reported that they are implementing the use case in single and multiple projects/sites. Using R&D innovation (i.e., generative design, digital twins for new products) as an example, 26% of all respondents reported implementing this use case this in a single site/project, and 21% in multiple sites/projects, for an adoption score of 47.

– **Impact**: We determined impact scores by first taking the percentage of adopters who said a given use case has had a **significant impact** on each of the 16 surveyed business outcomes, then averaging the percentage reporting "significant impact" across those 16 outcomes. For example, R&D innovation received an impact score of 13.5, which we determined by averaging the percentages of "significant impact" responses across the 16 business outcomes, including increasing revenue (27% said R&D innovation has had a significant impact), reducing operational costs (18%) and the 14 other categories.

Figure 6: Use case adoption and impact



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13 Employee safety and well-being
14 Connected worker assistance
15 Immersive training
16 Remote collaboration

Q. What is the current deployment stage for the following industrial metaverse use cases at your organization?
Base: All respondents (n=907).
Q. Please rate the impact of your organization's industrial metaverse use cases/planned use cases on the following business and financial outcomes.
Base: Respondents that have adopted/plan to adopt metaverse use cases (n=734).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

The data reveals a clear bifurcation in adoption and impact, with five industrial metaverse use cases leading. Traditionally, impact and adoption are not necessarily correlated for technology investments, but in this instance, highly adopted use cases are driving high impact.

Use cases in the bottom left quadrant (low impact, low adoption) should not be viewed as undesirable, but rather as emerging uses with relatively immature value propositions and technologies. However, this can change quickly, as technology innovations (AR/VR, generative AI) could propel any of these use cases into higher adoption and impact.

Two high-impact and highly adopted industrial metaverse use cases are:

Time to impact

"Certain areas, we see more easy-to-adapt solutions. We are looking at the low-hanging fruits... there's a lot of resistance in investing and people want to see results faster... we cannot say it is going to take us three, or two years, or one year to implement something and keep investing money in it. That's hard to fly... We want to see everything in three months."

CIO
Machinery and equipment
10,000-49,000 employees, North America

- **Employee safety and well-being:** The industrial workforce remains the most important factor for many manufacturing and industrial organizations. Faced with pressing skills shortages and challenges in recruiting and retaining staff, companies need to increase the attractiveness of the workplace, minimize safety incidents and maximize their productivity. Industrial metaverse use cases can add value here.

  For instance, new and existing employees are increasingly using VR to participate in safety training processes that simulate the unpredictable and dangerous industrial world. Additionally, AR is providing real-time safety protocol guidance for workers navigating their workspace and preempting potential hazardous events.

  Regarding adoption, 93% of industrial metaverse Leaders are implementing this use case in single or multiple projects and sites, compared to 85% of Challengers and 74% of Explorers.

- **Manufacturing process planning:** Rapidly changing customer preferences, mass customization and increasing product complexity are driving manufacturing production lines to rapidly adjust to shifting external forces and internal factors.

  Through industrial metaverse platforms embedded with native integrations, AI/ML and simulation capabilities, manufacturers can ingest the significant volume of supply chain, customer, product, manufacturing and other data to optimize their production capacity. Planning factory capacity and facility layouts virtually in 3D reduces time to market while reducing downtime required for changeovers to retool or change production lines.

  Regarding adoption, 91% of industrial metaverse Leaders are implementing this use case in single or multiple projects and sites, compared to 83% of Challengers and 56% of Explorers.

Manufacturing process planning

"In a lot of our sites, we do manufacturing where the mix is large and volume are low, which means there is a large changeover between a variety of products. There could be thousands of different products — SKUs with 50,000 variations of a single type of nail, varieties that are going to different countries. So, what we're doing right now is issuing digital twins to model what we should be producing based on availability of raw material to optimize our production schedules versus our demand against the availability of product so we can optimize gains. We use it in some of our endoscopy surgery products."

Senior director of global PMO
Industrial production/medical devices
10,000+ employees, North America

Emerging and future impactful use cases include:

- **Model-based systems engineering** (e.g., digital representation at system level, model-based requirements, system architecture modeling) **and immersive engineering** (e.g., 3D modeling and simulation; simulation- and test-based validation and verification). These start the digital thread for digital twins across the ecosystem.
- **Workforce capability and effectiveness** is enhanced by integration into systems with connected worker assistance, immersive training and remote collaboration. The ability for people to engage digitally with one another and with digital twins in real time is a major feature of an industrial metaverse.
- **Training of autonomous devices** can be achieved in accurate simulations and synthetic data representing the shop floor or other locations, either before a physical location has been created, or to upgrade the capability of an existing facility without disruption.

Enabling technologies for the industrial metaverse

Underlying the trends in use case adoption and impact, another critical aspect to explore is the technological foundation enabling these advancements. Key technologies such as digital twin integration, real-time interaction and data integration, and cloud streaming are driving the evolution and implementation of industrial metaverse use cases. Understanding these technological underpinnings provides deeper insights into how organizations are enhancing their operational efficiencies and achieving broader adoption of metaverse applications.

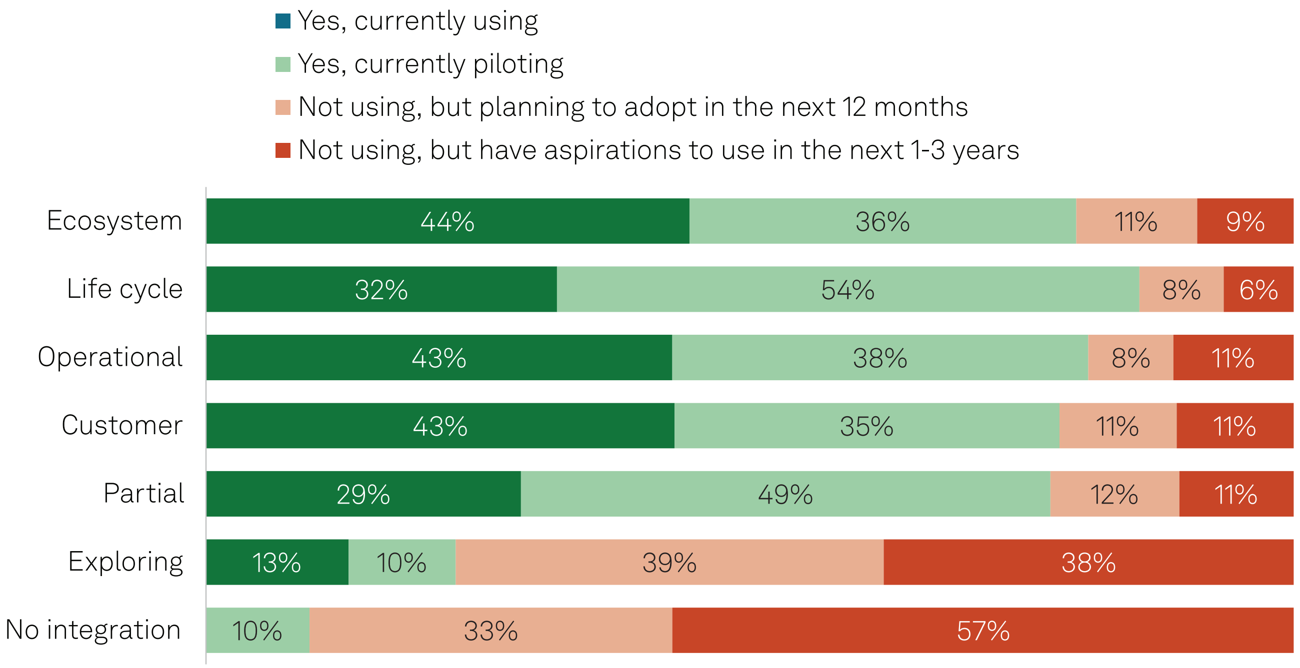
Digital twin integration

With multiple digital transformation projects implemented over time, many separate data sources become operational. In metaverse use cases, these data sources typically take the form of a digital twin. Combining and unifying data sources (i.e., integrating digital twins) is an important step. This integration ensures that both old and new applications can benefit from a single source of truth, enhancing accuracy and efficiency. By creating this unified data environment, organizations can facilitate seamless real-time interaction and data sharing, drive innovation, improve operational efficiencies, and achieve broader adoption of metaverse applications across the industrial value chain.

The survey asked respondents to describe how digital twin integration was progressing, if at all, for their companies.

Figure 7: Digital twin integration and metaverse adoption

Q. Does your organization use, or plan to adopt, any technologies that this survey might define as industrial metaverse?
Base: All respondents (n=907).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.



- **Ecosystem-wide integration:** Digital twins are part of a fully integrated ecosystem, including with external systems (e.g., suppliers, partners). This level encompasses a combination of customer/product and operations integration.
- **Customer integration:** Digital twins of products are primarily integrated with customer-facing platforms for enhanced service and feedback loops.
- **Operational integration**: Digital twins are integrated across core operational processes for real-time data sharing and decision-making.
- **Partial integration:** Some digital twins share data and insights with others at specific life-cycle stages.
- **No integration:** Siloed, stand-alone digital twins do not interact with one another.

Maturity of digital twin integration ranges from the highly integrated ecosystem-wide, customer and operational levels to the less advanced partial integration and exploratory stages. Survey results indicate that higher levels of digital twin integration correlate with more active engagement in industrial metaverse applications (see Figure 7). This highlights the critical role of digital twin integration in advancing industrial metaverse development.

It should be noted that there is often a discrepancy between respondents' perceptions of their company's own digital maturity versus peers and their actual integration levels. Surprisingly, 71% of respondents who reported no digital twin integration considered themselves somewhat or substantially more mature than their peers. By comparison, 74% of those with a more advanced ecosystem of digital twins identified themselves as more mature than their peers. This suggests a potential overestimation of maturity among some respondents.

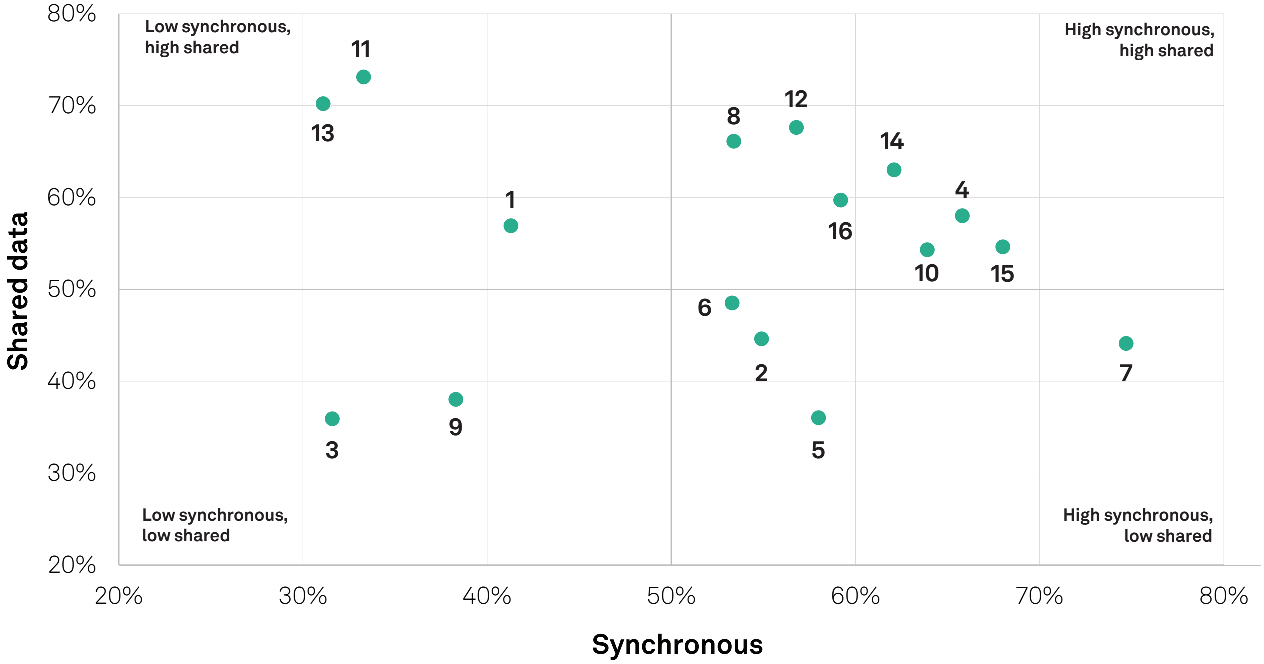
Real-time interaction and data integration

Visions of a true "industrial metaverse" application may take different forms. Generally, the truest technical form of an industrial metaverse application will have a high degree of synchronicity, leveraging constant communication with multiple users simultaneously, and extensive data sharing, making critical information available to different users, departments and applications. For example, consider the level of synchronicity and data sharing for engineers collaborating in real time on a production-line problem in the physical world, via a digital twin, or in both environments at once.

However, the level of synchronicity or data sharing is not necessarily an indicator of impact; some industrial metaverse applications with low synchronicity and usage may have high data sharing and be critical to thousands of users, whereas an app with low data sharing and high synchronicity may be highly impactful to the business even with few constant users.

Based on the respondents' assessment of current use cases, Figure 8 maps out how industrial metaverse applications are positioned along the key dimensions of data integration (shared data) and real-time interaction (synchronous communication).

Figure 8: Use case attributes



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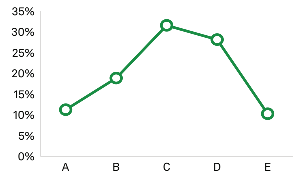
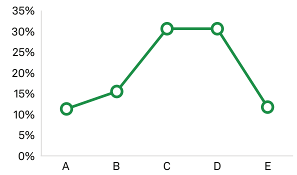
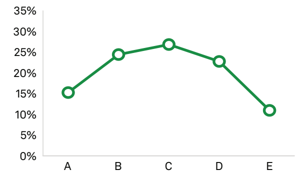
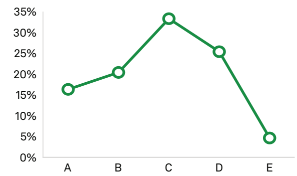
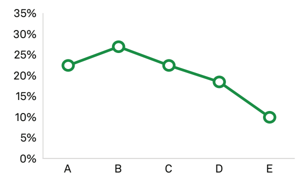
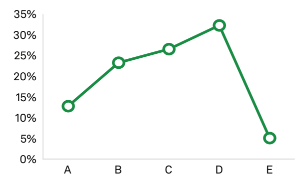
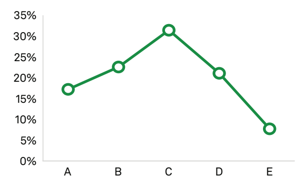
10. Supply chain optimization
11. Training autonomous systems
12. Generative AI for operations
13. Employee safety and well-being
14. Connected worker assistance
15. Immersive training
16. Remote collaboration

Q. For those industrial metaverse use cases you are using/planning, how are these architected in terms of the user experience? An asynchronous application gives each user their own single view (e.g., email client or task-training application). A synchronous application has multiple users working on the same data in real time (e.g., collaborative design review, virtual meeting).
Q. For those industrial metaverse use cases you are using/planning, how are these architected in terms of data sources (such as digital twin)? Stand-alone applications create and manage their own data, e.g., a training application with a custom 3D model. Shared data applications use the same base (e.g., digital twin) across multiple use cases.
Base: Respondents implementing/planning to implement metaverse use cases (n=635).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

High synchronicity, high data sharing

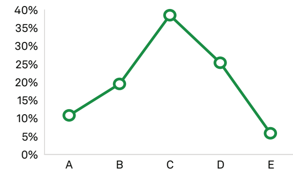
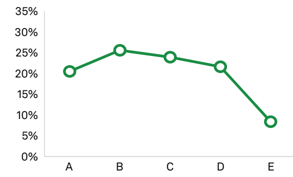
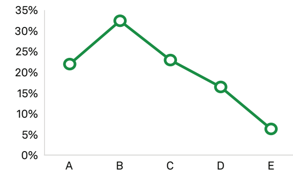
Respondents identified nearly half of the industrial metaverse use cases examined (seven out of 16) as having high synchronicity and high data sharing. These represent the most highly integrated industrial metaverse applications in use today.

Use case	Attributes	Adoption
Connected worker assistance (e.g., AR headsets for on-the-job guidance and support)	• An augmented physical-world experience, and a tool of the job. • Required for further efficiency once a plant is IIoT-instrumented.	
Remote support and telepresence (e.g., expert guidance through AR for field technicians)	• Common use case implemented in 1:1 situations via video/phone. • Synchronous aspects evolve when remote teams interact digitally with connected workers and plant digital twins.	
Generative AI for operations (e.g., AI copilots optimizing workflows based on production data)	• GenAI needs all contextual data and information to cross-reference and provide results. • Supports connected workers as another part of the toolbox.	
Remote collaboration (e.g., VR-enhanced environment for collaborative design and planning)	• A typical metaverse example in B2B environments. • Key is being able to pull together shared data and assets, rather than simply presenting avatars in a meeting room.	
Product demonstration and visualization (e.g., AR-guided product showcases, digital twin review with customer)	• Immersive and shared virtual space to provide the most compelling sales experience. • Ideally, this function interacts with accurate design digital twins.	
Immersive training (e.g., using VR to simulate work environments for safety and skill training)	• Typical fully immersive and shared virtual space to provide the most compelling user experience. • Ideally, this function interacts with the same digital twins used in operations.	
Supply chain optimization (e.g., AI for logistics planning, digital twins for inventory, supply chain management)	• Reaching out from an organization, this use case starts to create an industrial metaverse ecosystem that must be joined up digitally. • Requires shared platforms for "what if" simulations, cross-company conversation and negotiation.	

Categories: A - Actively using in multiple projects/locations; B - Actively using in a single project/location; C - PoCs/pilots; D - Interested and/or planning to adopt; E - Not planning to adopt

Low synchronicity, high data sharing

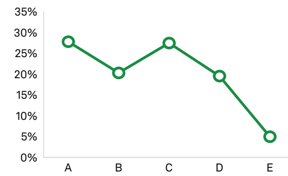
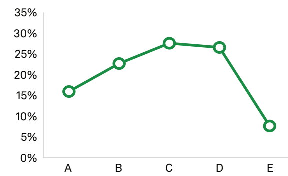
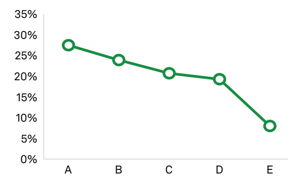
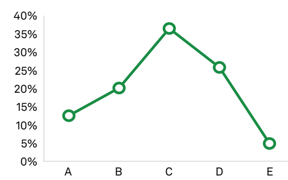
These use cases represent a data-focused side, with less need for or less obvious synchronicity with users. The level of data integration expected marks these as important for future metaverse applications.

Use case	Attributes	Adoption
Training autonomous systems (e.g., using simulations or synthetic data to train robots)	• Using an accurate simulation of a real-world (or yet to be built) location allows for autonomous models to be trained in multiple situations. • While operating synchronously, simulations can be considered a part of the digital twin.	
R&D innovation (e.g., generative design and digital twins for new products)	• Metaverse R&D has less synchronicity than fully rolled-out applications, but it is an important representation of intent to move toward the top right quadrant.	
Employee safety and well-being (e.g., VR for hazard recognition training, AR for safety protocol guidance)	• Applications currently operate in the context of the system seeing all, but workers are individual. • Shifting to more synchronous interaction as digital twins integrate system-wide.	

Categories: A - Actively using in multiple projects/locations; B - Actively using in a single project/location; C - PoCs/pilots; D - Interested and/or planning to adopt; E - Not planning to adopt

High synchronicity, low data sharing

Applications scoring low on data integration but high on synchronicity typically indicate a siloed or departmental focus, or legacy transformation efforts. In contrast, more metaverse-focused applications, found in the upper right quadrant, exhibit both high data integration and high synchronicity.

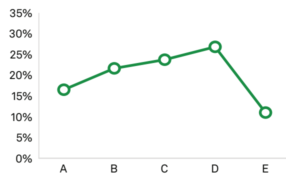
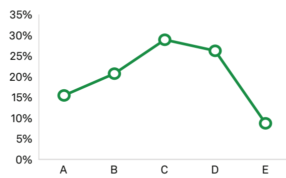
Use case	Attributes	Adoption
Remote operations (e.g., controlling and monitoring machinery or processes from a distance)	• Control centers were already a part of the industrial landscape, and typically, collaborative metaverse applications initially replicate existing systems. • Hence, this function is characterized by a relative lack of data sharing.	
Predictive maintenance	• As an evolving IIoT use case, using AI/ML on maintenance data will have been focused on a particular process, not general sharing of data. • Over time, these models will be based on the wider-system digital twin.	
Manufacturing process planning (e.g., virtual capacity planning, digital twin-based facility layout)	• The digital-first creation of a new facility is the start of a digital twin's life. • It is early days for this life cycle, interoperability and tooling. It is a collaborative, but low-data-sharing application today, and will move toward increased sharing.	
Model-based systems engineering (e.g., digital representation at system level, model-based requirements, system architecture modeling)	• Digital engineering becomes the metaverse application to build other metaverse applications because it is all the same data in a digital thread. • This function needs to mature, along with existing use cases, toward increased data sharing.	

Categories: A - Actively using in multiple projects/locations; B - Actively using in a single project/location; C - PoCs/pilots; D - Interested and/or planning to adopt; E - Not planning to adopt

Low synchronicity, low data sharing

Use cases with a lower degree of data sharing and very little synchronous use do not typically align with the metaverse adoption curve. They are unique applications used by a few people. Their position in this section indicates potential for further evolution: As other use cases mature and demonstrate their value, these applications are likely to become more synchronous and integrate into common digital twins.

However, despite their current lower levels of integration, use cases such as immersive engineering can already offer significant value, and they can play a crucial role in laying the groundwork for more integrated digital twin initiatives. After all, for digital twins that span the entire life cycle of a product or process, this foundational design work is the essential first step.

Use case	Attributes	Adoption
Immersive engineering, product design and testing (e.g., 3D modeling and simulation; simulation- and test-based validation and verification)	• Products are designed digitally, but now interoperability standards are developing to lift data from the design silos. • CAD applications have been high-end desktop applications, but cloud computing and rendering are helping to extend CAD applications' use.	
Production modeling (e.g., digital twin "what if" scenarios for production processes)	• Understanding what may happen across an interconnected system of suppliers, parts, raw materials, staff, autonomous robots and plant machinery requires all those elements to be in place and in a unified digital twin. • We can expect this to move toward the top right of the graph as industrial metaverse matures.	

Categories: A - Actively using in multiple projects/locations; B - Actively using in a single project/location; C - PoCs/pilots; D - Interested and/or planning to adopt; E - Not planning to adopt

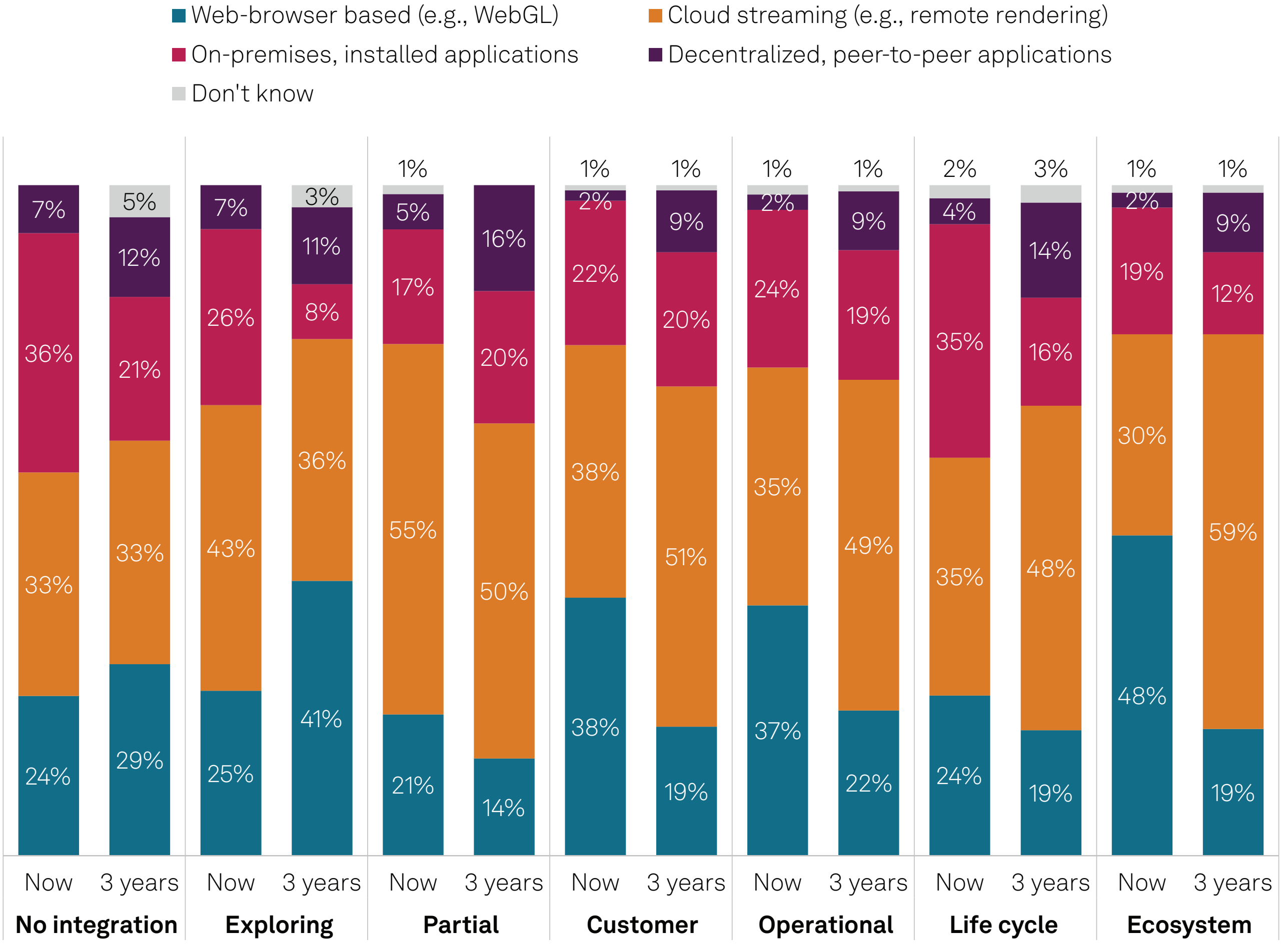
Evolving access methods: Cloud streaming

Metaverse adoption maturity leaders need to keep adapting and upgrading their approach if they wish to maintain competitive first-mover advantages. One example of this ongoing evolution can be seen in the use and expected use of cloud-based rendering of high-end computational tasks. This includes visualization and manipulation of detailed 3D models and the processing of simulations and analysis. This type of arrangement also enables interaction with live, large-scale digital twins in areas such as operations and maintenance from the factory floor. Many early adopters will be using applications that typically involve higher-end workstations with on-premises compute power needed to render complex engineering models.

Current developments are enabling remote manipulation and rendering of those models, which can then be streamed to less powerful endpoint devices such as tablets and laptops, and even accessed via web browser. In looking at respondents' expected integration of digital twins across various types of access technology three years from now, we can see that cloud rendering is the primary expectation (see Figure 9).

Yet those with only partial digital twin integration reported the most use of cloud rendering. This indicates a more unified and easily accessible approach among those in the early stages of data integration today, which helps to explain why these organizations may find it easier to roll out new functions.

Figure 9: Adoption of cloud now and in three years, by level of digital twin integration



Q. What is your primary/planned industrial metaverse access approach today? And, what is this expected to be in three years?
Base: All respondents (n=907).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

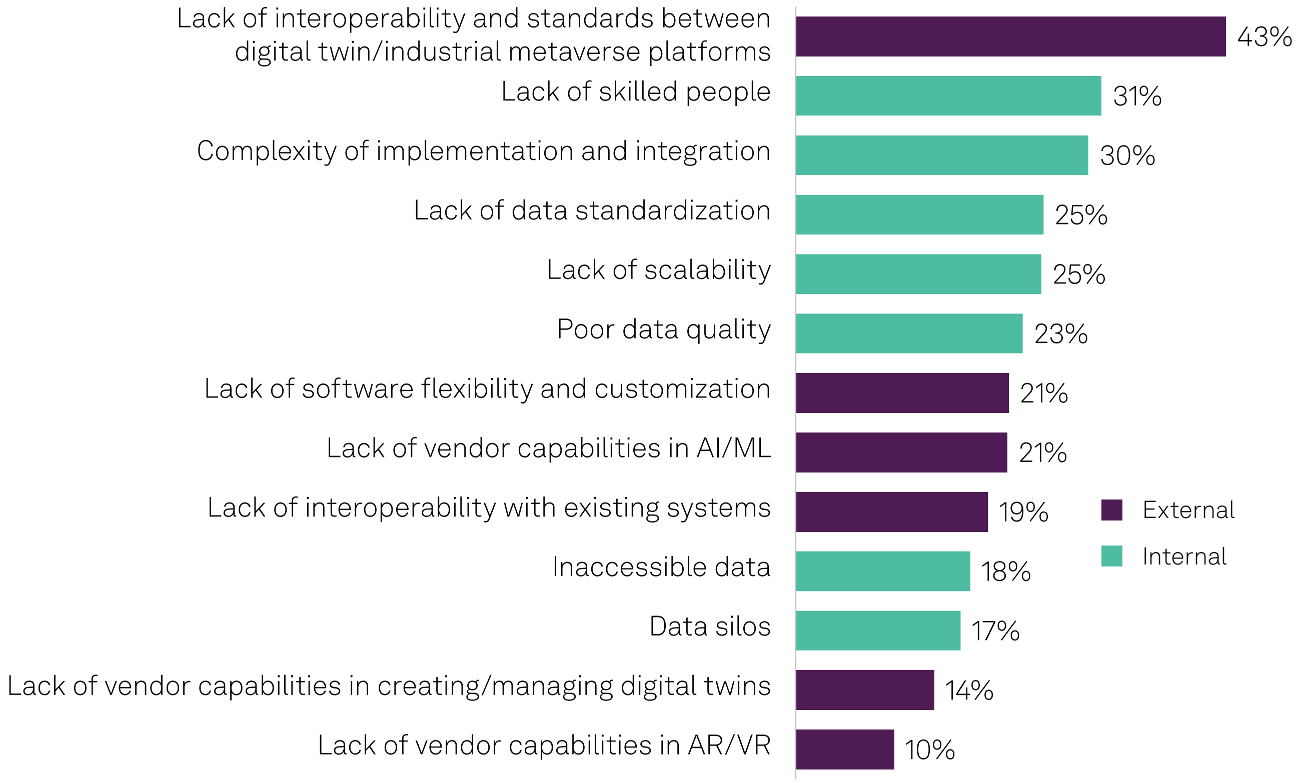
Challenges and partners in building the industrial metaverse

Just as a factory facility is made up of mechanical, electronic, electrical and digital components from many suppliers, so, too, will an industrial metaverse environment be made up of components and services from multiple suppliers. Each machine manufacturer may provide access to its data — or even, in time, its own digital twin — from design to operations, across the digital thread. Just as physical integration is essential in the factory facility, digital integration is needed to build a representative and accurate industrial metaverse. When fully realized, industrial metaverse applications represent the entire system, too, including buildings, people, supply chain, marketplace and enterprise operations. Open standards and digital interoperability are relatively new to the industrial sector, brought on by increasing digital transformation and adoption of IT practices. However, the metaverse presents a new range of real-time interactions and rich augmented data types combining 3D models, simulations and operational data. It is an emerging area with ecosystem challenges arising from a multitude of developments from IT and operational technology (OT) companies.

Lack of interoperability and standards for digital twin and metaverse applications is the most widely cited challenge facing industrial metaverse adopters, according to 43% of respondents (see Figure 10). A lack of skills, and complexity of integration are also both frequently cited, each at about 30%. This illustrates that the ecosystem of industrial metaverse partners and suppliers is still in a state of flux.

However, while official standards trail new technologies, interoperability approaches are emerging, and significant partnerships are nudging the ecosystem further in this direction, such as with openUSD (universal scene descriptor). Solving interoperability in turn reduces the level of complexity of implementation and reduces the impact of a lack of skilled people thanks to the use of common tooling and the presence of a larger pool of people to rely on. Collaborations in standards bodies that would have previously been based solely in the manufacturing and machine build industries, or solely in the IT world, are now seeing collaboration between these realms, as well as with companies in media, film and gaming. For example, a CAD model of a new vehicle may become a digital twin that feeds into a larger simulated digital twin of an automotive factory. Meanwhile, that car digital twin data may also feed into digitized supply chain and production processes, and eventually into customer service processes and user-support information. That same vehicle digital twin can also be used to drive rich advertising media and consumer-facing digital experiences. The utility and ubiquitous potential of a shared digital twin across all sectors is driving the adoption of data interoperability across this vast range of use cases and the specific tools and services they require to function.

Figure 10: Metaverse technical challenges



Q. Which of the following are key technical challenges (specific to industrial metaverse) within your organization?
Base: All respondents (n=907).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

Metaverse partner competencies

Across industrial metaverse maturity categories, there is some variance in the competencies that organizations say they value in partners. All respondents cited interoperability and pre-built integrations as the top competency they seek from a metaverse partner, which speaks to the significance of interoperability and integration challenges, whether an organization has only a few metaverse projects or many.

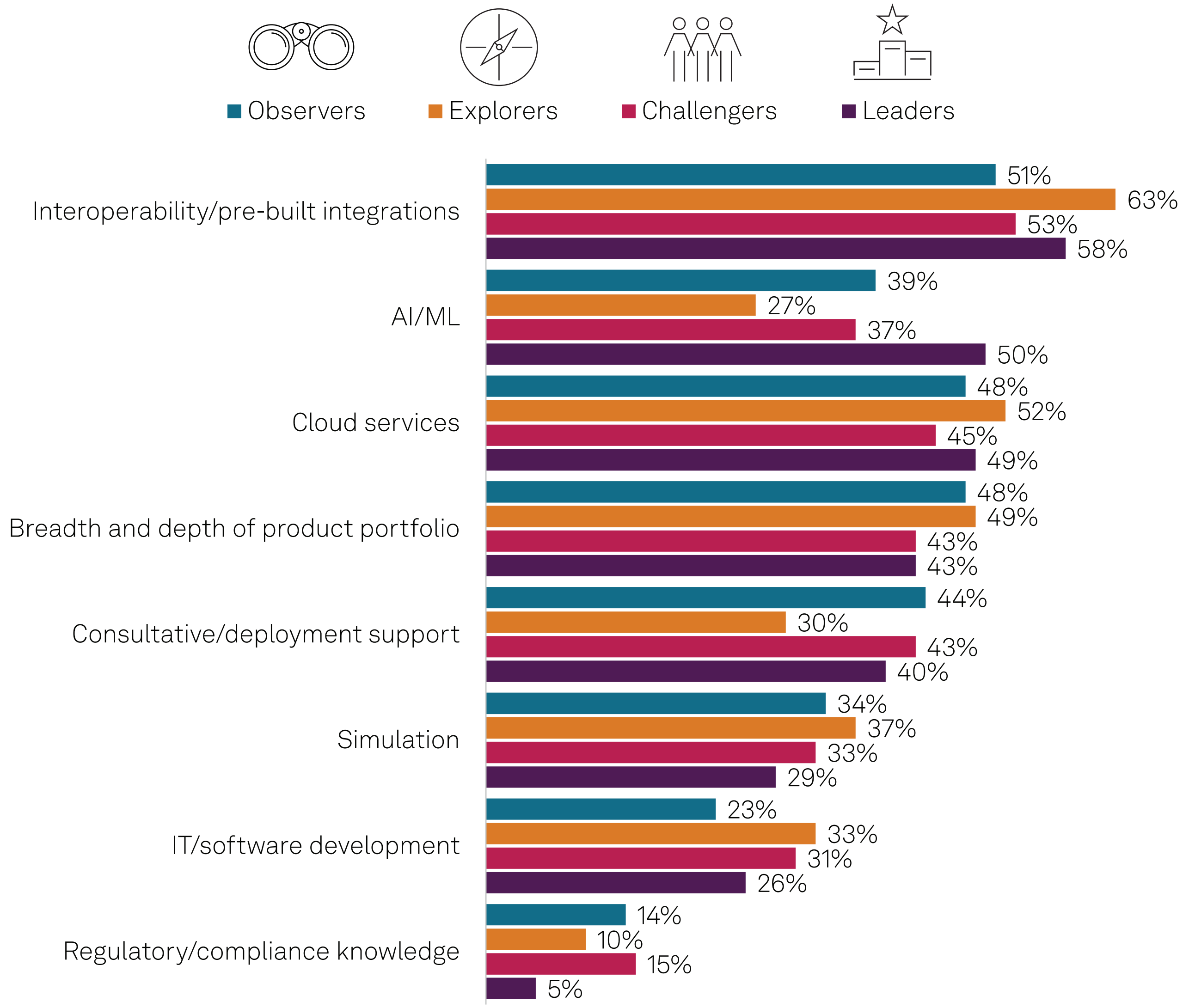
AI/ML had the greatest variance in answers, with 50% of Leaders citing it as an important competency of metaverse vendors, followed by 37% of Challengers, 27% of Explorers and 39% of Observers. The most likely explanation is that organizations with less mature metaverse projects do not have the range, scale or maturity of use cases to require significant AI/ML usage. Given that most industrial metaverse use cases involve some element of predicting outcomes, and considering recent advancements in generative AI, AI/ML will likely become a critical vendor consideration for all industrial organizations.

Standardization

"We've really gone with folks that have experience in our industry, are established and well-proven, and we've standardized across them and aren't going to veer off them. So, for MES, PLM, learning compliance system, CAQ, etc., there are seven in this ecosystem that are non-negotiable partners that we'll never leave."

Senior director of global PMO
Industrial production/medical devices
10,000+ employees, North America

Figure 11: Partner competencies



Q. What competencies or capabilities do you prioritize when considering which industrial metaverse provider to work with?
Base: All respondents (n=907).
Source: S&P Global Market Intelligence 451 Research custom metaverse survey, 2024.

The starting point for any digital twin and digital thread is the engineering and design of the product and the plant. Therefore, engineering and design will require enhanced levels of data integration to support downstream applications of digital twins, from production to customer support to media and advertising. Yet production functions will have the lead when it comes to real-time data collection, such as from industrial IoT, and media functions will be more in tune with rich animated and simulated content.

Conclusions

Given the complexity of the challenge and abundance of information, what are tangible steps industrial organizations can take to form, revitalize or propel their metaverse strategy?

1. **Start small:** Look for strategic, enterprise-wide approaches but start small with targeted use cases that can drive significant and immediate time to value. These use cases also drive the underlying foundation and architectures that evolving use cases can be layered upon.

2. **Think big:** It's crucial to adopt systemic thinking and enterprise-wide architecture rather than rely on point solutions that lead to pilot and scaling purgatory. This will often require starting with data integration, combining existing sources, and potentially deploying and/or integrating multiple digital twins.

3. **Developing a digital-native skill set:** While previous IIoT initiatives have been concerned primarily with instrumentation of industrial machinery, they should now prioritize selecting appropriate digital tools for their workforce. This is needed to attract a new generation of engineers to alleviate the global skills gap and maximize a system-wide approach to digital transformation.

4. **Weave together a data fabric to form a single source of truth:** The emergent industrial metaverse is the natural evolution of the digital transformation of industry. Unifying data across processes is key to create a single source of truth.

5. **Formalize digital or metaverse teams:** In parallel with the unification of data, it is imperative to formalize dedicated digital/metaverse teams. These teams, combining IT and OT expertise, play a crucial role in integrating the concepts of software and physical engineering.

6. **Partner with vendors with key technical competencies:** No single organization can undertake large-scale enterprise-wide metaverse projects alone; partners with key technical capabilities and domain knowledge are necessary. A key consideration across the ecosystem is interoperability. This forms the basis to leverage cloud services and AI/ML/GenAI. Embracing open source, or at the very least adhering to open standards for rich simulation and 3D data, is essential to avoid silos.

Start small, think big

"We want to move with technologies, and we want to be a leader in the market. At the same time, we need to be cautious in moving too fast. And because people who move fast make mistakes and waste money, and it does not deliver the expected results and sometimes it can backfire, we want to take one step at a time."

CIO
Machinery & equipment
10,000+ employees, North America

Interoperability and scale

"We work with a number of solutions, so integration of any software solution in our landscape is hugely important so we can make it fully integrated. That includes pre-built APIs and native integrations. Another important aspect is scale. We need it to support our global operations, which is an issue in small providers. We look at cost, particularly vendors that offer consumption-based rather than fixed costs."

Regional CIO
Global beverage manufacturer
10,000+ employees, Europe

7. **Metaverse maturity dictates current actions:** What you should do next will depend where you are on the metaverse maturity curve.

   - **Leaders** should pursue further digital twin integration as use-case applications mature and standards continue to develop for interoperability. Unifying fragmented data silos is crucial. Leaders can stay ahead of the pack by driving next-generation metaverse use cases and enforcing a culture that quickly extracts value from emerging technologies.
   - **Challengers** and **Explorers** should ensure the explored use cases fit into an open and interoperable future. Consider, for example, whether the use case also produces data that can contribute to a unified digital twin of the entire system.
   - **Observers**, there is still time to get started by leveraging the efficiencies of industrial metaverse to harness the evolution of industrial IoT instrumentation, predictive maintenance, autonomous robotics, among other use cases and technology innovations.

8. **Do not wait for AR, VR hardware:** Industrial metaverse is not tied to AR and VR hardware, though these devices can enhance some use cases. At its core, the focus is on utilizing data and digital twins across their life cycle, facilitating real-time interaction with other people, devices or applications. Be aware that without a systemic approach, hardware such as AR and VR can create a non-scalable silo, slowing down the wider systemic adoption and benefits of metaverse approaches. Many companies have AR and VR applications regardless of their actual metaverse maturity.

It is still early in the metaverse maturity journey, and well-informed decisions aligning strategy, business priorities, technical competencies and key stakeholders can propel your organization toward becoming a leader in both the emergent industrial metaverse and your industry.

Methodology

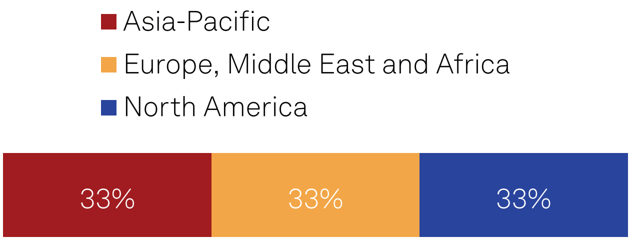
The findings presented in this report draw on a survey fielded in North America, Europe and Asia-Pacific in Q1 2024. The survey initially included 1,092 respondents but screened out 185 organizations that did not have plans to develop metaverse use cases within three years.

The industrial metaverse research study focused on 907 industrial metaverse decision-makers and leaders in organizations with more than 100 employees. The study prioritized respondents with industrial metaverse deployed in pilot and production environments. The research participants were spread across the following manufacturing industries: aerospace, automotive, batteries, chemicals, consumer goods, electronics, food and beverage, machine/industrial products, oil and gas, pharmaceuticals and life sciences, semiconductors and other manufacturing subsectors.

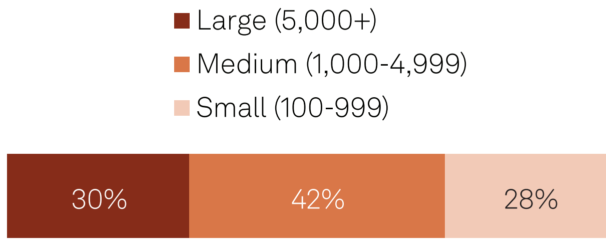
Additionally, there was industry representation from industrial and other related verticals: vehicle charging infrastructure, commercial building, healthcare, higher education, power utilities and rail. Respondent roles were a mix of C-suite, VP-level and directors, and there was a near-even split between respondents in IT, digital and innovation teams and OT/line-of-business. This report also draws on contextual knowledge of additional research conducted by S&P Global Market Intelligence as well as in-depth interviews with similar firmographic representation.

Research firmographics

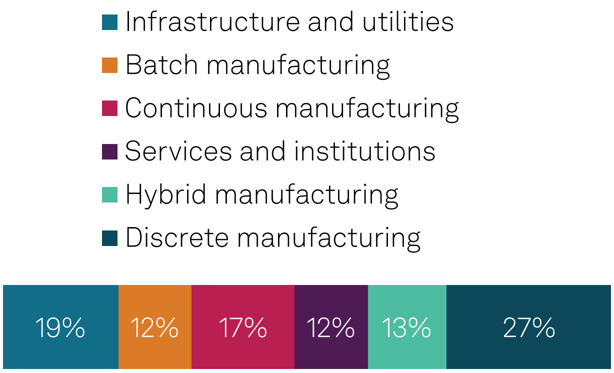
Region



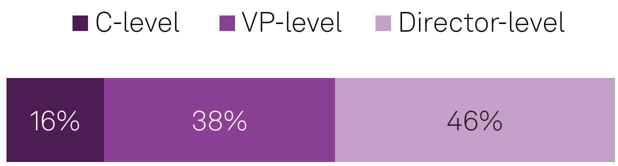
Organization size (number of employees)



Industry and manufacturing type

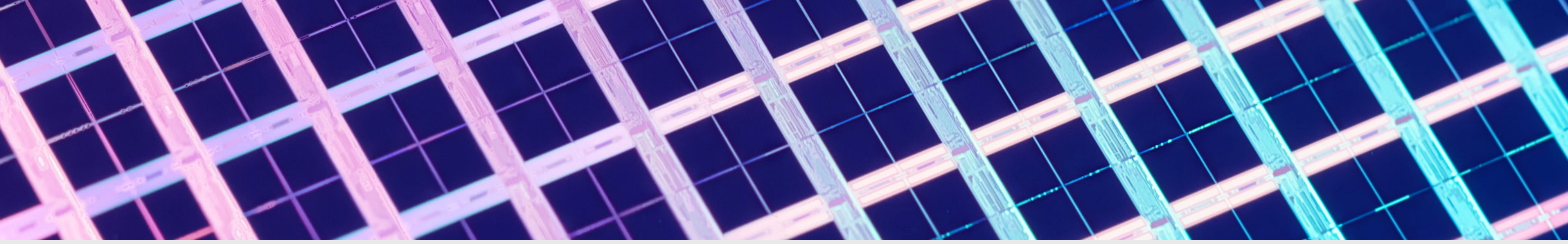


Job role/seniority



Source: S&P Global Market Intelligence 451 Research custom metaverse survey ,2024

We invite you to take the self-assessment and discover how you can leverage the industrial metaverse to drive innovation, efficiency, and competitive advantage in your business. Visit [link to self-assessment tool] to get started.



Content provided by SIEMENS

Is the Industrial Metaverse for You?

The results of this report clearly show that more businesses are embracing the industrial metaverse, with growing investment particularly from smaller companies and those just starting out. Early use cases are becoming more prevalent, mature, and interconnected, creating significant impact and value. Businesses are already experiencing enhanced innovation, increased revenue, improved customer service, and optimized operations.

However, significant challenges remain, including interoperability issues, a lack of skilled personnel, and the complexity of implementation. Facing these problems, you might ask: is the industrial metaverse really for me? Is it worth the effort? How do I compare to others in my industry? Depending on your maturity level, you might also wonder where to start or what to do next.

To help you navigate these challenges and seize the opportunities, Siemens and 451 Research have developed an online self-assessment tool designed to evaluate your industrial metaverse maturity. This tool provides insights and recommendations tailored to your specific situation and goals. By understanding your current position and identifying the next steps, you can strategically plan your journey towards embracing the industrial metaverse.

Additionally, exploring flexible and interoperable solutions can facilitate this transition. Digital business platforms like Siemens Xcelerator offer scalable options that integrate seamlessly with existing systems, providing a gateway to the industrial metaverse.

We invite you to take the self-assessment and discover how you can leverage the industrial metaverse to drive innovation, efficiency, and competitive advantage in your business. Click here to get started.

About the authors

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Ian Hughes is a senior research analyst at S&P Global Market Intelligence and has been covering the evolution of industrial IoT from the basics of instrumentation to richer data applications such as predictive maintenance and machine learning at the edge. This coverage is now moving toward digital twins and the real-time industrial metaverse. He looks at changes to the way we interact with technology, and one another, through AI, IoT, game technology and media across what will become the metaverse at work and play.

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David Immerman is a consulting analyst at S&P Global Market Intelligence. He is responsible for executing on a range of custom research initiatives and development of thought leadership across technology sectors including industrial IoT, digital transformation, edge computing, AI/machine learning and fintech, among others, and verticals such as manufacturing and automotive.

About this report

A Discovery report is a study based on primary research survey data that assesses the market dynamics of a key enterprise technology segment through the lens of the “on the ground” experience and opinions of real practitioners — what they are doing, and why they are doing it.

About S&P Global Market Intelligence

At S&P Global Market Intelligence, we understand the importance of accurate, deep and insightful information. Our team of experts delivers unrivaled insights and leading data and technology solutions, partnering with customers to expand their perspective, operate with confidence, and make decisions with conviction.

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