The industrial metaverse
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Table of Contents

Introduction to the industrial metaverse .................................................. 3
Understanding the industrial metaverse .................................................. 4
Benefits of the industrial metaverse ......................................................... 5
  Enhanced operational efficiency and effectiveness .................................. 5
  Real-time data analysis and decision-making ......................................... 5
Use cases for the industrial metaverse ..................................................... 7
Industrial metaverse architecture ............................................................... 10
Conclusion & outlook: The future of the industrial metaverse .................. 11
Contact  ................................................................................................. 12
Introduction to the industrial metaverse

 Companies face the ongoing challenge of boosting revenue and profitability in an ever-changing social and technological landscape. Companies must mitigate productivity losses caused by retiring baby boomers, adhere to stricter sustainability mandates, and navigate the rapid transformation of societies and economies driven by the Fourth Industrial Revolution and the accompanying digital technologies developing exponentially.¹ One of the latest disruptions, a leap in human-machine interaction, arrived at the end of 2022 with the introduction of ChatGPT from OpenAI.

 The Fourth Industrial Revolution has introduced concepts and technologies that offer transformative solutions for existing challenges.² One such paradigm-shifting concept is the industrial metaverse. Once predominantly viewed as a space for socialization and entertainment, the metaverse is now expanding its horizons to encompass applications in enterprise collaboration, remote work, and industrial operations.

 The authors believe that the industrial metaverse has the potential to address many current challenges, unlocking unprecedented levels of productivity, efficiency, innovation, and competitiveness. As a result, it will rapidly become a cornerstone for businesses aiming to establish comprehensive digital twins that seamlessly integrate every facet of their value chain—from inbound logistics and operations to outbound logistics, marketing and sales, and service.

 This whitepaper focuses on the industrial metaverse, covering its origins, concepts, and underlying technologies. It explores the main benefits and provides insights about the relevant use cases. It also discusses implementation through existing cloud services. This paper concludes by offering future outlooks and actionable insights for businesses undergoing digital transformations.

Understanding the industrial metaverse

The metaverse concept originated in science fiction and has been featured in many novels and movies. One prominent example is the holodeck from the television series “Star Trek: The Next Generation,” where the crew uses artificial intelligence (AI) to create immersive environments, essentially a metaverse, for different purposes like entertainment.

A popular way to conceptualize the metaverse is that it is the next evolution of the internet, succeeding Web 1.0, 2.0, and the so-called Web 3.0. However, that viewpoint is somewhat restricted because various metaverses do exist – consumer, enterprise, and industrial metaverses. Since there isn’t a common understanding, this paper adopts a broader definition of the concept:

The metaverse represents the convergence of the physical and virtually augmented realms. Users access it through a processing unit and software-powered devices such as headsets, smartphones, and computers. Inside the metaverse, users can interact, work, and play with the computer-generated environment, objects, and other users in real-time.

This paper divides the metaverse into consumer, enterprise, and industrial segments. They all share the capability to nurture interaction, communication, and collaboration. However, their primary purposes and use cases vary significantly.

The consumer metaverse primarily focuses on entertainment, social interaction, and personal applications. Conversely, the enterprise metaverse emphasizes business collaboration and communication. The use cases include virtual collaborative workspaces, allowing global teams to interact as if they share the same physical space, product showcases and launches in a digital environment, and virtual trade shows and conferences.

In contrast, the industrial metaverse prioritizes data analysis, decision support, and real-time interaction. Its primary aim is to enhance operational effectiveness, drive innovation, and open new avenues for growth. The use cases span from process automation and predictive maintenance to collaborative design and training.

The industrial metaverse encompasses the entire value chain, including inbound logistics, operations, outbound logistics, marketing, sales, and service. It integrates several digital twins, including a) digital process twins, which are virtual representations of machines, production lines, and manufacturing processes; b) digital supply chain twins, which are virtual depictions of logistical processes; and c) digital product twins, which are digital replicas of products operating throughout their life cycles. These sophisticated, virtual models enable firms to conduct millions of simulations and tests with just the push of a button, thereby optimizing the entire value chain.

This paper identifies four foundational concepts and technologies critical to the industrial metaverse, as illustrated in Figure 1. Conceptually, the Internet of Things (IoT) first integrates physical assets and data, enabling real-time analytics and remote maintenance. Second, AI leverages this data for pattern recognition, automation, and human task augmentation. Third, Industry 4.0 focuses on data-driven automation and optimization in manufacturing. Lastly, digital twins provide virtual replicas for simulation and testing.

This blog article provides a detailed explanation of the concepts and technologies. Demir, O. (2023, October 12). Decoding the Industrial Metaverse: Bridging Physical and Digital Frontiers. LinkedIn

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1. The metaverse concept has appeared in books such as ‘Neuromancer’ (1984), ‘Snow Crash’ (1992), and ‘Ready Player One’ (2011), as well as in movies like ‘Tron’ (1982) and ‘The Matrix’ (1999).
2. A holodeck is a fictional concept, primarily seen in the Star Trek franchise, designed to simulate an immersive, three-dimensional environment, for example, training, entertainment, or experimentation.
4. The blog article provides a detailed explanation of the concepts and technologies. Demir, O. (2023, October 12). Decoding the Industrial Metaverse: Bridging Physical and Digital Frontiers. LinkedIn
Benefits of the industrial metaverse

The industrial metaverse enables the creation of new realities that transcend the physical world. Businesses can create and explore new scenarios, environments, and experiences that are not possible or feasible in the real world. For example, they can simulate extreme conditions, test radical ideas, or create immersive training programs. The industrial metaverse goes beyond static data and allows for dynamic and interactive representations that respond to changes and feedback.\

Enhanced operational efficiency and effectiveness

The industrial metaverse can significantly improve operational efficiency and effectiveness in several ways. It can identify inefficiencies, predict and prevent unplanned downtimes, and optimize the manufacturing and supply chain processes.

Efficiency use cases optimize equipment settings to consume fewer input materials (e.g., raw materials, energy, and water) while maintaining the same output quantity and quality, leading to more sustainable and environmentally friendly industrial processes.

Moreover, through automation, software can automate repetitive or complex processes to improve efficiency and accuracy while eliminating human and organizational bottlenecks. IoT devices facilitate real-time monitoring of the conditions and performance of industrial processes and equipment. Remote maintenance of assets and systems via software updates and actuators reduces the need for physical intervention and enhances efficiency, allowing engineers to manage more assets.

Meanwhile, AI algorithms analyze the collected IoT data to identify patterns and provide insights. These insights are used for predictions, allowing businesses to anticipate future events and adjust accordingly. Furthermore, the collected data can also provide insights into how to handle various situations. For instance, predictive maintenance in industrial manufacturing can minimize unplanned downtimes by prescribing interventions based on machine failure predictions. This predictive and prescriptive capability can significantly improve equipment availability, boost overall equipment effectiveness (OEE) through enhanced asset availability and performance, and improve quality by minimizing waste.

A smart supply chain with connected parts and intelligent warehousing can offer added value by improving asset location and process visualization. For instance, implementing asset tracking in a smart factory allows organizations to optimize inventory management and reduce the risk of lost or misplaced assets.

Moreover, organizations can perform simulations to bolster supply chain resilience by establishing an industrial metaverse across the entire supply chain and plant network. These simulations also allow them to test new processes without disrupting existing operations. For example, users can create virtual models of physical environments and assets and monitor, control, and optimize them remotely.

Real-time data analysis and decision-making

Large companies struggle to understand what is happening on the ground floor, and the metaverse concept provides visibility. It enables real-time data collection and analysis, providing transparency and process insights. The metaverse empowers organizations to make better, faster, and more automated decisions.

Real-time data analysis existed before the metaverse, but what sets the metaverse apart is the integration of AI, contextual depth via IoT sensors, and immersive experiences in data analysis via AR and VR. While traditional real-time analytics primarily focuses on speed, the metaverse couples speed with high-quality information and actionable insights. Integrating AI capabilities enables predictive analytics, automated decision-making, and a nuanced understanding of data. Contextual richness and immersiveness further elevate user interaction and comprehension.

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7 In ‘Competing in the Age of AI,’ the authors assert that AI transforms business by lifting traditional limits on scale and scope. Through case studies, they reveal that AI enables unprecedented scalability and versatility, altering competitive strategy. Karim R. Lakhani & Marco Iansiti. (2020). “Competing in the Age of AI: Strategy and Leadership When Algorithms and Networks Run the World”. Harvard Business Review Press.

8 Demir, O. (2022, August 22). Internet of things: Condition monitoring part 1. LinkedIn.
Figure 2 illustrates the reduction of four types of latencies – information, analysis, decision, and action – through the industrial metaverse. By optimizing the reaction times, the industrial metaverse enables businesses to react faster, better, and even automate responses to changes, opportunities, or threats, reducing the overall reaction latency and contributing to heightened business agility. This agility is one of the keys to maintaining a competitive edge in today’s complex business landscape:

1. **Information latency**: By monitoring the performance of assets or entire systems in real-time and comparing them to the virtual representation, the metaverse can swiftly detect deviations from expected performance. Consequently, insights about a particular event become available faster.

2. **Analysis latency**: AI leverages IoT and additional data sources to make predictions or classifications, enabling businesses to gain a more accurate and nuanced understanding of ground-level issues. Consequently, it reduces the time required for in-depth analysis and leads to faster and better conclusions.

3. **Decision latency**: The metaverse elevates decision-making by offering rich insights through AI-driven analytics, contextual information, data visualization, real-time monitoring, and simulated scenarios. Prescriptive analytics enable faster decision-making by reducing communication and coordination time. Simultaneously, by augmenting human intelligence with machine learning and AI, the metaverse enhances the quality and accuracy of these decisions, leading to better outcomes. Multiple studies have shown that data-driven decision-making performs at least as well as, and often better than, expert assessments and decisions.

4. **Action latency**: Implementing automated workflows ensures that approved measures or countermeasures take effect without delay, which enhances operational efficiency. AI can automatically make decisions and improve responsiveness, reducing the reliance on human intervention. The industrial metaverse enables more intelligent automation by integrating sensor and machine data with software, leading to improved resource allocation, reduced human error, increased production effectiveness, and increased efficiency through reduced consumption of resources, for example, by minimizing waste.

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Use cases for the industrial metaverse

The industrial metaverse provides opportunities for business improvements and innovation beyond what is possible with physical assets alone. Figure 3 shows the multi-dimensional impact of the metaverse in industrial operations. The chart enumerates 12 key areas, from automation to training, enhanced by AI, IoT, AR, VR, and data analytics, collectively converging to improve effectiveness, agility, and innovation.

Figure 3: Eleven-facet metaverse impact on business (source: BearingPoint)
This paper will use the latency types to group industrial metaverse use cases. Each subsequent use case category increases business agility by reducing the overall reaction latency.

<table>
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<tr>
<th>Latency types</th>
<th>Use case categories</th>
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| **Action**    | Automation: Leveraging artificial intelligence (AI), data, software, and other digital technologies to standardize and automate repetitive or complex processes, improving efficiency and accuracy while eliminating human and organizational bottlenecks.  
Prediction: Using AI algorithms to analyze metaverse data for predictive outcomes, such as potential equipment failures, thereby enabling preventive actions.  
Prescription: Extending prediction to recommend specific actions to achieve desired outcomes, often through machine learning or AI systems.  
Teleoperation: Using augmented reality (AR) and virtual reality (VR) to create novel ways for humans to interact with assets, data, processes, and each other. Performing maintenance activities from a distance, including diagnostics, troubleshooting, or repairs.  
New business models: Metaverse helps create novel and innovative business models and could involve reimagining existing processes, services, or products or creating entirely new revenue streams. Data and AI often drive these models. |
| **Decision**  | Decision support: Enhancing decisions by utilizing digital technologies like AI and data analytics to improve decision-making processes. Decision support can involve using real-time data to make informed decisions, predictive analytics to anticipate future scenarios, or machine learning to automate decision-making processes.  
Monitoring: Implementing real-time monitoring of industrial assets and processes through the Internet of Things (IoT), often integrated with AI to highlight issues.  
Optimization: Applying AI and data gathered in the metaverse to optimize various processes, from resource allocation to supply chains, improving overall operational efficiency and effectiveness. |
| **Analysis**  | Augmentation: Enhancing labor capabilities by integrating digital technologies, such as AI, AR, and VR, into the work process to improve performance, efficiency, and innovation.  
Simulation: Utilizing physics-based calculation models to simulate real-world processes, testing, or experimentation in a risk-free environment. |
| **Information** | Collaboration: Utilizing the metaverse to facilitate real-time, global collaboration, allowing teams in different locations to work together seamlessly.  
Training: Leveraging the metaverse to create immersive training programs accessible 24/7, both on-site and remotely. |

Table 1: Overview of latency types and use case categories (source: BearingPoint)
The delineated use case categories are high-level frameworks that outline distinct facets of how the industrial metaverse can revolutionize various areas. These categories can be broken down further into numerous detailed use cases.

In the following section, we will delve into the use case of “closed-loop engineering & manufacturing,” which is designed to improve key performance indicators such as time-to-market, collaboration, and customer interaction. Within this closed-loop system, the industrial metaverse serves as an integrated platform, linking various elements of engineering, manufacturing, and quality processes. This interconnected environment offers valuable insights for development, collaboration, simulation, and testing. Moreover, it ensures a continuous flow of real-time information, significantly enhancing data exchange and transparency across different business units.

It can offer significant benefits to an organization, including process-specific instances such as a) quick changes and improvements through virtual simulations and testing, including significantly faster testing of prototypes compared with physical testing, b) spotting design issues early on, c) automated testing and simulation in engineering, d) product design for manufacturing in production, and e) automated quality control for quality assurance. All these use cases collectively bolster competitiveness, stimulate business growth, increase efficiency, and heighten agility, culminating in higher productivity, reduced costs, and a revenue boost.

Additionally, by generating a virtual version of a product, the metaverse establishes a reliable source of information about the design’s performance in real-world scenarios, allowing for immediate adjustments or redesigns as necessary.

Furthermore, a company can expand the metaverse by adding additional layers. For example, a manufacturer could connect digital twins for research and development (R&D), production, field service management, warehouse, supply chain, and customer service center, enabling the establishment of a closed-loop service platform. The metaverse can serve as an information hub, providing stakeholders with all necessary information. It addresses their specific needs, such as:

- Customer dashboards to increase the visibility of running equipment and breakdowns.
- Service management apps that inform field technicians about their upcoming tasks, providing all necessary information like breakdown reasons, required equipment, and spare parts (for one-time fixes).
- Smart equipment error message integration to enhance field service management effectiveness and enable more accurate planning for warehouse spare parts orders.

Available data can create novel digital services, providing opportunities to boost revenue streams or even establish entirely new business units.
Industrial metaverse architecture

The industrial metaverse serves as an integrated software platform, synthesizing diverse concepts and technologies.

Figure 4 provides a succinct yet comprehensive overview of the architectural components critical to establishing an industrial metaverse. It delineates how data, from real-time sensor readings to structured databases, flows through various processing layers, ultimately converting it into actionable insights.

The metaverse ingests information from various sources (data collection layer), channels it through digital models, and integrates it into applications. These data sources can be categorized into the following: engineering data (such as CAD/CAE files, mathematical models, and test data), real-time data (such as IoT sensors, PLC, and SCADA data), master data (such as customer IDs, product IDs, equipment IDs), metadata (“data about data”), and transactional data (such as purchasing, operations, sales, or similar value chain processes).

After data collection, the next layer involves connectivity and includes the infrastructure to transmit the collected data to cloud platforms or on-premises data centers. It often involves various communication protocols and networks, such as 5G, Wi-Fi, and Bluetooth, ensuring seamless and secure data transfer.

The integration and application layer are built on the data collection and connectivity layer. Both hold a pivotal role in the overall technology architecture and serve as the bedrock for delivering business value through technology, ensuring seamless data flow – bridging data silos – and transforming raw data into actionable information.

The integration layer integrates data from multiple sources and normalizes, cleans, and transforms the data into a consistent format. Reusable building blocks such as a data catalog, data registry, and asset models help the architecture to scale. The data is stored in various databases in this data ingestion layer, including structured and unstructured types. These databases organize entity metadata and generated data, such as operational state, performance metrics, and contextual factors like temperature and pressure. The integration layer also provides a common interface for accessing data and systems through APIs.

The application layer includes user interfaces, such as web and mobile apps, that allow users to interact with the applications and services. It leverages data analytics to turn raw data into actionable insights and contains applications. The application layer represents insights and knowledge derived from the data in a graphical or visual format for easier understanding and communication. Meanwhile, the software components are responsible for data and event processing, application workflows, and visualization techniques such as GUIs, augmented reality, and virtual reality. This data architecture serves to answer critical questions, namely: “What if?” for simulations, “What now?” for real-time conditions, and “What next?” for predictive analytics.

The integration and application layers provide a flexible and scalable platform for delivering business value through technology. By separating the data and systems integration from the applications, organizations can simplify their technology landscape, reduce costs, and improve time-to-value for new use cases and initiatives. Outputs from this structure can be seamlessly integrated into enterprise applications like MES (manufacturing execution system), ERP (enterprise resource planning), and SCP (supply chain planning).

All the technical prerequisites for establishing and sustaining an industrial metaverse, ranging from data collection and storage to analytics, are readily achievable through existing services from hyperscale cloud providers.

Figure 4: Architecture of an industrial metaverse: Data flow and layers (source: BearingPoint)
Conclusion & outlook: The future of the industrial metaverse

The concept of the industrial metaverse represents a shift in how firms operate, collaborate, and innovate. It provides a connected, immersive environment where physical and digital realities converge. Leveraging technologies such as the Internet of Things (IoT), artificial intelligence (AI), cloud and edge computing, virtual reality (VR), and augmented reality (AR), the industrial metaverse enables real-time data analytics, enhanced remote collaboration, and optimized asset utilization.

From digital twins that provide dynamic, 360-degree views of factory floors to AI algorithms that predict maintenance needs or optimize supply chains in real-time, the use cases are boundless. This evolution is not merely an extension of current digital transformation efforts but a radical rethinking of business operations and value propositions.

As we look to the future, several key trends and technologies will shape the development of the industrial metaverse:

- Convergence of cloud and edge computing: As data processing requirements grow, a hybrid approach utilizing edge and cloud computing will become essential.
- Standardization: Interoperability between different platforms and systems is crucial for the widespread adoption of the metaverse.
- Cybersecurity: With the influx of data and increased connectivity, robust security protocols will be imperative to protect people, services, and infrastructures end-to-end in a self-adaptive and context-aware fashion.

While the potential of the industrial metaverse is immense, the road to realization is challenging. Also, these challenges can be daunting, but with careful planning and execution, they can be overcome.

- Significant investment: Implementing the industrial metaverse requires substantial investments in technology, infrastructure, and people, including the necessary investment in hardware and software such as IoT devices, AI algorithms, AR and VR technologies, and in people such as upskilling and training.
- Managing change: The shift to a metaverse-powered operation can be a significant change for many organizations. It requires changes in mindset, processes, and even organizational structure. Effectively managing the changes is crucial for successful implementation.
- Data security: With the increased use of IoT devices and the generation of vast amounts of data, ensuring data security becomes a significant challenge. Protecting sensitive information from cyber threats is crucial.
- Technical obstacles: Overcoming technical obstacles like obsolete IT infrastructure, isolated solutions, a fragmentary process landscape, and issues with data harmonization and consistency is a significant challenge.
- Balancing trade-offs: Businesses must balance the trade-offs between efficiency and sustainability, innovation and standardization, and collaboration and competition.

Significant benefits offset the challenges. The industrial metaverse significantly enhances operational efficiency and effectiveness by leveraging IoT and AI technologies. It streamlines manufacturing and supply chain processes and reduces unplanned downtimes through predictive maintenance. The technology promotes sustainable operations by optimizing resource use and enables remote asset maintenance to improve efficiency. It contributes to supply chain resilience through real-time tracking and process simulation. It addresses the challenge of real-time data analysis and decision-making in large enterprises. By integrating AI, IoT sensors, and immersive technologies like AR and VR, the metaverse offers better, faster, and more automated decisions. It significantly reduces four types of latencies – information, analysis, decision, and action – leading to heightened business agility.

The industrial metaverse promises a future where the boundaries between the physical and digital worlds blur, ushering in unparalleled efficiencies, productivity, and new business models. Organizations that proactively engage with this concept, investing in the right technologies and strategies, are poised to lead the charge into this new world.

For organizations to thrive in this evolving landscape, a holistic approach is essential, one that marries technology with strategy, governance, and culture. As we embark on this journey, the industrial metaverse stands as both a challenge and an opportunity – a new frontier that beckons, but only for those prepared to navigate its complexities.
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