

Operational Benefits from Industrial Metaverse – The Most Feasible Use Cases

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ABSTRACT

The purpose of the paper is to identify and prioritize the most feasible use cases of the Industrial Metaverse (IM) to deliver operational benefits for companies. It is based on recent findings from a co-research project that consists of five case studies from different industrial enterprises representing different sectors.

The research is to pursue understanding and gain new insight on the companies' needs of how to utilize virtual IM applications in their digital transformation. The research represents a qualitative multiple case-study approach and follows inductive reasoning. Case study material includes company specific interviews and analysis as well as joint workshop discussions and surveys on potential use cases.

The paper includes the evolution of industry digitalization and the emerging concept of Industrial Metaverse with its expected benefits. The use cases are studied from the lens of industrial enterprises seeking benefits from new immersive technologies. Best practice sharing to apply new digital capabilities is an essential part of the study.

The findings of the case studies deliver new insights into the use of digital twins, video analytics, quadruped robots, as well as augmented reality (AR) and virtual reality (VR) -capabilities. The selected use cases emphasize the important role of advanced 5G and edge computing to provide an integrated platform offering full mobility, real time data capabilities, cybersecurity, and interoperability across information, communications, and automation system environments.

The main conclusion is a set of prioritized Industrial Metaverse use cases in the cost-efficiency, sustainability, and safety opportunity areas. Remote operations and VR training with simulation capabilities are considered the most feasible and high value use cases.

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Industrial Metaverse – The 3rd Wave of Industry Digitalization The Evolution of Industry Digitalization

For years, the importance of industry digitalization (Industry 4.0) has been widely recognized and accepted by top management of enterprises and governments [1]. Smart, connected products are in the middle of this transformation impacting heavily on market competition and companies [2,3]. The digitalization proceeds in distinct waves that eventually renew business models and reshape existing industry boundaries sector by sector [4]. As a result, products will become a part of bigger cyber-physical systems (CPS) providing industrial enterprises with new business opportunities on many fronts.

For traditional industry ecosystems where the life cycles of products and investments typically are long, digitalization takes place in parallel in running and maintaining existing industrial

operations [4]. Compared to consumer product markets, this makes a change journey more complicated and requires an evolutionary “brownfield approach” – contrasting with the “greenfield approach” where a new system is built from scratch.

During the last 15 years, we have witnessed the series of incremental changes where new digital capabilities supplement existing production systems one by one. On a company level, implementing the capabilities and harvesting operational benefits does not take place at once, but enterprises need to prioritize and adopt the changes to their own transformation journey. At a broader level, the realization of operational benefits can be understood as progressing through three sequential waves: the Industrial Internet, which enabled the large-scale connection of sensor data; Industrial 5G, which introduced secure and scalable edge computing platforms; and the Industrial Metaverse, which leverages these foundations to deploy virtual and immersive applications. All these waves deliver significant operational benefits to industrial enterprises.

In 2012 at the birth of Industry 4.0, the first wave of industry digitalization started with the basic capabilities of Industrial Internet of Things (IIoT). The concept of IIoT was defined as an internet of things, machines, computers, and people enabling intelligent industrial operations using advanced data analytics for transformational business outcomes [5]. In real life, the implementation of this wave was mainly limited to the collection and connection of sensor data to existing operations. The first set of new digital capabilities provided enterprises with a real-time connectivity backbone to integrate and utilize sensor data in their operations. In the beginning, the connections were realized with fixed connectivity in limited locations only, but later different wireless technologies (e.g. Wi-Fi, 4G/LTE, LoRa, and Sigfox) and 4G/5G private network solutions became dominant. These connectivity capabilities formed basic building blocks for real-time CPS and intelligent operations.

The second major wave was about cloud computing capabilities to store, compute, and analyse data with various machine learning (ML) and artificial intelligence (AI) algorithms. In principle, cloud computing can provide industrial operations with more flexibility, scalability, and cost efficiency to manage sensor data. However, industrial environment is characterized by strict requirements of data sovereignty, cybersecurity, high network availability and low latency as well as complex legacy integrations between Information Technology (IT), Communications Technology (CT), and Operational Technology (OT) systems. Many enterprises, therefore, decided to rely on costly private cloud solutions on-premises – that eventually could not bring full benefits. Later, a cloud-native Industrial 5G technology enabled an integrated connectivity and computing platform allowing more cost-efficient hybrid solutions to optimize network latency and security requirements. 5G edge was able to provide needed computing, storage, and networking resources located at the edge of networks [6]. Today, the combination of edge computing locations and 5G standalone capabilities – such as network slicing, service-based architecture, and private networks – enables companies flexibly to build secure, application-specific computing solutions.

Today, modern industry enterprises are approaching a third transformative wave that is characterized by virtual Industrial Metaverse applications onto real-time connectivity and computing platforms. IM applications practically make cyber-physical systems alive, enabling dynamic and interactive digital twins of industrial processes. It is expected that the metaverse can potentially solve the problem of creating a fully immersive and interconnected virtual world that can be experienced by people in a way that is similar to the physical world [7].

Industrial Metaverse and Expected Benefits

It is fair to say “metaverse”, as a new term, is fuzzy and has different interpretations among people. Broadly, it can be defined as a collective virtual online environment created by the fusion of physical and digital reality [4] Although the concept of metaverse is still emerging and its dependencies on other digital capabilities are somewhat blur, it can be considered as an umbrella term to the application layer of cyber physical systems in which users can effectively interact via various immersive technologies and extended reality (XR) applications, including augmented, virtual, and mixed realities (AR/VR/MR).

In its early phase, metaverse was dominated by consumer sectors such as gaming, social media, and advertising, but nowadays it is expanding into industrial domains [4]. The concept of metaverse

also represents the next generation of the internet leading the fourth industrial revolution [8]. Particularly, the adoption of digital twins has attracted many production-led companies.

The concept of Industrial Metaverse operationally combines physical-digital fusion and human augmentation for industrial applications used by enterprises to provide digital representations of physical industrial environments, systems, assets and spaces that people can control, communicate, and interact with [4]. It also integrates latest digital technologies – like XR, digital twins, IoT, ML, and AI – to create joint interactive and immersive tools for industrial ecosystems.

Among industrial enterprises, there are big future expectations for new, immersive technologies to provide a wide range of business benefits, including cost efficiency, safety, and sustainability [9]. The benefits go beyond internal productivity improvements, too. Industrial Metaverse can open new avenues for business growth by enabling the development of intelligent, connected online products and services. It is estimated that industrial application-driven developments within immersive technologies will expand into a market valued at approximately USD 100 billion by 2030 [10].

New capabilities of 5G advanced serve as key enablers for penetrating immersive industrial applications into smart, connected industrial products. These capabilities make it possible to deliver continuous, real-time services globally while the product is in use – thus, improving customer value and supporting new data-driven business models. Existing 5G networks with edge computing locations provide industrial ecosystems with a secure, flexible connectivity and computing platform for deploying real-time online applications across a wide range of use cases.

To summarize, Industrial Metaverse provides an integrated application layer for various interactive, immersive technologies to support the needs of cyber-physical systems. Future use cases are expected to boost operational efficiency and safety while also enabling new data-driven services with significant market projection. The application layer can be built on existing 5G networks providing the secure, real-time infrastructure necessary to support these kinds of applications worldwide.

Research Process and Material

The article is based on recent findings from an ongoing co-research project including five industry case studies. The selected companies represent mining (Case A), forest (Case B), lifting (Case C), energy (Case D), and telecom (Case E) industry sectors. Overall, the research examines enterprises’ real-time capabilities to adopt and utilize virtual, immersive industrial applications as part of their ongoing digital transformation efforts. The project aims to advance understanding of how metaverse related capabilities can be implemented in industrial contexts. Given the contemporary nature of the phenomenon, the research adopts a qualitative, multiple-case methodology grounded in inductive reasoning.

The article focuses on identifying the practical benefits and use cases that IM can offer to industrial enterprises seeking new business opportunities through the adoption of immersive technologies. An essential component of the research is the exchange of learnings and best practices across different industry sectors, enabling a broader understanding of how immersive solutions can be effectively leveraged in diverse operational contexts.

The research material is collected from two main sources: the in-depth analysis of each case company and common workshops representing the five distinctive industries. During 2025, five cross-company workshops were organized to discuss and share best practices among the case companies. Based on these learnings, the research process includes three steps as presented below.

Step 1: Analysis of Business Opportunities

The first step was to understand and analyze the business opportunities of Industrial Metaverse in each company separately.

This step was taken inside the company based on in-depth discussions and interviews at the beginning of the research case study. The analysis helped companies to focus on their most relevant business problems and select a feasible use case where immersive technologies can bring greatest value.

The identified Industrial Metaverse opportunities and the corresponding use cases selected by the participating companies are summarized in Table 1.

Table 1: The Expected Business Benefits from Industrial Metaverse

Industry Case Study	Business Opportunity Areas			Selected IM Use Case
	Cost-efficiency	Sustain-ability	Safety	
A: Mining industry	X	-	X	Increase safety and productivity by using spatial data and digital twins in underground operations.
B: Forest industry	X	X	-	Improve production efficiency of bioproduct mills by utilizing integrated digital twins.
C: Lifting industry	X	-	X	Improve the workflow and efficiency of field forces by implementing AR/VR supported tools.
D: Energy industry	X	-	X	Enhance predictive maintenance processes by utilizing robot dogs in power plants.
E: Telecom industry	X	X	-	Optimize the energy consumption of mobile networks by deploying digital twins for simulations.

Company A represents a world-class OEM technology provider for the mining industry that is undergoing a major transformation world-wide to digitalize operations for improved productivity and safer operations. For the company, digitalized operations require continuous innovations and improvements in their mining technology solutions. The utilization of reliable digital twins in planning, operating, and maintaining underground operations is one of the recent requirements in mines. Here, accurate spatial data and its integration into the rest of cyber-physical mining systems represent a fundamental future capability, where immersive IM applications will play a crucial role.

The forest company, Case B, also considers digital twins as a critical digital capability in improving the process automation and operational efficiency of their bioproduct mills even further. Most of the mission-critical production is already highly automated, and there are a few digital twins in use on production unit level. However, simulating and optimizing the whole production process requires an integrated, holistic approach for the existing digital twins.

Case C is an international lifting company seeking to enhance workflow efficiency and safety for its field workers by equipping them with additional AR/VR tools. The role of immersive IM technologies in designing, constructing, and maintaining customized lift solutions is becoming an important competitive factor in the markets. The implementation of XR-supported tools can bring substantial business opportunities to increase customer value and operational efficiencies. Furthermore, new data-driven service offerings can be developed to improve people flow during elevator use.

The electricity company, Case D, operates in power production, distribution, and sales. Tight market competition requires the company continuously to invest in operational innovations in its power plants. Its priority is the intelligent maintenance of power plants to improve efficiency and safety. New digital capabilities with robot dogs are tested and piloted in a thermal power station to

automate routine inspections and enhance predictive maintenance processes.

Case company E is a nationwide mobile network operator representing an already highly digitalized telecommunications industry. As digitalization advances across other sectors, the associated growth in data traffic and energy consumption within mobile networks continues to rise, placing additional pressure on the company’s sustainability objectives and cost-efficiency targets. Consequently, its primary Industrial Metaverse business opportunities focus on developing digital twins to simulate and optimize energy usage across the radio network infrastructure.

Step 2: Identification of Generic Use Cases

The next step was to identify and elaborate generic Industrial Metaverse related use cases together with the case companies. This process was done during and in between several industry workshops where the companies shared learnings and best practices from their own use cases and expected benefits. In 2025, five common workshops were organized to study and discuss the use cases. The case companies, one after the other, hosted the sessions and demonstrated their own use cases. These workshop discussions resulted in a shared list of potential use cases that can be practically implemented with the technologies currently available.

At a high level, the common business opportunities identified through the workshops cluster into three overarching areas: cost-efficiency, sustainability, and safety. Each of these areas comprises practical IM use cases that were considered feasible with contemporary digital technologies. Drawing on insights from the literature review as well as the collaborative discussions conducted during the workshops, the set of generic business opportunities and corresponding Industrial Metaverse use cases was concluded [9].

A summary of these findings is presented in Figure 1.

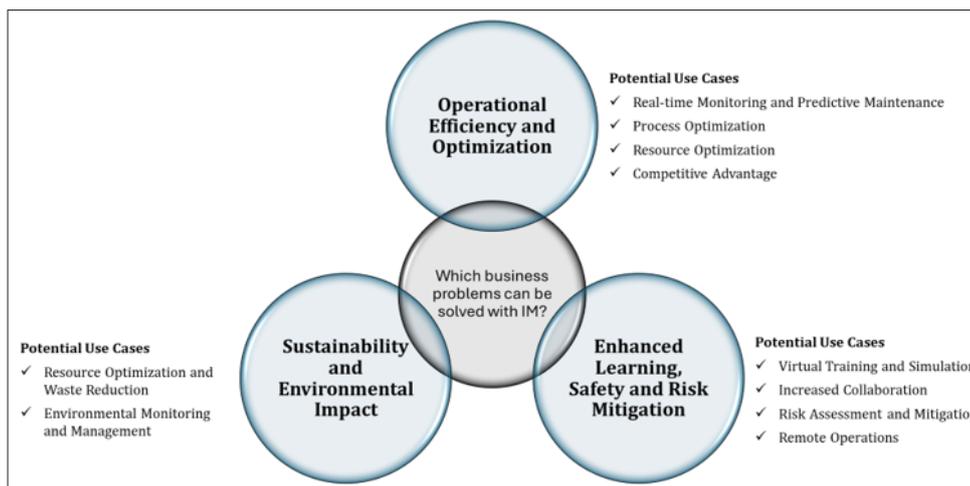


Figure 1: The Generic Use Cases of Industrial Metaverse

The first area, *Operational Efficiency and Optimization*, includes primarily cost-efficiency driven use cases. Enhancing operational efficiency through IM-enabled capabilities encompasses four generic use cases:

- Real-time monitoring and predictive maintenance,
- Process optimization,
- Resource optimization, and
- Increased competitive advantage.

In general, the above use cases aim to enhance the reliability, performance, and overall effectiveness of industrial operations.

The second area, *Sustainability and Environmental Impact*, focuses on virtual capabilities that strengthen the overall sustainability of industrial operations. Two generic IM use cases were identified within this domain:

- Resource optimization and waste reduction, and
- Environmental monitoring and management.

These applications were regarded as particularly relevant for industries that continuously refine their process optimization, energy efficiency, and environmental performance.

The third area, *Enhanced Learning, Safety and Risk Mitigation*, incorporates new forms of virtual training and simulation designed to improve Occupational Health and Safety (OHS). This category includes four IM use cases:

- Virtual training and simulation,
- Increased collaboration,
- Risk assessment and mitigation, and
- Remote operations.

Together, these use cases improve workforce skills, enhance safety performance, and support more resilient industrial operations.

Step 3: Prioritization of Use Cases

The final step was together with the case companies to prioritize the identified Industrial Metaverse use cases by using a Likert scale survey technique. Scaling is the process of generating the continuum, a continuous sequence of values, upon which the measured objects are placed [11]. In Likert scaling technique, a respondent indicates degree of agreement and disagreement with a variety of statements about some attitude, object, person, or event [11].

Here, prioritization was designed to measure the opinions of individual company respondents on the following survey question: Which business problems can be solved with IM. For each use case, the respondents were asked to rate their level of agreement with 10 points scaling from 1 ("Not true at all") to 10 ("completely true"). Fourteen respondents completed the survey simultaneously during one of the joint workshops. Scores were summed to generate prioritization values for each use case within each business opportunity area.

The results of the prioritization are presented separately for each area in Figure 2, Figure 3, and Figure 4.

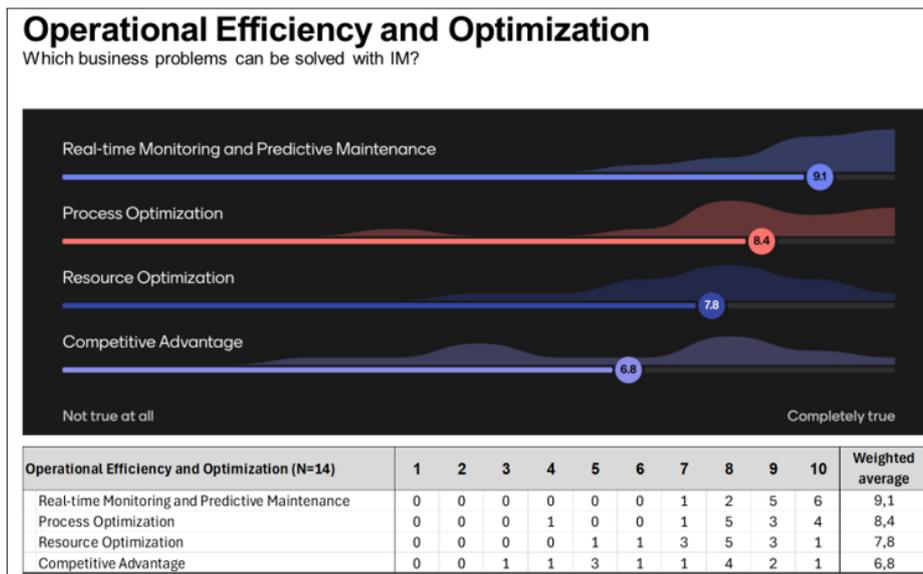


Figure 2: Prioritized IM Use Cases for Cost-Efficiency

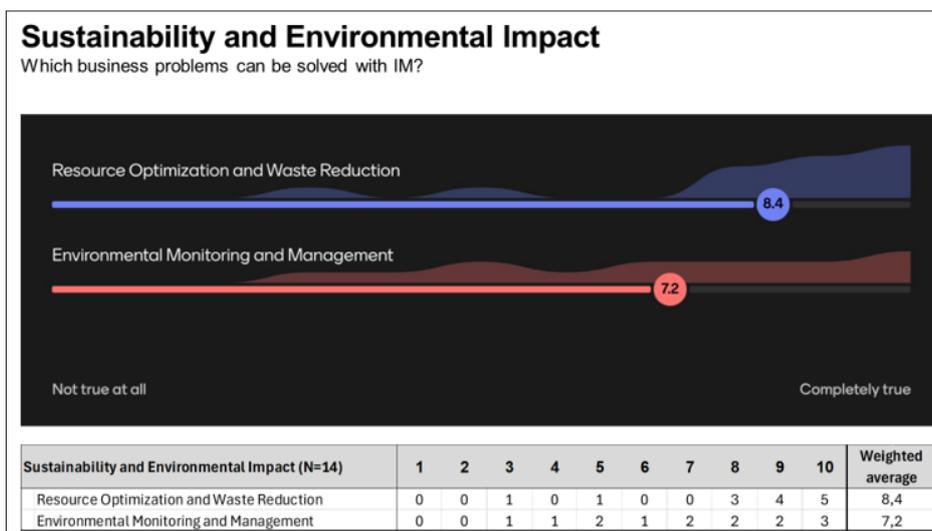


Figure 3: Prioritized IM Use Cases for Sustainability

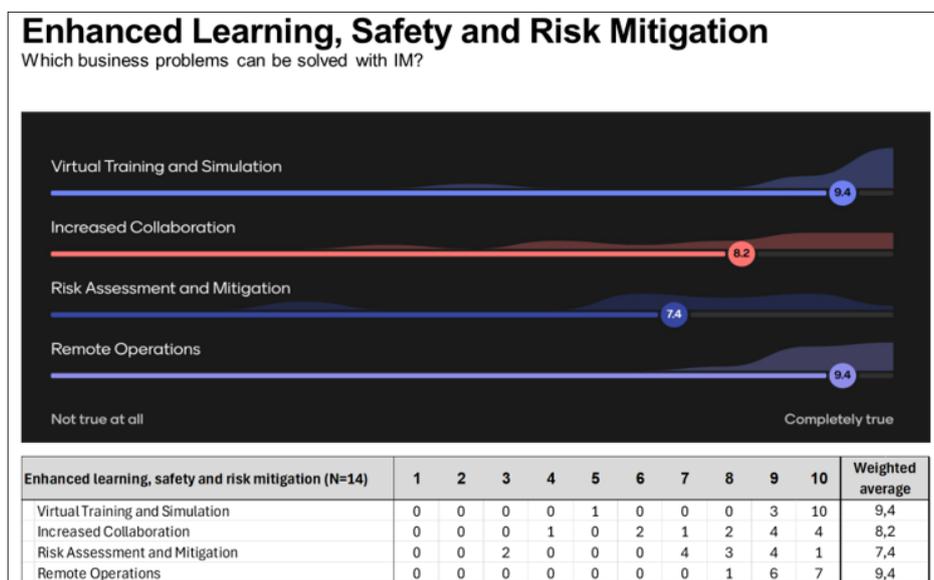


Figure 4: Prioritized IM Use Cases for Safety

Research Findings and Results

Our case study findings indicate that industrial enterprises primarily seek operational benefits from the Industrial Metaverse in three areas: improved cost-efficiency, enhanced sustainability, and strengthened safety performance. These expectations are pragmatic rather than visionary, focusing on foundational process capabilities instead of fancy advanced applications. In industrial environments, new virtual and immersive capabilities must be implemented on top of existing cyber-physical systems that integrate legacy ICT and OT technologies.

This layered approach reflects the realities of established industrial infrastructures, where the successful adoption of new solutions depends on their compatibility with long-standing systems and practices. Greenfield approach is simply not possible in this kind of industrial environment, and therefore digitalization proceeds in waves providing a set of complementary capabilities at a time. Industrial Metaverse represents the third wave of digitalization, adding a virtual application layer on top of the existing connectivity and computing layers built around sensor data.

The business opportunity areas and the corresponding Industrial Metaverse use cases identified in the study are summarized in Figure 1.

Operational Efficiency and Optimization

The first business opportunity area, *Operational Efficiency and Optimization*, simply refers to cost-efficient industrial processes with improved operational capabilities to maximize production yield and minimize waste. The optimization, in turn, involves data analysis for improved processes and decision-making. Together, they ensure that industrial workflows proceed smoothly and different resources are optimally utilized.

This area involves many cost-efficiency driven use cases. Increasing the efficiency of operations with IM-enabled capabilities embraces following generic use cases in a prioritized order:

1. Real-Time Monitoring and Predictive Maintenance (9.1)
2. Process Optimization (8.4)
3. Resource Optimization (7.8)
4. Increased Competitive Advantage (6.8)

The survey results clearly indicate that *Real-Time Monitoring and Predictive Maintenance* is perceived as the most feasible Industrial Metaverse use case. Real-time and predictive capabilities are viewed as among the most tangible and proven applications of digital technologies. Respondents appear to recognize the direct operational value these capabilities deliver – such as fewer equipment failures, reduced downtime, and significant cost avoidance. All company representatives gave scores seven or above. Predictive maintenance is also a relatively mature application area, where the return on investment is both measurable and readily understood, further reinforcing its strong prioritization.

Process Optimization is also viewed positively among many respondents, although it ranks clearly below real-time monitoring and predictive maintenance. New IM use cases are expected to proactively identify and remove bottlenecks across end-to-end production processes. Respondents likely consider optimization as a natural continuation of monitoring, as real-time data is basis for ongoing process refinement.

Resource Optimization received lower prioritization than many respondents anticipated. Inherent vagueness of the term “resource” may be the main reason, as companies can interpret it

differently depending on their industry sector’s terminology. While respondents consider Industrial Metaverse real-time capabilities as important for improving resource management, the perceived maturity and clarity of this benefit appear to be lower than for more established use cases.

Increased Competitive Advantage is not considered particularly important by the respondents. The distribution of scores was much wider compared to the other use cases. This outcome likely reflects the difficulty of quantifying competitive advantage and its dependence on external market factors. At this stage, respondents seem to view IM primarily as internal capabilities rather than as a differentiating competitive capability. The connection between improved operational benefits and broader market differentiation may not yet be fully recognized or realized.

Sustainability and Environmental Impact

According to United Nations, the concept of sustainability generally encompasses three dimensions: environmental, social, and economics. In this study, however, respondents associated the term primarily with its environmental dimension. From this perspective, *Sustainability and Environmental Impact* concern the extent to which industrial activities affect the climate and ecological footprint.

Two following Industrial Metaverse use cases were identified and prioritized as follows:

1. Resource Optimization and Waste Reduction (8.4)
2. Environmental Monitoring and Management (7.2)

Respondents view IM as an enabler for *Resource Optimization and Waste Reduction*, yet they do not consider this area as important as real-time monitoring and predictive maintenance. They see IM as a practical tool that can directly reduce environmental footprints while simultaneously improving operational efficiency and performance. Improvements in material utilization, energy consumption, inventory levels, and waste reduction are relatively easy to quantify, which contributes to a generally high level of confidence in this domain. Moreover, the underlying concepts are well-understood across industries, further reinforcing their perceived feasibility.

Environmental Monitoring and Management received clearly lower scores. Although respondents acknowledge that Industrial Metaverse applications can support environmental tracking, reporting, and regulatory compliance, its perceived impact remains moderate. The greater variability in responses suggests differing levels of technological maturity, digital readiness, and practical experience with environmental data across the participating companies.

Respondents generally regard IM as useful, but not yet fully leveraged or mature in the context of environmental management. Confidence levels vary considerably, reflecting wide differences in technological readiness, regulatory pressures, and the availability of reliable environmental data across organizations. The findings suggest that operational sustainability – including improvements in waste reduction, material efficiency, and energy use – is already a well-established area of IM impact, whereas Environmental Management remains an emerging domain that requires further digital maturity, data quality advancements, and targeted investment before its full potential can be realized.

Overall, the companies initially expected Industrial Metaverse to play a significant role in achieving positive sustainability and

environmental outcomes. However, the survey results indicate that respondents are not particularly inclined to use immersive technologies for addressing sustainability-related business challenges – an outcome that is somewhat surprising. This suggests that, despite recognizing the potential of IM, organizations may still prioritize operational efficiency and safety over sustainability when considering early-stage adoption.

Enhanced Learning, Safety and Risk Mitigation

The third business opportunity area, *Enhanced Learning, Safety and Risk Mitigation*, includes a variety of use cases to improve Occupational Health and Safety (OHS) capabilities. In industrial context, safety and business continuity are often considered top priority among top management.

Four IM use cases were evaluated and prioritized with the following results:

1. Virtual Training and Simulation (9.4)
2. Remote Operations (9.4)
3. Increased Collaboration (8.2)
4. Risk Assessment and Mitigation (7.4)

Virtual Training and Simulation received the highest score, indicating strong confidence in the ability of immersive technologies to significantly improve virtual learning environments. Ten respondents provided maximum score to this use case. The result aligns closely with the use cases selected by the companies. Digital twins, VR/AR, and advanced simulation capabilities enable highly realistic VR training platforms that can be accessed anytime and anywhere. High risk work tasks can be practiced safely in virtual environments with the same quality of instruction. Respondents clearly view digital learning and simulation as a mature, high value use case. Also, the benefits are well understood and widely realized, particularly in hazard environments and safety critical tasks.

Remote Operations achieved similarly the highest scores, reflecting strong confidence by the respondents to provide better support for remote work with new, immersive technologies. The respondents considered this use case significantly feasible, as they all provided scores eight or above. With IM capabilities, workforce can monitor and execute tasks from any location, ensuring operational continuity especially during disruptions and exceptional situations. The company representatives consider remote operations highly effective methods to improve the safety and business continuity of the operations.

Increased Collaboration also scored strongly, though clearly below the leading two use cases. This reflects the highly positive contribution of virtual technologies to connecting geographically dispersed expert and management teams. Respondents considered new immersive collaboration capabilities especially important for teams working in hazardous environments where access due to safety reasons is restricted. Although advanced tools for communication and data sharing are widely adopted, there are major differences in their feasibility due to industry specific needs – yielding greater variability in responses.

Risk Assessment and Mitigation was still evaluated positively but ranked clearly below the other use cases in this area. The results were also highly distributed, as scores varied between three and ten. Risk profiles differ substantially across industries: some companies have already mature predictive systems, while others are still in ramp-up phase. Moreover, the respondents

commented that risk management practices often vary between different industrial sites, making risk mitigation planning even more difficult. As a result, the respondents recognize the potential of this area, but report highly mixed levels of experience and maturity.

Overall, respondents perceive Industrial Metaverse as delivering very strong value in VR training with simulation capabilities and remote operations. Also improved collaboration via virtual technologies scored well. Collectively, these findings indicate that IM is regarded as a powerful tool for enhancing learning, operational safety, and organizational resilience.

Summary

The research findings indicate that industrial enterprises view IM as a practical, operational innovation rather than a new must-have technology. For the companies, it is another wave in the digitalization journey focusing on the application layer atop existing connectivity and computing infrastructures. The most immediate value lies in the areas of cost-efficiency, safety, and learning – with sustainability outcomes viewed as secondary and less mature. The most feasible IM use cases are related to VR training, simulation, and remote operations.

IM's strategic role is therefore evolving within the constraints of legacy industrial systems, advancing incrementally as part of a multi wave digital transformation journey. In contrast to greenfield digital ventures, industrial environments must integrate new virtual and immersive capabilities with long established ICT and OT systems.

Across all companies, the Industrial Metaverse is viewed primarily as a practical enabler of operational efficiency, safety, and learning, rather than a transformative or disruptive technology. Its value materializes most clearly in real time monitoring, predictive maintenance, immersive training, and remote operations. Sustainability benefits are acknowledged but less prioritized. As industrial digitalization continues to advance in waves, IM represents a significant – though evolutionary – step toward more intelligent, immersive, and resilient industrial operations.

Discussion

The findings of this research are based on five individual case studies and, therefore, should not be generalized to any larger industry ecosystems. Nevertheless, the results provide a solid foundation for further investigation into the most promising use cases of the Industrial Metaverse. Realizing these capabilities extends well beyond technological considerations; effective adoption also requires systematic assessment of organizational processes, data readiness, workforce competencies, and operational practices.

This research employs a qualitative methodology and contributes new insights to both academic scholarship and industrial practice. The conclusions are informed by interviews, direct observations, collaborative industry workshops, and complementary survey instruments.

As the deployment of Industrial Metaverse applications remains in its early stages, substantial learning and experimentation lie ahead. Consequently, the full extent of the benefits will only become evident as organizations continue to mature their digital capabilities and expand real world implementations.

In conclusion, the research contributes early empirical evidence to an emerging field, offering a conceptual and practical basis for future academic inquiry. Much learning remains ahead, and only through sustained organizational experimentation and scholarly investigation will the true value and impact of IM become fully understood.

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