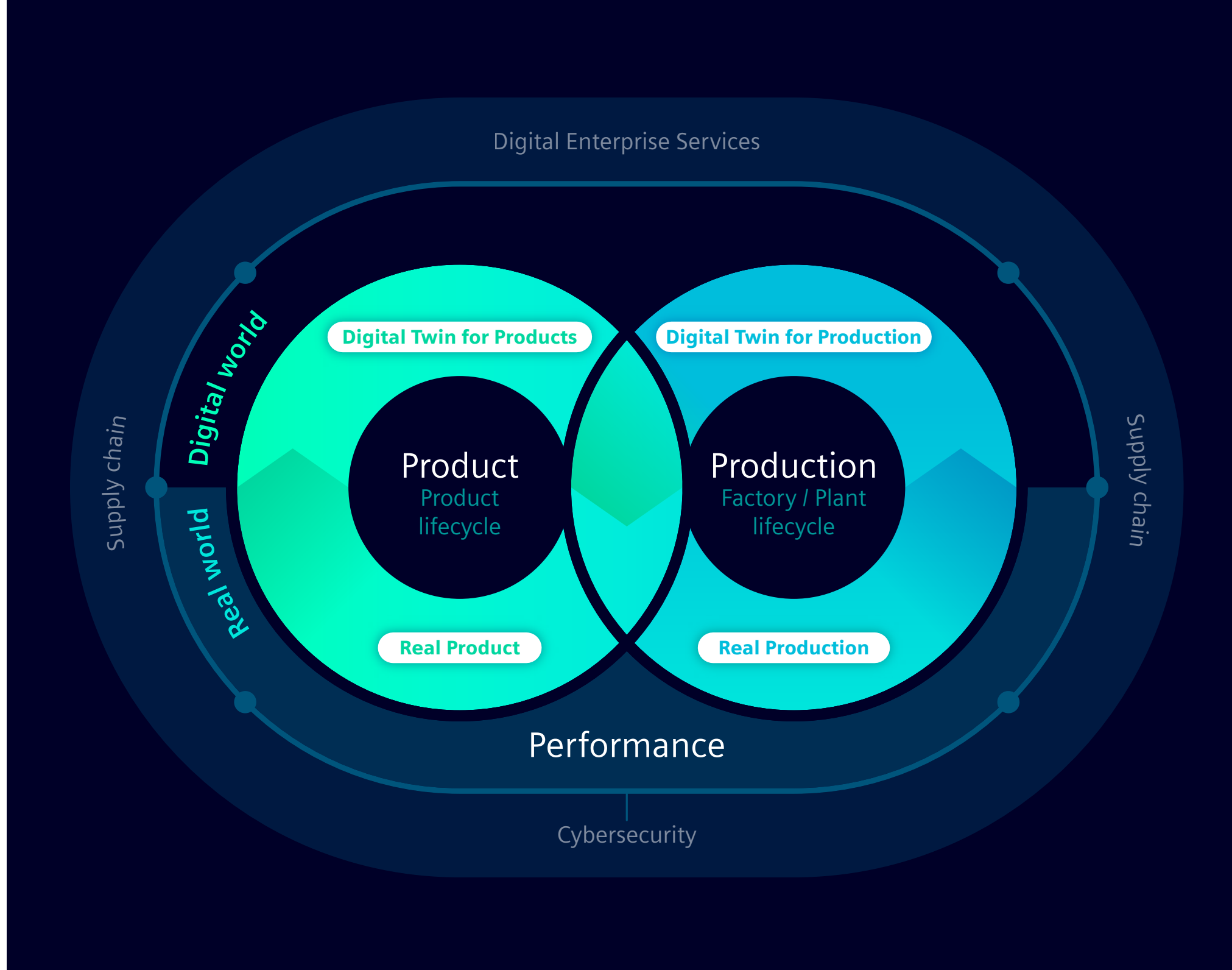


AI and the Digital Twin: **Turbocharging the Digital Enterprise**

SIEMENS

56 hours into its mission, 10pm EST on April 13th, 1970, an electrical short in a fan wire caused a fire that led to the explosion of an oxygen tank on Apollo 13. To diagnose the cause of the explosion and ensure the safe return of the Apollo 13 crew, NASA created a “living model” of the mission that included various simulators that extended beyond the physical into the digital world. This was the first Digital Twin (DT), and it enabled NASA engineers to leverage data to model the disaster and its precipitating events to understand its causes and plan actions for the crew.



Digital Enterprise: Siemens' unique approach of combining the real and digital worlds with the comprehensive Digital Twin. By deploying a closed-loop Digital Twin throughout a system's entire lifecycle, users can speed up processes, minimize costs and optimize efficiency.

The Digital Twin has been the engine of innovation ever since. Today, companies across all industries have embraced digitalization and the Digital Twin concept to become Digital Enterprises to accelerate product development, project execution and production system engineering in the virtual world.

Now, the emergence of artificial intelligence and machine learning (AI/ML) has Digital Twin technology poised to undergo its most rapid gains in years. AI/ML advancements in just the last five years have dramatically improved the ability of computers to make users lives easier, from automating mundane tasks to intuitive natural language interactions to summarizing and analyzing complex data sets. As AI/ML development continues, powerful synergies between AI and the Digital Twin will emerge.

In this paper we will demonstrate how the capabilities of AI will work with the Digital Twin to:

Breakdown data silos to accelerate Digital Twin creation and adoption

as well as facilitate easier interaction with the Digital Twin

Enhance Digital Twin fidelity and functionality

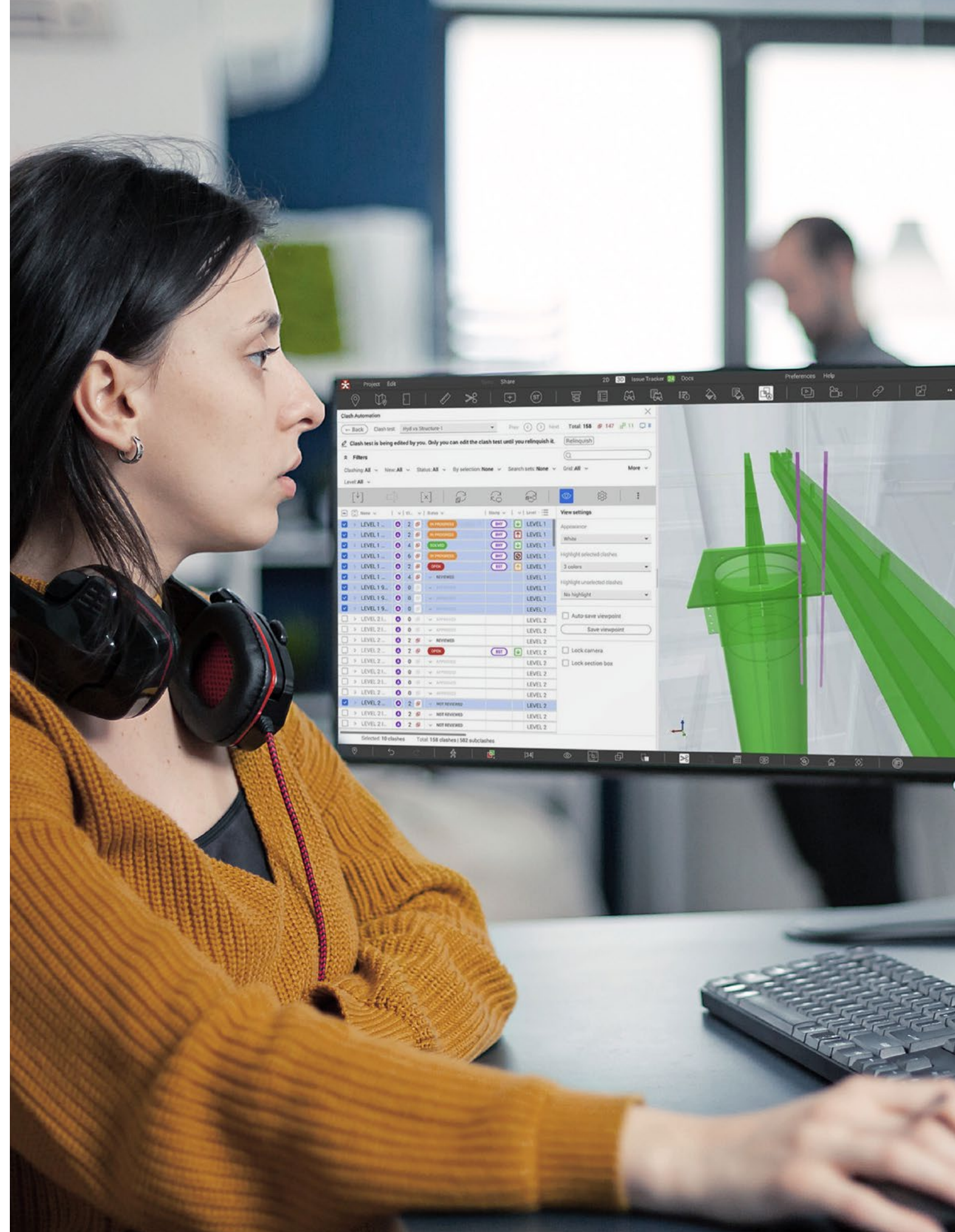
through AI accelerated predictions and ML driven models where no simulations exist

Feed into the Industrial Metaverse

as an environment for holistic, system-level engineering and simulation

AI Unlocks Data Silos for the Digital Twin

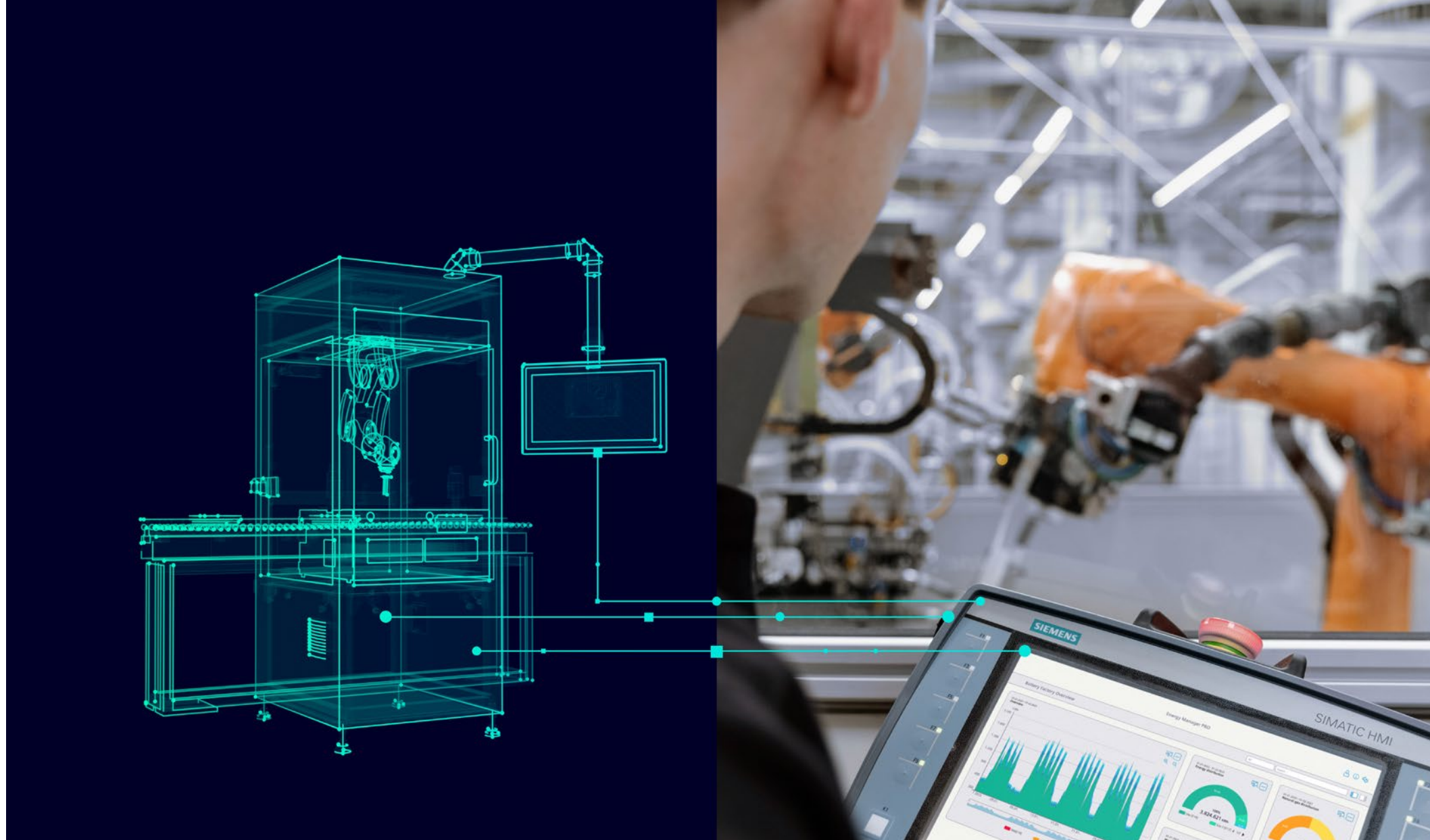
The Digital Twin of any product, process, production plant or system is assembled and updated with everything from structured data authored in various engineering teams and tools to data gathered from sensors. However, as much of this data is still siloed, ensuring all of it is used and updated within the Digital Twin is a difficult task that often fails to encompass all the available data. The structured data comprising the Digital Twin may include CAD/CAE data (in 1D, 2D, 3D, etc.), simulations, code, diagramming as well as sensor data such as image data, temperature, pressure, filling-levels and human feedback depending on the nature of the system.



However, high quality and user friendly, structured data is costly and time consuming to produce and store. As a result, the largest portion of any company's data is typically unstructured and uncontextualized, having neither a standard format nor descriptive metadata. Even more challenging, much of this data is contained in text, images, video files, and PDF documents that are difficult for traditional software to automatically import into existing data-driven systems, such as the Digital Twin.

2 TB

One smart production line of ten machines would produce more than two terabytes of data each year.



Consider one smart production line consisting of ten machines streaming live data to the facility's centralized OT system. A single connected machine may produce up to five gigabytes of data each week, meaning the production line would produce 50 gigabytes each week and more than two terabytes each year, multiplied across all production lines and factories, this number quickly balloons into a huge volume of information. This data comprises of sensor readings for various measurable phenomena (temperature, vibration, energy consumption, etc.) and is usually supplied in a time-series format by the machine's programmable logic controller (PLC).

This data, while structured, lacks the context needed for higher level analyses with the Digital Twin. The time-series data does not correlate with product and production data, key information such as what part was being produced when an error occurred, what processes were underway both on the machine itself and elsewhere in the factory. Any issues logged by human operators concurrent with the sensor readings are not connected with key indicators

found in time-series data. These related data points are crucial for analysts attempting to diagnose production issues, predict system performance, and optimize processes. AI can help efficiently connect both unstructured data and structured lacking context and unstructured data with the Digital Twin to further enhance its accuracy and completeness.

Design teams and suppliers face a similar challenge when trying to share complex information across disciplines. The data produced by an individual tool or toolchain is structured and well-contextualized but not easily shared with different tools specialized for different processes. The Digital Twin, which is formed by connecting structured data, broad context and true-to-life simulations across many domains, is key in addressing this by creating a broader backbone for all the connected data as well as serving as a single source of truth for different teams. Using the Digital Twin different teams have easy access to key information across disciplines, helping them to create the optimal design more efficiently.

AI breaks data preparation bottlenecks

Traditionally, preparing unstructured or uncontextualized data for further use has required tedious manual effort, including reformatting, tagging, and correlation with related data streams.

Therefore, only a fraction of the data created by a smart production line or design process is incorporated into the Digital Twin. Companies know that leveraging their vast reserves of untapped data is crucial to making the most of digitalization investments. But, until now taking full advantage of this wealth of data has been an expensive, time consuming and highly manual process.

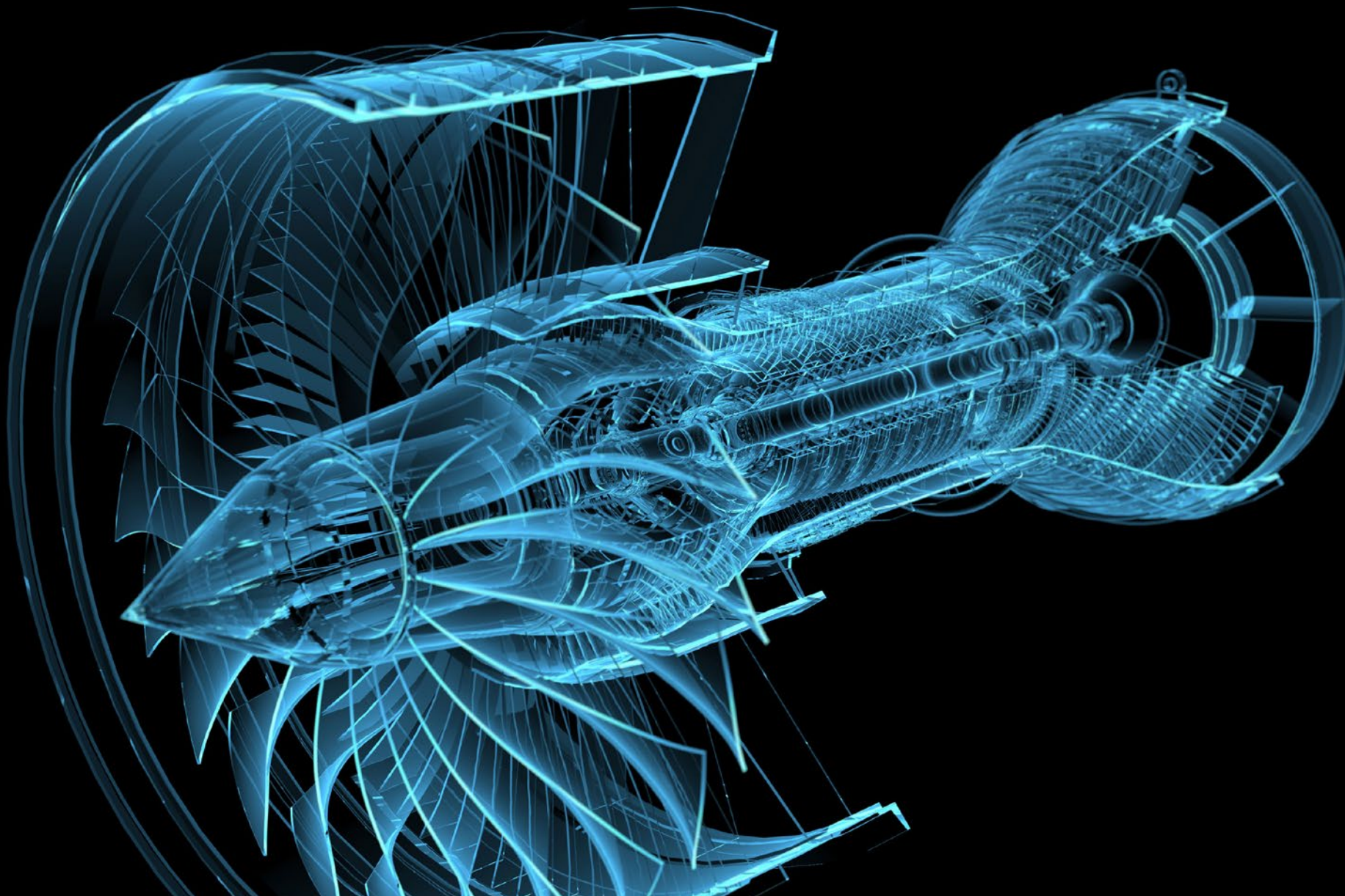
Moving forward, AI will vastly increase the speed and efficiency of connecting unstructured and uncontextualized data with the Digital Twin. This will alleviate the bottleneck that has prevented

companies from completely leveraging their data. Furthermore, as AI agents grow more advanced, they will help automate the creation and management of data pipelines, increasing the observability of data workflows and automating contextualization tasks – even for highly complex systems.

By applying AI data processing and classification to the production example above, the facility operator can automatically build connections and metadata between different data sources. Live sensor data from the shop floor can be combined automatically with information on material usage and production rates to produce structured and context-sensitive datasets for further analysis. These datasets can then be readily integrated into the Digital Twin of the production facility, improving the fidelity of the digital models and thus enhancing the accuracy of various simulations and potential optimizations.

AI agents will help fully automate customer workflows in the future, powered by Siemens' new AI agent architecture featuring a sophisticated orchestrator.





Designing products or production processes creates vast quantities of data in a variety of formats, especially in visual formats such as engineering drawings that are difficult for traditional software to understand such as engineering drawings. This historical information is valuable but accessing scattered paper and digital records is slow and tedious. This also applies to the process of connecting this data with the Digital Twin where it could be more easily used. Leveraging AI specially trained on industrial data, such as Siemens Industrial Foundation Models, to interpret this information makes it more directly accessible to users and the Digital Twin alike. AI creates an efficient bridge between unstructured source data and the Digital Twin, allowing data that once needed to be manually prepared to be connected automatically.

For example, AI is already being used in many industries, including the highly regulated aerospace industry, to reduce the time and effort

required to access and prepare complex datasets. To comply with the strict regulations on modern aircraft, design processes must produce significant, detailed documentation to accompany the design itself. The generative processes that create the wire harness design for an aircraft take thousands of man hours of effort to produce documentation for just this one task.

Using AI, it is now possible to reduce that number from thousands to hundreds or mere tens of hours, massively reducing the amount of time it takes to document and integrate a given part of a sub-assembly into a physical whole (an airplane) or a virtual whole (the Digital Twin). The removal of the data preparation bottleneck will further enhance the Digital Twin and ease its adoption in sectors that have historically lacked easy access to well-structured, contextualized data as well as those which have traditionally required significant manual effort in data preparation. All in all, AI will unlock the full potential of the comprehensive Digital Twin.

Using AI to Accelerate Digital Twin Applications and Methods

The Digital Twin also provides a critical function for AI-based engineering processes as it supplies a true-to-life digital sandbox for training AI models and the verification and validation of AI-generated results. Future AI design, engineering and operation assistants will rely on the Digital Twin as a ground truth for proposals and final design validation.



AI accelerates Digital Twin creation, optimizing products and processes digitally before physical implementation.

However, today the computational costs and specialized skills required to create and run accurate simulations and the Digital Twin limit its widespread adoption. AI is poised to help accelerate the slow speed of high-fidelity simulation and data processing, which are key to building and utilizing the real-time Digital Twin.

ROM accelerated simulation

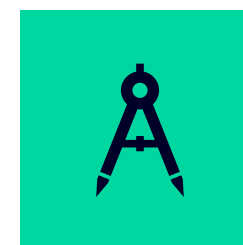
A key advancement to accelerate the access to simulation results has been the introduction of AI-powered reduced order models (ROMs). High fidelity simulation data created during traditional design processes is used as input to train these models. These resulting ROMs are both accurate and computationally efficient and able to reproduce system behavior under various conditions in seconds instead of hours or days. Deploying this technology within the comprehensive Digital Twin allows changes to be tested in a true-to-life digital environment as quickly as they can be imagined.

Reduced Order Model

A Reduced Order Model (ROM) is a simplified mathematical model that captures the essential dynamics of a complex system, reducing computational requirements. In the Digital Twin, the ROM provides an efficient representation of the physical asset, enabling real-time simulations, predictions, and optimizations without the need for a full, high-fidelity model. The ROM acts as an intermediary between detailed models and real-time applications, balancing accuracy and efficiency to allow the Digital Twin to rapidly respond, test scenarios, and optimize the physical asset's performance.

AI-powered ROMs enable hardware teams to more closely emulate software development practices. In the past, hardware and mechanical teams engaged in arduous design reviews involving multi-physics simulations and physical testing with prototypes to validate design changes before they were accepted.

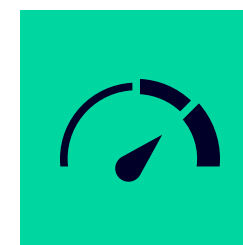
While effective this method is resource intensive which prevents teams from engaging in incremental improvements that would not justify the cost of hours of simulation or the construction of prototypes. By combining the Digital Twin with AI accelerated design and simulation tools, these teams can propose, test, and validate even small design changes to stay current with fast evolving design requirements.



accurate



computationally efficient



faster

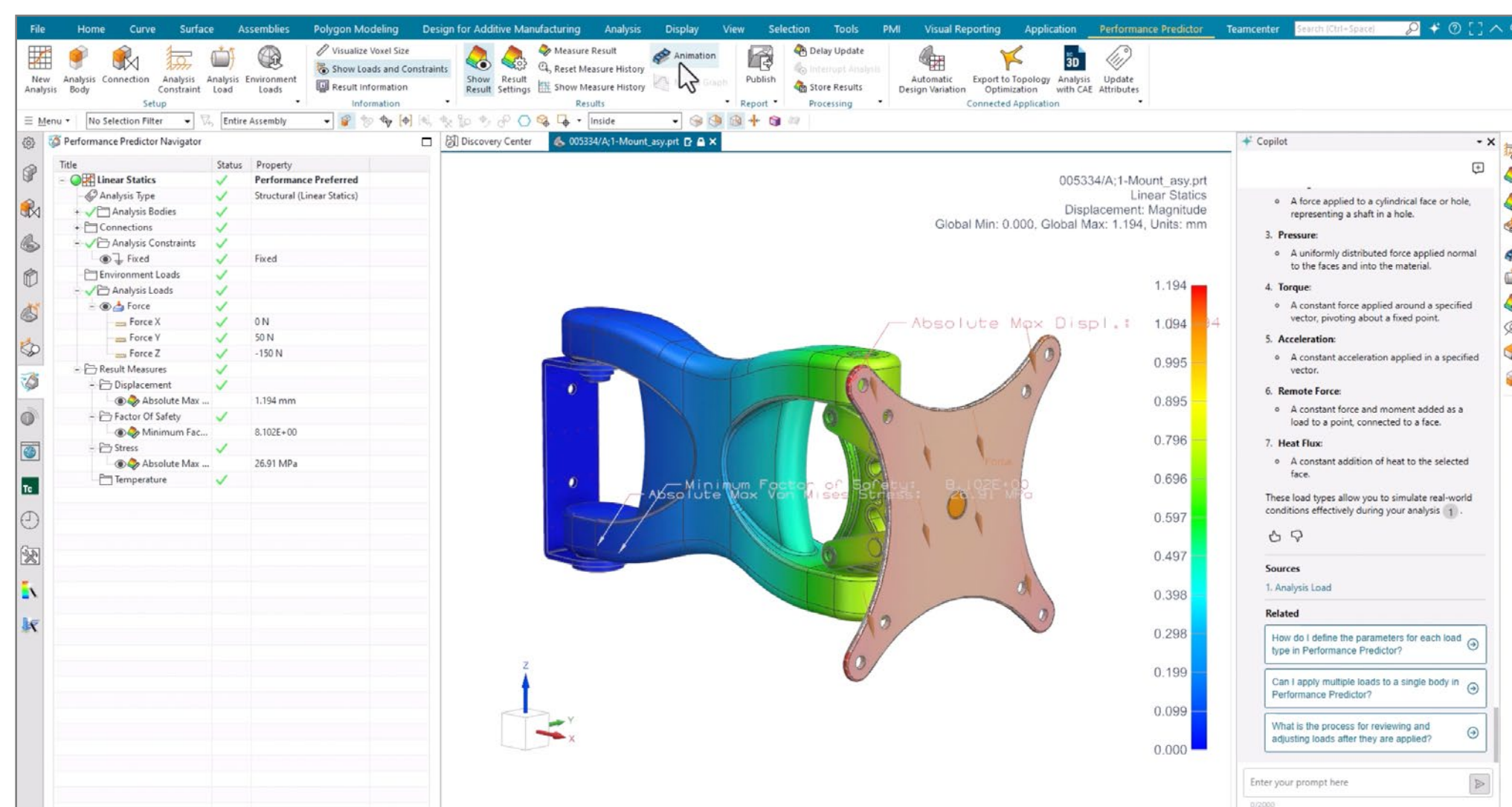
5,400x

ROM is more than 5,400x faster while using more than 200,000x less computing power

While there are still challenges to overcome in bringing ROMs to the Digital Twin, the first steps are being taken today with ROMs being used to accelerate simulation methods in CFD and design space exploration. Take, for example, the problem of optimizing a microorganism activity in a bioreactor. This involves maximizing oxygen content, minimizing power input and limiting shear force as much as possible while only modifying easy to change variables, such as impeller speed and configuration as well as the aeration rate. Even using these limited variables, an example of a bioreactor took 271 CFD simulations to find an optimal configuration with each run taking over 2 hours to complete on a 40 CPU core system.

Using Siemens Xcelerator's HEEDS AI Simulation Predictor to optimize the same bioreactor and achieve the same result reduces the number of full simulations run by more than 20%. In this process, the first 100 simulations run are also used to train a ROM which is then able to replace a portion of the remaining simulations, 59 of the 271 total runs in this case, greatly accelerating the design space exploration process. Compared to the CFD simulation, the ROM only takes 1.5 seconds to run on a single core or to put it plainly the ROM is more than 5,400x faster while using more than 200,000x less computing power.

ROMs cannot and will not completely replace simulations but by intelligently applying them to the Digital Twin, they can massively speed up slow-running processes. Using all the data available within the Digital Twin to train ROMs on various parts and production processes allows for the almost instant early validation of proposed changes, helps sharing between teams, and accelerates optimization and design processes.



The Designcenter NX Copilot capabilities provide an AI engineering assistant which is designed to revolutionize how users work by allowing them to simply ask natural language questions, providing instant access to detailed technical insights, and streamlining even the most complex design tasks.

Industrial Copilot

An Industrial Copilot represents a simple, yet powerful application of AI that allows end users to unlock the data and functionality inherent to the Digital Twin through simple natural language. By connecting users and tools with the Digital Twin, an Industrial Copilot makes tools smarter and easier to use by offering suggestions on how to complete tasks or use the tool itself based on historical information stored within the Digital Twin.

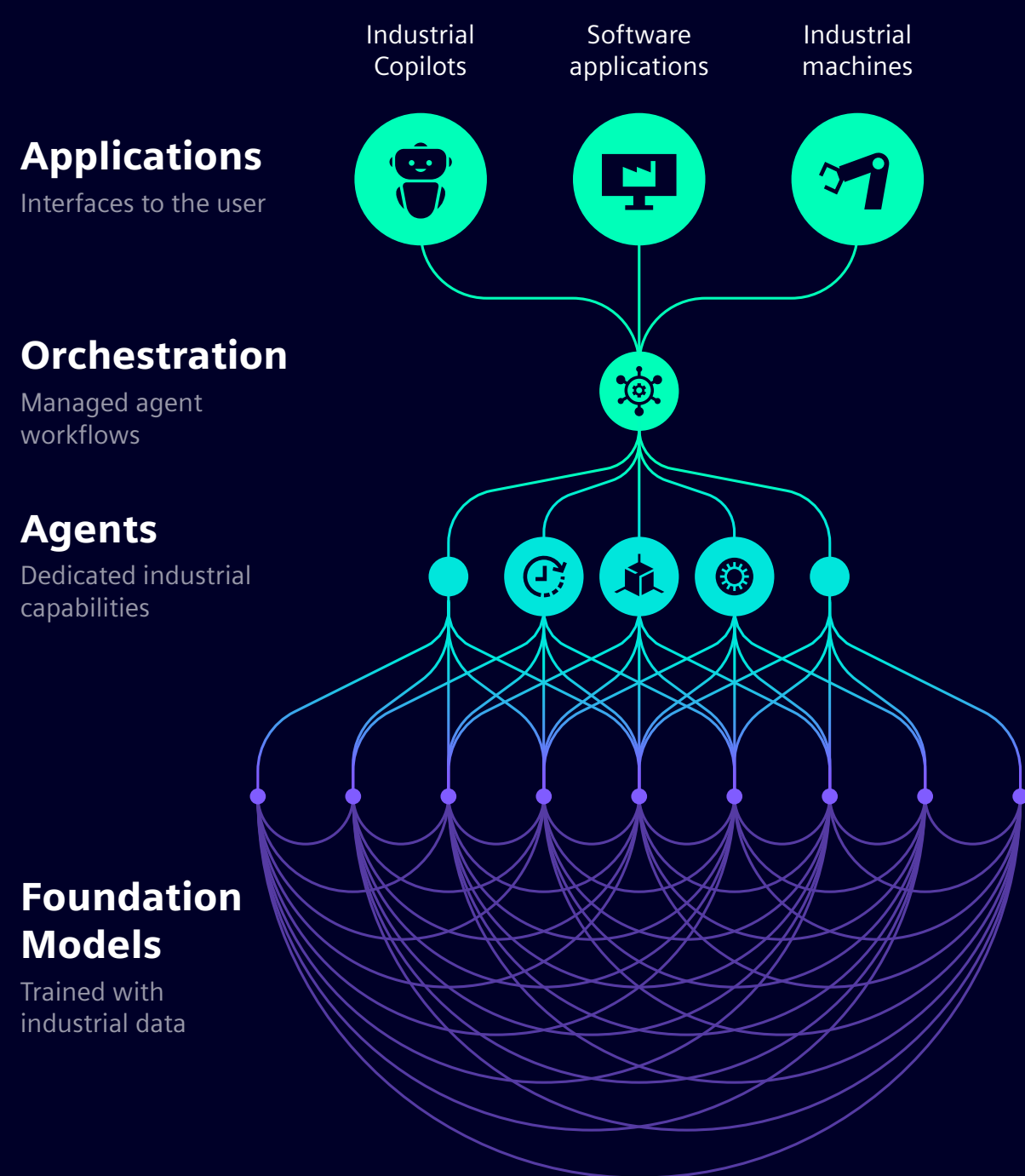
An Industrial Copilot not only makes data and tools more accessible, it also accelerates the Digital Twin creation process as well. Connecting all the data sources required to build a comprehensive Digital Twin is costly, requiring significant time investment from experienced engineers to create the workflows and data pipelines required to bring everything from sensor data to design documents into the Digital Twin. Using an

Industrial Copilot, the complex data preparation and connection steps can be automated and accessed through natural language, not only making them accessible to non-experts, but also greatly reducing the amount of manual effort required.

The next stage extends the power of AI and the Digital Twin to take feedback from products, production processes or an entire plant and systems in the field to drive further refinement after deployment. Here, AI data preparation, ROMs, and the Digital Twin combine to enable the accelerated closed-loop analysis and optimization of physical systems instead of just software. All manner of information, including user reports, sensor data, or supply chain partner data, will be gathered and integrated into the Digital Twin. Rapid simulations will enable engineers to investigate potential issues or model supply shortages and develop solutions faster than ever.



Industrial Copilots along the entire value chain help to improve human-machine collaboration and accelerate development and innovation cycles.



Agentic AI enables powerful automation

Going beyond what the Industrial Copilot can achieve, Agentic AI will offer far greater autonomy and intelligence to AI systems allowing their role to change from a reactive to a proactive one. AI agents will help simplify and accelerate workflows around the Digital Twin, further enhancing the ability of AI systems to build data pipelines while also supporting autonomous AI-driven task completion that leverages the power of the comprehensive Digital Twin.

The Future of industrial AI:
In industry, agentic AI will drive productivity by automating workflows, tailoring services, and powering intelligent, proactive assistants – fine tuned on the language of industry

AI agents can take a role similar to an API, sitting between data and other systems, such as the Digital Twin, and translating everything from raw sensor data to proprietary engineering documents into a format suitable for general use.

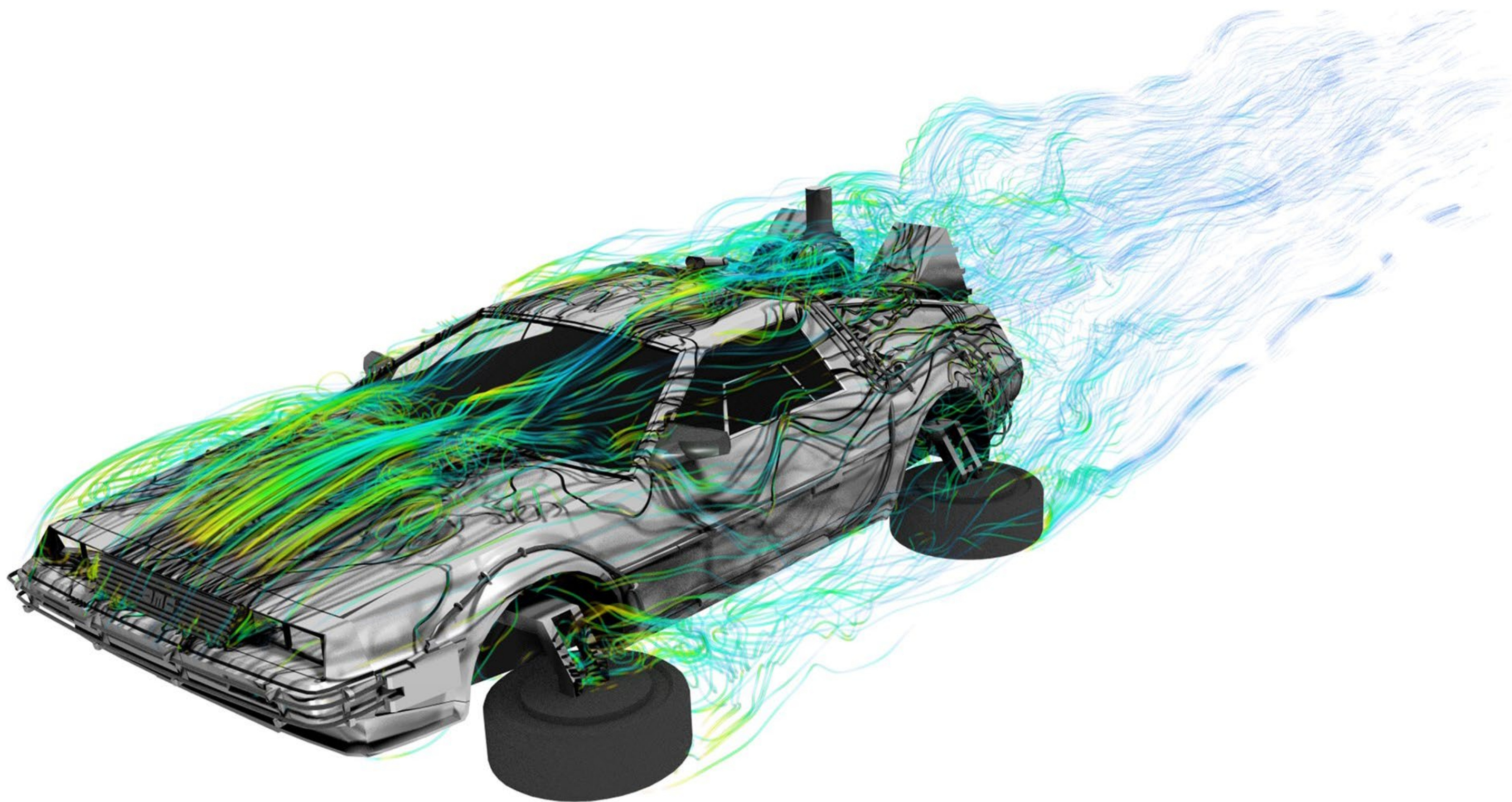
Not only does this speed up the import of data, it decreases the need for domain experts to manually import different data sources. Instead a multi-step agentic workflow could easily handle the import of data from different sources automatically.

Bringing data into the Digital Twin is not the only way AI agents are delivering value, they also have the potential to change how Digital Twins are used and interacted with as well. For example, based on changing shop floor conditions, an agentic AI workflow, using data from the Digital Twin, could propose and validate a new configuration autonomously and virtually before presenting the results to a human operator. Using this method, production systems could be rapidly optimized for even minute changes without increasing the workload of factory personnel while relying on the Digital Twin for validation to effectively mitigate risks.

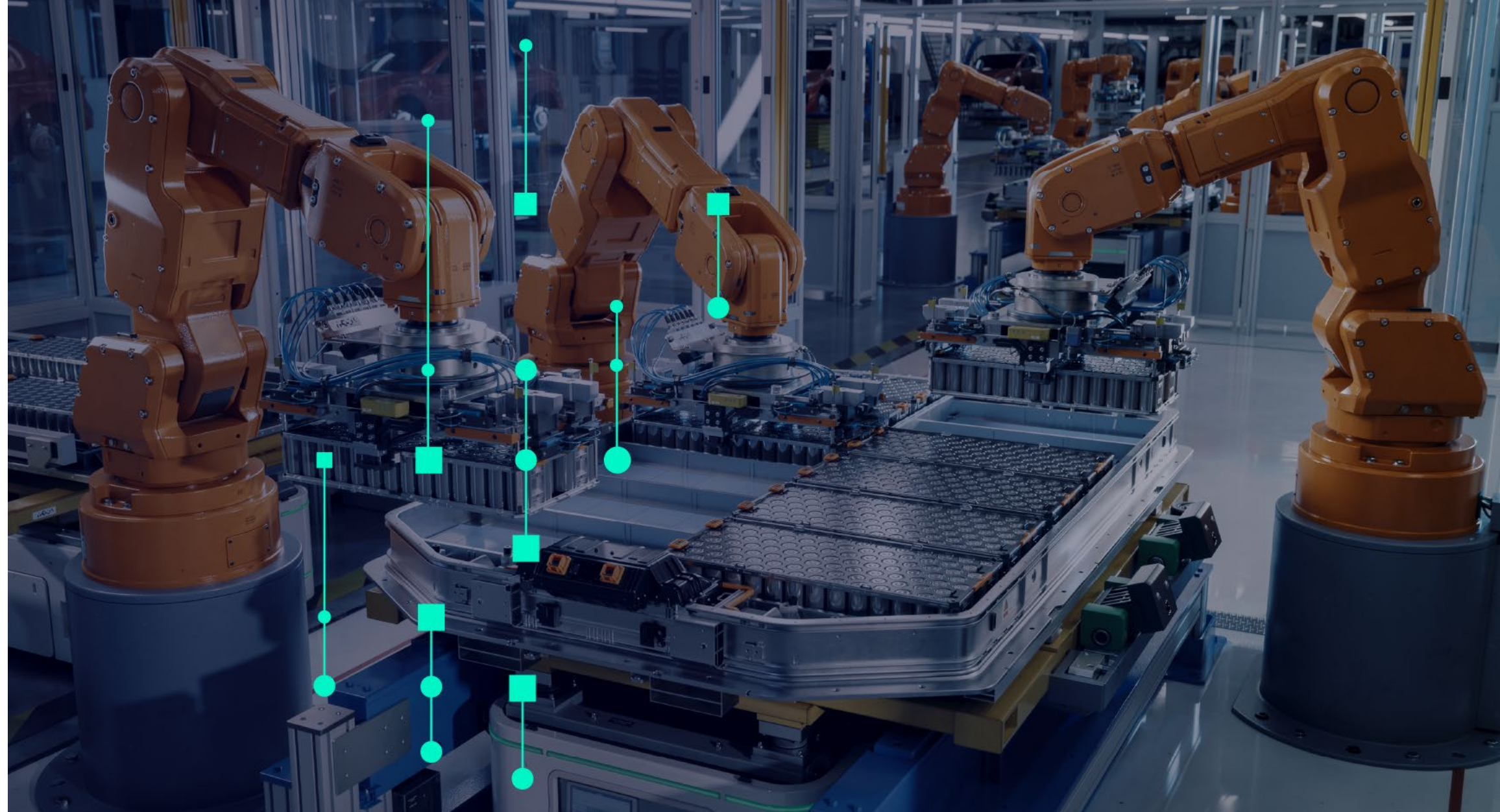
In the future, agentic workflows could massively change the way experts handle problems.

Due to the complexity of modern products and the degree to which sub-systems are interdependent, a system-level design validation demands a very broad set of skills and expertise. AI agents, connected to the Digital Twin, could access information and perform complex tasks across disciplines all from simple, natural language inputs. This will allow every user to have a team of experts at their fingertips.

AI and Digital Twin systems are expected to reduce the threshold of expertise required, such that the team of experts may be reduced to a single person with sufficient knowledge to validate a final result delivered by AI agents. These agents, drawing information from and using tools connected to the Digital Twin, could each serve as an expert in a different step in the process, autonomously working together to identify the problem, isolate the cause and propose a solution. While this level of autonomy is a long way off, the foundation of Digital Twin and AI technology is already being laid today.



Software-defined automation leverages software mechanisms and applies their benefits to the OT world



Welcome to the Industrial Metaverse

Software-defined Automation is an important element for supporting rapid innovation and quick adaption of production to new designs. Not only does it help to make data and production equipment more accessible for industrial AI but it also allows to deploy rapid & frequent updates to the automation program and thereby facilitate continuous optimization processes. Combined, these three technologies will create the foundation for the Industrial Metaverse (IMV), a place that connects the Digital Twin, data, AI and humans at every step of the product design and production process into a complete ecosystem where fast decisions are made leveraging precise and robust data.

The Industrial Metaverse can be thought of as a space for unlimited collaboration within a Digital Enterprise bringing together the comprehensive Digital Twins, AI workflows, AI agents, and all company data, enabling complete system-level modeling and simulation. This true system-of-systems-level simulation will unlock the potential for holistic optimization that accounts for all multi-domain interactions.

Software-defined automation (SDA) is the third pillar of the Industrial Metaverse, along with Industrial AI and the comprehensive Digital Twin. SDA describes how functionality will be deployed and managed in the future of industrial automation. Now, with the virtualization of PLC hardware and the increasing connectivity of robotics and machinery, the functionality of automation assets is no longer tied to a specific piece of hardware.

Instead, programming is centralized, with machines connected to the combined IT/OT infrastructure. Such centralization of machine programming and connectivity enables production management and monitoring for all connected machines to be accomplished in one interface. The result is a significant reduction in the time, cost, and difficulty of updating robotics and machinery with new functionality and identifying and resolving malfunctions. This also brings centralized data access with it for use with AI and the Digital Twin, but also the potential for the centralized AI optimization of physical assets.

In an overwhelmingly digital age, software defined automation is the bridge from the digital world to the factory floor. Critically, information flows in both directions. Live operational data is gathered from connected machines and supplied to the central computer and control systems. Facility managers and engineers can use this data to monitor the day-to-day production characteristics of individual machines, entire production lines, or even large-scale facility performance. In the other direction, programming updates can be delivered en masse, pushing new code to all machines of a given type, or updating an entire production line at once. This reduces the workload of technicians and overall downtime for upgrades.

Industrial Metaverse:
the comprehensive
Digital Twin and
Industrial AI for a new
level of efficiency.

Such a centralized structure lends itself to wide-scale AI optimization that starts during the product design phase considering everything from factory location to logistics all the way to optimizing a production line for a particular part. A robust AI solution is key to examining such a wide breadth of data which in turn allows an entire company to be optimized as a single entity rather than piece by piece or product by product.

In the IMV, humans and AI will be able to collaborate at unparalleled speeds to accomplish product or production optimizations, develop software updates, and understand complex supply chains. AI enhanced systems can investigate and validate thousands of design or optimization scenarios, offering only the best solutions for consideration and further detailed simulations by the human engineer. And, once an option is selected, a team of AI agents will rapidly implement the changes needed in product design, software, and even programming of production machines.



Conclusion

From its origins in crisis management during Apollo 13 to its role as a cornerstone of modern engineering, the Digital Twin has accelerated innovation across industries. Today, the integration of AI is pushing the boundaries of what is possible, removing longstanding bottlenecks, improving the fidelity of digital models, and enabling rapid simulation and optimization.

AI-powered reduced order models and automated data contextualization now allow engineers to iterate on designs with unprecedented speed. In the future, Agentic AI is poised to take the next leap with autonomous workflows, reducing the expertise threshold required for complex problem-solving, and seamlessly integrating tools and processes. As AI agents gain autonomy, human engineers will shift from manual execution to high-level



supervision, focusing on strategy and innovation rather than tedious technical tasks.

Looking ahead, the Industrial Metaverse will serve as the ultimate aggregation point for AI, the Digital Twin, and software-defined automation – creating a fully interconnected ecosystem of several Digital Enterprises for collaboration that enables real-time modeling, decision-making, and holistic optimization. Companies that embrace this transformation will redefine engineering, manufacturing, and industrial operations at every level.

The future is unfolding rapidly, and those who harness the synergy between AI and the Digital Twin on the path to the Industrial Metaverse will position themselves at the forefront of innovation.

Links

➤ [siemens.com/digital-twin](https://www.siemens.com/digital-twin)

➤ [siemens.com/industrial-ai](https://www.siemens.com/industrial-ai)