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The Factory of the Future: How AI, XR and Real-Time 3D Are Shaping Manufacturing

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INTRODUCTION

What will the factory of the future look like? Leadership pioneer Warren G. Bennis famously predicted one possibility:

“The factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment.”[1]

Today, factories typically have much more than two employees and a much higher ratio of humans to dogs. But the factory of the future that Bennis envisioned may be closer than you think. Emerging technologies including artificial intelligence (AI), extended reality (XR), and real-time 3D software platforms are poised to revolutionize every aspect of the modern factory.

We’re not just talking about adding a few extra robots here and there (though there will be more than a few extra robots both there and here). Factories are hurtling towards the future along every axis: factory design and layout, pre-commissioning, simulation and optimization, operator training, autonomous robots, monitoring and maintenance, re-configuration and upgrades, and quality assurance.

In this engineering.com research report, we’ll examine how the enabling technologies of AI, XR and real-time 3D are helping shape the factory of the future—and more importantly, what manufacturers can do to shape this future for themselves.

For starters, you might want to stock up on dog treats.

[1] Warren G. Bennis, cited in *The Millionaire’s Book of Quotations* (1991) by Mark Fisher, p. 15.

TECHNOLOGIES SHAPING THE FACTORY OF THE FUTURE

Technology is a broad term and there is no shortage of technological advancements. We've more or less perfected the wheel, but almost everything beyond that continues to evolve rapidly. While there are many technological intersections that are pushing factories into the future, for the purposes of this report we'll focus on three key technologies:

- Artificial intelligence (AI)
- Extended reality (XR)
- Real-time 3D platforms (a.k.a. game engines)

Let's take a brief look at each.

ARTIFICIAL INTELLIGENCE

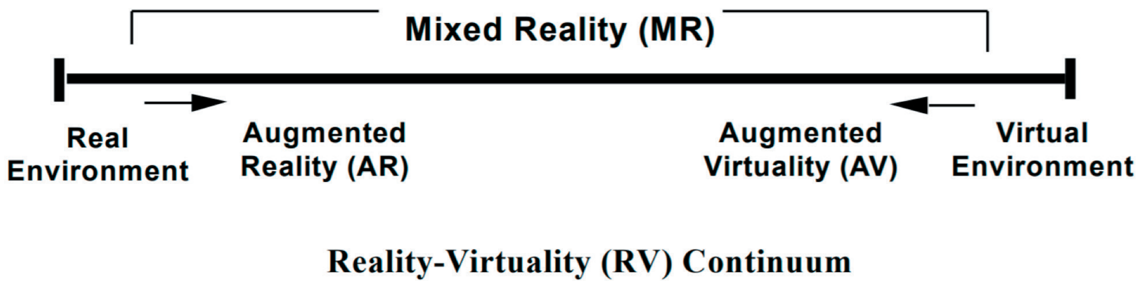
If you haven't heard of AI by now, you're either living on Mars or are yourself a poorly-trained AI. If you believe the buzz, AI will do anything from destroy humanity to solve all of its problems forever, and everything in between. It's a broad topic in itself, so we'll approach AI only so far as it slots into manufacturing. Nonetheless, you'll see it lurking in the background of almost everything we cover in this report.

When most people speak of AI today, they are almost always referring to a specific type of AI called machine learning. This is an increasingly effective approach of simulating intelligence by mimicking neurons in the human brain; such mimicries are called neural networks. While we can't go over the intricacies of this approach in detail, a crucial feature to understand is that neural networks require training. In this context, training means exposure to data. Lots of data. Much like humans, neural nets must see plenty of examples before they can generalize.

EXTENDED REALITY

XR is another flaming hot acronym that promises the world, and just might deliver. XR incorporates, among other things, the related technologies of augmented reality (AR) and virtual reality (VR). AR superimposes digital data on the real world, either through mobile devices like tablets or special head-mounted displays (HMDs), and VR uses HMDs to contain the user in a purely digital world. Both technologies offer a thrilling glimpse into a future that blurs—perhaps even deletes—the line between the physical and digital worlds.

One other term is often used in the context of XR: mixed reality (MR). The differences between XR, AR, VR and MR are best illustrated by diagram. Consider a spectrum: on one end is the physical world, the real material environment we all know and love, and on the other end is the virtual world of VR, an environment comprised purely of 1s and 0s and pixels on an HMD.



The reality-virtuality continuum.[2]

As you move from the real end to the virtual end, you pass through the realm of mixed reality, where more and more digital information is superimposed on the real world—here we pass through AR—until the virtual world is predominant and we superimpose on it a snippet of reality—call this augmented virtuality, or AV—until finally we arrive at a purely virtual reality, VR. Mixed reality, then, refers to any blend of real and virtual.

Subsuming this entire spectrum is extended reality, XR, which is simply a catch-all term for AR, VR, MR, and all related spatial computing technologies.

REAL-TIME 3D

Now, we arrive at a type of software platform that works to combine technologies like AI and XR and bundle them with 3D visualization for a broad range of use cases, such as manufacturing. These are known as real-time 3D platforms, but in another industry they go by a plainer name: game engines.

Yes, the very same software that is used to build modern video games is also being used for engineering and manufacturing projects. Game engines are surprisingly applicable to these industries, so don't dismiss them too quickly.

"We specialize in real-time technology that allows people to experience, visualize and feel objects in space as if they're real, or overlaying the real and the digital and merging those together," explained Bart Manning, Senior Account Executive at Unity, one of the most popular real-time 3D platforms available.

The real advantage of real-time 3D, in Manning's opinion, is its ability to aggregate engineering and manufacturing data and provide intuitive visualizations for users of all stripes. Video games may seem to some as mere diversions, but by looking closer you can find a geyser of professional potential waiting to blow.

"Games have to be instantly intuitively graspable," Manning continued. "You just open the game and you start playing. [Unity] is making all kinds of other endeavors equally intuitive and equally approachable."

[2] Paul Milgram, Haruo Takemura, Akira Utsumi, and Fumio Kishino "*Augmented reality: a class of displays on the reality-virtuality continuum*", Proc. SPIE 2351, Telemanipulator and Telepresence Technologies, (21 December 1995); https://doi.org/10.1117/12.197321

THE FACTORY OF THE FUTURE

There are many ways in which AI, XR and real-time 3D platforms are overlapping to disrupt the manufacturing industry. We'll now examine several use cases for these technologies, encompassing both what's possible today and what may be just over the horizon.

DESIGN AND LAYOUT

Factories don't magically spring up into existence overnight. They must be carefully designed to optimize machine layouts, assembly flows, employee interactions, and much more. A core element of this planning process is spatial, as Unity's Bart Manning pointed out, which naturally befits real-time 3D platforms.

"Unity is just fantastic at helping people understand how objects exist in relationship to each other in space," he said.

Let's face it—you'll never get it perfect on the first try. You may think your factory layout is fine, only to build it and realize that a robot arm swings perilously close to a human workstation or an automated guided vehicle is interrupting a common walkway. It is only by physically experiencing a space that we can intuitively grasp it; 2D drawings of a shop floor simply don't impact us in the same way. Since we can't physically experience something that doesn't exist, our next best option is to virtually experience it.

"You can create the experience of being in the factory and performing those jobs and seeing where those bottlenecks are before a single piece of machining has been done," Manning said.

"This is a very important point from a business perspective," added Ernest Zadef of Unity's Accelerate Solutions. "It allows you to make decisions quicker, spot potential issues sooner and ultimately communicate better."

Automaker Volkswagen is among the list of manufacturers already employing this approach. VW is using augmented reality at its Chattanooga factory in the U.S. to pre-visualize the layout of machinery. According to the company, its AR solution has helped identify unforeseen pinch points between machinery and parts.

"Once you see an idea in AR, you really believe it," commented Steffan Nunn, digital factory specialist at Volkswagen Chattanooga. "Anything we can do to help speed up decision making means we can get more efficient and focus on assembling high-quality vehicles for our customers."[3]

[3] *Volkswagen brings augmented reality to life along the factory line*, VW.com, March 10, 2020, https://newsroom.vw.com/company/volkswagen-brings-augmented-reality-to-life-along-the-factory-line/

Visualizing machinery in AR at Volkswagen's Chattanooga production line.[3]

PRE-COMMISSIONING

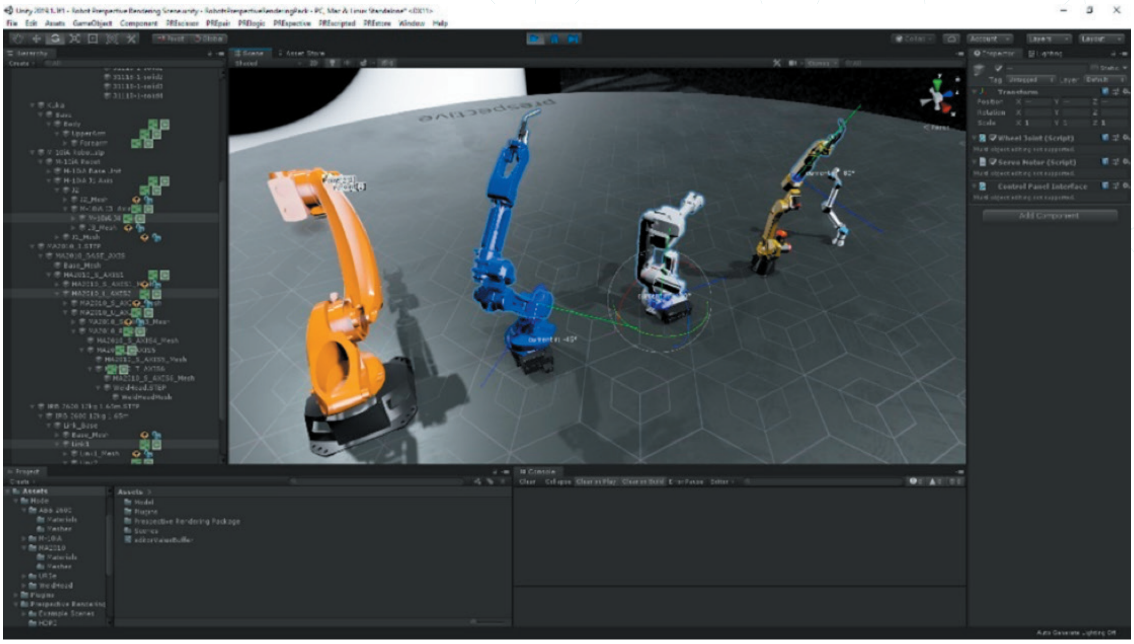
Your factory can't enter operation until you've thoroughly checked that all equipment is behaving as expected. There's no substitute for in-person inspections by qualified engineers, but there is a way to expedite the pre-commissioning process with real-time 3D platforms and simulation. This centers on the concept of a digital twin.

For factory design, it was enough to see a 3D model of a machine in its proper place. For pre-commissioning, we need a smarter model, one that replicates the functionality of a given machine. This is called a digital twin. It is programmed with all the logical inputs and outputs of its physical counterpart, and it runs the exact same code as well.

You may see where this is going: by building a digital twin of a factory, we can simulate its operation in a real-time 3D platform. By doing so, we can solve many of the issues we would have encountered through physical pre-commissioning, saving time and money at that stage.

This is just one of the many advantages of digital twins, which remain a topic of great interest and research across industries. But digital twin solutions currently on the market are already optimizing factory operations (we'll see more of this in the next section). One such solution is Prespective, an add-on to the Unity real-time 3D platform. This software aims to simplify the creation of digital twins in Unity and allows users to run high-fidelity simulations with a physics engine of their choice, including a custom materials handling system for high-accuracy throughput simulations.

"We enable Unity users to set up a digital twin of their system or factory and connect that to outside data to create a fully working virtual prototype," explained Daniel Fanego, head of marketing at Prespective's parent company Unit040.



Screenshot of Prespective in Unity, used to create digital twins for the factory.[4]

One organization making use of virtual commissioning is the Manufacturing Technology Centre, or MTC, a UK-based research and technology organization that partners with academia and industry to bridge the gap between them (a gap it refers to as "the valley of death") and guide manufacturers to promising new solutions.[5]

In partnership with Siemens, Birmingham Energy Institute and Loughborough University, the MTC has developed the Factory in a Box (FIAB) project, a demonstrative production facility in a shipping container. "It was a project focused on designing and building a manufacturing supply chain that was deployable, modular and remotely managed," explained Jose-Maria Blanco Gomez, an Advanced Research Engineer at MTC.

The FIAB and its successor FIAB 2 showcase how AI, XR and real-time 3D platforms can be applied to quickly deploy a production facility anywhere in the world. The MTC used Unity with production simulation data from Siemens PlantSim to develop an MR experience of FIAB 2 that proved the value of virtual commissioning.

"We brought in the CAD models of the whole facility and then we connected the PLCs [programmable logic controllers]. The PLC programmers could test and validate the code connected to the Unity models running in real time. And then we also connected the PlantSim software from Siemens to execute the physics simulation of all the sensors and actuators in the facility," described David Varela, former Product Development Manager for the MTC and now a Senior Technical Product Manager at Unity.

[4] *A New Prespective for the Digital Twin*, engineering.com, Feb 18 2021, https://www.engineering.com/story/a-new-prespective-for-the-digital-twin
[5] *All About Us*, The Manufacturing Technology Center, http://www.the-mtc.org/who-we-are/all-about-us

The Factory in a Box (FIAB) 2 mixed reality demonstrator.[6]

Varela continued: “Finally, we connected the [Siemens Simatic IT Manufacturing Execution System] to the whole facility, so we could also control the production workers going through the process. Meaning that before we could start cutting the first piece of metal to put the whole thing together, we already validated all the PLC codes, all the integrations with the manufacturing and enterprise systems, and everything was working. The commissioning time would have been cut to just a fraction.”

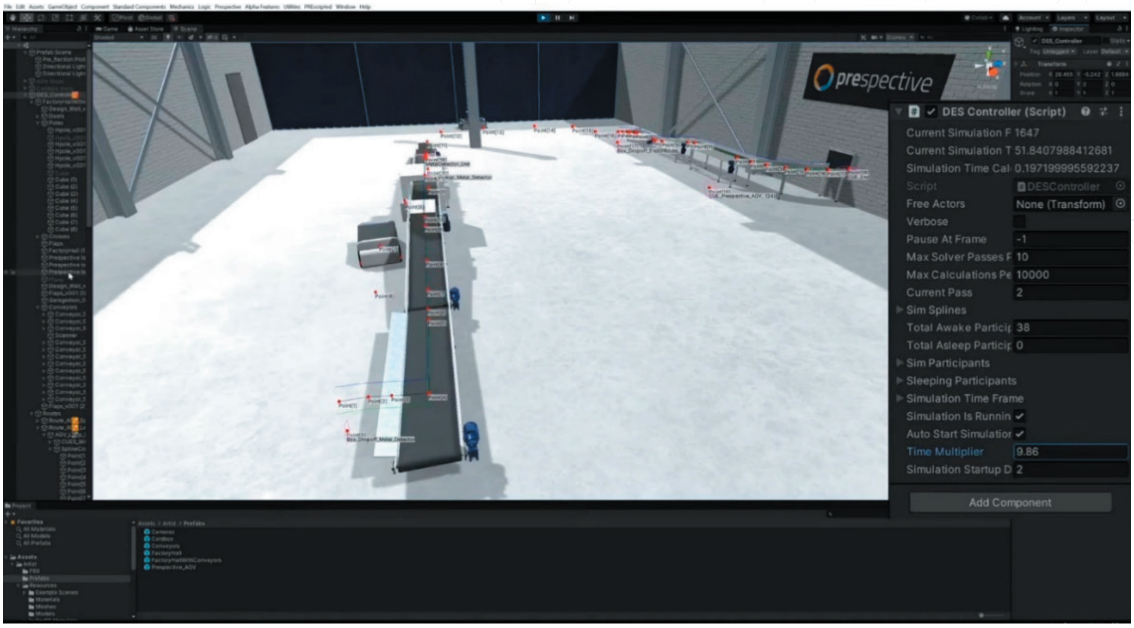
SIMULATION AND OPTIMIZATION

As we’ve seen, simulating factories via digital twins can expedite the pre-commissioning process. But these twins can serve throughout the lifetime of a factory. For factories already in operation, digital twins provide a means of virtually testing different setups and optimizing an existing assembly line.

Take the example of KMWE, a manufacturer of high-mix, low-volume components and systems for healthcare, aerospace, semiconductor, and other industries. In partnership with Prespective, the digital twin provider mentioned above, KMWE developed a digital twin of one of its processes with the goal of optimizing its automated guided vehicle (AGV) throughput. The digital twin simulation proved very informative, demonstrating that AGV collisions were a bigger problem than the company realized and revealing ways to optimize their operation.

“Simulations are an added value in the decision-making process,” reflected KMWE’s Koen Herps.[4]

[6] *‘Factory in a Box 2’ Mixed Reality Demonstrator At Smart Factory Expo,* Smart Manufacturing Accelerator, Nov 11 2019, https://smartmanufacturingaccelerator.co.uk/factory-in-a-box-2-mixed-reality-demonstrator-at-smart-factory-expo/



Simulating AGV throughput in Prespective.[4]

The MTC's Factory in a Box is another project that shows off how digital twins can be used for factory design, simulation and optimization. For the most recent iteration of this project, MTC used Prespective to develop a digital twin of its modular facility.

"It saved us something like 60 percent of the time in building the model and doing the virtual commissioning of the whole thing," praised Varela.

Digital twins aren't the only technology the MTC is using for factory optimization. The organization often provides advice to small and medium enterprises (SMEs) for how to improve their operations. In the recent past, MTC consultants would perform a line walk, where they would visit an SME's factory and search for ways their facility could be optimized.

"We quickly realized that our team was getting stretched really thin, because they had to do loads of miles in the car, just driving up and down the country," said Varela.

It didn't take long to come up with a better way: XR.

"We ended up creating a whole platform where we integrated a remote XR experience," Varela explained. "And we could conduct the line walks from our headquarters in Coventry while the different SMEs were wearing the [HMD] and walking around their facility. And we were able to share 3D models and documents and collect the data that we needed to make an assessment of what could be done within their organization."

Used in this way, XR is like a Zoom meeting on steroids, enabling real-time collaboration in a 3D space. The benefits here extend far beyond virtual line walks. But as we've seen, XR can also represent what doesn't yet exist, and can be combined with simulations to optimize a facility yet to be built. For example, for SMEs looking to get into microelectronics, the MTC developed a virtual printed electronics facility to use as a testing and training ground.

"They can just go in and go through the process of making PCBs [printed circuit boards] using the complex equipment and expensive process equipment that they have in-house," Varela said. "And that's all using virtual reality."

We'll explore this topic more in the section on operator training. But first, let's tap into one of the most promising components of the factory of the future: robots.

INDUSTRIAL ROBOTS

There is little doubt that robots will play a large role in the factory of the future, since they already play a large role in the factory of today. Between now and then, robots will evolve in the direction of full autonomy, self-adapting to changing circumstances without human intervention. Or perhaps a better phrase is human interference, as Warren G. Bennis and his proverbial dog might prefer.

Let's set aside these future robots and focus on what's possible today. We don't have to wait around for breakthroughs in robotics, because according to the experts, there's a huge potential for industrial robots already within grasp.

"In the short-term, you want to automate tasks that are really repetitive but have more variability," explained Sarah Gibson, Senior Engineering Manager of Robotics at Unity. "Think about unstructured bin picking, sorting items coming down a line, things like that. These are tasks that humans find really dull and repetitive, but it's just unstructured enough to make it really difficult for classical robotics up until now. But computer vision and other learning-based techniques are right on the cusp of unlocking this, and so there's a lot of opportunities for robotics to make an impact there."

AI has made enough strides that these dull but difficult tasks can be delegated to a robot, but it's a bit more involved than asking Siri to watch your assembly line. The "learning-based techniques" that Gibson is referring to require large amounts of training data. For instance, to train a robot to pick up different items from a bin, you must expose it to hundreds of thousands of possible scenarios. You must then test the behavior of the robot before you can plug it into your factory.

This is where real-time 3D platforms like Unity enter the picture once again. Gibson oversees several Unity packages for robotics simulation, which provide users with tools to train, test and operate industrial robots.

"Customers can use Unity to generate synthetic data to train perception systems and control policies for their robots, and then use Unity to test whether or not these algorithms work in simulation before deploying the code to the real robots. And Unity can also be used as the operator interface for a robot that requires user control from a human," Gibson said.

The KIcker foosball system.[7]

A lighthearted demonstration of this process comes by way of KIcker, an AI foosball player developed by engineering firm Bosch Rexroth and IT services provider DXC Technology. KIcker is a standard foosball table equipped with an overhead camera to keep track of the ball, servomotors to control the player rods, and industrial PCs and controllers that provide the system's intelligence, a neural network.

"We initiated our foosball study because we wanted to know how to apply artificial intelligence, especially machine learning, in industrial automation," explained Bosch Rexroth's Hans Michael Krause.[7]

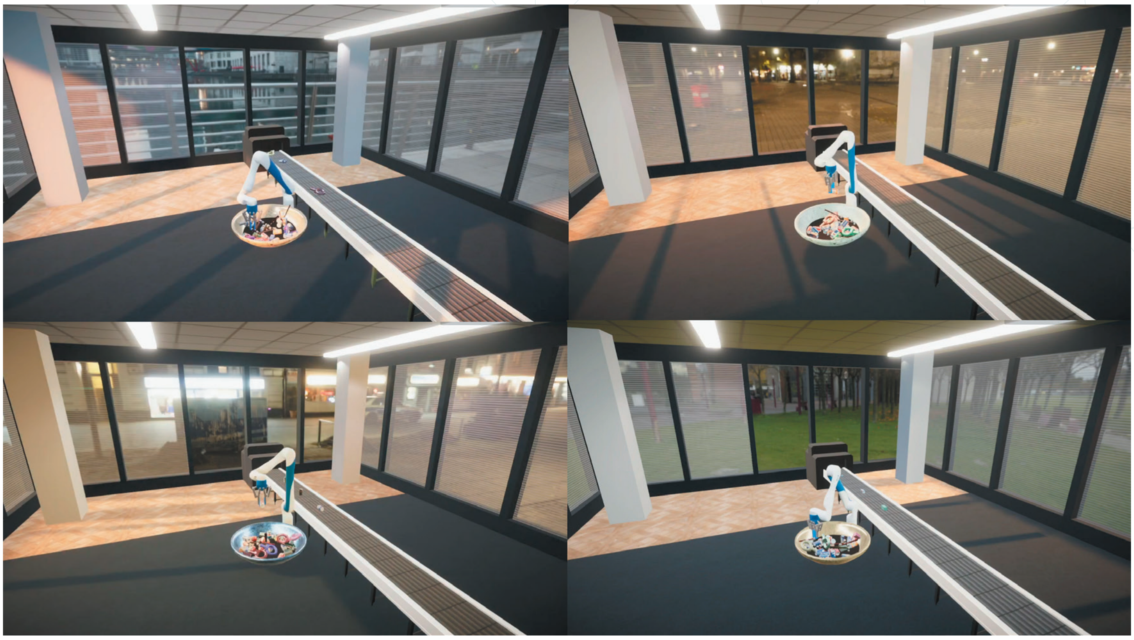
KIcker's neural network was trained using the Unity real-time 3D platform to run thousands of simulated games of foosball in parallel. By generating training data virtually, the team saved what would have amounted to weeks if not months of effort manually playing games against the fledgling AI. Industrial robots could likewise be trained on simulated data, vastly expediting the process of training, and then virtually tested in the same platform.

One caveat with simulated training is a problem called the sim-to-real gap, which refers to the difference between an idealized simulation and the slipshod imperfections of reality. One technique to get around this is called domain randomization, which entails that simulation parameters (like the size of a foosball) be variable ranges rather than fixed values. In this way, the neural network is not overfitted to one specific scenario.

"We believe that the key to closing the gap is in being able to generate large amounts of diverse data that you can use to make your ML [machine learning] models more robust and unbiased and to generalize better," Gibson said. "To that end, we have a set of computer vision tools, the Perception package, to allow you to generate these large synthetic labeled datasets. And part of this, which is important, is it includes randomizers for injecting variation into different aspects like lighting, color, texture and camera position, but it also provides the hooks and instructions for users to add their own custom randomizers."

Gibson added that developers need not choose simulated or real training exclusively; the best approach may be a mixture of the two.

[7] *The KIcker Story: Foosball and Deep Reinforcement Learning,* engineering.com, Oct 22 2020, https://www.engineering.com/story/the-kicker-story-foosball-and-deep-reinforcement-learning



Cross Compass varied a range of lighting, background and texture conditions in Unity to train a robot arm with meteorological domain randomization.[9]

"You can augment your simulated dataset with real data, and that does improve performance of the models," she noted. "If you need 100,000 images to train a model, it's much easier to get 99,000 simulated images and 1,000 real images than to get a 100,000 real images. And just adding a few real images does have a pretty significant impact on performance."

AI consultant Cross Compass can attest to this. The Japanese company uses Unity to simulate and train factory robots for its manufacturing clients. With simulation, Cross Compass can generate unlimited data for AI training that uses domain randomization to bridge the sim-to-real gap. Once the AI has been trained, Cross Compass uses Unity simulation to validate its performance and demo the results to its clients.

"Unity has allowed us to significantly reduce the time and cost involved in training, testing and deploying AI solutions to our clients and partners. The result is higher levels of safety, an increase in the value of human intervention on the factory floor, and a higher quality product delivered to end users. Unity's physics engine and features allow us to control every aspect of the simulated factory floor, resulting in more precise and robust AI solutions than ever before," wrote Cross Compass' Romain Angénieux, Steven Weigh, and Antoine Pasquali.[8]

Let's return to the long-term vision of autonomous industrial robots. Nobody knows when these will be realized, just as nobody knows when autonomous vehicles will chauffeur them around town. However, autonomous industrial robots are a more tractable goal than AVs, according to Gibson. They operate in predictable environmental conditions—there's no snow in a factory—and the consequences of failure are much less—an interrupted assembly line rather than a fatal car crash.

8 *The power of Unity in AI,* Unity Blog, July 24 2020, https://blogs.unity3d.com/2020/07/24/the-power-of-unity-in-ai/

9 *Meteorological Domain Randomization (MDR) in Unity,* YouTube, July 15 2020, https://www.youtube.com/watch?v=709B5qnrHTs

Gibson paints a picture of what could be in store:

“Robotics has the potential to usher in the real Industry 4.0 transformation that people talk about. We’ll go from automating just individual tasks to automating entire processes. Imagine the entire supply chain automated, starting with automated extraction and processing devices to get raw materials and sort them without human operators, which would remove people from these really labor intensive and dangerous environments.”

“The next stage would be using robotic arms and automated gantries to do assembly and manufacturing; everything from processing those raw materials to producing the finished products. And then once you have the finished products, you can move the finished products onto indoor autonomous sleds that move the products to autonomous trucks and ship the products to fully automated distribution centers. Then from the distribution centers, products can be finally delivered by autonomous vehicles or drones or other last-mile devices with autonomous navigation capabilities.”

“So, the long-term vision for Industry 4.0 is a completely automated economy that can minimize human exposure to these repetitive and dangerous jobs,” Gibson mused.

Even in this futuristic vision, Gibson anticipates that humans will be directly involved in programming and overseeing autonomous robots. Her Unity colleague Alexandra Sugurel, another robotics expert, agrees.

“Humans will always, always have a central place in the manufacturing process,” claimed Sugurel, Solutions Architect for Robotics, AI and Machine Learning at Unity’s Accelerate Solutions group.

Sugurel has spent her entire career focused on social robots, seeking to understand how humans and robots can work together. In the context of manufacturing, this concept is often called collaborative robotics, and such a robot is called a cobot.

“While mainstream robotic automation usually consists of large pieces of static hardware, performing repetitive tasks to produce or assemble a finished set of products or parts, cobot automation is actually more scalable because of its ability to adapt with human guidance,” Sugurel explained.

A cobot is versatile enough to take instructions from its human collaborator. For example, imagine a fabrication robot that can produce a wide range of parts and can be easily reconfigured to a new task. Another example is a materials handling robot that can be intuitively piloted by a human operator. Such cobots could serve as human avatars in tasks that are hazardous for our frail organic containers.

“The focus right now is automating these repetitive, low-skilled tasks, and specifically the dangerous ones. This means that the workforce has the opportunity to concentrate on higher skill tasks, even on the assembly line,” Sugurel said.

As manufacturers adopt more robotic solutions, they will see productivity gains and improved profit margins. However, Sugurel emphasized that these gains should be reinvested back into humans.

"Companies that don't reinvest those improved margin gains into their human workforce will likely lag behind companies that do," she predicted. "I can see a future where human beings continue to be at the heart of manufacturing. And it's a future where some workers add a higher level of craftsmanship to products and others manage and pilot the fleet of robots, both the static ones and the autonomous ones."

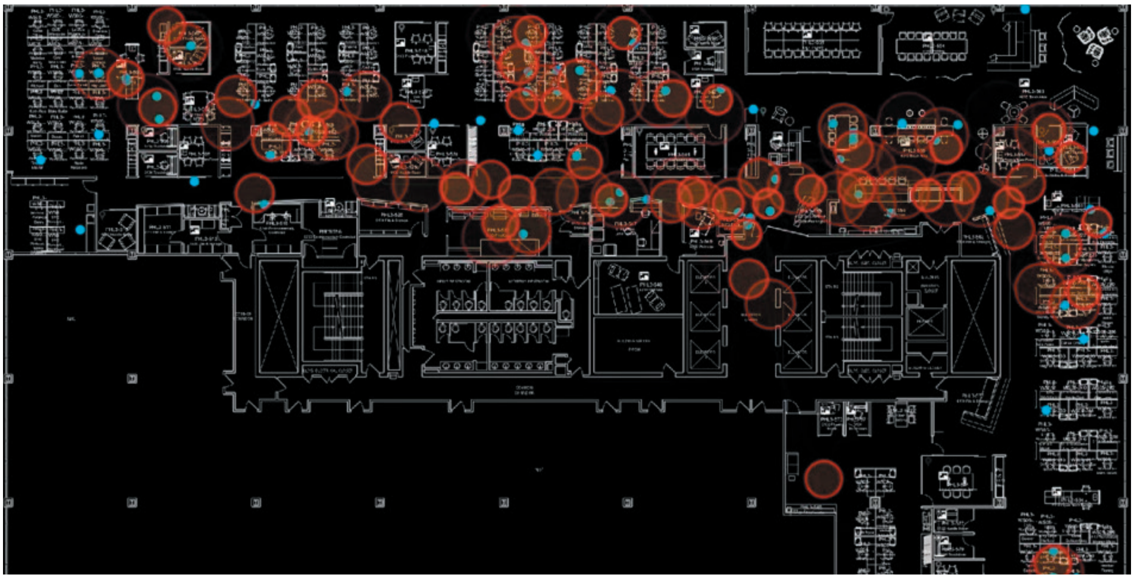
SAFETY AND ERGONOMICS

Worker safety is a prime concern for manufacturers, who must take all steps possible to improve safety conditions. Fortunately, AI, XR and real-time 3D platforms each offer such steps. In fact, we have already seen several ways in which the factory of the future will be safer for humans, such as using cobots to perform dangerous tasks or handle hazardous substances, or using simulation to ensure a factory layout does not invite collisions with machinery or vehicles.

One company working towards this latter goal is Pathr, self-described as a spatial intelligence company. Pathr uses Unity to create 3D and behavioral models of factories, offices, retail stores and other environments that involve people moving en masse. Using these models, Pathr can simulate an infinite variety of floor plans and flows to determine the optimal space.

During the onset of the COVID-19 pandemic, one of Pathr's customers was a manufacturing facility that wanted to ensure its employees could socially-distance properly. After Pathr reported the results of its Unity simulations, the facility made several practical changes involving the timing of shifts and the organization of break rooms.

"We built this massive simulation, many billions of base data points, and then we ran our social distance analytics on that location dataset and gave them results that they actually used to change the way they manage their shifts," explained George Shaw, founder and CEO of Pathr.[10]



A simulation used by Pathr to optimize social distancing in an office environment.[10]

[10] *How Spatial Intelligence is Improving Our Environments,* engineering.com, September 14 2021, https://www.engineering.com/story/how-spatial-intelligence-is-improving-our-environments

Simulating worker ergonomics in VR with XR ERGO from Light & Shadows.[11]

AR/VR software provider Light & Shadows is using XR to improve worker ergonomics. Their XR ERGO application allows users to evaluate workstation designs and employee postures in VR, simulating the movements of a real worker and obtaining precise feedback about the ergonomics of this movement. XR ERGO and other tools like it enable process designers to optimize worker conditions and mitigate the long-term harm that can come from strain such as awkward positions or repeated bending.

Unity's Alexandra Sugurel pointed out how AI and autonomous robots can contribute to higher levels of worker safety.

"With robots becoming more agile and autonomous and nimble, we're seeing a huge opportunity to automate the most dangerous parts of the assembly line and to protect the human workers from injuries," she said. "Computer vision and AI technologies are helping manufacturers practically identify as well as resolve the dangerous points in their manufacturing process to ultimately improve worker safety."

OPERATOR TRAINING

We have hinted at some of the ways that AI, XR, and real-time 3D are changing how factory operators can be trained. For instance, the XR ERGO application discussed above is meant for optimizing worker ergonomics, but could just as easily be tweaked for operator training (indeed, Light & Shadows offers XR software for this express purpose).

[11] *How can ergonomic simulation improve work conditions?*, Light & Shadows, August 27 2019, https://light-and-shadows.com/ergonomic-simulation-improves-work-conditions/

Collaborative VR assembly training with Light & Shadows' INTERACT.[12]

In the same way that industrial robots can be trained via faithful factory simulations, so too can employees be trained in simulations with the aid of XR. By strapping on a VR headset and optional peripherals (such as haptic feedback gloves or immersive audio headsets), users can simulate a factory workstation or step through an assembly process as many times as necessary. It's learning on the job before the job ever starts.

"What's key here is that you can train the operators before the factory is even there," highlighted Unity's Ernest Zadef.

Zadef pointed to the example of communications technology provider Ericsson, which in March 2020 launched its USA 5G Smart Factory in Lewisville, Texas to produce 5G base stations for the North American market. To onboard employees for the new factory, Ericcson used VR to connect operators in Dallas with their colleagues at an existing 5G smart factory in Tallinn, Estonia. Employees at the Tallinn site participated as live VR avatars on top of a 360° guided tour of the existing factory and fielded questions from overseas.

"We were able to provide our new employees with training for a physical environment that at the time didn't even exist without having to get them on a plane and fly them long distances, all because of the power of connectivity and virtual reality," said Ericsson's Anna Cau.[13]

[12] *Workstation design, optimization and training with INTERACT,* YouTube, February 15 2018, https://www.youtube.com/watch?v=utVRxbGXBSE

[13] *Ericsson's USA 5G factory: staffed by professionals – trained by VR,* Ericsson, May 18 2020, https://www.ericsson.com/en/news/2020/5/ericsson-onboards-staff-with-vr

Ericsson's USA 5G Smart Factory in Lewisville, Texas is staffed by operators trained in VR.[14]

Once operator training is divorced from the physical factory, many things become possible. As Ericsson demonstrated, XR training means manufacturers can instruct their workforce while simultaneously building their factory, without regard to the location of workers, teachers or the factory itself. XR simulations also allow manufacturers to train employees across a range of unfamiliar situations, such as a toxic gas leak. It's one thing to memorize a checklist in case of an emergency—it's another thing to viscerally experience one in VR.

"Your body triggers that fight or flight response, your heart rate goes up, and your body is reacting to a frightening situation," explained Unity's Bart Manning. "That is invaluable in training people on how to deal with a crisis, because you can conduct the training where their body is experiencing the fear that it would feel in the actual situation. You never put them in danger, but you get the body to react as if they're in danger. And so the learning is much more effective and the retention is much higher when they actually find themselves in real danger."

MONITORING, GUIDED MAINTENANCE AND REPAIR

In the context of monitoring, real-time 3D platforms like Unity show glimmers of their game engine origins. There's a concept called gamification, and it refers to taking elements of games (like high scores) and layering them over real-world activities (like counting steps during the day). Gamification aims to make dull or rote activities as engaging as playing Super Mario.

[14] *Ericsson USA 5G Smart Factory recognized as 'Global Lighthouse' by the World Economic Forum,* Ericsson, March 15 2021, https://www.ericsson.com/en/press-releases/2021/3/ericsson-usa-5g-smart-factory-recognized-as-global-lighthouse-by-the-world-economic-forum

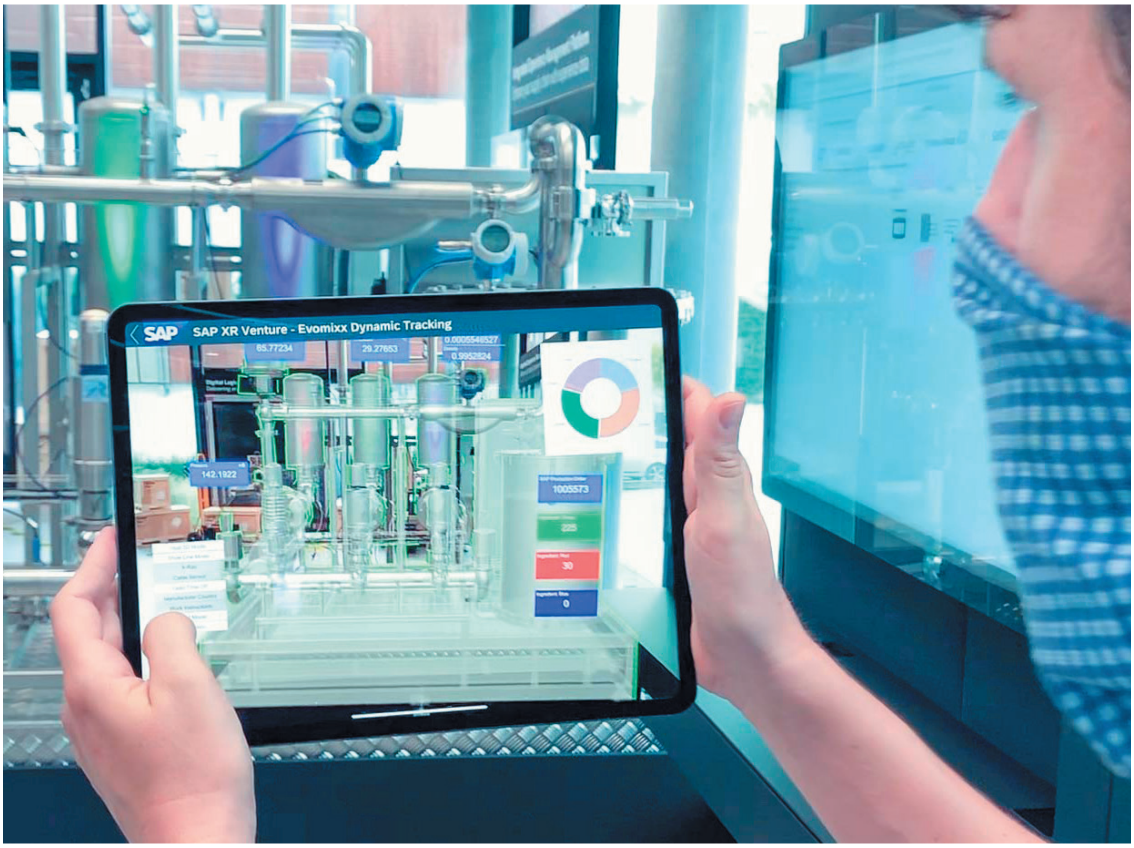
"Take an operator who monitors manufacturing processes—it can become quite boring to sit there in your operator cell and just look at the process to ensure it's running smoothly," said Unity's Ernest Zadef. "But imagine trying to take a game away from kids. It's really difficult because the game itself focuses you."

The same principles that keep kids glued to games like Minecraft and hold their attention for hours can be exploited to keep operators much more engaged with their work.

Zadef elaborated: "Let's say you have an HMI, a human machine interface, for a production process. Right now, it's actually quite schematic and, perhaps, a little bit boring. For instance, you might be looking at some operational assets and then maybe some information next to them and it all looks like a nicely evolved Excel spreadsheet, and that's what you're monitoring.

"Well, what you could do is to make it look like a car dashboard or even the games that people are playing right now. And maybe have some cool-looking intelligent chatbot technology that communicates with you while you're monitoring the process and reminds you of things to do. So, something is constantly happening and it's not happening in a predictive way, it's happening in a way that focuses you and keeps both your attention and creativity going for a long time."

Which would you prefer to stare at for a shift—a static Excel spreadsheet, or a gamified human machine interface (HMI) that's designed to keep your attention?



Visualizing augmented digital twin and Internet of Things data on an Evomixx machine. (Image copyright SAP SE.)

A field operator uses AR to assist in a repair procedure.[15]

Bringing XR into the mix, we can extend these same principles to guided maintenance and repair. Field operators can strap on an AR headset that guides them step-by-step through a procedure, providing 3D models, real-time data (including Internet of Things data), visual or textual instructions and other virtual elements at a literal glance. Not only does this make the procedure easier for operators, it also alleviates the need for expensive training.

"That's why game technology is great, because when was the last time you heard of anybody sitting down and taking a training course to play a game? It is really just about making information instantly, intuitively accessible to people," commented Unity's Bart Manning.

Automation company ABB has embraced this vision with an AR application called ABB Ability Augmented Field Procedures. Built on top of the Unity game engine and compatible with Microsoft's HoloLens device, ABB's app gives field operators access to procedural knowledge while connecting them back to the control room in real-time. The app also allows operators to take pictures and record data to provide an audit trail and document procedural knowledge.

"From a business perspective, monitoring, guided maintenance and repair is actually a series of best practices for transforming procedures into completely paperless processes," Zadef summarized. "Using virtual reality and augmented reality in particular, you can move away from the paper-based processes."

[15] *Best practices for bringing AR applications to the field,* Unity Blog, February 28 2020, https://blogs.unity3d.com/2020/02/28/best-practices-for-bringing-ar-applications-to-the-field/

RE-CONFIGURATION, UPDATES AND UPGRADES

During the onset of the COVID-19 pandemic, many manufacturers pivoted to help in whatever ways they could. Ford, for example, partnered with GE Healthcare to produce ventilators at its Rawsonville, Michigan Components Plant,[16] and the automaker was far from alone in addressing the ventilator shortage.[17] A wave of distilleries and breweries shifted from producing liquor to producing hand sanitizer.[18] These humanitarian efforts were a heartwarming demonstration of compassion, but they serve to demonstrate something else as well.

“The one constant is change,” asserted Unity’s Bart Manning. “There’s always going to be adjustments that manufacturers have to make. And sometimes those adjustments are big and dramatic, like trying to retool to respond to a crisis, but just in the ordinary course of business, they need to make adjustments. It’s a big part of Industry 4.0 that manufacturing facilities become more adaptable and more flexible.”

The same methods we examined for factory design and layout can be applied to re-configuration. For instance, a virtual version of the factory could be created that allows users to simulate new pieces or poses of equipment. These changes could also be viewed in the physical factory with an AR headset. As we saw in the section on simulation and optimization, existing data from the factory can be used to fuel behavioral models and predict the effect of changes, such as the position of different workstations or pathways.

“We need quicker ways of making decisions,” said Barry Maybank, Chief Digital Officer of The Manufacturing Technology Centre. “Data models, simulation, even things like virtual commissioning are where we’re starting to envision how a hybrid workforce might look on an optimized production line with rebalanced products. We’re really starting to use digital techniques to answer some of those questions in real time, rather than physically provisioning things and designing an operating model when, all of a sudden, it’s changing.”

Maybank’s former colleague David Varela emphasized that having this degree of flexibility is not a luxury; it’s a business necessity.

“Companies are already experiencing a competitive advantage because of that flexibility and the capability to redeploy people and assets at a much faster pace,” Varela said. “It’s becoming almost a dead-or-alive situation for the other businesses—you either go digital or you just can’t react to the fast changes in the market demand.”

16 *Ford to produce 50,000 ventilators in Michigan in next 100 days; partnering with GE Healthcare will help coronavirus patients,* Ford Media Center, March 30 2020, https://media.ford.com/content/fordmedia/fna/us/en/news/2020/03/30/ford-to-produce-50-000-ventilators-in-michigan-in-next-100-days.html

17 *Manufacturers Respond to the Global Shortage of Ventilators,* engineering.com, April 6 2020, https://www.engineering.com/story/manufacturers-respond-to-the-global-shortage-of-ventilators

18 *Distillers making sanitizer are lobbying Congress and FDA to keep producing,* engineering.com, April 14 2020, https://www.engineering.com/story/distillers-making-sanitizer-are-lobbying-congress-and-fda-to-keep-producing

QUALITY ASSURANCE

Even the factory of the future will need to check its work. For quality assurance, artificial intelligence and extended reality will have large roles to play. AI is a perfect fit for predicting problems and offering suggestions to human quality inspectors.

“As the product comes along, you can use artificial intelligence to establish where the manufacturing process tends to produce more errors,” explained Unity’s Bart Manning.

The AI could flag potential errors to human inspectors, and in the same style as guided maintenance, these inspectors could use an AR device to guide them through the inspection. The entire procedure could be recorded to document the QA process.

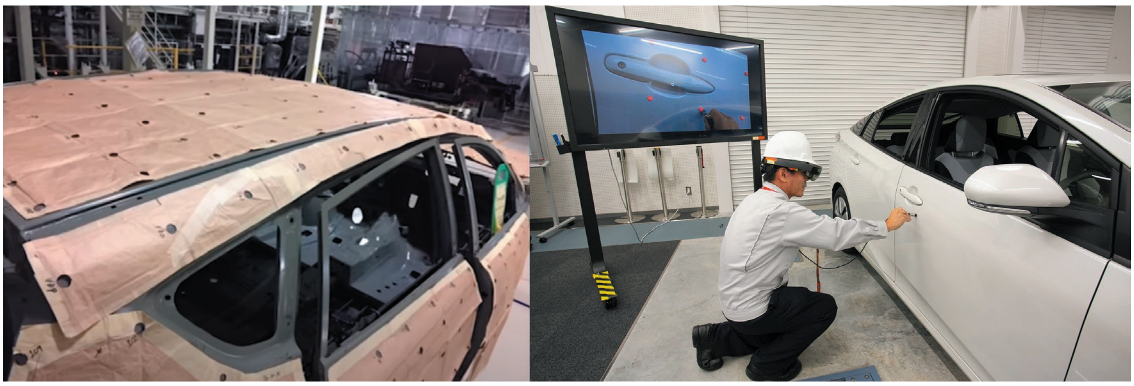
Automotive manufacturer Toyota is one company taking advantage of AR inspection. To inspect paint thickness on its vehicles, Toyota used to employ a paper-based approach. Very paper-based. Inspectors would carefully apply paper cutouts around the entire car body to guide the thickness measurements. Now, Toyota has replaced this approach with a virtual guide via the Microsoft HoloLens AR headset. What used to take two inspectors an entire day now takes one inspector two hours.

“It’s revolutionized the way we work,” praised Koichi Kayano, a project manager at Toyota.[19]

As AI advances, Manning predicts it will play an increasing role in QA, perhaps shifting its relationship with its human counterparts.

“Computer vision can automatically detect [an error] and flag it for the inspector so that the inspector is, if you like, a supervisor of the automated QA, rather than the full QA themself,” Manning said.

Perhaps, not too long afterwards, that AI supervisor will need their own supervisor, and perhaps it will have four legs and a tail.



Toyota replaced its paper-based approach to paint thickness inspection (left) with augmented reality (right).[19]

[19] *TOYOTA transforms its business with Microsoft HoloLens,* YouTube, March 4 2019, https://www.youtube.com/watch?v=Rcct5aBGWs8

CONCLUSION

Throughout this report, we have seen many ways in which manufacturers are improving their processes with the help of artificial intelligence, extended reality and real-time 3D platforms. Though we have hinted at the possibilities to come, we have largely remained grounded in the present. The use cases we've discussed and the technologies that enable them are in use by real manufacturers who are experiencing real benefits. These benefits are available to all manufacturers willing to explore new approaches.

"You need to know what you don't know," advised Barry Maybank of the Manufacturing Technology Centre. "Within organizations, it's really important not just to be talking about technology, but to be bringing the operational team in, the technology team in, and the product team in as well."

Once you've identified your opportunities, Maybank suggests looking to external organizations for guidance. "Everybody's unique, but not that unique," he jokes, urging manufacturers to look to other successful implementations of a technology and to partner with research and technology organizations with experience in such implementations.

The MTC's David Varela also advises having a route to scale new technology throughout your organization. In this report, we've seen a broad range of use cases of AI, XR and real-time 3D platforms. If you invest in a technology, ensure you use it to its fullest extent.

"If you are to adopt XR, for example, don't just limit it to a specific use case like end-of-line inspection," Varela said. "Because you might be able to reuse the same equipment, the same technology, to solve problems in other places of the organization as well."

If there's one thing to take away from this report, it's that the factory of the future is not a long way off from the factory of today; the factories of the future will be direct descendants of the factories that successfully implement the technologies we've discussed in this report. Manufacturers that embrace this fact may be the only ones whose factories are still around in that future.

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