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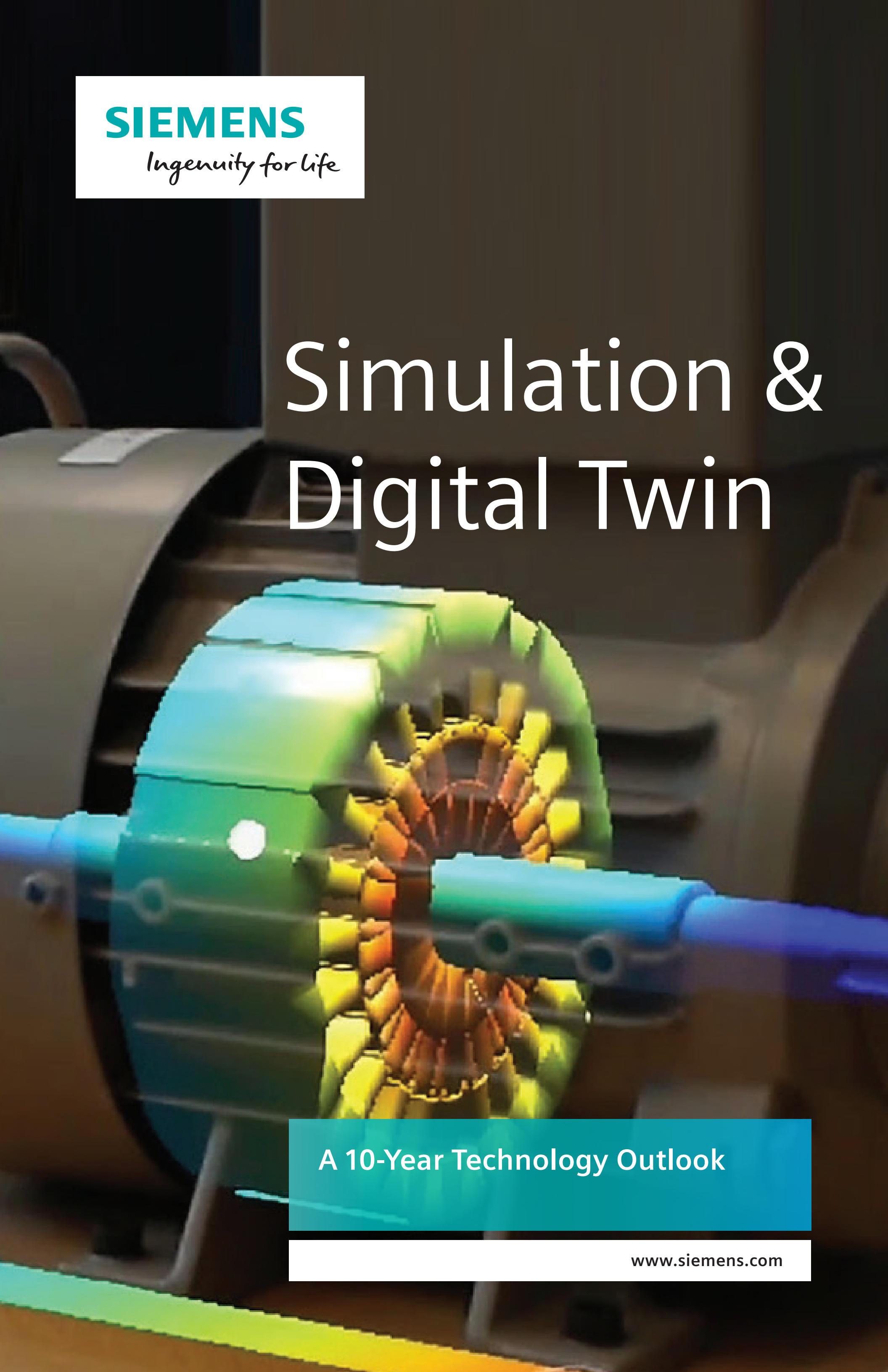
Simulation & Digital Twin



A 10-Year Technology Outlook

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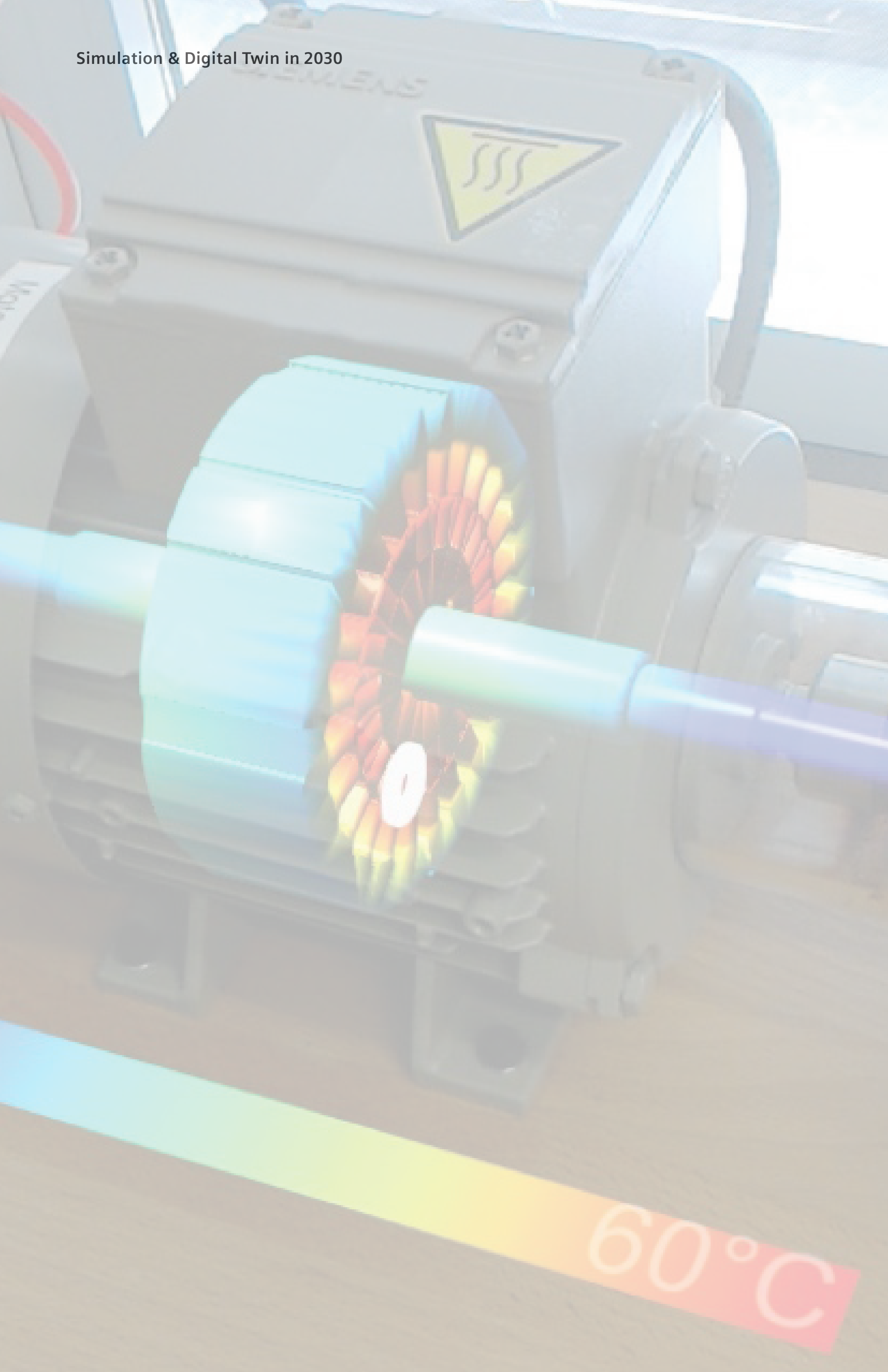
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Simulation & Digital Twin

A 10-Year Technology Outlook

Simulation and Digital Twin in 2030

Today, the methodologies that facilitate processes of continuous optimization like no other for design, engineering, operation and service in various industrial products are known as a 'digital twin' and 'simulation'. Digital twins are mostly referred to as the virtual replica of physical assets, be it a product, a machine, a process, or even an entire factory throughout its whole lifecycle. They contain all the information, data and descriptive and executable models relevant to the management of its real planned or already realized counterpart with simulation as a core technology.

During the design and development phase, digital twins and simulations allow best decisions for various design alternatives and optimization of system properties. When in operation, they also help to ensure the best performance, usage and to realize advanced service solutions of an industrial asset. They even support end-of-life-management. This means a digital twin can accompany an industrial product over the whole lifecycle, seamlessly linking together all stages of the value chain. And what's more, all the data collected during its lifecycle can inform the design and use for the next generation of a product.

But we are just at the beginning of realizing the potential of digital twins and simulations – be it the close relationship between the two, the creation of ecosystems around them, the role of Artificial Intelligence (AI), or creating unique business opportunities with their help. For that reason, we conducted interviews with experts worldwide – from major technology companies, academia, and research institutions – to assess what these technologies will turn into within ten years.
We condensed their outlook into ten statements, illustrating the immense potential of this technology for industry and the economy at large.

A Digital Twin For Each Industrial Product

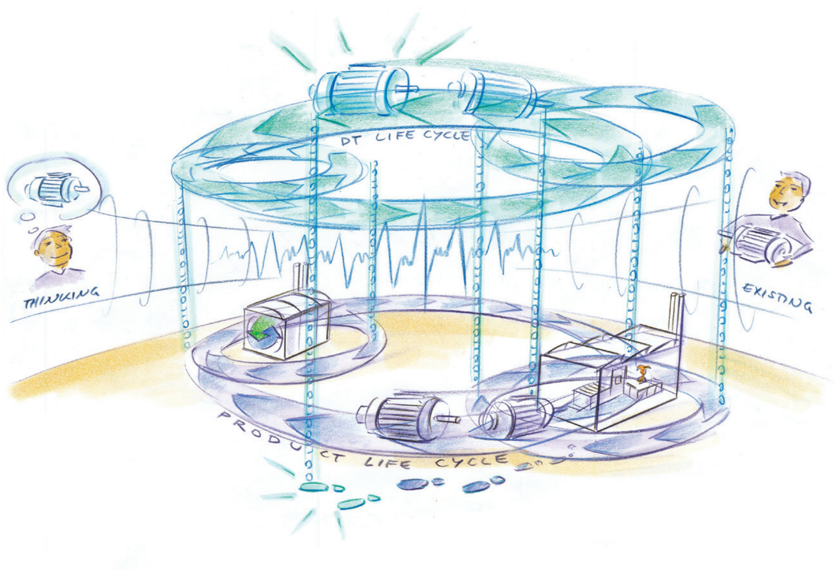
Today, digital twins are commonly understood as virtual representations of components, machines, entire production plants, or infrastructures, that leverage operational data to mirror their current state in real-time, helping to manage and control their counterparts in the real world. In the coming years, nearly every industrial or technical product – be it a machine tool, a building, a factory, a production plant, or an electric grid – will come with such a digital twin, enabling detailed simulations and their management over the whole lifecycle.

A product's digital twin typically consists of descriptive as well as dynamic models representing different aspects of the system. If the system is rather large or complex – like a manufacturing or power plant – subsystems will have their own digital twins, some of which can be defined by a certain purpose, such as sensing or diagnosis, and therefore only reflect certain aspects of a twin. This also implies that they need standards in order to work together.

In some industries like automotive, digital twins already evolve seamlessly aalong a product's whole lifecycle. They start as twins of a product type with the original design information, engineering models, and testing data. They continue after manufacturing as repre¬sentations of specific instances of a product using the data collected during operation to support maintenance and service along with other activities. And finally, the digital twin helps to facilitate end-of-life-usage, which could help a circular economy.

Currently, a focus of interest is on the operational phase, allowing for digital twins to be adjusted when the real product gets modified. Another one is using regular simulations to predict the need for maintenance or repair. This allows for better product service, time and cost savings, and an unprecedented flexibility for operation.

A digital twin as a synchronous image of a system in operation enables advanced solutions like extended monitoring, simulation of changes, and simplified control. Since production in nearly all industries is required to be flexible, these digital twins will also support real-time adjustments during operation.



A digital twin for each industrial product

It is important to note that digital twins are not complete or total representations of a product – they are made up of various models and data specific for a certain purpose, and apply suitable precision for the required solution. Another important distinction is the difference between a digital twin representing a type – the information of which may be located in the cloud – and its instances, which are additionally characterized by operational data, its operational context, and technical configurations.
For digital twins to fully use their potential it is important that they have an open format, allowing it to be modified and extended when new models and new data come along. This requires structure as well as pre-planning and management. As the digital twins evolve in such a manner, they morph into continuously new states of the digital twin.

Improving Energy Systems

Energy systems are going through a digital transformation. We can expect that by 2030 all major components will be delivered with their own digital sensors and digital twins. This in turn will allow for a closer observation and management of energy generation, distribution and consumption than ever before.

The more data that is created, the more perfect a virtual counterpart can mirror the real world. This allows for flexibility which will become increasingly important as renewable energy sources become part of our energy supply. Digital twins will allow faster reactions to changing conditions – e.g., as part of assistance systems for operators or automated systems.

One example for this development is the DynaGridCenter project, a German R&D project supported by German Ministry of Economic Affairs and Energy (BMWi), a prototype for an automated grid control and outage prevention system. This intelligent control center quickly and effectively reacts to a grid's changing state, addressing instabilities in frequency and voltage, ultimately increasing the loadability of power systems. While safety limits for expected upcoming conditions must be ensured, margins for potential future situations can be reduced. A better observability and system assessment combined with forecasts enable curative security margins and higher asset utilization. Assistance systems based on digital twins simulate contingencies and enable high quality system prediction for autonomous system operation so operators can focus on other upcoming tasks.

A follow-up project to the DynaGridCenter called InnoSys 2030 (also funded by BMWI) will prove whether the systems also work for real power grids. It aims to realize an innovative power grid solution by coordinated use of curative measures, performance flow controlling resources, and a higher degree of automation in the system management while still maintaining the highest system and network security.

All this is necessary, as by 2030 the allowed reaction time will be shorter than anything a human could accomplish. Improved observability and system assessment combined with forecasts based in part on digital twins will enable security margins and higher asset utilization. In the same way, advanced assist systems simulate contingencies and enable high quality system prediction for autonomous system operation.

Cost is obviously a concern – digital twins will only be widespread if they have a positive benefit-cost-ratio. And while today a digital twin may be still expensive to build and maintain, the technical and economic advantages they enable will help with scaling so that by 2030, digital twins will become more commonly incorporated in industrial business models. One lever is the connection of vast amounts of data through semantic technologies.

Even more, digital twins can also be seen as marketable solutions by themselves enabling detailed simulations, supporting product innovation and research. Taken together, all of this will lead to the development of a digital-twin-ecosystem within a decade.

Digital Twins Will Form An Ecosystem

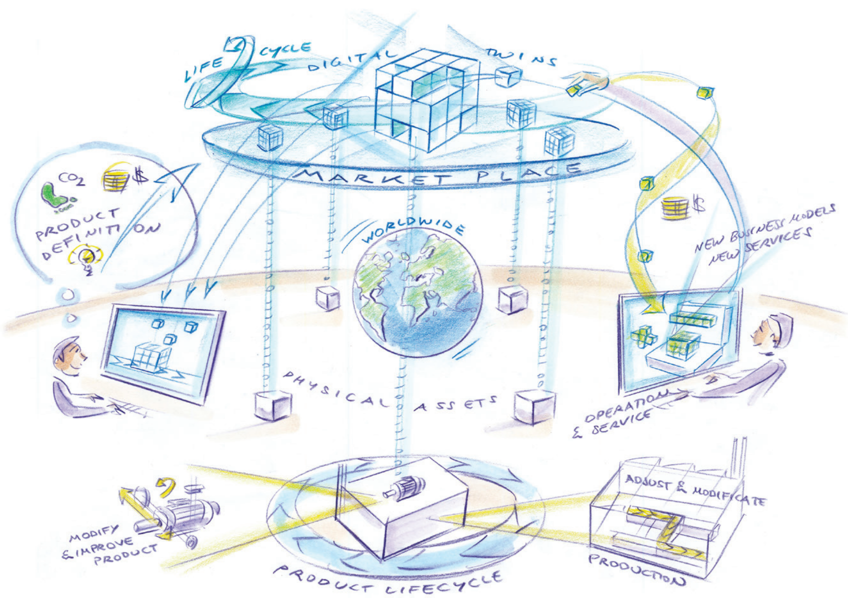
For any industrial product to come to life it has to pass through several stages that in many industries – from a digital point of view – are still only loosely interconnected today: from the design and development phase to manufacturing, implementation, operation, end-of-life, and recycling. Digital twins have the potential to build bridges within and between different value chains such as Product Lifecycle Management (PLM) or Supply Chain Management (SCM). This way, they create a whole interconnected ecosystem that will result in cost and time savings, better designs, more efficient and sustainable production and operations, and also new business models.

The continuous thread throughout an industrial value chain are digital twins which today as most probably in the future are linked to an IT system such as a cloud platform. They are often complex and hierarchically structured, with many components and subsystems that come with their own digital twins. This way, a digital twin gains value by facilitating to engineer better and more complex systems, e.g. by using a component's digital twin for the development of a larger system and then to create its digital twin.

This highlights that digital twins are not tied to their real counterpart – they are transferrable goods that can be traded and that enable new applications. By 2030, this should lead to platforms that allow the creation, exchange and trade of digital twins to be used for various industrial applications, in the same way as platforms for Computer Aided Design (CAD) models are a reality today. For this to work seamlessly, it is necessary to develop modular digital twins that function as building blocks for more complex virtual representations, some of which already exist for manufacturing plants today.

And because of the specific demands of various industries, we and others foresee specialized platforms and ecosystems enabling automotive, aerospace or the pharmaceutical industry to be developed.

Digital twin online marketplaces should be standard by 2030 – especially within industry verticals, and including automated digital twin-transfers between trusted partners. Some of the digital twins being traded may use vendor independent open standards, e.g. in case a supplier wants quick market penetration.



The digital twin ecosystem

Online platforms with their own digital-twin-operating-system should enable virtual system integration. This also means that the bar for entering certain markets will be lowered so new players will have an easier start in a market. It also implies faster innovation cycles, and faster time-to-market. On the other hand, some suppliers may use encapsulated models within their digital twins in order to protect intellectual property. Finally, for those who want to create and use digital twins, we can also expect online platforms offering services to generate and use them.

Simulation Algorithms Will Evolve And Spread

Simulating a digital twin's physical counterpart can be a challenge – because of material properties, dynamic processes, technical complexity, or contextual conditions. But since the 1960s steady progress in terms of hardware and algorithm development has made it feasible to simulate various aspects of a technical system.

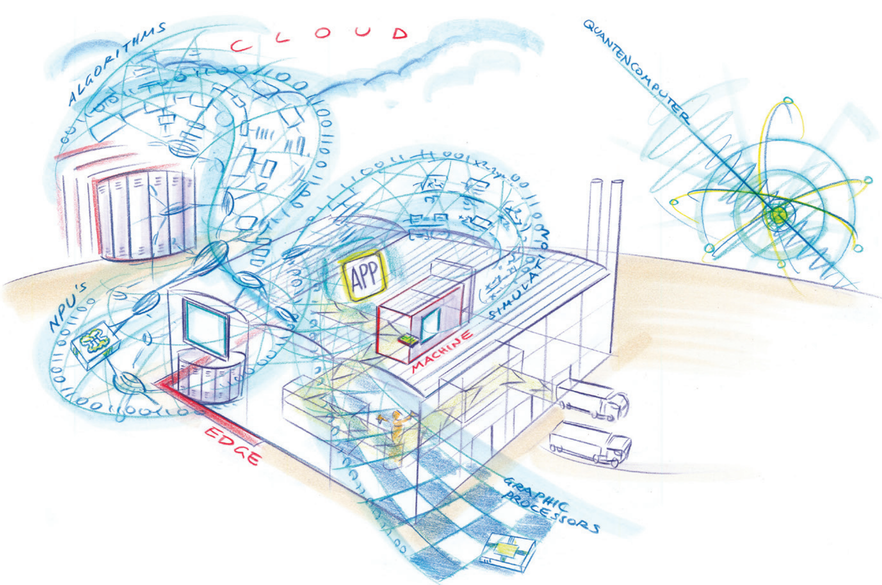
Today, simulation models already are a core functionality of digital twins by means of their seamless assistance along a technical system's entire life cycle. As these capabilities continue to grow, we predict simulation will master more complex tasks and will do so faster because of more advanced and innovative algorithms, increased computing power, and novel hardware architectures. This takes place hand in hand with an increasing complexity of systems, which are partly enabled by these powerful simulations.

While we do not expect disruptive developments in the development of algorithms, we do foresee many micro-disruptive steps within specific areas. E.g., algorithms for simulation today are often based on the so called 'finite element method', in which an object is subdivided into a grid of small elements. Sophisticated algorithms then calculate values like temperature behavior for each element. Combined with the use of Graphics Processing Units (GPUs), which allows a large number of parallel calculations, these simulations become multiple times faster than before.

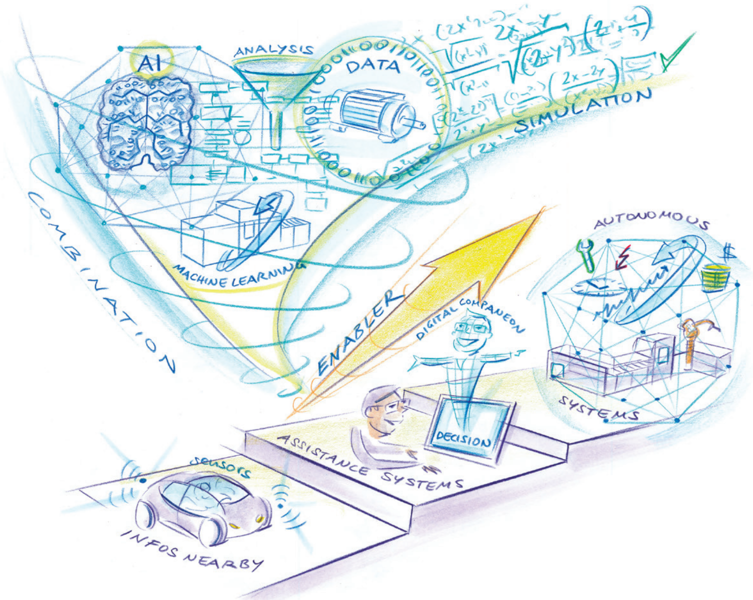
Alternatively, simulation approaches such as Model Order Reduction (MOR) are investigated, as some of which bypass the classical meshing and discretization process. They work directly with the shape and geometry information, offering accelerations in terms of orders of magnitude, thereby enabling real-time usage.

One key challenge is a more and more heterogeneous distribution of computing power, away from the desktop towards the cloud as well as edge computing. This will force simulation models to adapt to a variety of different hardware architectures, platforms and operations systems. Of note, even though Quantum Computing is currently much hyped, it will likely not play a significant role for simulation, although it may have value for special applications.

Other hardware developments – such as Neural Processing Units (NPUs) and Tensor Processing Units (TPUs) – lend themselves toward Machine Learning (ML) and AI applications. Improved algorithms for simulation in combination with ML and AI methods will form the basis of state-of-the-art digital twin and simulation methods by 2030 and improve simulation and digital twin applications as well.



Simulation algorithms will evolve and spread



Combination of AI and simulation supports the evolution of digital twins

Combination Of AI And Simulation Will Facilitate Progress

Machine learning, artificial intelligence and simulation can work together to analyze, understand, predict, and optimize complex systems, but they go about it in different ways: ML and AI rely on data, while simulation is typically based on physical models.

Both approaches have been developed with little interaction over the last years. Today, design and engineering are mostly dominated by simulation, while operation and service mainly employ ML and AI. Going forward the advantages of each approach will be combined, enabling new solutions.

The strength of each approach compensates the other's weakness: Simulation requires very deep expertise in the application area, high manual effort and is limited to phenomena which are well understood and descriptive in a predictive way. Here AI/ML can help out: They offer flexible approaches for (big/mass) data, which are not well understood yet. On the other hand, there is a high chance for AI/ML to fail if applied to novel areas with limited data, whereas simulation probably will do much better, as long as an area is well understood.

Therefore, combining both approaches will be a key enabler for tomorrow's digital twins of complex systems.

In fact, in research this is already happening, e.g., with the development of so-called 'physics informed neural networks', which ensures that neural learning represents correct physics. Also, there is significant funding directed to this effort , such as with DARPA's 'Physics of AI' and other similar government funded research, especially in the United States. These physics and simulation models can be way of helping the public to trust and adopt AI-methods more than today.

At the same time more hierarchical approaches combining simulation and ML will also become standard.

This push comes as no surprise considering which systems are considered prime candidates for the combination of AI/ML and physics-based simulation: autonomous systems, such as self-driving cars.

Mobility Management, Railroad Infrastructure

The rail industry has been an early adopter of digital technologies in various domains. Today digital twins are standards for rail technology, including trains, signaling components, building infrastructure, or the rail network, and include contextual data such as gradients, slopes or frequency of use. They are being used over the whole lifecycle – using data sets from older products to optimize designs, feed data streams during operation into models for dynamic scheduling and dispatching, for predictive maintenance, and better End-of-Life management. One important applications is to perform simulations of various scenarios to allow for, among other things, more realistic driver trainings.

In the coming years there will be a focus on enabling semantic technologies to analyze various kinds of data sources with the help of AI. Increasing in-depth know-ledge of the underlying relationship between various systems making up the rail infrastructure will enhance its performance.

In part, this is already happening. For example, Siemens is currently building a digital twin for Norwegian customer, Bane NOR. First, the railway infrastructure is scanned with the help of cameras, lidars and GPS on a modified locomotive. With this data, a digital site survey is performed, meaning identifying and extracting the different system components. After this, a full-scale system layout is created. Based on this, a 3D-model with correct geo-referenced positions is developed. The data provided in this model can then be transferred to engineering tools, helping the customer plan the new European Rail Traffic Management Control System and other infrastructure upgrades.

Beyond infrastructure, another important application of digital twins for the rail industry supports railway stations, as many rail companies also manage built up infrastructure. Currently, Building Information Modeling (BIM) is mainly used for the planning and building of rail infrastructure. By 2030, it can be expected that these models will be extended into extensive digital twins that – aided by AI – predict the performance of rail roads and stations, ensuring improved operations, maintenance and improved planning.

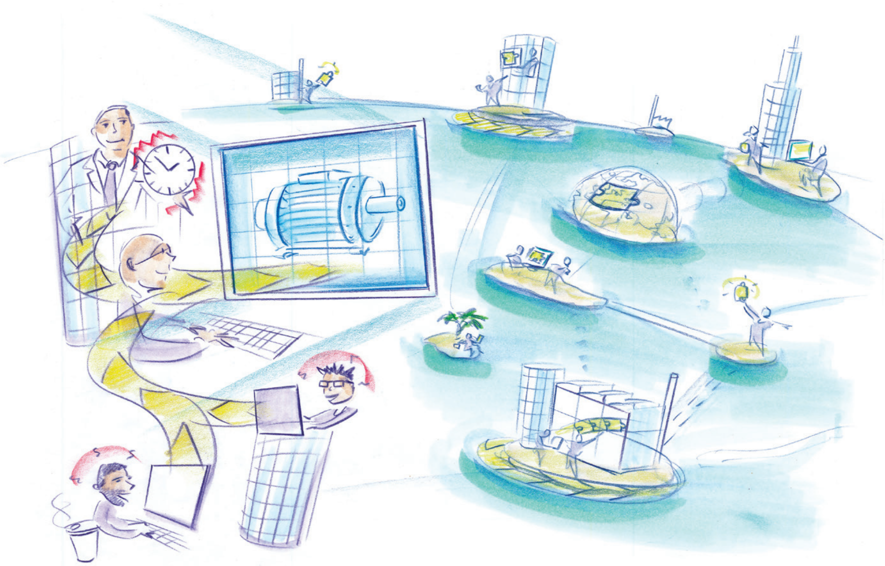
They have to be tested in virtual environments, that are based on the simulation of physics and real-world processes.
At the same time, they also need ML/AI in order to be trained on real- world examples, such as differentiating between animate and inanimate objects, or to be capable of calculating probabilities for critical situations, e.g. if a car may have to brake or initiate evasive maneuvers. Within a decade, we can therefore expect these models to be part of digital twins of autonomous systems that enable reactions in real-time.

Decision support using digital twins based on simulation and ML/AI will feed into so-called 'Digital Companions', which we envision to become part of people's daily lives. One example for such support are assistants that will be used by 'Generative Engineering' systems. They allow engineers to find the best solution not just based on digital twins, but also on a company's entire knowledge base, data on past designs, manufacturing processes, or an engineer's personal preferences. Likewise, in similar fashion these digital assistants will also support operators of plants and infrastructures as well as service engineers.

Finally, the combination of ML/AI and simulation will enable improved workflows and user interfaces that allow not just engineers to use these tools in design and engineering, but also non-experts. By 2030, simplified tool usage based on these technologies will become available for everyone.

Standards Facilitating Sustainable Digital Twins' Economic Success

By 2030, creating a digital twin in many instances will be within reach of many consumers; likewise using a digital twin



Islands of standards – in different domains, different standards will establish themselves within its limitations and restrictions. Passing them on or including them in other systems should become a routine task as well. All of this is facilitated by standards – without them, there is no real productive transfer of digital twins, no use for new applications. Standards facilitate an efficient use of digital twins, and this in turn enables the creation of economic value.

To date, there are no genuine standards developed solely for digital twins. The reason for this is that digital twins are still created within the context of established standards in different domains, such as the automotive or aerospace industries, different disciplines like mechanical or electrical engineering, and with respect to very specific uses, be it testing, production or maintenance.

By 2030, existing standards in these areas – like CAD standards, Functional Mock-up Interface / Functional Mock-up Unit (FMI/FMU), FMI for embedded systems (eFMI), Automation Markup Language (AutomationML), or Building Information Modeling (BIM) – will continue to characterize digital twins. They will not become the main drivers for new standards themselves, but rather their beneficiaries.

It is possible though that within a certain industry vertical a few companies – e.g., a supplier, a systems integrator and a manufacturer – create a quasi-standard if it helps their interests; for example, to enable a fast exchange of digital twins. Regardless, long-term it is to be expected that industries agree on which standards to use for digital twins in order be able to use the models they contain, e.g. for simulation. This will also enable seamless exchanges between various engineering, design or operation tools.

Within the next decade the process of standardization relevant to digital twins will not come to a standstill or even slow down. Since new applications and technologies are continuously being developed, standardization will continue to lag behind these developments, just as it's the case today. Additionally, companies are often hesitant to accept new standards, if they see risks of giving up their Intellectual Property (IP) and losing their competitive edge, thereby delaying their widespread use.

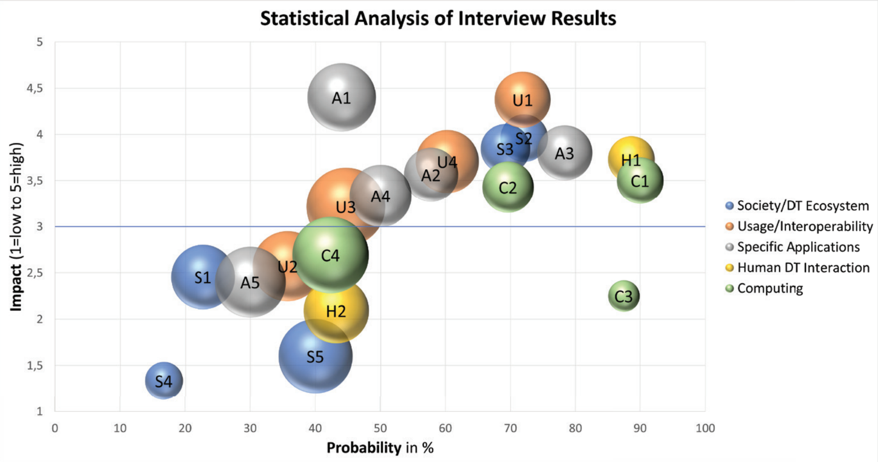
But in the end, it will be a lot easier for digital twins to create real value based on standards. Businesses can use them to create unique products that can be easily traded, incorporated in other systems, and applied towards testing, maintenance or operation. Also, a single digital twin can use encapsulated models to guarantee IP protection for the supplier and include open models which allow further development processes on the customer's end, e.g. for the integration of a product within a car factory.

Our Approach

The technology outlook is based on interviews with approximately 40 experts from industry, universities and research centers. In one to two-hour interviews, we asked them what the state of digital twins and simulation would be by 2030. We did that by confronting them with various hypotheses, which we posed in the form of questions. Each related to a specific aspect of these technologies such as the role of standards, public acceptance or potentially disruptive developments.
All interviewees were asked to estimate (in percent) the probability of these statements to become reality by 2030 and to give an estimate on their relative impact (from 1=low to 5=high).
The table below shows the list of these hypotheses posed as questions.

ID	Hypothesis
S1	Will human society reject digital twins?
S2	Will each technical product have a digital twin?
S3	Will digital twins be valuable good by themselves and will they form their own eco-system?
S4	Will open source does not play a role for digital twins, as it is not as trusted by the public?
S5	Will digital twins always remain a fantasy?
U1	Will simulation be used in design and engineering by everyone without specific skills?
U2	Will artificial intelligence tools / algorithms be the main driver for democratization of simulation within the next 5 years?
U3	Will simulation models be described in a fully standardized way (model content, validity, level of detail, ...)?
U4	Will seamless & accurate model transfer between various tools be possible / standard?
A1	Will virtual homologation by simulation replace all physical tests in homologation?
A2	Will detailed simulation models be trusted more than the experience of domain experts?
A3	Will simulation increasingly be used in safety critical situations to ensure the correct behavior of critical systems?
A4	Will cooperative cyber-physical systems as well as autonomous systems only be realized by artificial intelligence?
A5	Will simulation replace artificial intelligence in operation?
H1	Will technologies from consumer market impact digital twin interaction?
H2	Will emotions / brain interfaces be considered in the design loop?
C1	Will simulation / digital twin applications move from desktops to the cloud and edge?
C2	Will simulation adapt to faster innovation cycles of computing hardware?
C3	Will quantum computers not play any role for simulation within the next 10 years?
C4	Will simulation algorithms see a disruptive development like e.g. model order reduction?

The letters in the ID represent the cluster of questions or hypotheses they were part of (S – Society / DT ecosystem, U – Usage / interoperability, A – specific Application, H – Human / DT interaction, / C – Computing)



Short Analysis

The graph shows the evaluation of all the answers, based on their likelihood of becoming true by 2030, and what their expected impact is (if a certain development is expected to happen). The expected impact is a value expressed in a number between 1 to 5 (low to high). The bubble size indicates the deviation of the answers regarding probability and impact.

Of course, the interviews themselves and their evaluation formed the basis for our 10 statements in this technology outlook. However, here are some short comments on the hypotheses with an expected impact greater than 3.

Hypotheses with an Expected High Likelihood (>75%):

A3: We have a high degree of confidence that digital twins in general and simulations in particular will achieve high accuracy and reliability by 2030, so their use in safety-critical systems is widespread. (related to A2)

H1: The use e.g. of Virtual Reality eyewear in the consumer market has already begun. There is little doubt that this trend will continue. The uses of technologies like this will be taken for granted.

C1: Most interviewees see cloud and edge as part of the wide distribution and use of computing power (ubiquitous computing). In addition to technical requirements (e.g. transfer rates, latency) and technicaldevelopments (such as 5G), cost factors will determine the location of the application.

Hypotheses with Median Likelihood (between 50% and 75%):

A2: A common statement was that it would be of great benefit to pair human knowledge, our power of deduction and intuition with the results of simulations or suggestions of digital twins. For that to happen, simulation and digital twins will have to reach a high level of confidence. (related to A3).

U4: Exchange and reuse of models and other parts of digital twins was mostly regarded as a noble goal, but its feasibility was questioned (related to U3).

Hypotheses with Median Likelihood (between 50% and 75%) continued:

C2: Simulation and simulation algorithms will clearly benefit from improved hardware. Many interviewees also predict some time lag and possibly limited scope of application.

S3: Most interviewees foresee the development of a digital twin ecosystem. Specifics are not clear yet but will most likely depend on the task at hand and the area of application.

S2: Here were had nearly perfect agreement among all interviewees. An important aspect was the cost-benefit ratio.

U1: Nearly everybody we talked to saw a high impact of digital twins and simulation for development tasks due to a large and expanding circle of users. For this not just AI, but also improved workflows and user interfaces will be important.

Hypotheses with a Lower Likelihood (<50%):

A1: All experts agreed that digital twins will depend on their acceptance by society. The strong wording of the question lead to an estimated low probability of occurrence. The fact that in the future many (but by no means all) physical tests can be replaced by simulations was a common theme during the interviews.

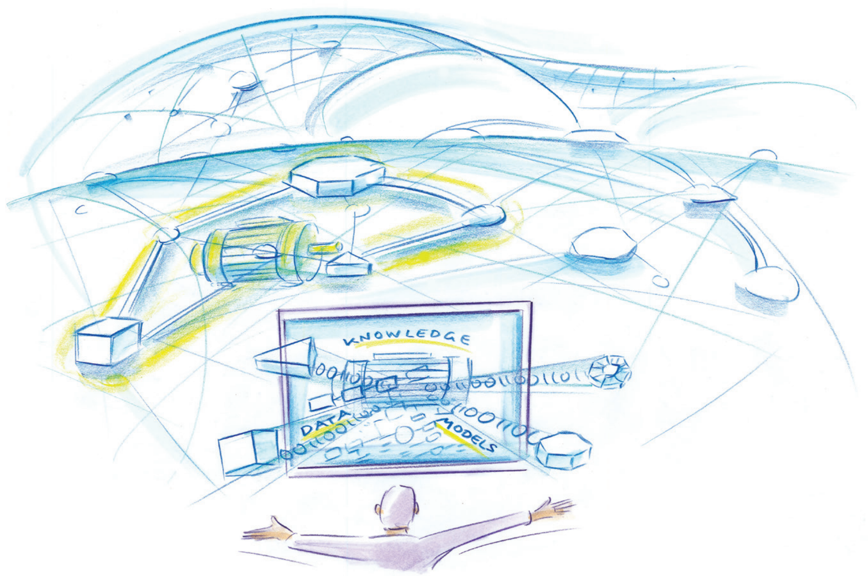
U3: Standardized modeling via modeling languages (or similar approaches) was seen as right, but ambitious goal. However, the variety of modeling aspects and of modeling purposes causes that these standards will probably not be adopted before 2030 (related to U4).

A4: In the opinion of most experts, AI unquestionably includes powerful technologies. In order to realize autonomy, however, additional technologies are needed - simulation being one of them.

Digital Twins Will Be Highly Dynamic

Digital twins – as they already exist in parts in the automotive and aerospace industry, and as they will be used in many other areas by 2030 – consist of descriptive models, i.e. information and data, and executable models, e.g. simulation models, which describe components, products, systems and infrastructures as well as processes. As these models change or are added to, the digital twin changes – digital twins are therefore highly dynamic.

There is a great variety of digital twins' content: They include knowledge and ideas by many people with different tasks and roles, such as design concepts, technical requirements, cost analyses, technical descriptions (e.g. CAD models), calculation data and, in later phases, measurement data and maintenance information.



Digital twins will be highly dynamic

Digital twins are subject to change over time: During development, requirements and corresponding design concepts are being refined. Technical solutions are tested and changed, while outdated information is still retained for documentation. Once in operation, measurement and operating data are added. If the asset is being modified, e.g. components are exchanged, this is mirrored in its digital twin, too. At the same time, they also need to be flexible enough to be part of a hierarchical and changing IT-environment. So overall, an open structure is and will continue to be a necessity for digital twins.

As digital twins include models and data sets of various kinds, it is key for their future development that they are well-aligned with the help of ontologies organizing available data sets and models in such a way that they are commensurable. Based on this, semantic technologies will allow to recognize connections between various data sets and build knowledge graphs. They will also integrate more and more complex behavior models into one digital twin, instantaneously adjusting to modifications which change a product's setup – be it a motor or a plant. It also supplies various other purposes such as service planning.

All this makes it possible for digital twins to be used for various purposes and, in synchronicity with its real counterparts, to react to contextual changes.

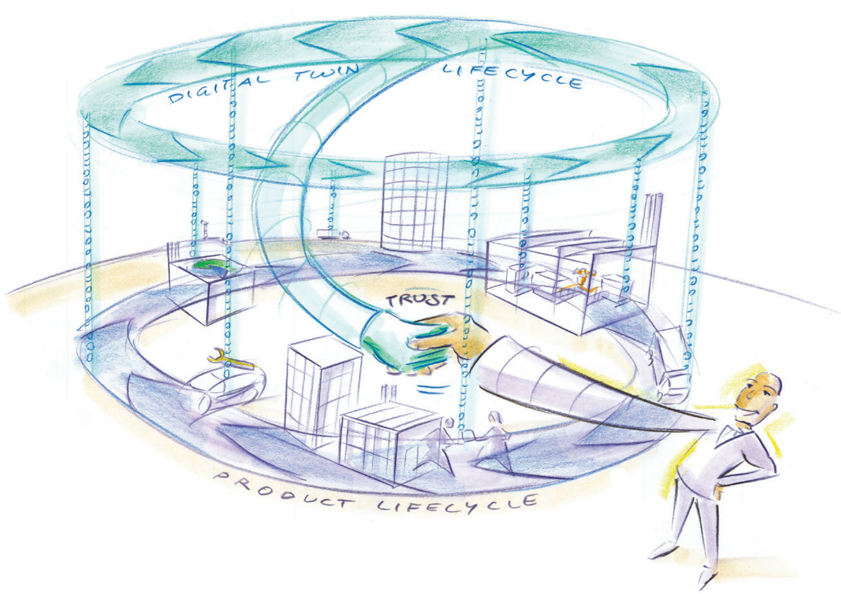
Digital Twins Will Be Highly Trusted

Every day we use virtual maps for navigation while driving or walking. These maps are digital twins, if we consider them not just as representations of technical, but also of physical assets. Today, we use navigation systems based on digital maps without much thinking, because they are convenient, reliable and even more trusted than a local person might be.

Similarly, we also trust other assistants more and more, such as lane keeping assistants in our cars. By 2030, digital twins should have become trusted just as much as these current systems and enable autonomous systems in many other areas.

The situation for simulation models is similar. They are currently widely used for the design and validation of industrial systems. In the coming years these simulations will arise more and more from digital twins.

A prime example in the area of testing and homologation
is autonomous driving. Millions of test kilometers are required to validate autonomous driving functions on all levels. A considerable part of these test kilometers will be executed in a simulated way. Positive experiences like these will increase our trust in digital twins for industrial use. It will also increase the demand of their use for design reviews, validations, tests and virtual commissioning.



Digital twins will be highly trusted

With digital twins becoming established in development, they can also be expected to be used more for applications in operation and service. When operating complex systems like aircrafts, a digital twin running in parallel will make suggestions for appropriate actions that pilots can refer to in critical situations. Likewise, digital twins will enable decision support for operation and service in all industrial areas in addition to human expertise be it for production sites, energy production, or management for infrastructure. Even more, when it comes to interpreting large data sets or complex systems, digital twins may become more trusted than some humans with limited experience and training.

Eventually, by 2030 decisions made with the support of digital twins should be more trusted than those made without. Even more, they will be considered a necessary part of those decisions, not the least because of the complexity of systems being modelled by digital twins. Still, for their continued acceptance it is also important to avoid feelings of powerlessness in the face of digital twins. We need to make sure that all wide-ranging decisions will be made by humans in the end, not by machines.

If as society we see that digital twins are helpful for decisions that matter to us most, we will continue to embrace them.

Better Logistics

By 2030, the logistics industry and its complex supply chains will use an unprecedented number of new data sources. Data is going to be transferred (secure and reliable) to a network of platforms feeding a supply chain's digital twin, thereby enabling – with the help of Machine Learning – its fast, precise and flexible management.

Industry is strongly moving in this direction. For example, Siemens Logistics has extended and enhanced its software portfolio for parcel handling. The so-called 'Hub Booster' uses intelligent software for optimized management of day-to-day parcel operations. Thanks to the real-time collection of operational data, the software automatically generates recommendations for operators and ensures the timeliest intervention possible.

Its modular architecture allows for demand-driven responses, and its nearly complete visibility along the overall process chain assists in operating a hub at optimal performance. For example, it can advise vehicle loading teams on which docks trucks should be changed to avoid loading capacity bottlenecks. The software also provides information on sorter occupancy to detect unbalanced situations. Overall, this increases efficiency, transparency, and quickly allows to respond to challenges such as volume volatility and other unplanned situations.

In short, as digital twins and the simulations they enable become the new industry standard, supply chain management will become more resilient and flexible. Everybody, production companies, logistics partners, and customers will benefit.

Digital Twins Are Deployed Everywhere

A digital twin can be located on a technical product, e.g. with a geometric model describing its physical makeup and a dynamic one fed by sensors. In this case, the place of the digital twin is on the product. A manufacturing plant, on the contrary, consists of multiple subsystems with their own digital twins. These, in turn, are being fed by thousands of sensors collecting data. This data then enables dynamic models located on these machines, on devices and edge computers of a plant's network and in the cloud. They are used for various applications, such as monitoring, efficiency optimization, maintenance projection, or simulation of configuration changes. In these cases, the over-arching digital twin of an asset is located basically everywhere.

Digital Twins Help Process Industries To Achieve Their Goals

By 2030, the continued development of digital twins should lead to full-scale intelligent digital process plants being the new standard. A digital twin of a process plant – with numerous subsystems with their own digital twins feeding data into it – will monitor production in real time using sensors that collect quality and performance data to be sent to dashboards. This will also enable supporting operators with the help of 'Digital Companions' to run a plant smoothly and avoid any critical situations. For production, the digital twin of a plant will also use more data sources than today, like weather patterns, tapping into both structured and unstructured data for insights. Even autonomously operated process plants will be feasible.

One of the major trends in pharma and fine chemicals is towards more modular and flexible plants. More flexible and sustainable production will be made possible for smaller-batch production of pharmaceuticals or special chemicals via standardized, modular, plug-and-produce plants. This is largely enabled with the help of digital twins and simulation,
as they allow operators to make quick changes to production with confidence.

Hand in hand with this, we will see the digital integration across the value chain, connecting supply chain partners and customers via digital collaboration platforms. By driving this horizontal integration, process industry companies can increase efficiency, speed of communication and create value from real time business process data.

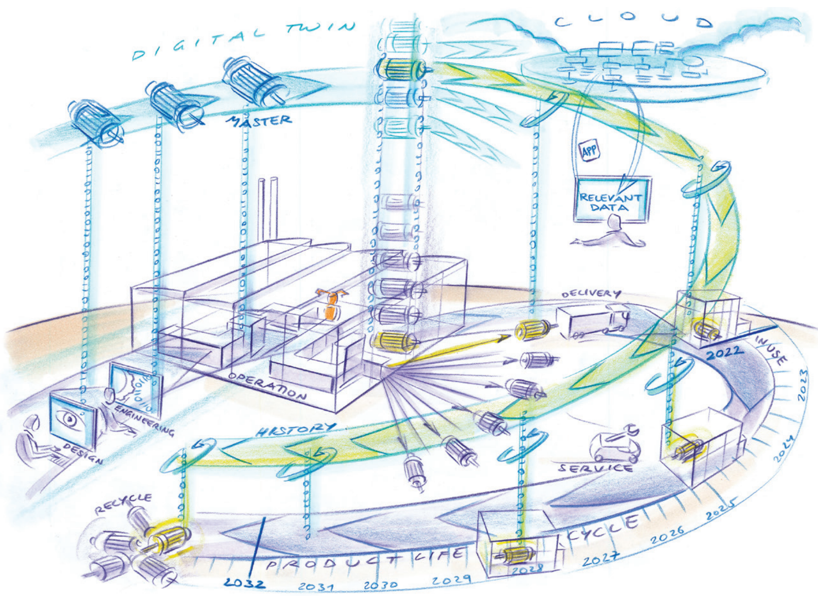
In the end, this will also help to achieve the goal for more sustainable production in process industries, since it will allow to reduce toxic by-products and waste, as well as improve use of energy and materials. For example, in many cases it will enable using renewable feedstocks instead of fossil fuels or mined resources, or to design chemical products that can be reused or recycled.

While digital twins can solely be located on its physical product, it is clear that the trend over the coming years is to put digital twins everywhere – and to call them up when and wherever they are needed.

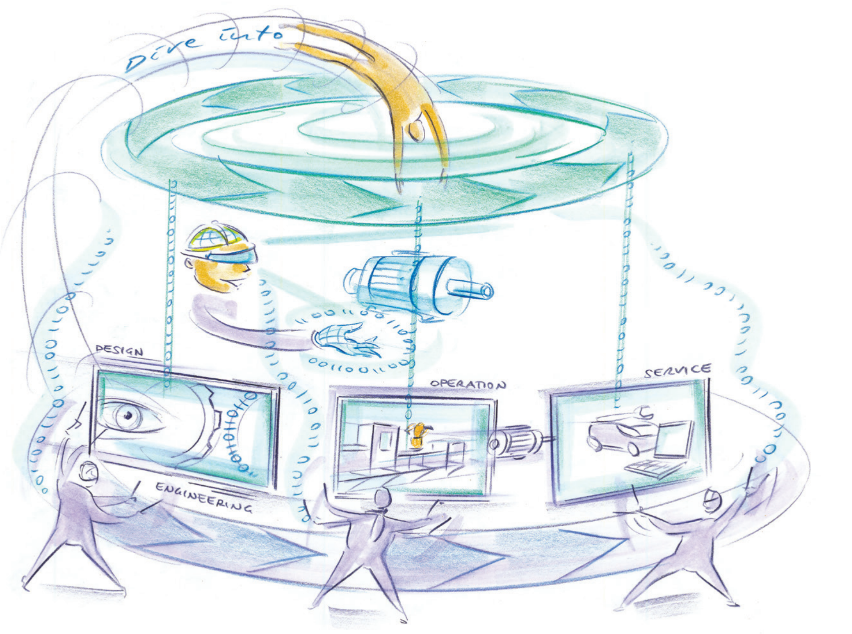
For example, an instance of a digital twin may be found solely on its physical doppelganger, let's say a car, collecting data on gas consumption and running motor diagnostics. While it may not be important or desired to run more applications on this specific vehicle, it may still be helpful to have a link embedded to the manufacturer's cloud. There this car´s digital twin can be connected to more general information on this model – such as causal analysis of common or even specific problems, representing the type of the car as opposed to a specific instance.

This exchange of data – which Tesla already employs – should only happen when necessary, though, as a reasonable handling of data transfers and computing power ensures energy savings and reducing CO_2 consumption. Likewise, it can be expected that limits of data security will be enforced, and safety ensured.

But even more, digital twins are be found throughout the value chain's timeline. For example, data collected through the ideation phase – descriptions such as material properties, thermal and mechanical analysis, electrical and automation aspects – an be part of a product's digital twin during the development phase. Most of this information will probably not be part of the digital twin of the serial product.



Digital twins will be deployed everywhere



Enhanced human digital twin interaction

The serial product's operational digital twin will collect data relevant for running it. Some of this information may be important for other instances and therefore be sent to a 'master digital twin' that links its instances together in the cloud and thereby updates it, but most data probably do not need to be shared.

Finally, when evaluating a product's end-of-life, one could feed its data into a specific digital twin assessing potential reuse or how to recycle it. The paradigm of a 'Circular Economy' is helped by the digital twin concept, as it allows to consider the principle of reuses of a product, spare parts, and even aid with efficient recycling, especially in cases of products made of various materials. At least, data collected by various instances of a product's digital twin can help – after the product is no longer in use – to shape its next generation.

By 2030, therefore, digital twins will not only will be present physically nearly everywhere, throughout the whole product's lifetime and effectively, our whole economy. Their models, applications and data sets will be available where and when called upon within the large and heterogenous digital twin ecosystems stretching from micro controller units to data centers hosting the cloud.

Interaction With Digital Twins Will Become Immersive And Intuitive

Since a digital twin has, by definition, no physical embodiment, interacting with it requires the use of intuitive and efficient human-machine interfaces.

Nowadays, these are often still computer screens and keyboards or even local panels, especially in professional applications. Using these typically requires expert knowledge and therefore limits the use of digital twins to experts. The growing capabilities and thus complexity of digital twins require that user interfaces even for professionals become more intuitive to reduce the complexity of interaction.

While this trend is true for expert applications, it is especially true and necessary when less trained personnel or consumers are supposed to interact with digital twins. The goal of targeting a broader user base for simulation tools and digital twins therefore demands the introduction of easy, efficient and intuitive interaction technologies.

Fortunately, this goal will be supported by an ongoing trend in the consumer area of increased use of Augmented/ Virtual Reality (AR/VR) applications in gaming and other home or leisure applications.

This has two effects: Its deployment at broad scale helps these technologies to mature and to reduce their production cost. Simultaneously, it creates a large base of experienced (non-professional) users of AR/VR technologies who will happily adopt these technologies when interacting with digital twins. For these reasons by 2030 most non-trivial digital twin application will be used through AR/VR or other immersive technologies, including assistance from voice-controls and eye-tracking, which will help establishing digital companions in industrial applications. Naturally, for digital companions in design and engineering it will be a great benefit to have a high-fidelity, real-time digital twin, thereby enabling what is called 'Immersive Human-Digital-Twin–Interaction'.

Further into the future other modalities of interaction will be included. Senses like touch, sound and motion have already started to be introduced in interfaces, and other senses like smell and taste will follow in cases where this brings a real benefit, assuming the required technology matures. Another current field of research is to understand the objectivation of emotions in designs themselves, such as comfort or the feeling of driving a car in the automotive industries.

Today, research also uses AI to understand users' intentions and emotions and incorporates them in various forms of interaction with digital twins. Some of these approaches employ advanced technology like brain interfaces. While we believe that these technologies have useful applications (e.g. for medical, automotive, or other human machine interfaces), we do not expect to see them anytime soon.

Digital Twins Enhance People's Creativity

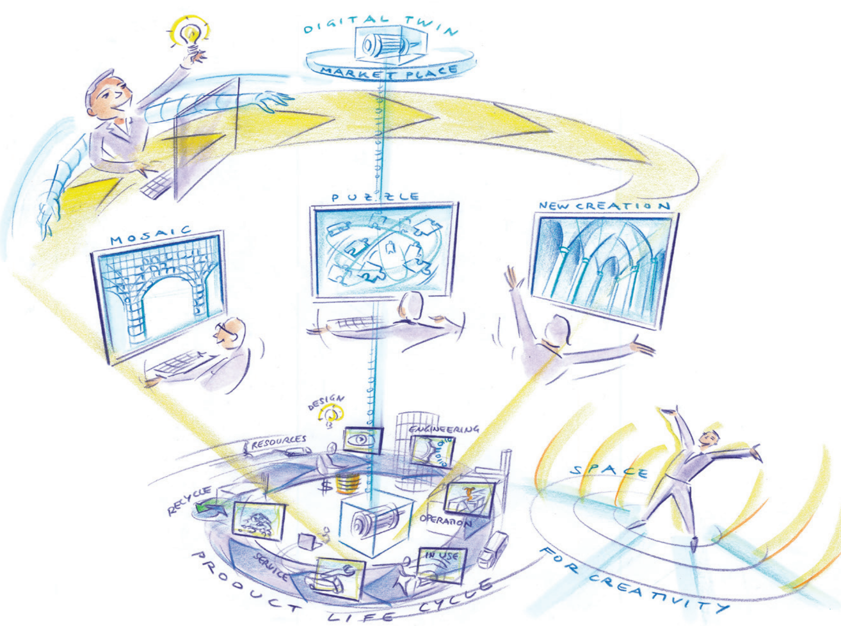
Digital twins – with their well-defined and structured set of data and knowledge – will enhance people's creativity in design and engineering of technical systems, their efforts to optimize a plan for a building or even a manufacturing plant's setup. For example, a digital twin's simulation model can autonomously determine its technical feasibility. This is especially helpful for complex systems which beforehand could not be evaluated accurately or only with much effort.

A concept taking the idea of autonomous support to the next level is 'Generative Engineering'. It refers to an industrial system comprehensively supporting product design with a whole set of tools. These include digital twins and their simulation models; design software generating design options; and AI that analyzes large data sets such a company's earlier designs, or even an engineer's personal preferences. These systems learn with each new project, keeping an engineer's tool set current.

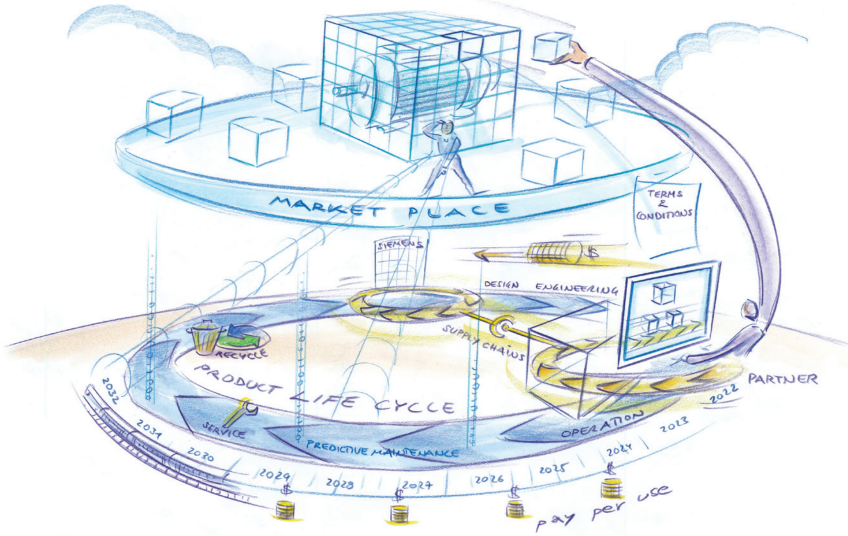
Based on smart dynamic platforms like these, an engineer saves time in order to pursue other, more creative tasks by adjusting and directing the design of a technical system. Also, engineering teams with members who have different priorities get more time to work out inventive solutions to their problems if they are not bogged down by what will soon be considered menial tasks.

These advantages do not just concern design and initial engineering, it extends to all phases of the lifecycle by reducing time and effort for many tasks. They free up time which equals more time to deal with other issues. For example, spending less time on standard operation and maintenance tasks means that personnel can focus more complex questions such as plant-wide improvements or implementation of new production machines.

Finally, people who are not professional engineers, architects or part of another technical profession can get creative with the help of digital twins.
They enable them to find solutions for problems they couldn´t tackle beforehand. For example, decisions regarding the energy system for a house can be designed quickly based on a digital twin's simulation models.



Digital twins will empower human creativity



Digital twins will help and be part of various business models

Building A Future With Digital Twins

More and more, digital twins and simulation will become an essential part of our technical future. Along the value chain from design, operation, maintenance, to end-of-life-management, situated within their own ecosystems, these tools will be indispensable – for production, autonomous systems or digital companions – helping us to navigate complicated tasks.

But recognizing the future does not relieve industry, researchers, any stakeholder from the responsibility to take action to make this future become reality. For example, automation is not just driven by our technical prowess, but by sheer need, as we must counter climate change, conserve resources and deal with a scarcity of qualified personnel.

It is important to have a business case for the application of digital twins. However, with solutions for optimized designs, increased efficiencies, more flexibility, and higher production, these are not hard to find. Digital twins and the applications that enable them are building blocks of our future.

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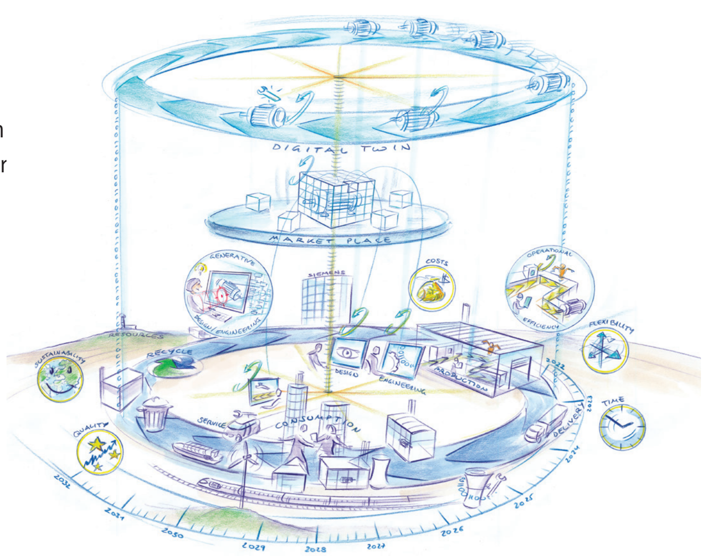
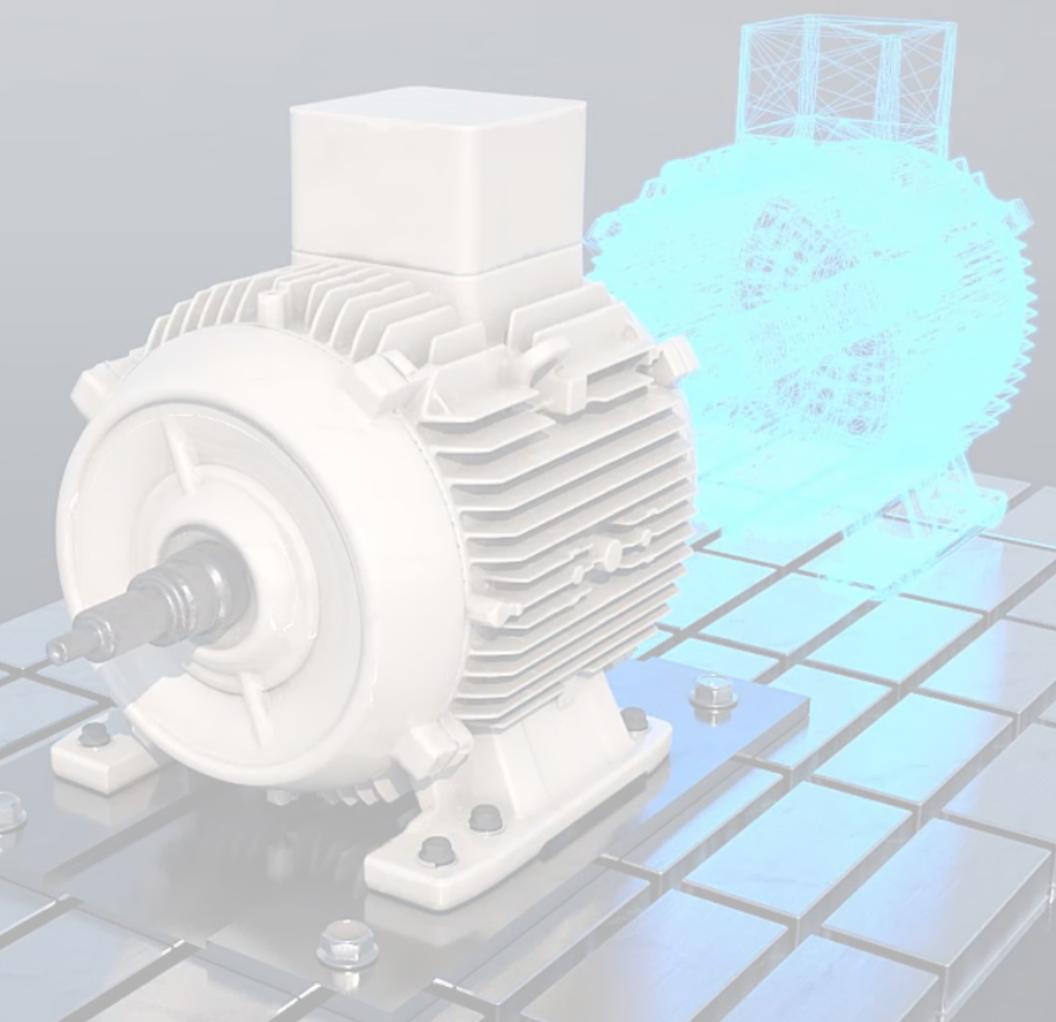


Simulation & Digital Twin



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