DIGITAL TWIN REPORT

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Disclaimer:

The information sourced in this document has been extracted from various companies' websites and reports and are written in their words to preserve the integrity of the industry experts' knowledge and descriptions of software. All information that has been derived from outside sources has been cited from its original content and we do not claim ownership of it. This document is intended to act as an informative report of the function, capabilities, types, and producers of Digital Twin Technology.

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Abstract

Digital twin technology is a virtual replica of a physical object, process, or system that is used for simulation, analysis, monitoring, and optimization. The technology creates a digital representation of the physical world by capturing data from sensors, IoT devices, and other sources that are used to monitor and control the physical object or system. This data is then used to create a virtual model that can be used to simulate and analyze different scenarios, predict performance, and optimize operations. Digital twin technology is used in various industries, including manufacturing, healthcare, transportation, and consumer products. It has the potential to revolutionize these industries by improving efficiency, reducing costs, and optimizing performance. With continuous advancements in technology and increasing availability of data, digital twin technology is expected to play an increasingly significant role in shaping the future of various industries.

Throughout this paper, we will explore the digital twin market and the product growth rate of the next decade. This will take into account the various geographical locations that are using this technology and in what capacity they are utilizing it. This will be accomplished by exploring various use cases and case studies of companies implementing digital twins, walking through the detailed implementation journey and the results the technology produces. In addition to understanding what a digital twin is, this will also cover the variety of different technology companies and the various offerings and applications of their products. Finally, closing out with the current competitive market for consulting companies operating in the digital transformation space.

Digital Twin Overview

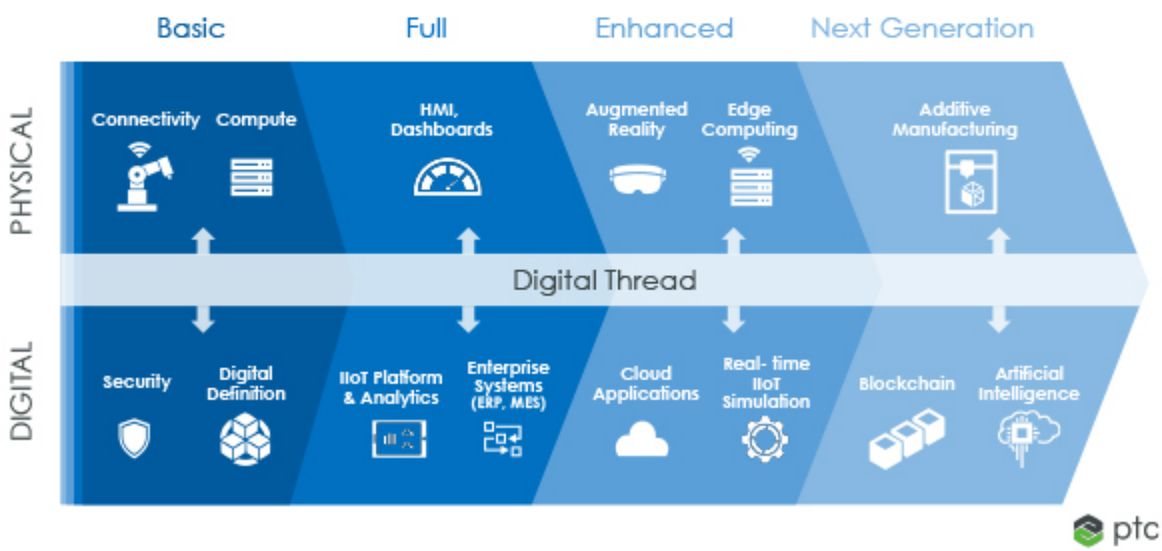
As discussed in the abstract, digital twin technology is a virtual replica of a physical object, process, or system that is used for simulation, analysis, monitoring, and optimization. But to better understand the concept and its inception, we will discuss its origins and development over the course of time. The first concept and real application use was in the 1960s in the aerospace industry. NASA first started developing the concept to help run simulations on the Apollo 13 mission set to take place in 1970. Initially the concept, called basic twinning ideas, was used to create an additional physical model on earth to help simulate any potential mishaps or accidents while the Apollo 13 was airborne. As technology advanced, the physical model was able to be digitalized and NASA was now able to assess and simulate conditions on board the Apollo. During the expedition, the Apollo encountered severe technical complications, however, as a result of the virtual twin NASA created, the engineers on the ground were able to run simulations to assist the Apollo 200,000 miles away.

The first use of the phrase, "Digital Twin" was not mentioned until 1998 and later gained significant popularity in 2002. The last major technological advancement was in 2017, when digital twins became one of the top strategic technological trends in the emerging technology industry. With the enhancement of cloud computing and storage and the emergence of the Internet of Things, digital twins became more cost-efficient, which led to the concept being adapted by companies in a variety of industries.

Source: https://www.challenge.org/insights/digital-twin-history/

What Technologies Are Powering Current and Next-Generation Digital Twins?

There are innovative and emerging technologies spanning the digital twin stack creating tangible business value for smart connected products and smart connected operations use cases. However, each type differs in some form of functionality, complexity, integrations, and technologies. The more technology systems added, the more 'full' the twin becomes, creating a digital thread, which adds challenges and opportunities for enterprise adopters and technology providers alike. Fundamental technologies up-through emerging ones span the physical and digital realms and enable increasingly valuable digital twin outcomes.



Basic Thread

There are a few core underlying technologies to fulfill table stakes requirements of a digital twin, surpassing lighter digital replicas and shadow categorizations in terms of value created. The physical asset must have the compute power to generate data and access to servers on-premises, in the cloud or at the edge for further processing and storage. The means to transmit this data requires reliable connectivity, which can *come in the form of an LTE cellular network for geographically dispersed assets or a private low-power wide area network (LPWAN) in an operations deployment, among others. Any form of connectivity and device with internet access requires prudent security systems ensuring the integrity of the device, network, data, and server. At some level, there must be an accessible digital definition of the asset's historical systems of records, which could include computer-aided design (CAD) models, product lifecycle management (PLM) integrations and increasingly real-time characteristics.*

Full Thread

As the digital twin matures, there needs to be another layer of control and actionability to truly satisfy its term; 451 Research claims that 'Twin implies that what *happens to one happens to the other, in a mutable fashion'. To fulfill this, an IIoT Platform is required to connect, contextualize, and interact with these disparate physical systems as well as provide the virtual lens of the digital twin equipped with real-time sensor data and predictive analytics. Equally important context comes from enterprise-wide business systems integrations at the organizational (ERP) and factory floor (MES) levels. This twin data is made available to a variety of front-line personnel through HMIs, supervisory computers, and dashboards.*

Enhanced Thread

Emerging technologies will elevate functionality and related business impact in the near future. Edge computing and analytics enables the physical connected asset to locally process data, only sending prudent data off the device; a potentially critical factor for transmitting large 3D twin model data files and optimizing an asset's compute power, bandwidth, and latency constraints. This local availability of twin *data could then be extended to front-line worker's increasingly available augmented reality headsets, portraying its digital representation and analytics alongside the physical asset for more immersive experiences. Cloud-based applications and IIoT simulation models further predict real-time machine outcomes based on historical and real-world performance data using the IIoT platform as an insight entryway to further power the digital twin.*

Next-Generation Thread

The future digital twin will have a transformative business effect on revolutionary industrial product models like additive manufacturing. Product designers equipped with real-world operational performance via a feedback loop can adapt virtual product models and 3D print the next rendition or replacement spare parts. Technologies under the artificial intelligence domain, including machine learning and deep learning algorithms, are poised to reveal new operational insights and improve asset efficiencies from these abundant integrated twin data sources. Blockchain provides a decentralized digital ledger capable of validating data feeds from multiple stakeholders in the product life cycle across a supply chain and creating new insights for the twin, improving transparency and security.

Source: https://www.ptc.com/en/blogs/corporate/digital-twin-technologies-driving-adoption

Types of Digital Twin

In addition to the complex digital thread, the term digital twin is also an umbrella term that encompasses several subcategories of digital twins. Across the various industries, there are several types of digital twins that are used in a variety of different applications.

The first twin model is the Product Digital Twin, which is a virtual representation of a physical product. This is most commonly used in manufacturing of products in the consumer products, automobile, aerospace and defense, life sciences and construction sectors. It includes detailed information about the product's design, components, and performance characteristics. Product digital twins are used to optimize product design and development, improve quality control, and enhance customer experience. Companies will often create a digital product and run various analyses and simulations on the product before ever manufacturing a physical product. The creation of a digital product model enables companies to reduce manufacturing and R&D costs by analyzing the product in a digital space.

The next variation of a digital twin model is the Process Digital Twin. A process digital twin is a virtual model of a manufacturing or production process. This model can include one aspect of the manufacturing process or incorporate the entire process flow. The process twin includes information about the process flow, equipment, materials, and environmental conditions. Using data collected during the analysis and simulations run by the virtual twin, the user is able to establish the current KPIs and adjust variable inputs within the virtual process to derive different output results. From the information run in the digital simulations, the company is then able to adjust the physical process flow, which will enable them to optimize production efficiency, reduce costs, and improve quality control.

The third digital twin model is the System Digital Twin. A system digital twin is a virtual model of a complex system, such as a power plant, a transportation network, or a city. This model includes information about the system's components, interdependencies, and performance characteristics. System digital twins are used to simulate and optimize system performance, identify potential issues, and improve decision-making.

Performance Digital Twin: A performance digital twin is a virtual model of a physical object or system that is used to monitor and analyze real-time performance data. It includes information about the object or system's behavior, operation, and maintenance. Performance digital twins are used to detect potential issues, predict maintenance needs, and optimize performance.

Overall, digital twin technology has many applications across different industries, and the type of digital twin used depends on the specific needs and goals of the application.

In addition to the various types of digital twins, there are other technology components that help support and are composed within a digital twin model.

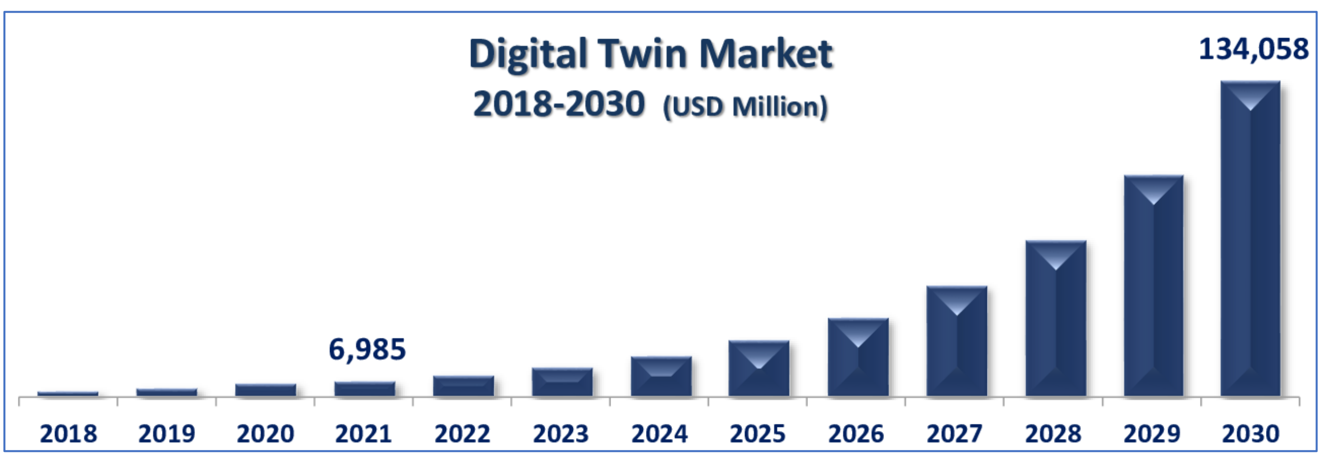
Source 1: https://www.tributech.io/blog/the-4-types-of-digital-twins

Source 2:https://vidyatec.com/blog/the-3-levels-of-the-digital-twin-technology-2/

Industry Growth & Financial Projections

The adoption of digital twins has been growing rapidly over the last few years and will continue to grow over the next decade. It is projected that by 2030, the digital twin market will be $ 134 billion market. The market will be growing at an annual CAGR of 39.3% over the next 10 years.

The projected adoption can be found below.



Source: https://www.acumenresearchandconsulting.com/digital-twin-market

Use by Country

(Altair commissioned an independent, international online survey of 2,007 professionals employed throughout many target industries who perform job functions related to data science, IoT and analytics, software engineering, research, and development (R&D), engineering, information technology (IT) and information systems (IS), product development, and executive management.)

Below are the numbers of professionals surveyed in each country and the graph represents the percentage of individuals that answered yes to using the technology for that specific application:

Individuals per Country

- *United States (N=200)*
- *China (N=200)*
- *France (N=200)*
- *India (N=206)*
- *Germany (N=200)*
- *United Kingdom (N=201)*
- *South Korea (N=200)*
- *Italy (N=200)*
- *Japan (N=200)*
- *Spain (N=200)*

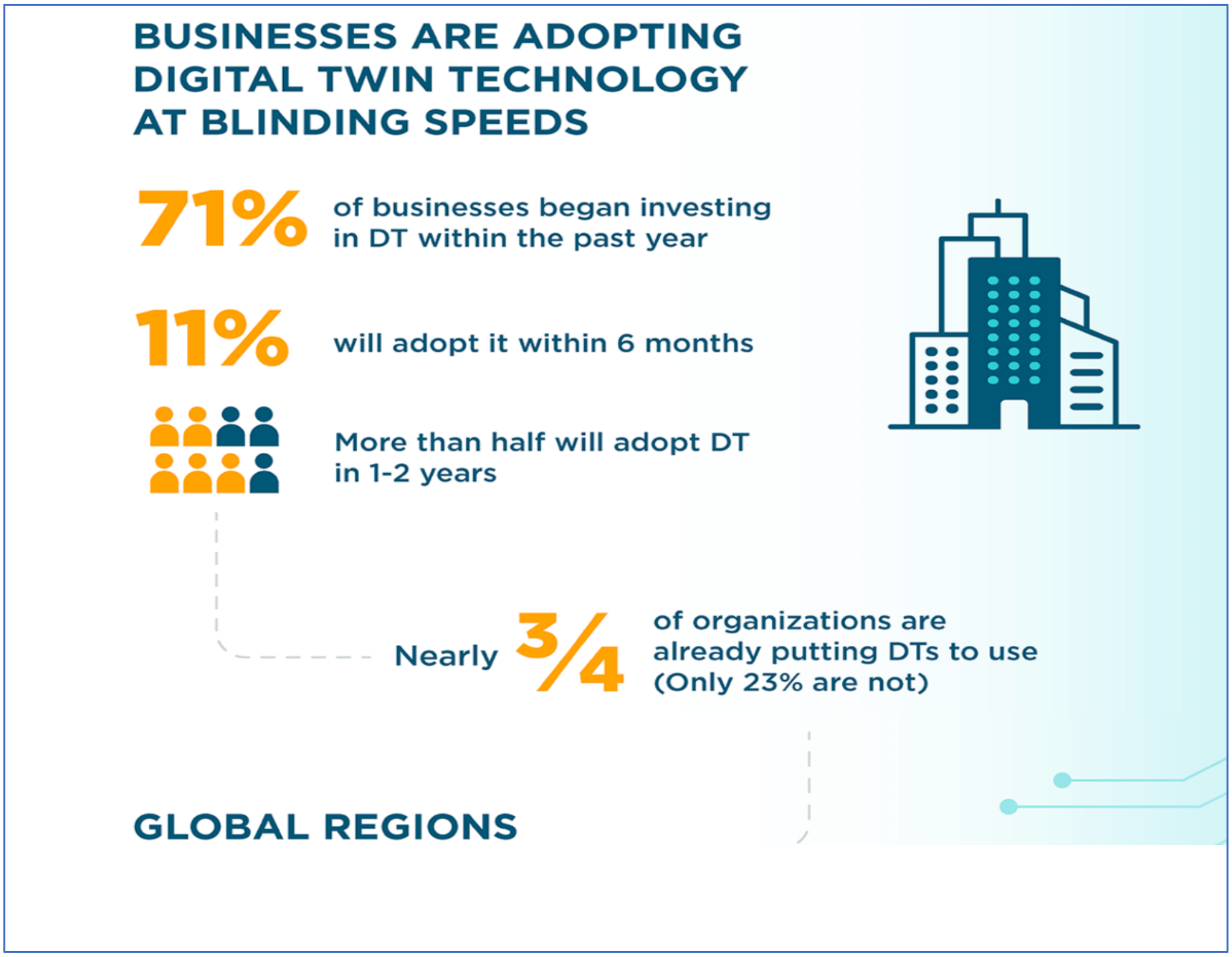
Please find below the results of the research undertaken by Altair.

	United States	China	France	Germany	India	Italy	Japan	Republic of Korea (South Korea)	Spain	United Kingdom
To simulate products that are not yet connected to real-world, physical objects	46%	51%	35%	43%	46%	31%	44%	43%	41%	33%
To digitally monitor (near) real-time state and behavior of real-world, physical objects	49%	57%	43%	50%	59%	53%	49%	51%	41%	38%
To predict the future state and behavior of physical assets using predictive analytics	36%	59%	31%	42%	57%	46%	53%	54%	44%	42%
To create smart digital objects that self-diagnose and recommend corrective or preventive actions on a physical asset	49%	68%	38%	33%	69%	43%	54%	45%	42%	45%
To autonomously operate and fully control the behavior of physical assets	46%	47%	35%	36%	52%	31%	38%	48%	34%	42%
To better understand and optimize a business process	54%	55%	38%	37%	62%	53%	47%	44%	46%	41%
Other, please specify	0%	1%	0%	1%	0%	0%	0%	0%	0%	0%

Source: https://altair.com/docs/default-source/pdfs/altair_dt-global-survey-report_web.pdf?sfvrsn=b5aceaa9_28

Adoption rates

With a technology revolution happening right now with the advancements of artificial intelligence (AI), the Internet of Things (IoT), machine learning (ML), and virtual and augmented reality (VR/AR), companies are quickly realizing the benefits these technologies can provide for them. An overwhelming number of CEOs and executives have begun investing in some form of digital technology. The Altair report states that 71% of businesses surveyed have begun investing in digital twins within the past year and 11% plan to adopt it within the next six months.



Source: https://altair.com/newsroom/articles/why-digital-twin-adoption-rates-are-skyrocketing

Digital Twin Use Cases

Consumer Products

Introduction

Digital twin technology is becoming increasingly popular in the consumer product industry, providing a virtual replica of a physical product or system that can be used for simulation, analysis, and optimization. This technology has the potential to revolutionize product development and design, as well as improve product *performance and reduce costs. This paper explores the role of digital twin technology in the consumer product industry and its potential for improving product development, design, and performance.*

Background

In the consumer product industry, the ability to develop and design products quickly and efficiently is critical to success. Digital twin technology provides a virtual environment for experimentation, optimization, and prediction, helping manufacturers to develop products that meet consumer needs and preferences. The technology has already been applied in several areas of the consumer product industry, including automotive, aerospace, and electronics.

Application of Digital Twin Technology in Consumer Product Industry

Product Design

Digital twin technology can be used to design and test products before they are manufactured. This can reduce the time and cost of developing new products, as well as improve their quality and performance. Digital twins can also be used to simulate the effects of different design options on product performance, allowing manufacturers to optimize their products for different use cases.

Product Performance

Digital twin technology can be used to monitor the performance of products in real-time, providing manufacturers with valuable insights into how their products are being used. This can help manufacturers to identify and address issues with their products before they become major problems, as well as optimize product performance for different use cases.

Supply Chain Optimization

Digital twin technology can be used to model and optimize supply chain operations, helping manufacturers to reduce costs and improve efficiency. Digital twins can simulate the effects of different supply chain strategies and identify areas for improvement, allowing manufacturers to make data-driven decisions about their operations.

Challenges and Limitations

Despite its potential benefits, there are several challenges and limitations to the use of digital twin technology in the consumer product industry. One of the biggest challenges is the availability and quality of data. Digital twins require large amounts of data to accurately model products and systems, and the data must be of high quality to ensure accurate predictions.

Another challenge is the complexity of product systems. Product systems are highly complex and difficult to model accurately, which can limit the usefulness of digital twin technology in certain applications.

Conclusion

Digital twin technology has the potential to revolutionize the consumer product industry by providing a virtual environment for experimentation, optimization, and prediction. The technology has already been applied in several areas of the consumer product industry, including product design, product performance, and supply chain optimization. However, there are several challenges and limitations to the use of digital twin technology in the consumer product industry, including the availability and quality of data and the complexity of product systems. Despite these challenges, digital twin technology is a promising new tool for improving product development, design, and performance in the consumer product industry.

Life Sciences

Introduction

Digital twin technology is a rapidly evolving field that has the potential to revolutionize the life science industry. A digital twin is a virtual replica of a physical product, process, or system that can be used for simulation, analysis, and prediction. In the life science industry, digital twins are used to model biological systems, drugs, and medical devices. This paper explores the role of digital twin technology in the life science industry and its potential for improving patient outcomes.

Background

The life science industry is constantly looking for ways to improve patient outcomes and reduce costs. Digital twin technology can help achieve both objectives by providing a virtual environment for experimentation, optimization, and prediction. The technology has already been applied in several areas of the life science industry, including drug development, medical device design, and patient monitoring.

Application of Digital Twin Technology in Life Science Industry

Drug Development

Digital twin technology can be used to model the behavior of drugs in the body, allowing researchers to optimize dosage and delivery mechanisms. Digital twins can also be used to simulate the effects of different drugs on different patient populations, reducing the need for costly and time-consuming clinical trials.

Medical Device Design

Digital twins can be used to design and test medical devices before they are manufactured. This can reduce the time and cost of developing new devices, as well as improve their safety and efficacy.

Patient Monitoring

Digital twins can be used to monitor the health of patients in real-time, providing doctors with valuable insights into their condition. This can help doctors to make more informed decisions about patient care and improve patient outcomes.

Challenges and Limitations

Despite its potential benefits, there are several challenges and limitations to the use of digital twin technology in the life science industry. One of the biggest challenges is the availability and quality of data. Digital twins require large amounts of data to accurately model biological systems, and the data must be of high quality to ensure accurate predictions.

Another challenge is the complexity of biological systems. Biological systems are highly complex and difficult to model accurately, which can limit the usefulness of digital twin technology in certain applications.

FDA Approval Process

Developing New Drugs

American consumers benefit from having access to the safest and most advanced pharmaceutical system in the world. The main consumer watchdog in this system is FDA's Center for Drug Evaluation and Research (CDER).

The center's best-known job is to evaluate new drugs before they can be sold. CDER's evaluation not only prevents quackery, but also provides doctors and patients the information they need to use medicines wisely. The center ensures that drugs, both brand-name and generic, work correctly and that their health benefits outweigh their known risks.

Drug companies seeking to sell a drug in the United States must first test it. The company then sends CDER the evidence from these tests to prove the drug is safe and effective for its intended use. A team of CDER physicians, statisticians, chemists, pharmacologists, and other scientists reviews the company's data and proposed labeling. If this independent and unbiased review establishes that a drug's health benefits outweigh its known risks, the drug is approved for sale. The center doesn't actually test drugs itself, although it does conduct limited research in the areas of drug quality, safety, and effectiveness standards.

Before a drug can be tested in people, the drug company or sponsor performs laboratory and animal tests to discover how the drug works and whether it's likely to be safe and work well in humans. Next, a series of tests in people is begun to determine whether the drug is safe when used to treat a disease and whether it provides a real health benefit.

FDA Approval: What it means.

FDA approval of a drug means that data on the drug's effects have been reviewed by CDER, and the drug is determined to provide benefits that outweigh its known and potential risks for the intended population. The drug approval process takes place within a structured framework that includes:

- ***Analysis of the target condition and available treatments**—FDA reviewers analyze the condition or illness for which the drug is intended and evaluate the current treatment landscape, which provides the context for weighing the* *drug's risks and benefits. For example, a drug intended to treat patients with a life-threatening disease for which no other therapy exists may be considered to have benefits that outweigh the risks even if those risks would be considered unacceptable for a condition that is not life threatening.*

- ***Assessment of benefits and risks from clinical data****—FDA reviewers evaluate clinical benefit and risk information submitted by the drug maker, taking into account any uncertainties that may result from imperfect or incomplete data. Generally, the agency expects that the drug maker will submit results from two well-designed clinical trials, to be sure that the findings from the first trial are not the result of chance or bias. In certain cases, especially if the disease is rare and multiple trials may not be feasible, convincing evidence from one clinical trial may be enough. Evidence that the drug will benefit the target population should outweigh any risks and uncertainties.*
- ***Strategies for managing risks****—All drugs have risks. Risk management strategies include an FDA-approved drug label, which clearly describes the drug's benefits and risks, and how the risks can be detected and managed. Sometimes, more effort is needed to manage risks. In these cases, a drug maker may need to implement a Risk Management and Mitigation Strategy (REMS).*

Although many of the FDA's risk-benefit assessments and decisions are straightforward, sometimes the benefits and risks are uncertain and may be difficult to interpret or predict. The agency and the drug maker may reach different conclusions after analyzing the same data, or there may be differences of opinion among members of the FDA's review team. As a science-led organization, FDA uses the best scientific and technological information available to make decisions through a deliberative process.

Accelerated Approval

In some cases, the approval of a new drug is expedited. Accelerated Approval can be applied to promising therapies that treat a serious or life-threatening condition and provide therapeutic benefit over available therapies. This approach allows for the approval of a drug that demonstrates an effect on a "surrogate endpoint" that is reasonably likely to predict clinical benefit, or on a clinical endpoint that occurs earlier but may not be as robust as the standard endpoint used for approval. This approval pathway is especially useful when the drug is meant to treat a disease whose course is long, and an extended period of time is needed to measure its effect. After the drug enters the market, the drug maker is required to conduct post-marketing clinical trials to verify and describe the drug's benefit. If further trials fail to verify the predicted clinical benefit, FDA may withdraw approval.

Since the Accelerated Approval pathway was established in 1992, many drugs that treat life-threatening diseases have successfully been brought to market this way and have made a significant impact on disease course. For example, many antiretroviral drugs used to treat HIV/AIDS entered the market via accelerated approval, and subsequently altered the treatment paradigm. A number of targeted cancer-fighting drugs also have come onto the market through this pathway.

Drug Development Designations

The agency also employs several approaches to encourage the development of certain drugs, especially drugs that may represent the first available treatment for an illness, or ones that have a significant benefit over existing drugs. These approaches, or designations, are meant to address specific needs, and a new drug application may receive more than one designation, if applicable. Each designation helps ensure that therapies for serious conditions are made available to patients as soon as reviewers can conclude that their benefits justify their risks.

- ***Fast Track*** *is a* ***process*** *designed to facilitate the development and advance the review of drugs that treat serious conditions, and fill an unmet medical need, based on promising animal or human data. Fast tracking can get important new drugs to the patient earlier. The drug company must request the Fast Track process.*

- ***Breakthrough Therapy*** *designation expedites the development and review of drugs that are intended to treat a serious condition, and preliminary clinical evidence indicates that the drug may demonstrate substantial improvement over available therapy. A drug with Breakthrough Therapy designation is also eligible for the Fast Track process. The drug company must request a Breakthrough Therapy designation.*

- ***Priority Review*** *means that FDA aims to take action on an application within six months, compared to 10 months under standard review. A Priority Review designation directs attention and resources to evaluate drugs that would significantly improve* ***the*** *treatment, diagnosis, or prevention of serious conditions.*

FDA, Implementation & Benefits

FDA

- The process is submitted for FDA's approval.
- FDA analyses the digital twin implementation process for drug manufacturing and approves the drug to be produced in small batches for clinical trials.
- Phase I, II and III of human trials are conducted and during this phase the predictive modelling used in digital twins is perfected further to make the drug better and this in turn is incorporated back into the manufacturing process to optimize the process.
- Best version of the drug is created for mass production.
- FDA approves the newly developed drug for mass production.
- Digital Twin tech is used to optimize the production process, the supply chain for distribution, collection of data (how effective the drug is), and predicting the future positive & defective nature of the drug.

FINAL PRODUCTION AND BENEFITS !

Ansys

- Identified/optimized data for planning, sourcing and quality
- Reduced equipment failure by 30%
- Reduced revenue loss
- Improved product quality by 40%
- Helped improve manufacturing efficiency by 15%
- Got FDA approval for launch of new drugs in the space.

FDA APPROVES DIGITAL TWIN FOR MAMMOGRAM TESTING

STEP 1

FDA team simulated the Virtual Imaging Clinical Trial for Regulatory Evaluation (VICTRE) study for digital breast examinations.

STEP 2

2,986 in silico patients created to evaluate performance of Digital Breast Tomosynthesis (DBT) as a replacement of full-field digital mammography

STEP 3

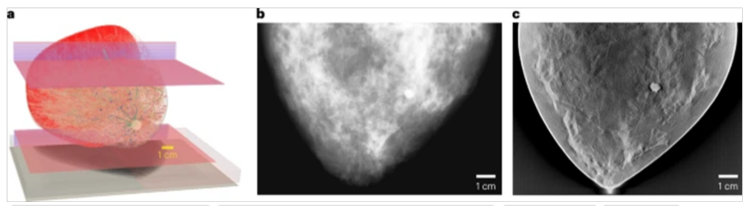
Study demonstrated that simulation tools may be viable sources of evidence for regulatory evaluation of imaging devices.

STEP 4

The entire imaging chain was simulated and validated, including virtual patients with and without breast cancer, 2D and 3D X-ray mammographic image acquisition processes and image interpretation.

RESULTS

The increased lesion detectability of DBT in the VICTRE trial was consistent with the results from a comparative trial using human patients and radiologists that was submitted to the FDA in a pre-market application for approval of a DBT device.



A virtual breast model (a) corresponding mammography (b) and DBT (c) images simulated with a digital twin of a clinical X-ray imaging device. [41]

Conclusion

Digital twin technology has the potential to revolutionize the life science industry by providing a virtual environment for experimentation, optimization, and prediction. The technology has already been applied in several areas of the life science industry, including drug development, medical device design, and patient monitoring. However, there are several challenges and limitations to the use of digital twin technology in the life science industry, including the availability and quality of data and the complexity of biological systems. Despite these challenges, digital twin technology is a promising new tool for improving patient outcomes and reducing costs in the life science industry.

Digital Twin Implementers

Siemens

Siemens Company Core Technologies

1. *Additive Manufacturing & Materials*
2. *Sustainable Energy & Infrastructure*
3. *Connectivity & Edge*
4. *Cybersecurity & Trust*
5. *Data Analytics & Artificial Intelligence*
6. *Power Electronics*
7. ***Simulation & Digital Twin***
8. *Automation*
9. *Integrated Circuits & Electronics*

Siemens approach to the Digital Twin

The Siemens approach to the Digital Twin covers the entire lifecycle of assets, from their design and production to operation, servicing, and maintenance. They build digital twins for products like trains, machines, and aircraft and for complex systems like buildings, chemical plants, and electricity grids.

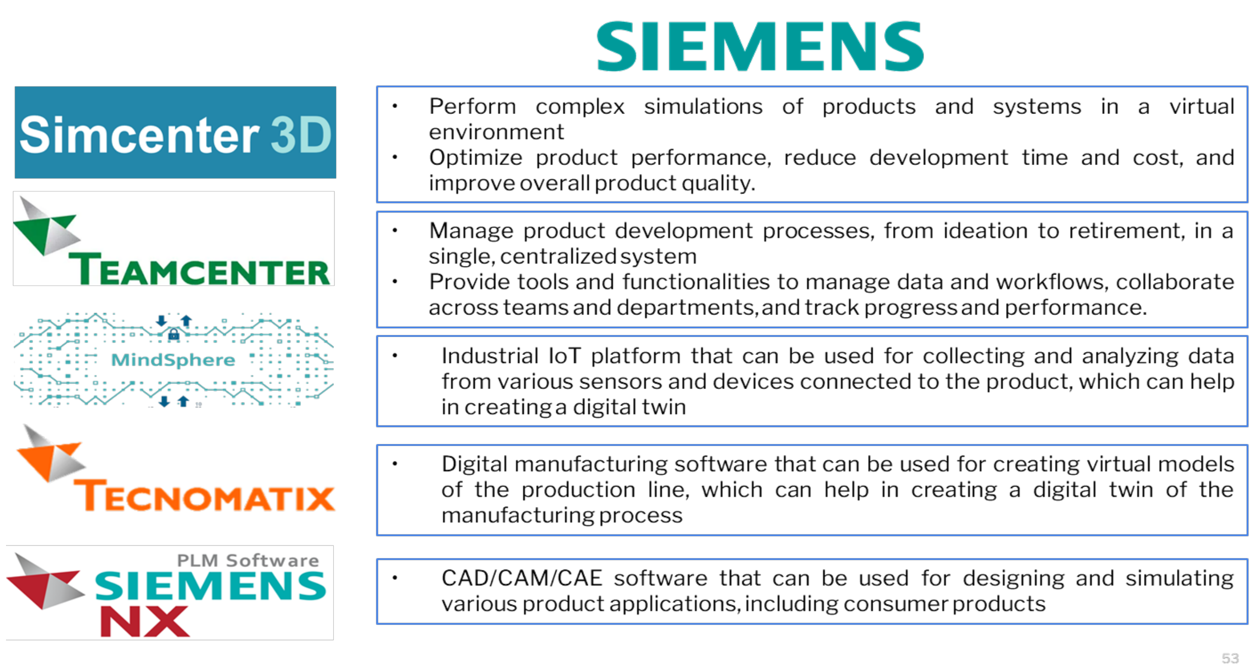
Simulation is the execution of a (mathematical) model to study the object's behavior and predict and optimize its performance along its lifecycle. The generated performance data captured in the physical world, enables a continuous and open loop of optimization for both the product and the production.

At Siemens, they build complex technological products. Siemens creates digital twins of their products so we can design them faster, make them more powerful, and enable their customers to operate them more effectively.

Siemens' s software solutions also provide their customers with tools to create and use digital twins for their own products.

While those products and solutions cover a broad range of applications, there are significant universal challenges across the domains that we address in the CCT Simulation and Digital Twin such as the simulation of complex multi-physical and multidisciplinary systems; semantics and knowledge graph technologies to create a digital twinfabric; combining machine learning and simulation; Siemens executable digital twin that can be leveraged in real time during the operation of an actual asset; generative engineering methods for automated support of design engineers; and virtual and augmented reality technologies.

Software/Platform



Major Players and Solutions in Various Industries

CONSUMER PRODUCTS

CONSUMER PRODUCTS — DASSAULT SYSTEMES

3DEXPERIENCE

- Platform for product lifecycle management (PLM) that can be used for managing product data and digital twins throughout the product lifecycle

CATIA

- CAD/CAM/CAE software that can be used for designing and simulating various product applications, including consumer products

SIMULIA

- Used to simulate the performance of various consumer products, such as household appliances, sporting goods, and personal care products.
- Simulation capabilities can help optimize product performance, reduce development time and cost, and improve overall product quality.

DELMIA

- Digital manufacturing software that can be used for creating virtual models of the production line, which can help in creating a digital twin of the manufacturing process

E-commerce – Consumer Products — ptc

thingworx

- Industrial Internet of Things (IIoT) platform that can be used to create and manage digital twins of various product applications, including consumer products

creo®

- Create a 3D CAD model of a physical product, which can then be used as the basis for a digital twin.
- Used to simulate the performance of a consumer product in a virtual environment such as heat transfer, structural integrity, and fluid dynamics.

windchill®

- Product lifecycle management (PLM) software that can be used for managing product data and digital twins throughout the product lifecycle.

vuforia™

- Augmented reality (AR) platform that can be used to create interactive experiences and visualize digital twins of products in real-world environments.

kepware®

- An industrial connectivity software that can be used to collect and integrate data from various sensors and machines

Life Sciences

Ansys

Ansys TWIN BUILDER

- Platform for building, validating, and deploying digital twins. It includes tools for modeling, simulation, and analytics and can be used for medical devices, drug development, and patient simulations.

ANSYS FLUENT

- Computational fluid dynamics (CFD) software that can be used for modeling fluid flow, heat transfer, and chemical reactions. Used in drug delivery, bioreactors, and medical devices.

Ansys MECHANICAL

- Finite element analysis (FEA) software that can be used for modeling and analyzing the mechanical behavior of structures, fluids, and Multiphysics systems. Used for implant design, tissue mechanics, and medical devices.

Ansys LS-DYNA

- Software tool for simulating complex, nonlinear, and transient phenomena in biomedical applications. Used for Crash and impact analysis, Biomechanical modeling, and Medical device design

ANSYS Chemkin Pro v17.0

- Software tool for modeling complex chemical kinetics and reacting flow problems such as Combustion modeling, Chemical reaction modeling, and Atmospheric chemistry modeling.

ALTAIR

Altair HYPERMESH

- HyperMesh is a software tool for finite element modeling and meshing, which enables users to create and modify complex 3D models of biomedical structures, such as bones, implants, and soft tissues, and prepare them for simulation using FEA methods

ALTAIR HyperWorks

- HyperWorks is a suite for simulation and optimization, which includes tools for FEA, computational fluid dynamics (CFD), and electromagnetics simulations. Can be used for medical device design and optimization, drug delivery simulations, and patient-specific simulations

Altair AcuSolve™

- Finite element analysis (FEA) software that can be used for modeling and analyzing the mechanical behavior of structures, fluids, and Multiphysics systems. Used for implant design, tissue mechanics, and medical devices.

Altair FEKO Comprehensive Electromagnetic Solutions

- FEKO is used for electromagnetic simulations, which enables engineers and researchers to model and simulate electromagnetic fields in and around biomedical devices, such as MRI machines, pacemakers, and other medical implants.

Construction

AUTODESK

AUTODESK BIM 360

- Allows for the creation of a digital twin of a construction project, which can be used to improve design, construction, and maintenance.

AUTODESK REVIT

- Allows for the creation of 3D models of buildings and infrastructure projects.

AUTODESK AutoCAD 2023

- A design and drafting software solution that can be used to create 2D and 3D models of buildings and infrastructure projects.

AUTODESK INSIGHT

- A simulation tool that allows for the analysis of building performance and energy use. Insight can be used to simulate different scenarios and optimize the design of a building and can be integrated with BIM software to create a digital twin of the project.

AUTODESK RECAP PRO

- A reality capture solution that allows for the creation of 3D models of existing buildings and infrastructure. ReCap can be used to capture real-world data and integrate it with BIM software to create a digital twin of a project.

Manufacturing

IBM

IBM maximo

- Enterprise asset management (EAM) software platform that is used to manage asset lifecycle and maintenance processes. The platform includes tools for managing asset data, workflows, and analytics

IBM Watson

- Internet of Things (IoT) platform that is used to collect and analyze data from manufacturing processes. The platform includes tools for data management, visualization, and analytics.

IBM TRIRIGA

- Real estate and facilities management software platform that is used to manage space and facilities processes. The platform includes tools for managing space data, workflows, and analytics.

IBM Engineering Lifecycle Management

- Software platform that is used to manage product development and manufacturing processes. The platform includes tools for managing product data, processes, and workflows, as well as collaboration and communication tools.

Healthcare

GE HealthCare

GE HealthCare Command Centers

- Real-time monitoring of patient, staff, and equipment data.
- Advanced analytics and machine learning algorithms for insights and optimization.
- Collaboration and coordination across departments and locations.

GE Health Cloud

- A cloud-based platform that is used by GE Healthcare to manage and analyze data from digital twin models. This software allows for real-time monitoring and analysis of device performance, which can help to improve operational efficiency and reduce downtime.

Edison

- It is a digital platform that is used by GE Healthcare to develop and deploy new digital twin solutions for healthcare. Allows for the creation of new applications and services used to improve patient outcomes and reduce costs in healthcare.

Centricity Practice Solution®

- A healthcare information technology platform that is used by GE Healthcare to manage and collaborate on digital twin projects. This platform allows for the sharing of data and models across teams and departments, which can help to streamline development and improve efficiency.

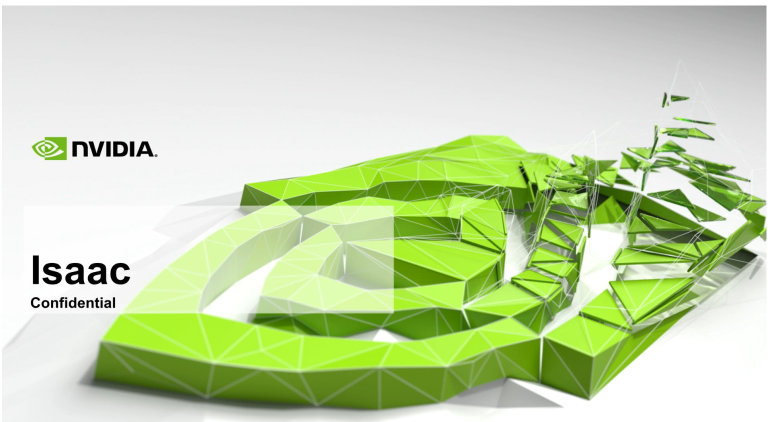
Upcoming Big Player

NVIDIA Solutions for Digital Twins

NVIDIA Omniverse Enterprise

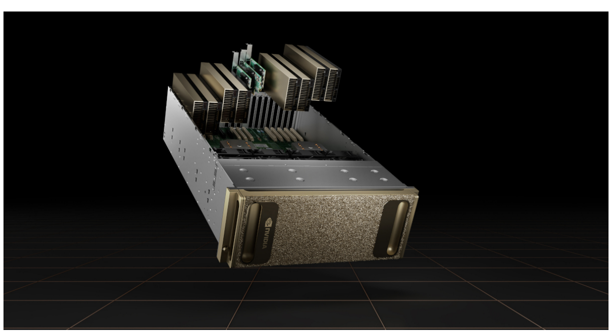
Orchestrate 3D data pipelines to design, develop, and visualize digital twins and large-scale virtual simulation environments.

NVIDIA Isaac Sim



Power photorealistic, physically accurate virtual environments with scalable robotics simulation and synthetic data generation.

NVIDIA OVX



Power digital twins and complex simulation workloads at scale with a purpose-built system.

NVIDIA IGX

Deliver AI safely and securely to support human and machine collaboration.

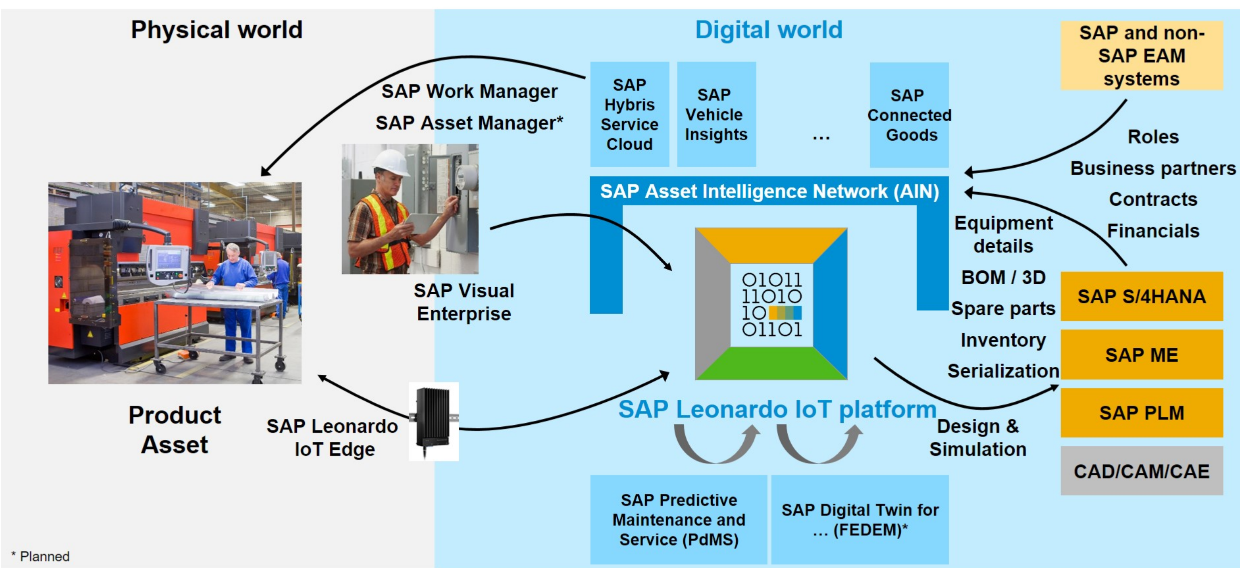
NVIDIA Omniverse™ Cloud

NVIDIA Omniverse™ Cloud is a platform-as-a-service providing developers and enterprises a full-stack cloud environment to design, develop, deploy, and manage industrial metaverse applications.

SAP 's Digital Twin Process

SAP Leonardo portfolio for digital twin

With SAP Leonardo, SAP has launched a complete portfolio to enable the vision of digital twin in a live and networked business ecosystem. The main SAP capabilities of a hybrid solution architecture with components at the edge, in the cloud, and in relevant business and engineering systems are shown here:



SAP Leonardo IoT platform and IoT Edge

Extending SAP Cloud Platform into a comprehensive IoT platform, SAP Leonardo IoT platform services provide digital twin modeling (thing modeler), device management, connectivity, messaging and data ingestion, time series and event storage and archiving, and APIs as the foundation of the digital twin implementation; a corresponding SAP Leonardo IoT Edge component delivers IoT gateway capabilities and local connectivity as well as edge persistence, rules, and streaming analytics.

The SAP Leonardo IoT platform is composed of SAP Cloud Platform Internet of Things and SAP IoT Application Enablement. Edge functionality is delivered via the IoT Gateway component of SAP Cloud Platform Internet of Things and SAP Edge Services for additional persistence and streaming analytics at the edge (see also here).

A great starting point is also the IoT community. The IoT platform will be a focus area at SAP TechEd. Follow this agenda to get started.

SAP Predictive Maintenance and Services (PdMS)

Built on top of the SAP Leonardo IoT platform, SAP PdMS uses sophisticated predictive models to detect anomalies, calculate asset-specific health scores and remaining lifetimes, predict failures, and provide a decision support basis for maintenance schedulers.

An extension is SAP Leonardo Machine Learning. Again, TechEd is a great learning opportunity.

SAP Digital Twin for structural dynamics (planned, based on former FEDEM)

Dynamic structural analysis for physics-based modeling of digital twin provides a sophisticated digital twin. See this video from SAPPHIRE 2017.

SAP Asset Intelligence Network (AIN)

As a cornerstone of the asset network, SAP AIN serves as the shared asset repository and collaboration platform for all business partners during the lifecycle of assets; deeply integrated with the digital twin exposed through SAP Leonardo Foundation services, AIN not only keeps all network participants updated from a single source, but also allows a fine-granular authorization management for collaboration scenarios around the digital twin.

SAP Vehicle Insights

SAP Vehicle Insights is a cloud-based solution to realize a variety of scenarios and new business models for any type of moving assets and connected cars. It empowers fleet decision makers by correlating car fleet telematics data with geo data and business information on a large scale. SAP Vehicle Insights allows to monitor live vehicle conditions and failures to support data-driven remote diagnostic scenarios, and it enables more precise usage-based services and pay-as-you-drive contracting.

SAP Connected Goods

SAP Connected Goods is a cloud-based solution, designed to maximize the value of mass market devices (such as coolers, vending machines, or power tools) through remote monitoring, management, and central control. SAP Connected Goods helps enterprises to reduce operational costs, increase revenue, and improve customer *satisfaction. At the same time, it allows enterprises to avoid lost sales and missed revenue opportunities.*

SAP Hybris Service Cloud

SAP Hybris Service Cloud manages the entire service engagement. Issues created by notifications from digital twins are efficiently resolved while keeping all participants informed across multiple channels.

SAP Asset Manager and SAP Work Manager

The SAP Asset Manager and SAP Work Manager mobile apps provide all information to service technicians and repair teams to efficiently install, inspect, maintain, and repair assets in the field.

SAP 3D Visual Enterprise

SAP 3D Visual Enterprise Solutions combine visual product, plant and process information with textual business content to provide a combination of traditional business information with fully interactive visuals.

Conclusions

Implementing a connected assets or product strategy with a digital twin as the foundation for live business processes and innovative asset- and product-centric business models is a core requirement in every digital transformation agenda for industrial goods manufacturers and asset operators. The starting point for such a journey certainly varies as the immediate business value may be highest in after-

sales service expansion for manufacturers while operators may focus on predictive maintenance or asset risk and performance management. ***SAP Leonardo*** *provides a comprehensive portfolio of software solutions to create tangible business outcomes by implementing digital twins.*

Source 1: https://blogs.sap.com/2017/09/09/digital-twins-and-the-internet-of-things-iot/

Source 2: https://blogs.sap.com/2017/09/09/digital-twin-implementation/

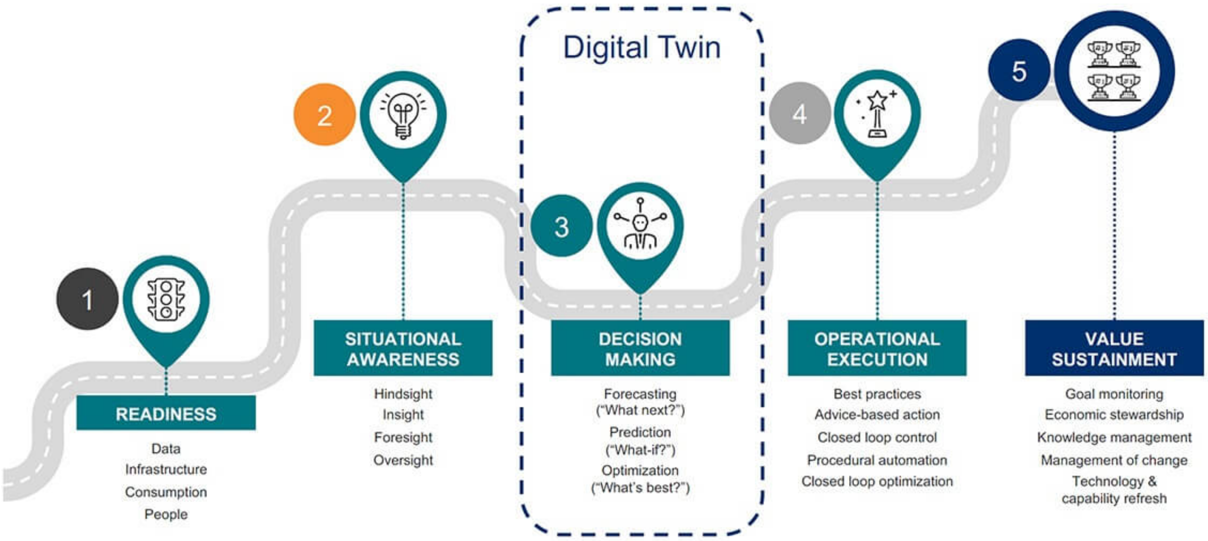
Digital Twin Implementation

Timeline & Journey

At its root, and as its name suggests, digital transformation looks to leverage digital technologies to accelerate business strategy and operations to meet changing market conditions, workforce dynamics, environmental regulations, sustainability goals, geopolitical uncertainties, and other factors.

In a holistic context of process manufacturing, digital transformation focuses on digitization efforts across the areas of asset life cycle, smart manufacturing, and value-chain optimization. It achieves this in part by exploiting emerging technologies in big data, cloud computing, control systems, automation networks, AI, ***IIoT*** *, edge devices, and digital twins.*

More specifically, digital transformation allows process manufacturers to use real-time data to improve plant processes, perform predictive maintenance, identify production bottlenecks, and strengthen their market position through the use of data analytics. The digital twin concept is a vital tool in the process industry's drive toward digital transformation. How so?



01
Identify a Use Case

The most important question to tackle at the outset of your digital twin journey is 'Why do you need a digital twin?', or, rather, 'What problems could a digital twin address for your organization?'

Starting with this simple exercise should help surface opportunities worth exploring further. For example, for manufacturers, discussions might center on highly manual, disconnected, and inefficient operational processes like a section of the production line that frequently goes down and creates process back-ups for teams and customers. Retailers might focus on optimizing the layout of their stores and warehouses to improve customer experience and worker safety and ergonomics.

If you're looking for additional inspiration, check out some examples of how companies spanning energy, manufacturing, retail, telecommunications, and transportation are transforming their organizations and industries with digital twins today.

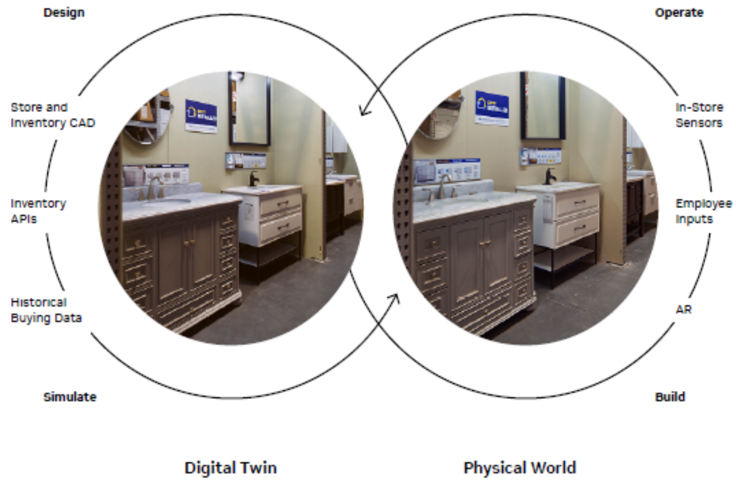
Once you've identified some opportunities for your organization, look to prioritize down to a single use case based on the potential value to the organization, key success criteria, and timelines.

Value	Success Criteria	Timeline
Prioritize a use case aligned with business strategy and likely to deliver not only quick wins but also enough impact to secure executive support and the resources required to pursue it. Whether your focus is on reducing costs, waste, and downtime, improving operational efficiency, or something else entirely, ensure that your use case and plan ties directly to important business objectives and measurable results. Ideally, choose a use case connected to other problems and opportunities across the organization so you can easily scale and replicate success later on.	Defining what success looks like and how it will be measured is critical. You should be able to measure and quantify the impact of your use case. Your initial use case should be supported by readily available data and a good understanding of the processes and environments to be modeled. Establish a clear execution plan with specific, measurable, attainable, relevant, and time-bound goals and milestones.	While starting with a grand vision is tempting, developing digital twins doesn't happen overnight. It's important to break execution down into manageable increments that will deliver tangible business value within a reasonable and realistic timeframe (e.g., 3-6 months). Use key near-term project milestones to build momentum and establish support for scaling your efforts over time.

02
Evaluate Data and Environment

Digital twins, like the physical elements they're modeled on, rely on access to the right data. Therefore, an essential early consideration is whether your target use case can be readily tackled with available data - starting with 3D models or point cloud scans.

While data requirements will vary based on industry and use case, much of the data needed to get started will be 3D in nature. Datasets will likely blend architecture, engineering, product, process, and geospatial data, as well as important metadata. These data will likely be sourced from various CAD, CAE, PLM, MRO, GIS, BIM, robotics, analytics, and IoT systems.



Establish a Data Strategy

Data preparation for digital twins can be extremely time consuming. So, before having teams spend hours collecting and preparing data, establish a clear strategy. Limiting the scope of your initial target use case, as suggested in step 1, will help focus your data strategy.

Identify key stakeholders in the organization with the necessary end-to-end understanding of the relevant data, processes, and environments that must be modeled to create a digital twin that supports your use case. These individuals can help determine which data are required and readily available, who has access to it, where it currently resides, and if it is in a usable format.

Spending time upfront to establish a clear plan for what data are needed and how it will be used will allow you to accelerate your efforts later on.

Partner with Technology and Data Teams

Early on, work collaboratively with your technology and data teams to ensure the right technology and data architectures are in place to support your use case and future ambitions.

For example, you might partner with data engineers and integration specialists to build the appropriate data pipeline, processes, and workflows to support the initial ingestion and aggregation of 3D datasets and models. Work with them to determine how to handle the interchange of data among different tools. For example, due to its power and versatility, Universal Scene Description (USD) is being widely adopted not only in the visual effects community but also in architecture, design, robotics, manufacturing, and other disciplines.

Once these critical foundations are in place and your data and models are aggregated, teams might want to apply photo-realistic materials, lighting, textures, and rendering. This detail will let stakeholders across the organization visualize your digital twin in full design fidelity and share feedback seamlessly, in real time.

Development teams might want to build custom tools to orchestrate and enhance existing workflows.

Engineering and product teams might want to identify sources of proceduralism and add real-world physics to models to simulate and visualize behavior.

And robotics and AI teams might start thinking about bringing in sensors and robotic models, connecting existing AI pipelines, and building synthetic data pipelines to train, test, and optimize autonomous systems.

By proactively working with the right teams to establish a solid foundation and the right technology architecture for your use case, you'll be set up to build momentum and successfully scale your efforts over time.

03
Build a Team

Building a team with the right roles and skills is key to a successful digital twin initiative and digital twin teams will likely look vastly different from any team you've built in the past.

Regardless of your use case and industry, teams will likely consist of individuals from across your internal technology, engineering, data science, and line of business organizations. They might also include extended resources from systems integrators and software development and delivery partners.

Identify Talent Pool

When building your first digital twin team, start by developing a resourcing strategy and identifying your existing talent pool. Prioritize individuals with experience with the assets, processes, and environments you need to model. Also, include those that understand your critical technology and data architectures, as well as individuals with 3D design and programming experience.

Common Digital Twin Team Roles

When building your first digital twin, you can get started by yourself or with a small team of internal or external software engineers and developers and then scale your resources as your use case and needs evolve.

While team size, roles, and skills vary based on industry and use case, here is a reference guide of the kind of roles we've seen working on digital twin teams. Note, this is by no means exhaustive, and you don't require all of these to get started.

Technical 3D Artists (Modelers, Animators, Texture Artists)	> Experience with creating/modifying 3D models in tools such as Autodesk Maya, 3DS Max, Blender, Houdini, Substance 3D, SketchUp, and AutoCAD
Industrial Designers	> Experience with developing models and concept designs for visualization and review in tools such as Rhino, and 3DS Max
Mechanical Engineers	> Experience with CAD, creation of engineering accurate 3D models and assets, and improving meshes to accurately define physics for collisions in tools such as PTC Creo, Catia, and PTC Onshape
Engine/Tooling/Software Engineers and Developers	> Experience with custom Python scripting and partnering with 3D artists to optimize 3D assets in tools such as Unity and Unreal
Simulation Engineers	> Experience using CAE and simulation tools to load, simulate, add constraints, and apply physics simulation in tools such as Matlab, Ansys Fluent, and Paraview
ML Engineers	> Experience with labeling objects in scenes, defining parameters for synthetic data generation, training of AI models, computer vision, text-to-speech, NLP, and reinforcement learning > Experience with Pytorch and TensorFlow
Robotics Engineers	> Experience with ROS, control theory, testing manipulation algorithms in simulation, and development of robotic perception from sensors
DevOps/IT Engineers	> Experience with server installation and configuration, implementing caching architecture, managing access and security through SSL/SSO > Experience with tools such as Docker and Kubernetes
UI/UX Developers	> Experience with designing and implementing UI interfaces with tools such as Adobe Creative Cloud and Figma
Planners and Managers	> Experience with core business operations

04
Start Small

When starting with digital twins, it's tempting to begin with lofty visions and grand plans. Unfortunately, overly ambitious plans often lead to unrealistic expectations, poor execution, and project failure. Instead, keep the scope of your use case small and keep teams focused on delivering a minimum valuable solution.

The Benefits of Starting Small

By starting with a small scope, digital twin initiatives can be ramped up in waves, mitigating the risk of scaling too quickly. Proof of concept projects provide lower-risk environments in which teams can quickly test, learn, and iterate. These smaller projects also allow teams to build momentum quickly, demonstrate organizational impact, and secure the buy-in and resources needed to scale to larger digital twin programs.

05
Measure and Communicate Impact

Digital twins are truly transformational capabilities that enable organizations to unlock incredible operational efficiencies and improve and accelerate organizational decision-making.

As highlighted in step one, you will likely start your journey with multiple opportunities in mind before focusing on one specific use case. Measuring and communicating the impact of this initial proof of concept project is the key to scaling your efforts to other opportunities across the organization.

When communicating the impact of your use case, tie outcomes back to your original problem statement and the goals and outcomes it addresses. By highlighting your progress and success against your initial goals and success criteria, you'll be more likely to drive interest, support, and funding for broader digital twin initiatives.

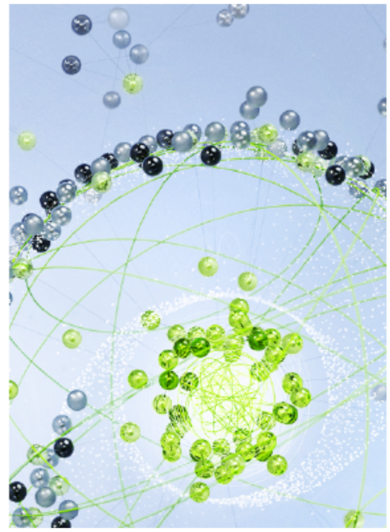
In addition to promoting key wins along the way, be sure to document and share best practices, lessons learned, and key barriers that might prevent scaling your efforts across the organization. Doing so can better guide future digital twin initiatives and increase their velocity.

The Big Picture

Whether you are embarking on your digital twin journey or beginning to scale your efforts, continue to align your plans back to these five important steps and you'll be poised to unlock the vast potential of digital twins for your organization.

To help accelerate and sustain your efforts, continue investing in your purpose, people, and process, and check out our growing library of digital twin resources below.

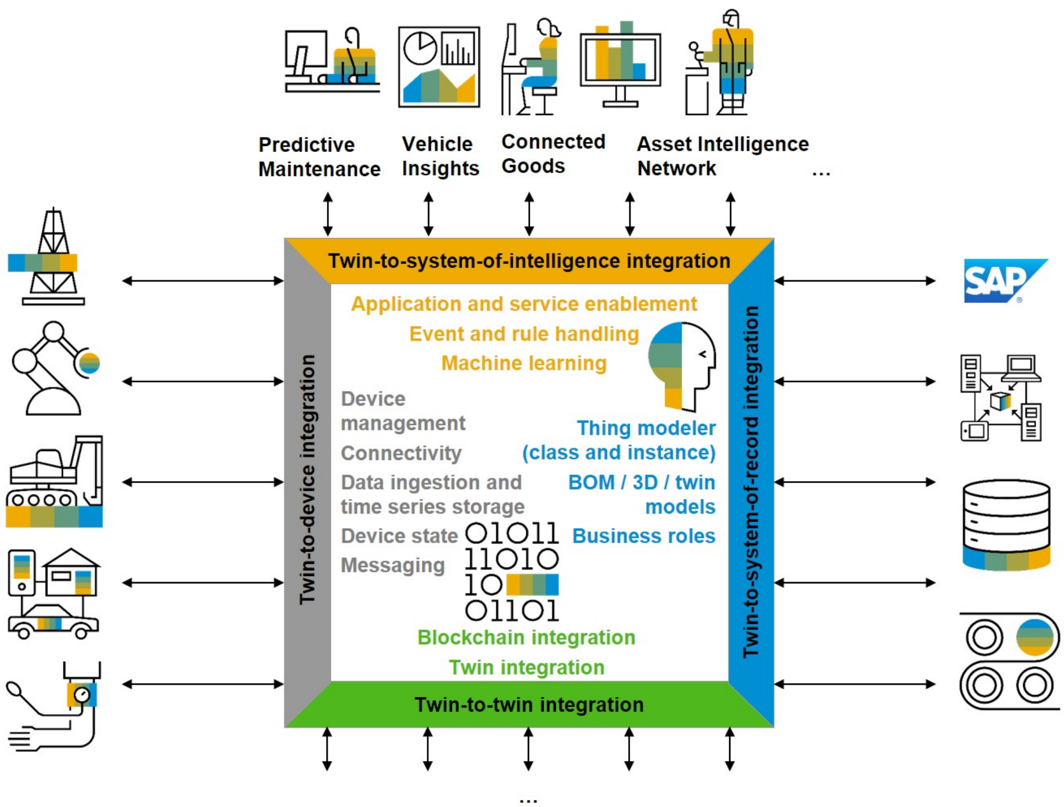
Purpose	> Reflect on what worked well to help guide you to other areas where digital twins can have an impact. This awareness can also help the organization to align on future strategic goals of digital twins.
People	> Invest in digital twin skills, roles, and teams. Seek out networking events and conferences that will help individuals develop interdisciplinary and problem-solving skills.
Process	> Building organizational momentum with digital twins can take time. Continue testing and gathering data to exploit opportunities and gaps in your organization.



Source: https://resources.nvidia.com/en-us-omniverse-industrial-digital-twins/omniverse-enterprise-5-steps?lx=deNrXD

Digital Twin Implementation Concept (SAP)

The actual implementation of a digital twin depends on the intended business outcome and sophistication of business logic. For most connected products and connected assets scenarios described above, the following capabilities and integration scenarios are required:



- ***Twin-to-device integration:*** *The physical object needs to be securely connected and managed. Onboarding established a relationship to an instance. This may happen before installation (e.g., during configuration or production) or after installation (in a two-phased approach with certificates being pre-installed earlier). Streams or batches of live data often require protocol conversion, semantic mapping, and transformation before being ingested into* *a big data store infrastructure. This allows to query object state and historic information captured as time series.*

- ***Twin-to-twin integration:*** *As an optional component, an integration to a digital twin managed by a* ***service*** *provider (e.g. a telematics vendor) or by supplier (e.g. by an automation equipment vendor) may be needed if the physical object is not managed by the provider of the digital twin.*
- ***Twin-to-system-of-record integration:*** *Integration with business information and engineering systems provides essential context along the lifecycle of the physical object.*
    - *PLM for engineering bill of material, components and spare parts, software versioning (for embedded systems)*
    - *CAD/CAM/CAE for 2D and 3D models, layouts, assembly information*
    - *Manufacturing systems for product traceability, serialization, manufacturing bill of material*
    - *ERP for product variants, financial information (e.g. depreciation), equipment and spare parts inventory*
    - *ERP/CRM and supplier networks for service contracts, business partners and roles, SLAs*
- ***Twin-to-system-of-intelligence integration*** *Most digital twins are not consumed directly by end users, but interact with systems of intelligence through events and notifications while exposing condition monitoring and historic information; rule handling, data science algorithms, and machine learning create insight from streams of live data (e.g., anomaly detection, issue segmentation, health scores) and provide predictions on future state (e.g. remaining lifetime, time of arrival forecasts).*

The digital twin implementation will largely be managed from the cloud to facilitate the network-centric engagement models described above. However, most scenarios will distribute actual data and algorithms between an edge or gateway implementation (located on or near the physical object) and the cloud in a distributed architecture. Learning and model development are primary functions in the cloud, however, not all data is relevant to be transmitted. In many cases, only change information and events will be sent into the cloud as a stream while data locally and temporally persisted can be replicated to resolve underlying issues and to evolve algorithms.

Infrastructure

DT will consist of five parts. All these parts are dependent on each other and have an equal role in constructing a full DT. These five main parts are described as follows:

1. ***Physical space:*** *is the physical environment where the physical entities are existing, and the manufacturing activities are performed. It is considered as the main container of all the physical manufacturing resources. This space includes, for instance, different smart devices, machines, materials, sensors, robots, human-machine interfaces (HMI), etc. (Zheng & Sivabalan, 2020 ; Tao, et al., 2019b).*

The various types of physical entities in the physical space are described in detail as follows:

- ***Physical environment:*** *it also refers to the physical world or physical space where the physical entity lies. It refers to any measurable parameter that impacts the environment and entities and can be provided to the digital environment (Jones, et al., 2020).*

- ***Physical component:*** *it can be an individual part of equipment or machine, etc. (Leskovský, et al., 2020).*
- ***Physical object:*** *it can be a product or smart manufacturing device that includes several connected components (Leskovský, et al., 2020). This object cannot interact or execute anything in the real environment (Josifovska, et al., 2019).*
- ***Physical process:*** *it is the activities performed in the physical world (Leskovský, et al., 2020).*
- ***Physical system:*** *it is a combination of many objects, components, etc. (Leskovský, et al., 2020).*
- ***Physical node:*** *is the part that can recognize the physical object and collect its data, operational conditions, and behavioral status and provide it to the digital world. Nodes can also interact with other nodes in order to execute a task in the physical environment. Some examples of these nodes: different types of sensors, smart gateways, actuators, interfaces, etc. (Josifovska, et al., 2019 ; Parrott & Warshaw, 2017).*
- ***Human:*** *humans can be recognized by the physical nodes. However, there is no evidence from the literature that humans can be included in DT's building process, but humans can have a role in the main production process (Josifovska, et al., 2019).*

2. ***Digital space:*** *it is the space where the high-fidelity models of DT are created. It contains all the manufacturing resources in the virtual environment. Further, this space contains different applications and services related to data management, analytics, and computing such as AI, machine learning, cloud computing, etc. (Jones, et al., 2020).*

The modeling process is the basis for making a factual representation of the physical world in the digital world based on real-time data and historical data that help provide information about different aspects of the physical entities and optimize its performance (Tao, et al., 2019b).

3. ***Data:*** *DT is working with massive data that came from different sources with multi-dimensions and scales. Therefore, data is an indispensable enabling part of building the digital models of DT. Data sources can be machinery, historical data, real-world data, virtual world data, products, environment, equipment, services, etc. (Qi, et al., 2019).*

4. ***Services****: it is basically integrated software platforms that include different applications for providing services such as management, improvement, monitoring and prognosis and prognostic and supplying it to the physical or digital world (Barricelli, et al., 2019 ; Qi, et al., 2019). Services can facilitate the application of DT, especially in product design. Other services are called third-party services, which can be achieved through Digital Twin (e.g. data service, equipment service, algorithm service, knowledge service, simulation services, etc.) (Josifovska, et al., 2019 ; Tao, et al., 2019d).*

5. ***Connection****: this part has a significant role in enabling the connection among the physical space, digital space, data, and services; it enables the real-time data transmission between the physical and digital parts. The connection between all Digital Twin parts can be classified into six types: physical-digital models connection, physical-data connection, physical-services connection, digital models-data connection, and digital models-services connection (Qi 2, et al., 2019).*

The fundamental requirements for enabling each part of Digital Twin

DT is a complicated and long operation that requires a diverse mix of technologies and tools for enabling all its parts, i.e. physical space, digital model, data, service, and connection between them. Each part of DT is enabled by a related tool or technology that is significant to facilitate the respective parts' role in the Digital Twin (Qi, et al., 2019). This section presents the main requirements provided with some examples for recommended tools and technologies needed to enable each part of Digital Twin as follows:

1. ***Physical world requirements:*** *the physical world entities must be smart to enable the collection of data, integrate, and coevolve with the digital world. Besides, it is necessary to use different enabling tools and technologies to recognize and control the physical environments, collect its data, and enable its entities to work effectively and safely. Such technologies can be, for instance: RFID, sensors, etc. Using these technologies, the physical world (i.e., entities and processes) are mapped to the digital world to create models that are high fidelity to reality (Qi, et al., 2019).*

2. ***Virtual world requirements:*** *to build ultra-high-fidelity models, the physical world data must be recognized, managed, and visualized to be exploited in the modeling process. By using different sophisticated technologies such as machine learning, artificial intelligence, cloud computing, etc., virtual models will be created to mirror the real world's current behaviors and operating conditions. As the real world is always changing, the virtual models must be updated according to the new changes using related technologies (Qi, et al., 2019).*

The modeling process comprises various types of semantic models, these types are:

- ***Geometric Models:*** *describe and represent the geometric features of the physical objects, for instance: volume, shape, structure, etc. Tools that can be used in these models, for instance: 3D MAX, AutoCAD, etc.*
- ***Physical Models:*** *represent the physical characteristics of the physical entities such as functionality, distortion, deformation, cracking, corrosion, etc. by using different methods such as the Finite Element Model (FEM) (Qi, et al., 2019 ; Tao & Zhang, 2017).*
- ***Behavioral Models:*** *describe the behavior of the physical entities, its reaction to the changes that could happen in the real environment, and its efficiency by using different methods such as Finite state machine, neural network, etc. (Qi, et al., 2019 ; Tao & Zhang, 2017).*
- ***Rule Model:*** *this type of model represents the rules and limitations of the equipment and provides DT with the ability to judge, assess, improve, and predict. Rules can be derived from historical data or expert's knowledge, For instance, using data mining algorithms (Qi, et al., 2019 ;Tao & Zhang, 2017).*
- ***Process Model:*** *this model explains the main process that the physical entity is involved in (Josifovska, et al., 2019).*

3. ***Data:*** *data is considered as a prerequisite for building new knowledge (Tao, et al., 2019d). DT is such a system that deals with large amounts of data generated from different sources. Therefore, data is situated in the center of DT. Using different analytics and fusion technologies, these data are gathered, transmitted, processed, analyzed, integrated, visualized, and stored to extract valuable information from it and show some invisible patterns. All these stages that manage data represent its lifecycle. Arguably, any changes in the operating condition and physical environment will affect and change data.*

Some examples of data sources and how they gathered can be summarized as follows:

- ***Hardware data:*** *this type of data can be gathered from hardware systems by using different technologies such as sensors, IIoT technologies, Barcodes, QR codes, (RFID), etc. (Qi, et al., 2019).*
- ***Software data:*** *This type of data is gathered by using different application programming interfaces (APIs).*
- ***Network data:*** *this type can be gathered through the internet by using different search engines or APIs.*
- ***Historical data:*** *is collected from the physical entity, and it helps in understanding the current and previous situation of the physical entities and predicting its future state (Leskovský, et al., 2020).*
- ***Data related to materials and products such as performance, stock****, etc. are gathered through service systems or from the product or material itself (Qi & Tao, 2018).*
- ***Environmental data*** *which includes the changes that affect the physical environment for instance, temperature, humidity, vibration, etc. (Qi & Tao, 2018).*
- ***Management data:*** *this type comprises data related to the manufacturing information systems and computer-aided systems. It could be related to design schemes, production planning, etc. (Qi & Tao, 2018).*
- ***Customer data:*** *this data are related to customer feedback and comments that are collected from e-commerce platforms and online websites for instance: amazon or social media platforms such as Facebook, LinkedIn, YouTube, etc. (Qi & Tao, 2018).*

4. ***Services:*** *DT requires different services that consist of different software applications, platforms. Services are crucial for providing the real system and virtual space with appropriate services and solutions based on their requirements (Barricelli, et al., 2019 ; Qi, et al., 2019).*

5. ***Connection:*** *different tools and technologies such as networking, communication protocols, communication standards, and interfaces technologies, sensors, etc. are needed to enable two-way communication and data exchange between the physical and virtual world (Barricelli, et al., 2019 ; Qi, et al., 2019).*

Link to the detailed report:
https://drive.google.com/file/d/1fwlsvap0I6pLFWeY5nX52JyOuJNlpCTP/view?usp=share_link

Periodic table

The Digital Twin Capabilities Periodic Table (CPT) is an architecture and technology agnostic requirements definition framework. It is aimed at organizations who want to design, develop, deploy, and operate digital twins based on use case capability requirements versus the features of technology solutions.

The CPT framework facilitates collaboration for teams that need to create digital twin requirements specifications in large-scale, complex environments. The framework keeps the focus on the capability requirements of individual use cases. These use cases can then be aggregated to determine the overall capability requirements, the digital twin platforms, and other technology solutions that are required to address the specific business needs.

The CPT follows a periodic table approach with capabilities grouped or "clustered" around common characteristics. It is easy to interpret at both the boardroom when explaining the business case to get funding for a Digital Twin project, and the shopfloor when gathering requirements for a Digital Twin application. It provides visual guidance for collaboration, brainstorming and making capability requirements explicit.

Periodic table Requirements

1. CAPABILITY VS TECHNOLOGY

Capability is the ability to perform certain actions or achieve certain outcomes. The ability to drill a hole is a simple example of a capability. There are multiple use cases that require holes and each of them will have unique requirements in terms of the size, the depth or the substance that is drilled. This may be one of many capabilities required to complete a project where the hole is part of a successful solution.

The CPT is focused on technology-based capabilities but is agnostic to specific technology or product solutions. For example, machine learning capability can be *provided by several technology providers, each with different products. During the assessment of vendor capabilities, the technology solution should fulfill the technological capability requirement of the business use case.*

The approach used in the Digital Twins Capabilities Periodic Table to describe these capabilities follows a simple structure:

- *What it is (capability name),*
- *What it does (cap-ability description) and*
- *What it means or purpose (what does it enable).*

The CPT is not a reference architecture; it supports multiple architectural approaches. It highlights the capability building blocks for composable digital twins. The Digital Twin Consortium reference architecture provides recommended structures and integrations of Internet of Things (IoT), Information Technology (IT), Operational Technology (OT) and Engineering Technology (ET) products and services to form a digital twin solution. The CPT supports reference architectures that end-users may have developed using their own corporate standards, in addition to the DTC reference architecture.

2. ***ENABLE COMPOSABLE DIGITAL TWINS***

Composable Digital Twins (CDT) is an application development approach for digital twins that is based on the composable enterprise architectural pattern. Composable applications, such as CDTs, focus on faster time to value, service-based orchestration and reusing packaged business capabilities to develop and adapt applications as business requirements evolve.

Packaged Business Capabilities (PBC) are modular combinations of technical capabilities that are presented as bundled services. These PBCs are orchestrated together through an application composition platform to deliver digital twin *applications for specific use cases. The CPT provides a consistent framework to identify the capabilities that can be grouped together to create these PBCs. Figure 1-1shows a composable Digital Twin reference model that outlines the different data types and data sources that are leveraged by PBCs to create reusable and agile Digital Twin compositions.*

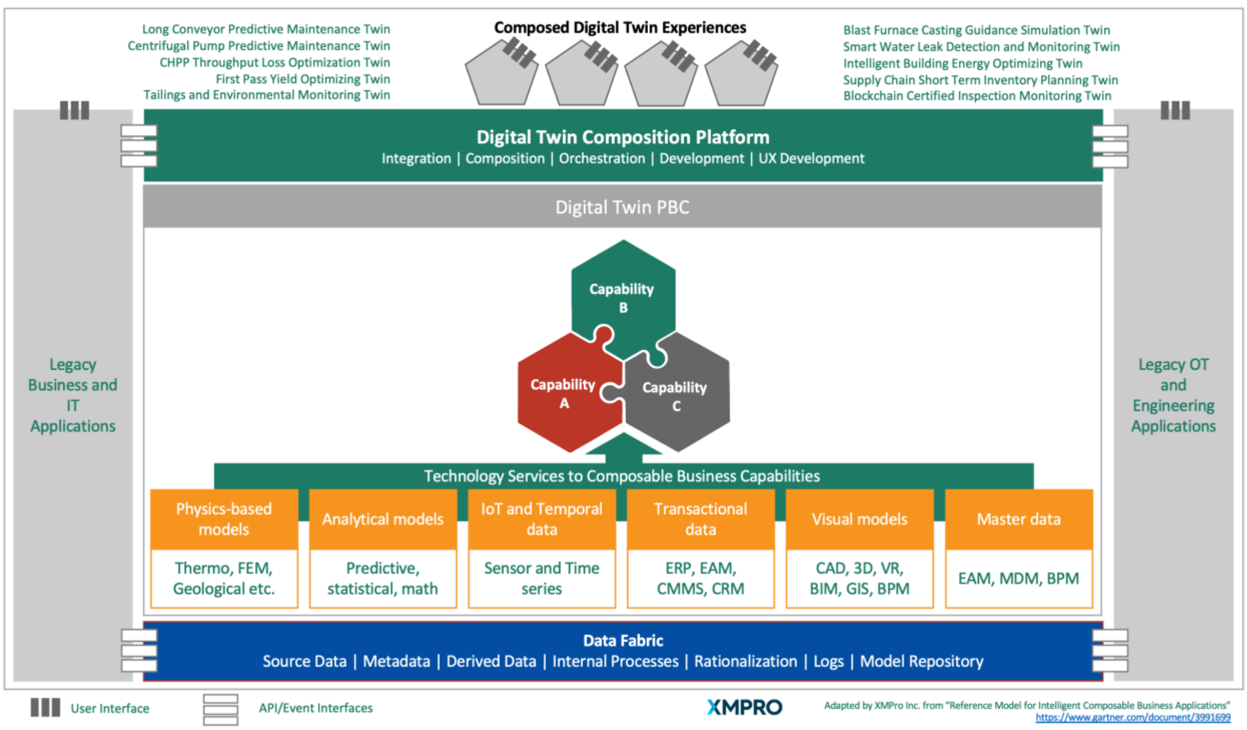


Figure 1-1: Composable Digital Twin Reference Model for discrete and system of systems digital twins.

A key characteristic of a composable digital twin is that it is typically a combination of capabilities from multiple technology vendors. Composite or system-of-systems digital twins are based on an ecosystem of capabilities rather than a single vendor.

3. ECOSYSTEM VS SINGLE VENDOR

The smorgasbord of capabilities that are all captured in the CPT are beyond the scope of any single vendor. It requires an ecosystem of interoperable technical capabilities to address large scale, complex digital twin use cases. The CPT provides *a common framework for multiple vendors to identify and present key capabilities that they provide for a digital twin solution.*

This common framework is a major benefit of the CPT for an end user organization that is clarifying requirements for a digital twin. It removes the focus from vendor-specific technologies and places it on the key capabilities that are required to deliver a digital twin solution successfully. It is useful in analyzing a vendor solution to see if it is complete. It provides the opportunity to light up the capabilities in the requirements and then overlay the capabilities in the solution to see how well they align.

4. FITS ACROSS THE DIGITAL TWINS LIFECYCLE

The CPT is applicable across the full lifecycle of the digital twin. The capabilities may differ during the different phases but identifying the key capabilities for each phase remains the same throughout the lifecycle.

Some capabilities may transfer between lifecycle phases, others may become obsolete, and others may be added. Capabilities during the design and construction phase may not all transfer to the operations and maintenance phase of an entity like a production plant. This facilitates the development of the digital thread as it transitions through the different lifecycle phases. As shown in Figure 1-2,, the digital twin supports the digital thread through these capabilities. The digital twin Capabilities Periodic table can also be used to identify capabilities for the digital thread.

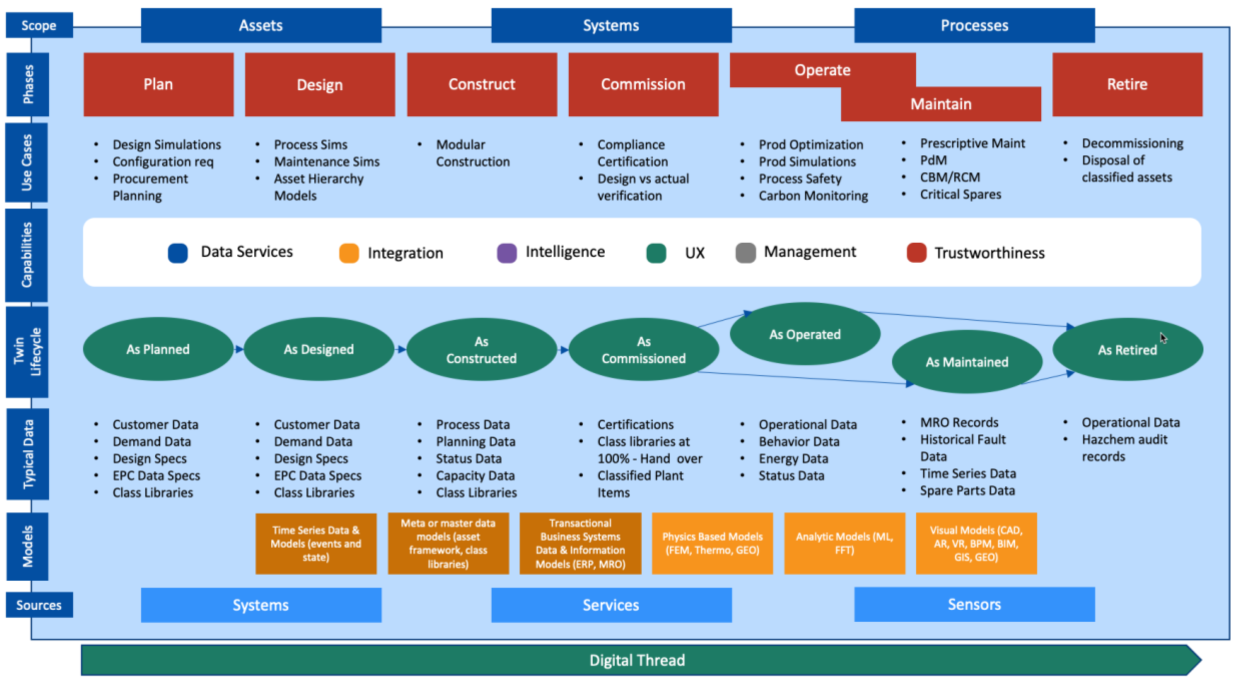


Figure 1-2: Capabilities during the digital twin and digital thread lifecycle.

The CPT provides a consistent approach for increasing capability maturity at both project and organizational levels throughout full product life cycles.

Detailed Reports on the periodic table and its use case can be found at:

1. *https://drive.google.com/file/d/11sXQkvxocCaR8h_jik6S5X9OymDB-UA_/view?usp=sharing*
2. *https://docs.google.com/spreadsheets/d/1RMY70eVsbL6zqEwDOmOyW1pJ9BgW76K4/edit?usp=sharing&ouid=106599580585035269352&rtpof=true&sd=true*
3. *https://www.digitaltwinconsortium.org/initiatives/capabilities-periodic-table/* ***(Highly Recommended)***

Architecture

Common set of characteristics that is present in nearly every digital twin:

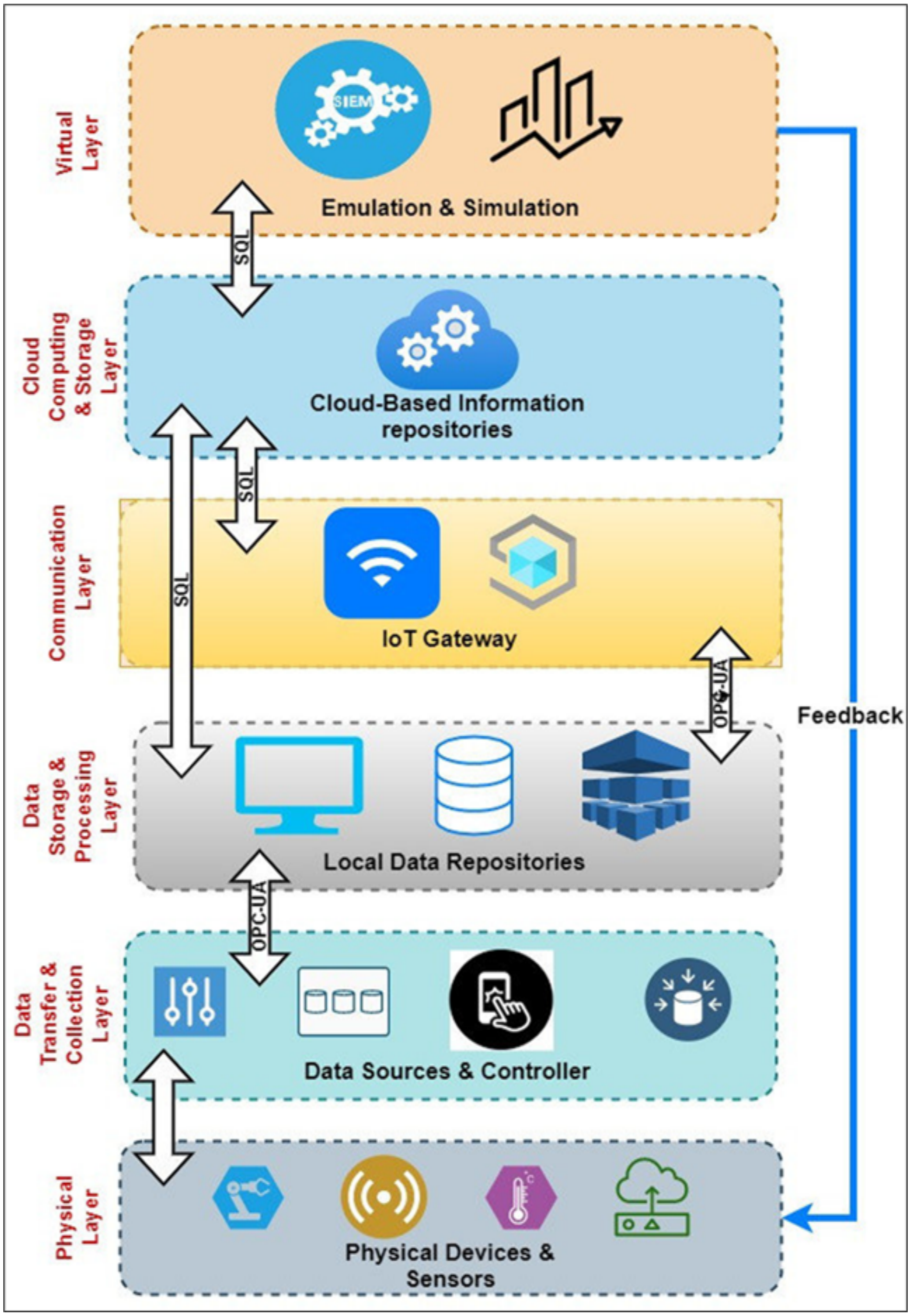
- ***Connectivity** created by IoT sensors on the physical product to obtain data and integrate through various technologies. Alternatively, capture on field information of assets through drone photography or LIDAR scans followed by 3D reconstruction using different techniques.*
- ***Digital Thread**, a key enabler interconnecting all relevant systems and functional processes homogenization, decouples the information from its physical form.*
- ***Re-programmable and smart**, enabling a physical product to be reprogramed manually and in an automatic manner.*
- ***Digital traces and modularity**, to diagnose the source of a problem.*

A Digital Twin is not a single technology play, rather it is realized through an amalgamation of multiple technologies such as:

- ***Visualization, AR/ VR**: Usually the topmost layer in a digital twin that combines the data and insights to present, advise and interact with the user or other machines.*
- ***Workflow and APIs**: Extract and share data from multiple sources in creating the digital twin and/ or infuses the insights within workflow of digital twin.*
- ***Artificial Intelligence/ analytics:** Using machine learning framework and analytics to make real- time decision based on historical and streaming data.*

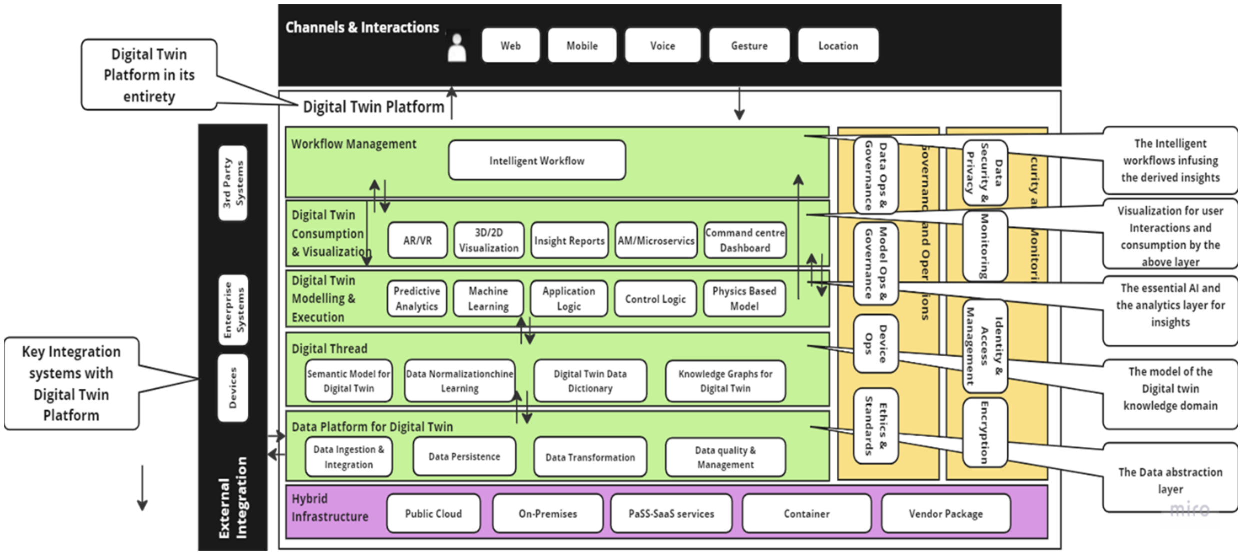
- ***Knowledge graph:*** *Creates a digital thread based on semantic model, data dictionary and knowledge graph.*
- ***Internet of Things and Data Platform:*** *Real-time data ingestion, gathered via sensors and gateways from physical asset/ objects related to state, conditions, and events. And to integrate, persist, transform, and govern the data collected.*
- ***Digital infrastructure:*** *Hybrid infrastructure including cloud, edge compute, in-plant infrastructure, etc.*
- ***Physical infrastructure:*** *Instrumentation of physical objects via sensors, gateways, network (IT/ OT), etc.*

Emerging architecture of Digital Twin



Architecture for digital twin essentially comprises of all the elements as described in the above section. Objective is to be able to support the functionality to connect, monitor, predict and simulate multiple physical objects, assets and/ or processes.

Figure 1: Digital Twin Logical Architecture



Source: https://www.ibm.com/blog/building-the-digital-representation-with-digital-twin-using-aws-stack/

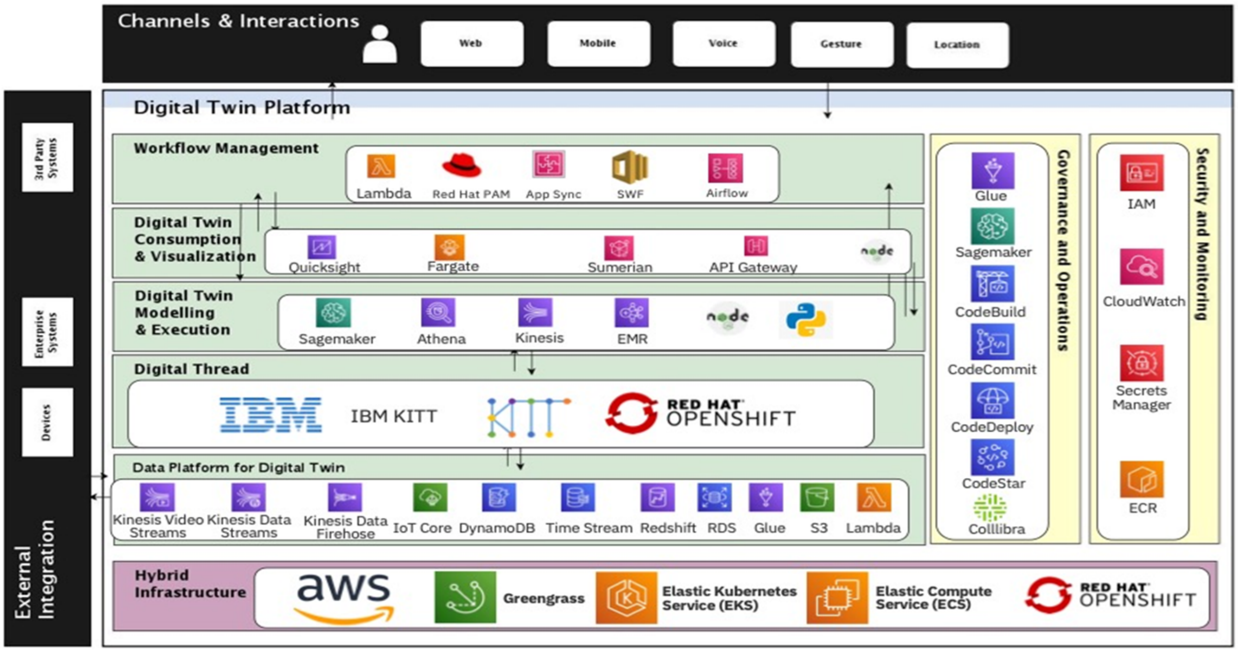
Editable Version:

https://miro.com/app/board/uXjVP8RGUbY=/?moveToWidget=3458764550527510709&cot=10

Building Digital Twin with AWS technology stack:

Propose here is a digital twin that is primarily based on the AWS software stack:

Figure 2: Digital Twin Technology Architecture with AWS



Source: https://www.ibm.com/blog/building-the-digital-representation-with-digital-twin-using-aws-stack/

Architecture Layer	Technology	Vendor	Purpose
Data Platform: Ingestion	Kinesis Data Streams, Kinesis Data Firehose, IoT Core	AWS	Ingesting and processing device telemetry securely is one of the key requirements in Digital twins. A combination of IoT Core and Kinesis will allow connecting to heterogenous data sources, multiple protocol and support streaming ingestion.
Data Platform: Persistence	DynamoDB, RDS/ Aurora, S3, Timestream, Redshift	AWS	Considering the diverse nature of data that will be handled by Digital Twin, polyglot storage is recommended. Thus, a combination of relational, non-relational, time-series, data lake and warehouse are required.
Data Platform: Integration, Transformation & Quality	Glue, Lambda	AWS	Meant to provide consistency of data through the validation, enrichment, cataloguing, and transformation conforming to the standard and integrate with the other systems.

Digital Thread: Knowledge Graph	*KITT*	*IBM*	*The Knowledge Graph represents a collection of interlinked descriptions of entities – objects, events, or concepts. It will put data in context via linking and semantic metadata. The IBM asset KITT is a general-purpose knowledge graph that enables the Digital Thread required to link lifecycle information and data together. Kitt is proposed to be deployed on Red Hat OpenShift.*
Modelling & Execution: Analytics, Machine Learning	*SageMaker, Athena, Kinesis Data Analytics, EMR*	*AWS*	*Cloud based Machine Learning Platform for building, training and deploying models based on the data collected via data platform. Also provides the ability to perform analytics on streaming data. We have proposed here an interactive query service that makes it easy to analyze data from e.g., S3 using standard SQL. Further to process the mass of data and analyze the same we also propose AWS EMR.*

Consumption & Visualization: Dashboard, Apps	*Quicksight, Fargate*	*AWS*	*For portal, real-time dashboards and command centers we have proposed here Quicksight for BI service and Fargate to build web apps.*
Consumption & Visualization: AR/VR/3D/2D	*Sumerian*	*AWS*	*AR and VR services are required to visualize diagnostics, predictions, and recommendations for the physical world. An extension of dashboard visualization is also required in digital twin to provide a view in 3D/2D.*
Consumption & Visualization: API & Microservices	*API Gateway, Node JS, SpringBoot,*	*AWS*	*To provide secured access to application APIs and batch files we propose Microservice based applications built using AWS API Gateway, Node JS/ SpringBoot and exposed via API Gateway.*
Workflow Mgmt.: Intelligent Workflow	*Lambda, AppSync, Simple Workflow Service, Airflow, RedHat Process Automation*	*AWS, Apache , RedHat*	*Workflow Management in digital twin is intended to deal with the business processes, simulation, and event-based flows. Besides the AWS stack we also propose RedHat Process Automation and Apache Airflow either of*

			which could be hosted in the RHOS on AWS.
Governance & Operations: DataOps	*Glue*	*AWS*	*DataOps is an essential element of Digital Twin that sits atop the big data which must be available on time, be automated and managed well to extract value. AWS Glue with its end-end data capability to discover, prepare, and combine data for analytics, machine learning is the right fit for the purpose.*
Governance & Operations: DevOps	*CloudFormation, CodeBuild, CodePipeline, CodeDeploy, CodeStar*	*AWS*	*AWS CodePipeline helps to build a continuous integration or continuous delivery workflow that uses AWS CodeBuild, AWS CodeDeploy, and other tools, or use each service separately. With AWS CodeStar the entire continuous delivery chain could be set up for a scalable DevOps solution.*

Governance & Operations: MLOps	*SageMaker*	*AWS*	*AWS SageMaker as MLOps fulfills the AI@Scale goals providing capability to build, train, deploy and maintain machine learning models in production reliably and efficiently.*
Governance & Operations: Data Governance	*Collibra*	*Collibra on AWS*	*The Collibra Data Governance and Catalog solutions will help find, understand, and trust the data, ensuring quality, and accessibility in a digital twin.*
Hybrid Infrastructure: Edge & Cloud	*Greengrass, Elastic Kubernetes Service, Elastic Compute Cloud, RedHat OpenShift on AWS*	*AWS, RedHat*	*Hybrid infrastructure that transcends beyond the cloud is a reality in digital. However, the core components will be on cloud with edge as a key component residing outside. EKS and/ or ROSA based containers are the ideal choice for the non-serverless component. Those requiring VM kind of infrastructure can be catered via EC2 instances.*

Security and Monitoring:	*ECR, IAM, Secrets Manager, CloudWatch*	*AWS*	*Digital Twin has multiple aspects of security that needs to be catered for including identity management, information protection, managing infra secrets, monitoring etc.*

Conclusion:

Creating an end-to-end digital twin platform, requires lot more than single set of capabilities with heterogenous software and hardware stack, multiple set of architecture with the principal theme being data, read more about Data architecture here – https://www.ibm.com/in-en/analytics/data-fabric. There are specialized software vendors for each layer or architecture, the flexibility comes from adopting a hybrid approach wherein the Hyperscalers form the core part of the solution. The individual customer environment will determine Hyperscalers.

Consulting Competitor Analysis

McKinsey

Nearly every aspect of work can take place solely digitally or, at the least, before it does so physically. Immersive experiences, enabled by augmented (AR) and virtual reality (VR), will allow employees to gain real-world product design experience and training from their desks as they manipulate 3-D digital replicas of equipment. Mass simulations and AI technologies will use data streams from across and beyond the enterprise to help senior executives predict what's next with tremendous precision and prescribe the best course of action in even the most turbulent of times.

This is the enterprise metaverse—a digital and often immersive environment that replicates and connects every aspect of an organization to optimize experiences and decision making. The journey toward the enterprise metaverse, while still aspirational, has already begun with the development of the engines that will power it: digital twins.

Imagine this future in the enterprise metaverse: A digital version of your end-to-end supply chain, from raw materials to delivery, continuously replicates in real time.

It's linked to supplier information, so it provides an early warning of a disruption in one vendor's production capabilities. Managers receive a real-time report of existing inventory buffers, alternative suppliers, and comparable parts. After agreeing to find a new supplier, managers can simulate their vendor transition plans and choose the company that minimizes the impact of the changeover.

Upon selecting the new source, vendor-onboarding and purchasing-order processes are automatically initiated. Now that a component from the new supplier has been chosen, the R&D organization receives a 3-D replica of it, and its impact on customers and existing processes is automatically simulated.

Next, your virtual factory simulates any resulting production disruptions and gives leaders recommendations to ensure that production quality remains high by optimizing workforce and shipping schedules during the changeover.

Your virtual retail store proactively sends store managers recommendations for updating store layouts and product mixes to fill any temporary gaps on shelves and for training employees so they're ready to answer customers' questions about any product changes.

The result: the time the item is out of stock falls from months to days, financial costs are near zero, employees experience minimal disruptions, and customer satisfaction increases. The enterprise metaverse could make this scenario a reality.

The metaverse could enable optimized decision making from the C-suite to the front lines, customized and immersive employee and customer experiences enabled by augmented and virtual reality, autonomous AI use cases (such as proactively self-healing equipment) that aren't possible today, and entirely new product development mechanisms and processes.

Although it will take time for this vision to fully materialize, leading companies around the world are already building its foundations: digital twins. Ultimately, the enterprise metaverse will be powered by dozens of interconnected digital twins that replicate everything from physical assets (like products and office buildings) to people (such as customers and employees) to core business processes and often interact with the physical environment without human intervention.

Sufficient technology and know-how exist to build digital twins today, and doing so creates significant value now rather than taking years. One telecom and technology player, for instance, reduced its capital and operating expenses by 10 percent thanks to a digital twin of its network assets. The twin can optimize capital spending, regulate usage patterns, identify failure points, and automatically initiate digital interventions based on unique network insights. Over the next decade, the company estimates that *its digital twins will deliver billions of dollars in cumulative financial impact as they enable additional AI use cases and increase the amount of data-driven decision making across the organization.*

The beginning: One digital twin Which twin an organization builds first is determined by its priority value drivers and potential for reuse, balanced by business support and feasibility factors, such as the availability, quality, and accessibility of data. These are some examples: A pharmaceutical company prioritized helping providers to improve patient outcomes. It started with a patient twin that enabled providers to deliver the right drug-safety content in the channel the patients would prefer at a given moment.

Once the data product is supporting a few use cases, its capabilities can be rapidly expanded. Teams can, for example, enrich it with layers of behavioral data, such as propensity models and likely interaction responses, by feeding data generated by the use of the data product back into it. Visualizations can also be added to enable simulations of different scenarios. These enhancements unlock more (and more powerful) predictive and prescriptive use cases and turn your data product into a digital twin.

Organizations don't need perfect data or a state-of-the-art technology platform to get started. We've seen companies with varying levels of data and platform maturity successfully build digital twins. There are, however, several keys to building a successful digital twin.

They include the following:

***Build a strong, balanced data model.** Base the data model on the most demanding use cases and aggregate the data at the lowest levels of granularity. Strive for the appropriate level of accuracy in the data model. Higher accuracy comes with higher marginal costs. Lower accuracy will not have an impact.*

Establish governance and benefits attribution from the start. *Set up the right data governance and ownership model for using the digital twin, implement the process for attributing its impact, and manage the economics of all use cases built on top of the twin.*

Ensure cross-team engagement. *Dedicate people from business, IT, and data science teams, and ensure that technical and business teams create solutions and visualizations together. Assign a strong product manager who can lead the build team in an agile manner and persuade it and other stakeholders to accept an iterative approach.*

Boost capabilities *- Once the digital twin's initial use cases are up and running, it's time to expand its capabilities by adding more data layers and analytics to support new use cases. At this stage, companies often advance their twins from simply representing assets, people, or processes to providing simulations and prescriptions through the use of AI and advanced modeling techniques.*

Deloitte

As the capabilities and sophistication of digital twins continue to expand, their numbers are increasing. However, unlocking their full potential may necessitate integrating systems and data throughout entire organizational ecosystems.

Companies today are utilizing digital twin capabilities in a variety of ways. In the automotive and aircraft industries, digital twins are crucial for optimizing entire manufacturing value chains and for innovating new products. In the energy sector, oil field service operators are using digital twins to analyze vast amounts of in-hole data to guide real-time drilling efforts. In healthcare, cardiovascular researchers are creating accurate digital twins of the human heart for clinical diagnoses, education, *and training. Additionally, Singapore uses a virtual model of itself in urban planning, maintenance, and disaster readiness projects. Digital twins can simulate any aspect of a physical object or process and may take many forms. The digital twins' market is projected to grow from US$3.8 billion in 2019 to US$35.8 billion in 2025. This growth is driven by evolving simulation and modeling capabilities, better interoperability, and IoT sensors, and more availability of tools and computing infrastructure. As a result, digital twin capabilities are more accessible to organizations across industries. Access to larger volumes of data is also making it possible to create simulations that are more detailed and dynamic than ever before.*

Models & data - insights and real value

Initially designed as a tool for engineers to streamline the design process and eliminate the need for extensive prototype testing, digital twin capabilities have evolved to revolutionize the way companies perform predictive maintenance, optimize supply chains, and even enhance worker performance. By using 3D simulations and human-computer interfaces such as augmented reality and virtual reality, engineers can determine a product's specifications, how it will be built, and how it measures against relevant policies, standards, and regulations. This allows engineers to identify potential issues with manufacturing, quality, and durability before the final design is approved, reducing prototyping costs and accelerating the product launch process. Digital twins also enable the collection of performance data from sensors embedded in machines in real-time, allowing companies to identify and address malfunctions before they happen, tailor service and maintenance plans, and optimize production output. For instance, Royal Dutch Shell launched a digital twin initiative to manage offshore assets more effectively and explore predictive maintenance opportunities. Moreover, digital twins are also being used to optimize supply chains, distribution, and fulfillment operations, and enhance worker *performance. Unilever, for example, has launched a digital twin project that aims to create virtual models of its factories, where IoT sensors embedded in factory machines feed performance data into AI and machine learning applications for analysis. This allows the simulations to identify opportunities for workers to perform predictive maintenance, optimize output, and limit waste from substandard products. Digital twins are also transforming smart city initiatives by addressing traffic congestion, urban planning, and emergency response. Singapore's Virtual Singapore initiative, for example, simulates traffic patterns and foot traffic, which may be used to enable emergency evacuation planning and routing during the city's annual street*

What's new?

The deployment of digital twin capabilities has accelerated in the past decade due to various factors:

***Simulation** tools have become more powerful and sophisticated, allowing for complex what-if scenarios and millions of simulation processes without overloading systems. The increasing number of vendors has also expanded the range of options available, while machine learning is enhancing insights.*

***New sources of data**, such as real-time asset monitoring technologies like LIDAR and FLIR, and IoT sensors embedded in machinery or throughout supply chains, can feed operational data directly into digital twin simulations for continuous real-time monitoring.*

***Interoperability** has improved dramatically, allowing for better integration between digital technology and the real world, thanks to enhanced industry standards for communications between IoT sensors, operational technology hardware, and diverse platforms.*

Visualization *tools have advanced to include interactive 3D, VR and AR-based visualizations, AI-enabled visualizations, and real-time streaming, which help filter and distill information in real-time.*

Instrumentation *has improved with the development of smaller, more accurate, cheaper, and more powerful IoT sensors, which can provide granular, timely, and accurate information on real-world conditions to integrate with virtual models. Increased availability of powerful and inexpensive computing power, network, and storage have enabled the development of digital twins. Software companies are investing in cloud-based platforms, IoT, and analytics capabilities to streamline the development of industry-specific digital twin use cases.*

Costs versus benefits

Digital twins rely heavily on AI and machine learning algorithms, which require substantial amounts of data. However, this data may be incomplete or unavailable due to data corruption, loss, or inconsistent collection from sensors on the production floor. Therefore, it is essential for teams to start collecting data now, particularly in areas with the highest number of issues and the most significant outage costs. Establishing the necessary infrastructure and data management approach now can reduce the time to benefit. Even when digital twin simulations are created for new processes, systems, and devices, it may not always be feasible to instrument the process perfectly. In cases where chemical and biological reactions or extreme conditions occur, it may not be possible to measure the process directly. In such cases, organizations should consider proxies, such as relying on the instrumentation and sensors in a vehicle, or detectable phenomena like heat or light emanating from chemical or biological reactions. As sensors' cost continues to decrease, it becomes challenging to strike a balance between cost and benefit. For *instance, modern aircraft engines may have thousands or tens of thousands of sensors, generating terabytes of data every second. By combining digital twins, machine learning, and predictive models, manufacturers can make recommendations to optimize fuel consumption, enable proactive maintenance, and help fleets manage costs. However, most use cases only require a few strategically placed sensors to detect key inputs, outputs, and stages within the process.*

Source: https://www2.deloitte.com/us/en/insights/focus/tech-trends/2020/digital-twin-applications-bridging-the-physical-and-digital.html

Ernst & Young

What can EY do for you?

In health care, there are many ecosystems, quickly evolving technologies and massive amounts of data, all untidy and uncoordinated. EY teams have a strategic vision on how to use those tools, ecosystems, structures, and data to drive better experiences for all stakeholders—including both patients and clinicians.

To bring the smart health vision to life, EY teams convene and connect the entire healthcare ecosystem. We explore where opportunities for collaboration exist and use our experience in technology, strategic planning, organizational design, and process transformation to drive better outcomes for all.

EY Smart Health Experience

Accustomed to self-directed experiences in other areas of their digital lives, consumers and clinicians expect something more from health care. Smart health *experiences reposition how care is organized and delivered, optimizing the wellness journey — a key differentiator in long-term value for the health industry.*

Smart health starts by getting the consumer experience right through human-centered design, which is, quite simply, designing for people. By focusing on what matters most to the healthcare consumer and to the workforce, EY teams work with organizations to create a more personalized technology-enabled health and well-being experience and a modernized work environment.

In a smart health system, automation and digitization are reshaping how the entire system works together for a better care experience.

*We use an experience-led approach and work with hospitals and health systems to introduce digitally enabled front-, middle- and back-office operations that support the end-to-end consumer and clinician experience. P**lay Video***

EY Smart Health Experience

The EY Smart Health Experience suite of solutions includes:

- *Persona definition*
- *Patient, provider, employee, and broker journey mapping and service design*
- *Ecosystem definition*
- *Customer behavioral insights*
- *Customer-led strategy, capability, and roadmap creation*
- *Business case definition*
- *Digital employee and caregiver onboarding*
- *Definition of wireframes and prototypes*
- *Product development, launch and scale*
- *Operating model definition*
- *Experience-led digital enterprise transformation*

EY Smart Health Analytics

EY teams are working with health organizations to help them use smarter analytics that provide a more complete view of the patients and communities they serve. Combining and analyzing data from the wealth of available sources – from wearable devices to social and economic indicators – makes health care more personal, more effective, more efficient, and more equitable. That means better insights for you, driving better healthcare for everyone.

How EY Smart Health Analytics supports you

1. Curate live data sets that you control

Combine data from a full range of internal and external sources to create live data sets that provide a comprehensive view of each patient. Retain full control of your data and how it is used.

2. Analyze your data in ways that matter to you

Use data sets and algorithms that are customized to meet your specific needs, so you create relevant insights based on a fuller understanding of the patients and populations you serve. Identify how a patient's wider context could affect their health today and, in the future, and how you could provide better care and support with the resources at your disposal.

3. Drive action that makes a real difference

Make it easier for people across your health ecosystem – including clinicians, management, and partners – to understand your insights so they can take action that makes a difference. Use powerful visualizations to filter out what doesn't matter and to focus on what does. Share relevant insights with patients in ways that improve their care and build trust.

EY teams are working with health organizations to help them use smarter analytics and algorithms that give them a more complete view of the patients and communities they serve. Combining and analyzing data from the widest possible range of sources – from wearable devices to social and economic indicators – makes health care more personal, more effective, more efficient, and more equitable. Better insights for you can mean better health care for everyone.

EY Smart Hospital and Health Care Transformation

Health care transformation connects the dots between operations, people, the environment, and technology to deliver more connected and efficient care. The EY Health Care Transformation team supports health care providers and payers in their journey from traditional to smart by leveraging virtual care platforms, interoperable patient records and digital enablers (e.g., the internet of things (IoT), 5G, artificial intelligence (AI), remote monitoring) to optimize care and shift the focus from volume to value in a controlled and agile way.

We bring deep knowledge and insights that help you balance clinical outcomes, cost and operational optimization, patient experience, and talent management to transform and optimize your organization.

EY Health care Transformation teams work across the health ecosystem: from establishing clinical operations initiatives to implementing the architecture and operations around digital assets and analytics. Our goal is to help our clients realize efficiencies and drive a differentiated experience by sharing leading practices that optimize performance and enable better outcomes.

EY Virtual Care

EY teams are working with health organizations to help them design and implement virtual care models that transform what they do, how they do it, and the results they achieve. Virtual care can mean better health and a better care experience for patients and their families, greater job satisfaction for health workers at every level, and better *outcomes for health systems overall. Virtual care works best when it works for everyone.*

How EY Virtual Care supports you.

1. See where virtual care can transform how you work

Create and model different scenarios that reveal where your resources are currently focused. Identify how virtual care could help you make better use of scarce facilities, finances, and people. Access the business, health management, and clinical knowledge needed to understand the complexity of your organization and to find ways of making it work better.

2. Identify clear benefits and actionable priorities

Define where specific virtual care investments could make a measurable difference to health outcomes for the patients and populations you serve. See how better outcomes and better performance translates into financial value for your organization. Create a roadmap and actionable plans to capture this value and to make it happen at scale.

3. Move forward at speed

Build cultural and financial support for virtual care by showing that the interventions you are putting in place achieve the expected return on investment and make a measurable improvement patient outcomes. Help implement new virtual care models and technologies, integrate them with your existing digital and data infrastructure, and help manage growing user demand.

EY teams are working with health organizations to help them design and implement virtual care models that transform what they do, how they do it, and the results they achieve. That means better health and a better care experience for patients and their families, greater job satisfaction for health workers at every level, and better *outcomes for health systems overall. Virtual care works best when it works for everyone.*

EY Connected Health Cloud

EY teams are working with health organizations to create open, connected technology ecosystems that help enable better patient experiences and better health outcomes. And when it's quicker and easier to share deeper data, everyone serving the patient benefits. Connected health care means better health care.

How EY Connected Health Cloud supports you

1. Makes data available in a format that works

Create and structure data in a computer readable format that captures the rich complexity of information needed to transform patient experiences and outcomes. Modern healthcare interoperability standards like Health Level Seven (HL7) fast healthcare interoperability resources (FHIR) only capture a fraction of the data needed for the ecosystems of the future.

By contrast, EY Connected Health Cloud is built with the combination of openEHR, a semantically rich format that captures far more patient information, to store and publish data and HL7 FHIR for exchanging data for specific use cases. The openEHR data definitions are publicly available in multiple languages, and link with broadly accepted health terminology standards like SNOMED clinical terms (CT) and logical observation identifiers names and codes (LOINC) and are independent of any technology vendor. The better the data you collect, the better the health care you can provide.

2. Makes data available where and when it's needed

Create open data platforms, so everyone can provide and access data from a range of devices and systems. When data is connected and flowing easily, you can support people to do their best work – from frontline clinical staff caring for patients today, to *health managers and leaders planning for the future. These open data platforms should adhere to the findable, accessible, interoperable, and reusable (FAIR) principles and allow data to be captured once and shared in a secure, private way many times.*

3. Builds a future-ready data infrastructure

Modern open data interfaces, including representational state transfer application programming interfaces (REST APIs) make it easier for you to add new technologies and partners to your ecosystem, so you can innovate faster. Semantically rich data formats that capture a more complete picture of the patient give you the platform needed to deliver personalized care over the patient's lifetime.

EY teams are working with health organizations to create open, connected technology ecosystems that help enable better patient experiences and better health outcomes. When it's quicker and easier to share deeper data, everyone serving the patient benefits. Connected health care means better health care.

Source: https://www.ey.com/en_us/health/smart-health-solutions

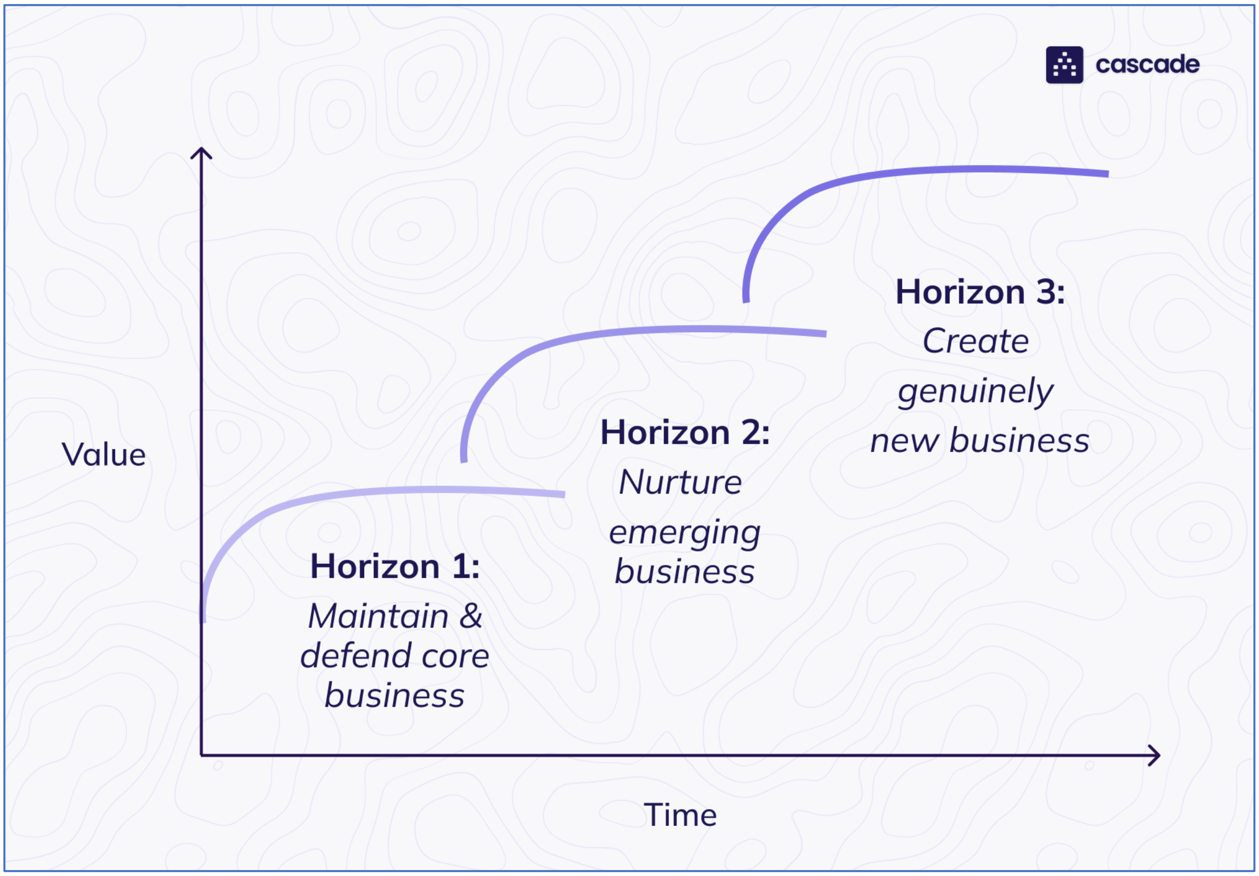
Recommendations

McKinsey' s Three Horizons

McKinsey' s Three Horizons Framework To Help You Grow

What is the Three Horizons Framework?

McKinsey's Three Horizons Framework is a strategic planning approach used to help organizations manage their growth strategy and unlock transformational potential. It *takes an adaptive management approach based on three distinct categories of growth—Horizon 1, Horizon 2, and Horizon 3—which provide a framework for identifying and responding to changes in the business environment.*



What Are The Three Horizons Of Growth?

The Three Horizons Framework, also known as the Three Horizons of Growth, consists of three horizons:

- ***Horizon 1**: Maintain and defend the core business.*
- ***Horizon 2:** Nurture emerging business.*
- ***Horizon 3**: Create genuinely new business.*

Horizon 1: Maintain & defend core business

This is the first horizon of growth and focuses on leveraging existing products and services. Think of it as "business as usual." For a retailer, this would include the day-to-day goals associated with selling, marketing, and serving your product and customers.

Some other examples of Horizon 1 initiatives could include product upgrades, new features, or adding new services to existing products. Or introducing a subscription model for existing products or launching new services such as customer service, technical support, or digital marketing.

Your goals in Horizon 1 should be focused on improving margins, improving current business processes, and increasing short-term profits.

Horizon 2: Nurture emerging business

The second horizon of growth focuses on taking what you already have and extending it into new areas of revenue-driving activity. It's all about trying out new approaches as a response to the shifts in the market. You should focus on creating new innovations in the existing market or exploring new markets.

There may be an initial cost associated with your Horizon 2 activities, but these investments should return reliably.

This is based on them being an extension of your existing business model. Examples of Horizon 2 strategic initiatives include launching new product lines or expanding your business geographically.

Some of these initiatives will be absorbed into your business as usual, others will pave the way for the emergence of radically different strategic initiatives under Horizon 3.

Horizon 3: Create genuinely new business.

This horizon is the third and most distant of the planning horizons. It's typically characterized by long-term goals and investments that have unprecedented strategic or competitive implications. The third horizon can encompass up to ten years or more and focuses on creating opportunities, exploring new markets, and making discretionary investments to capitalize on those opportunities.

For example, your organization could invest in the development of new products, the research and development of AI or automation, and the development of new technologies or services. This could also involve things like research projects, pilot programs, or the startup of completely new business units through mergers and acquisitions.

What Does McKinsey's Three Horizons of Growth Help You to Achieve?

Most organizations want growth. Most organizations also acknowledge that innovation is a critical component of achieving that growth. Yet so many of them treat innovation as a one-off event, such as a huge project to be delivered or a set "innovation program" to be introduced.

One of the most common reasons for this approach is the perceived gap between the innovation of tomorrow and the reality of running a business today.

McKinsey's Three Horizons of Growth aims to help you bridge this intellectual gap. It does this by ***creating steppingstones*** *between running your business profitably today and* ***growing it*** *for the future.*

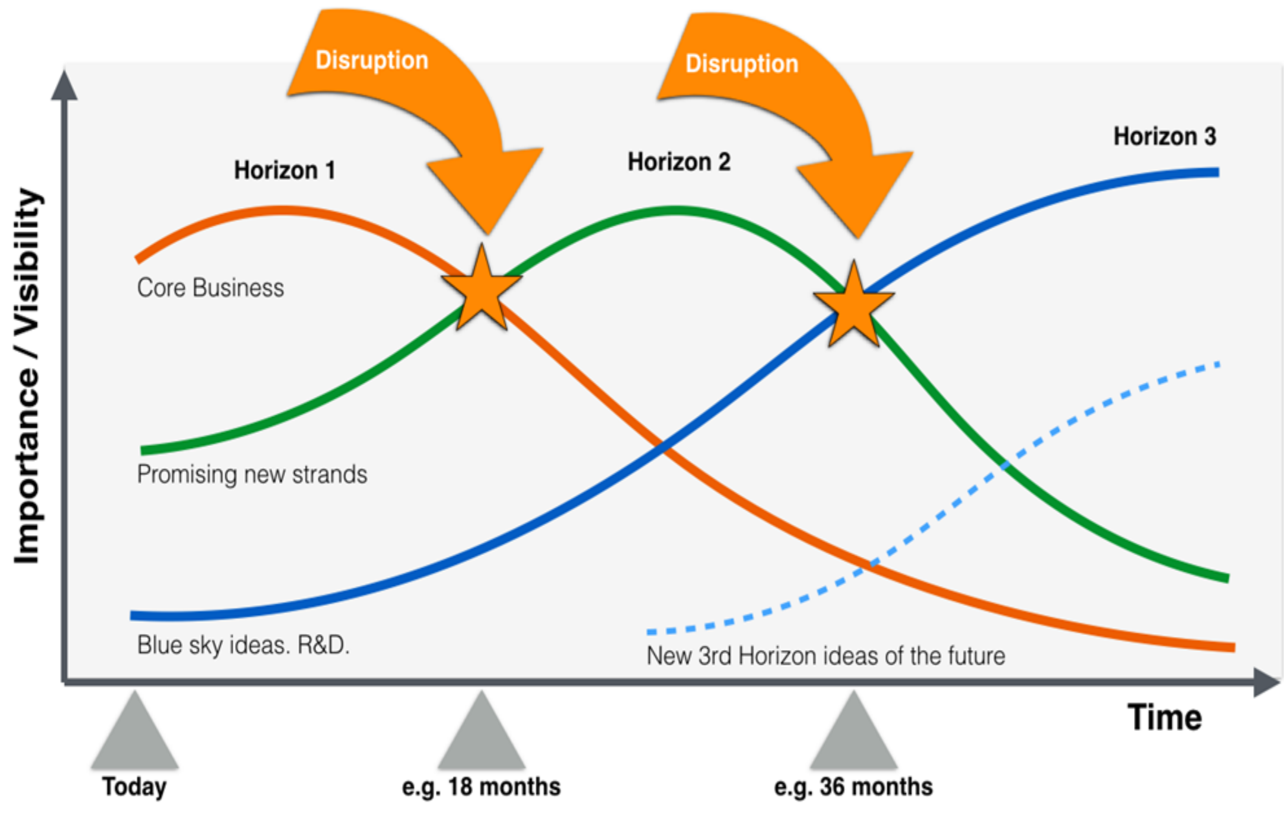
This strategy framework helps ensure that you consistently balance your ***focus*** *between the needs of today (Horizon 1), the future state of your business (Horizon 3), and the steps that you need to take to get there (Horizon 2).*

The Three Horizons of Growth framework is an extremely versatile strategy framework applicable to most organizations. In particular, the framework lends itself *to organizations that have identified that growth and innovation have been a stumbling block.*

If you feel as though your organization is mired in "chugging along" and delivering business as usual, McKinsey's Three Horizons of Growth might just be the right strategic framework for you.

How Do You Apply the Three Horizons Model to Your Business?

OK, so you've decided that growth and innovation are indeed critical to your business, and you're willing to give McKinsey's Three Horizons Model a shot at helping you get there. This is how to go about applying it to your own organization:



1. Start with a deep understanding of your Horizon 1

You first need to identify your biggest assets today. The main reasons why your business makes revenue or succeeds at what it does. If you were Starbucks, this would be your brand and perhaps your distribution channels.

If you were Microsoft back in the 1990s, it would be your enterprise products and perhaps your partner network.

Name these drivers of success for your business today.

Now, imagine that you lost them entirely. Imagine that you're Microsoft, and businesses refuse to buy your software anymore...

2. Your Horizon 3 is what you would do if that were to happen

Yep, that's not a typo. We're moving straight to Horizon 3. Let's stick with Microsoft as an example. The Microsoft Xbox was launched in 2001. On the surface, it was a million miles away from playing to Microsoft's core strengths at the time, which was firmly in the business and productivity space. And that was exactly the point.

The Xbox wasn't a shot in the dark—it was Microsoft's Horizon 3. They'd identified something at which they thought they could succeed (you still need core capabilities that will allow you to win). However, they didn't rely on the things that were making them a success today.

But how did they go from strength in business software/productivity to winning in the ultra-competitive gaming hardware industry?

3. Horizon 2 is the bridge that gets you there

This is where Horizon 2 comes in. Once you know what you want to do for your Horizon 3, work backward from that (and forward from your Horizon 1) to create a plan of action that will bridge the gaps.

For Microsoft, that involved launching their own line of computer games (famous ones include Age of Empires and Microsoft Flight Simulator). It also included a range of "light" hardware, such as keyboards and mice.

This gave them the experiences they needed (and a bit of extra revenue too) in both gaming and hardware, which ultimately resulted in them creating the Xbox.

Your Horizon Two doesn't have to be a revenue generator per se, but it should contain enough of your core assets from Horizon One to give you a fighting chance of it being profitable.

The bigger picture, though, is that it helps you to bridge the gap between your current state and your desired future state (Horizon 3).

The 70 / 20 / 10 Rule

To put this into practice for your strategic plan, try to ensure that around 70% of your activity is playing toward your Horizon 1. After all, you need to survive and thrive today to have any chance of succeeding tomorrow.

Then, allocate around 20% of your effort to those Horizon 2 "bridging' opportunities. That might sound like a lot, but Horizon 2 will contain failures and false starts, so it's important that you have enough irons in the fire to get you to Horizon 3.

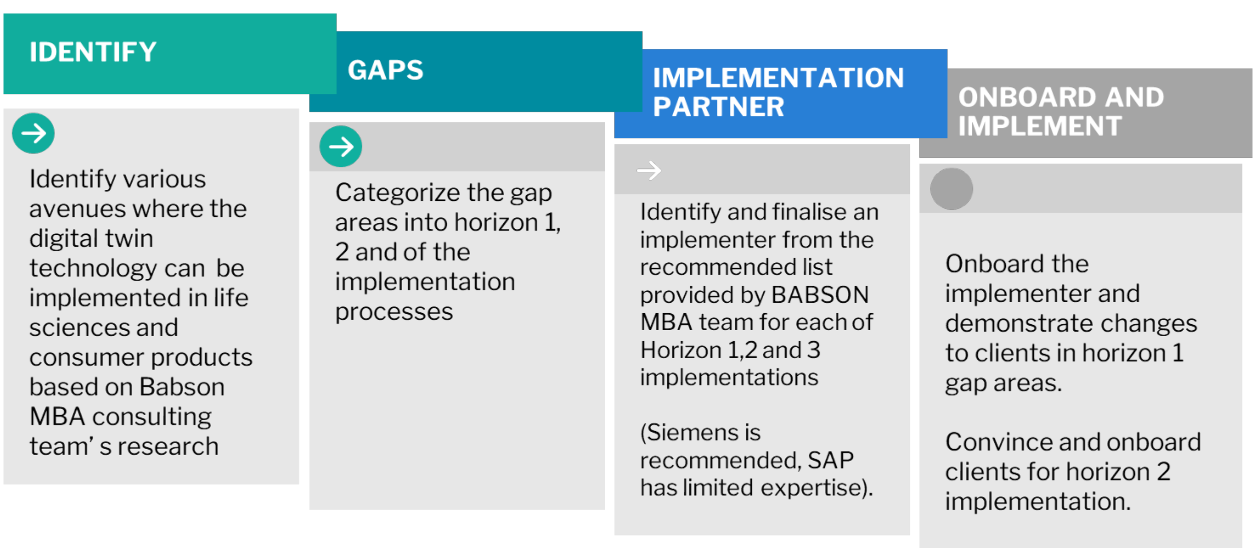
For Horizon 3, that leaves 10% of your overall effort. That 10% is important. Without it, you can easily lose sight of your ultimate goals, and get lost in a never-ending cycle of horizon 2's.

Microsoft, for example, experimented with a range of simple game controllers throughout the 1990s called the Microsoft Sidewinder. Most of your Horizon 3 10% efforts will be on research and experimentation, with a few light product launches towards the end if you're lucky.

Source: https://www.cascade.app/blog/mckinseys-three-horizons-of-growth

FINAL RECOMMENDATION

"We believe large scale implementation of DIGITAL TWINS will be a ***Horizon 2*** *decision for Clarkston Consulting."*



Conclusion

In conclusion, the concept of "digital twins" has become a ground-breaking technology with enormous potential across numerous industries, which Clarkston should unquestionably use for its clients.

This report offers a thorough examination of digital twins, several use cases from various businesses, the implementation schedule, the implementation architecture, digital twin applications, their advantages, challenges, and potential in the future.

We investigate, assess, and draw the conclusion that digital twins have proven to be invaluable tools for organizations, enabling them to construct virtual replicas of physical assets, processes, and systems. We base this on the use cases of various enterprises.

Digital twins enable improved monitoring, analysis, and optimization by gathering real-time data, which enhances productivity, efficiency, and decision-making. They provide a comprehensive perspective of complex systems, enabling firms to spot problems early and take proactive action to fix them, reducing downtime and maintaining expenses. We also calculated the advantages of digital twins and their quantitative effects on various firms based on the report.

We have looked at the various uses of digital twins in the consumer goods and life sciences industries throughout this report. Digital twins have proven their potential to transform conventional procedures and open new opportunities for innovation, from simulating and optimizing industrial lines to monitoring and assessing patient health.

Digital twins have a lot of potential, but they also have some drawbacks. Significant topics that need attention are the high costs of initial investment, the requirement for interoperability, and standardization.

To protect the sensitive data generated and used by digital twins, businesses must also invest in strong cybersecurity procedures.

Additionally, we discovered that the market for digital twins will expand at a 40% compound annual growth rate (CAGR) during the following eight years, suggesting that the future of digital twins is bright. Digital twins will become even more promising and advance as a result of technological developments in areas like artificial intelligence, machine learning, and the Internet of Things. Near-instantaneous decision-making will be possible because of the combination of digital twins with cutting-edge technologies like 5G and edge computing.

We may predict revolutionary shifts in the way industry's function and how products and services are delivered as long as enterprises continue to embrace digital twins. There are countless opportunities for innovation, optimization, and sustainability when it is possible to make digital replicas of the real environment.

In conclusion, digital twins have become a potent technology with enormous promise for businesses in a variety of industries. Organizations can take advantage of new potential for growth, efficiency, and competitiveness in the increasingly digital and interconnected world by utilizing the capabilities of digital twins and overcoming the accompanying hurdles.