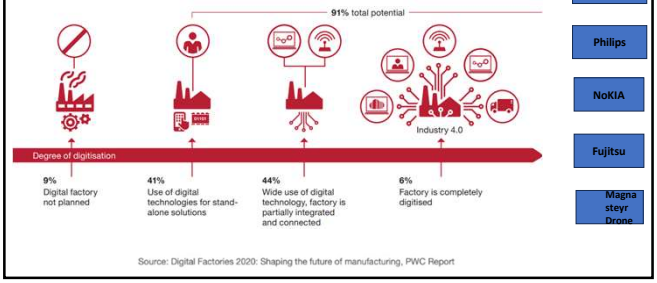
Digital Twin

1

2

Digital Factories



Source: Digital Factories 2020: Shaping the future of manufacturing, PWC Report

3

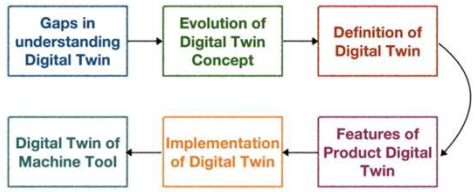
Technologies shaping the future of Manufacturing

	In use today	Change over the next five years	In use in five years
Predictive maintenance	28%	+38%	66%
Big data driven process and quality optimisation	30%	+35%	65%
Process visualisation/automation	28%	+34%	62%
Connected factory	29%	+31%	60%
Integrated planning	32%	+29%	61%
Data-enabled resource optimisation	52%	+25%	77%
Digital twin of the factory	19%	+25%	44%
Digital twin of the production asset	18%	+21%	39%
Digital twin of the product	23%	+20%	43%
Autonomous intra-plant logistics	17%	+18%	35%
Flexible production methods	18%	+16%	34%
Transfer of production parameters	16%	+16%	32%
Modular production assets	29%	+7%	36%
Fully autonomous digital factory	5%	+6%	11%

Source: Digital Factories 2020: Shaping the future of manufacturing, PWC Report

4

Outline



5

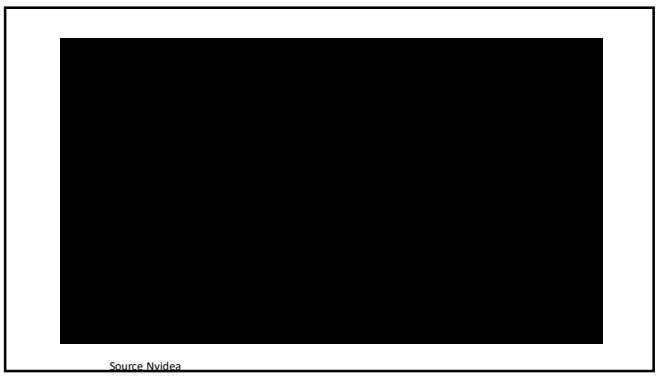
Human Twins

Source: https://www.istockphoto.com

6


Digital Human Twin

7


Source Nvidea

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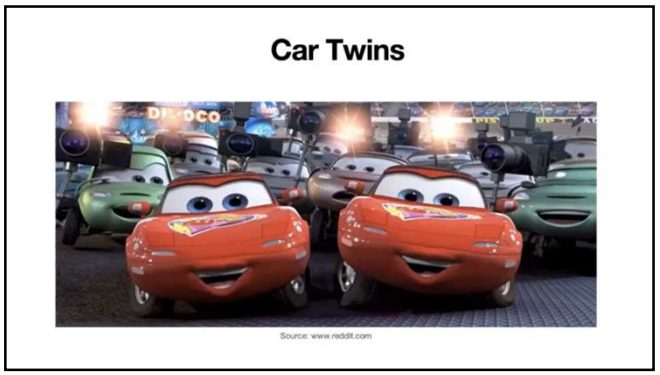
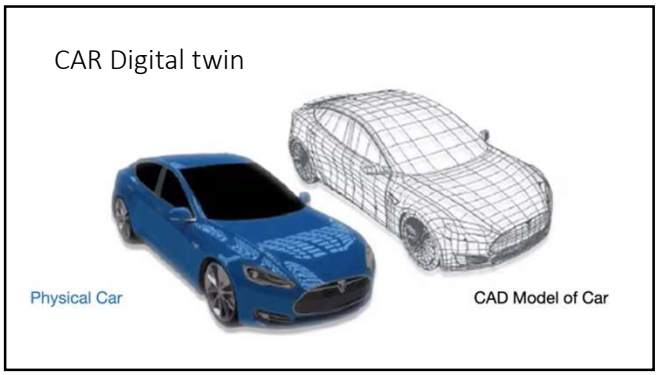
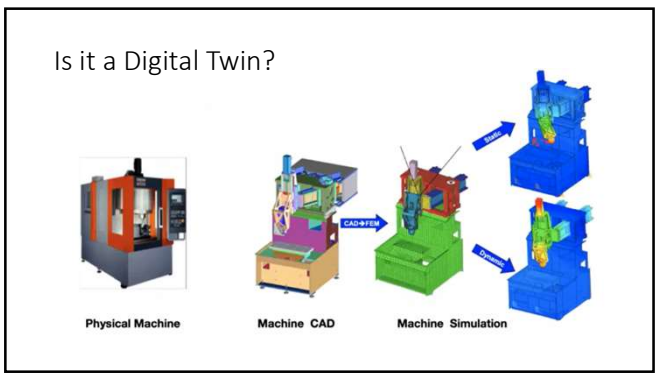

Car Twins
Source: www.reddit.com

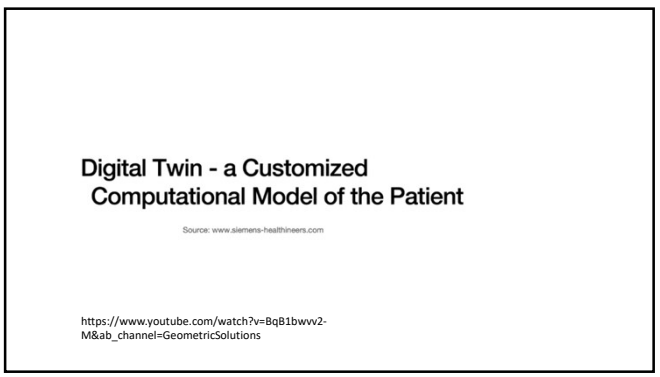
10


CAR Digital twin
Physical Car
CAD Model of Car

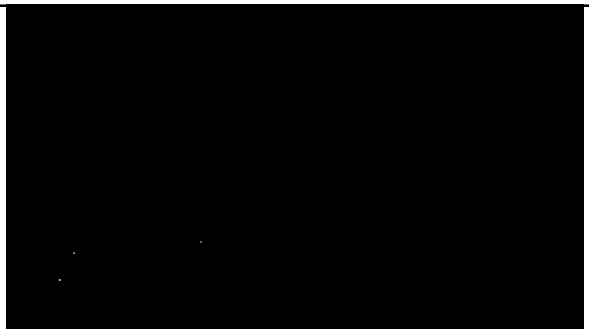
11


Is it a Digital Twin?
Physical Machine
Machine CAD
CAD+FEM
Machine Simulation

12


Digital Twin - a Customized Computational Model of the Patient
Source: www.siemens-healthineers.com
https://www.youtube.com/watch?v=BqB1bwvv2-M&ab_channel=GeometricSolutions

13



https://www.youtube.com/watch?v=BqB1bwvv2-M&ab_channel=GeometricSolutions

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Physical Twin 1969

•The use of the "twin/twins" concept in the **manufacturing** can be traced back to NASA's Apollo program.
•In the project, NASA needs to make **two identical spacecraft**.
•The aircraft left on earth is called a **twin** and is used to reflect the **status/condition** of the space vehicle in action.
•During the **flight preparation**, the space vehicle known as the twins is widely used in **training**.

•During the mission, the twins were used to **simulate the space model** on the ground, and it can accurately reflect and predict the status of the space vehicle in operation as much as possible.

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Twin

Twins are actually a **prototype** or **model** that reflects the **real operation** situation in real-time through **simulation**.
It has **TWO** significant characteristics:

1.The twins with the objects to be reflected are almost **exactly** the same as the **appearance** (*the geometry and size of the product*), **content** (*the structure of the product and its macro- and microphysical properties*), and **properties** (*the function and performance of the product*); and

2.It allows you to **mirror/reflect real operation/state** by means of **simulation**, etc. It needs to be pointed out that the twin at this time is still **physical**.

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Twin: Historical Development

2003 Prof. Michael Grieves proposed the concept of Virtual Digital Representations (VDR) equivalent to physical products.

Definition: *VDR is a Digital copy of one or a set of specific devices that can abstractly represent a Real device and can be used as a basis for testing under real or simulated conditions*

2006 The US National Science Foundation (NSF) first proposed the concept of the information physics system, Cyber-Physical Systems (CPS)

Industry 4.0 - Impact on Intelligent Logistics and Manufacturing, Digital Twin Technology, Zongyan Wang, http://dx.doi.org/10.5772/intechopen.80974

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Digital Twin

2011 Prof. Michael Grieves, in his book "*Virtually perfect: driving innovative and lean products through product lifecycle management*"cited the conceptual model of the noun digital twin model (Digital twin)

The Digital Twin was proposed and further developed by the US Air Force Research Laboratory in **2011**; the aim is to solve the maintenance and life prediction of aircraft in the future complex service environment

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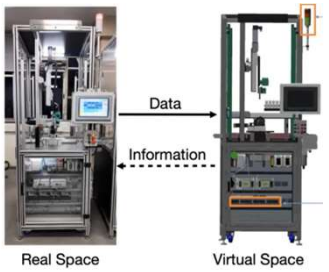
Digital Twin



- A **digital** counterpart in the cyber world of the **physical** entity in real world.
- Two-way **communication** between the physical entity and the digital counterpart
- The digital counterpart is the representation or model of the physical entity, and the digital model can simulate the physical entity in real time
- The model behaves according to the information just as the real entity since it is modelled in terms of its real part working principles or mechanisms
- Model can **validate**, **optimize**, **evaluate**, **diagnose** the real part, and give suggestions, prediction by data analyses, Artificial Intelligence (AI), etc. for people to make decisions and exert controls on the real part if necessary.

Digital Twin: Manufacturing Excellence through Virtual Factory Replication, A Whitepaper by Dr. Michael Grieves, 2015

20

21

Industry4.0:Digital Twin

2013 Germany proposed the "Industry 4.0," whose core technology is *Cyber-Physical System (CPS)*. CPS is a multidimensional complex system which is integrated with computing, communication, control, network and the physical environment

On the basis of the physical entity modelling, the static model, through the real-time data acquisition, data integration and monitoring, dynamic tracking of working status and progress measurement,

22

Industry4.0:Digital Twin

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On the basis of the physical entity modelling, the static model, through the real-time data acquisition, data integration and monitoring, dynamic tracking of working status and progress measurement,

the **physical** entities in the **physical** space are reconstructed in the information space, forming **Digital Twin** with the ability of perception analysis and decision execution.

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Digital Twin

2014 Prof. Michael Grieves elaborated **Digital twin** in detail in his white paper "*Digital Twin: Manufacturing Excellence through Virtual Factory Replication*"

2015 **General Electric** Company planned to implement real-time monitoring, timely inspection and predictive maintenance of turbines based on digital hygiene and through its own cloud service platform—**Predix**, using advanced technologies such as big data and Internet of Things

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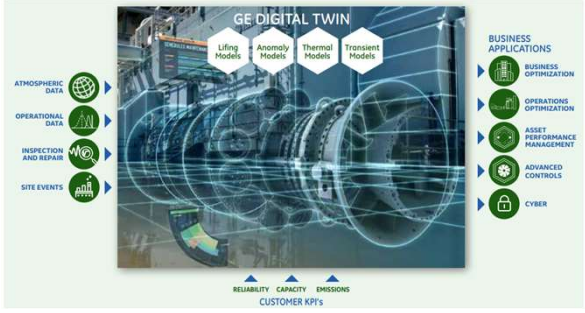
Digital Twin of Gas Turbines: Product



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Minds + Machines: Meet A Digital Twin 2016

https://www.youtube.com/watch?v=2dC23oL2rTw&ab_channel=GEDigital

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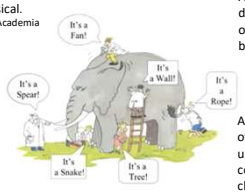
Definition of Digital Twin

A digital twin is a realistic digital representation of something physical.
cambridge centre for digital built britain, Academia

A digital twin is a near-real-time digital image of a physical object/ It's a or process that helps optimise business performance. Spear!
DELOITTE, Consulting

A digital twin is a virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning.
IBM, Software



A digital twin is a virtual representation of a physical product or process, used to understand and predict the physical counterpart's performance characteristics.
SIEMENS, Conglomerate

A digital twin is a living model that drives a business outcome.
GENERAL ELECTRIC, Conglomerate

A "Virtual Twin" is a virtual representation of what has been produced. We can compare a Virtual Twin to its engineering design to better understand what was produced versus what was designed, tightening the loop between design and execution.
DASSAULT SYSTÈMES, Software

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Definition of Digital Twin

A digital twin is a digital representation of a real-world entity or system. The implementation of a digital twin is an encapsulated software object or model that mirrors a unique physical object, process, organisation, person or other abstraction. Data from multiple digital twins can be aggregated for a composite view across a number of real-world entities, such as a power plant or a city, and their related processes.
GARTNER, IT

A digital twin integrates ultra-high fidelity simulation with the vehicle's on-board integrated vehicle health management system, maintenance history and all available historical and fleet data to mirror the life of its flying twin and enable unprecedented levels of safety and reliability.
NASA, Government/Research

A digital twin is a virtual model of a process, product, production asset or service. Sensor-enabled and IoT- connected machines and devices, combined with machine learning and advanced analytics, can be used to view the device's state in real-time. When combined with both 2D and 3D design information, a digital twin can visualise the physical world and provide a method to simulate electronic, mechanical, and combined system outcomes.
MICROSOFT, Software

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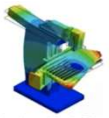
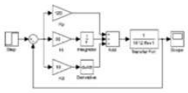
What is Digital Twin

A) Computer Aided Design of the Product



B) Mechanical Simulation of the Product



C) Control System Simulation of the Product

D) Real Time Dashboard showing state of the Product

E) None of the above

30

Definition of Digital Twin

Digital twin refers to the **processes** and **methods** for **describing** and **modeling** the **characteristics**, **behavior**, **formation process**, and **performance** of **physical objects** using digital technology.

•The **Digital Twin Model** refers to a **virtual model** that completely corresponds to and is consistent with the **physical entities** in the real world, and can **simulate** its **behavior** and **performances** in a **real-time environment** in **real time**.

•For example, the physical factory has a corresponding factory digital twin model in the virtual space.

•**Digital twin** is the foundation of the **intelligent manufacturing system**.

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Factory Based Digital twin:

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Definition of Product Digital Twin

- full-element reconstruction and digitized mapping of the physical entity's working state
- work progress in the information space
- is an integrated multiphysics, multiscale, hyperrealistic, dynamic, probability simulation model
- that can be used for simulating, monitoring, diagnosing, predicting, and controlling the formation process, state, and behavior of physical entities in the real world

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Definition of Product Digital Twin

It can be seen from the definition of the product digital twin model that:

(1) the product digital twin model is a **simulation model** in which **product physical entities** are integrated in the **information space**, *a digital file of the entire lifecycle of product physical entities*, and the integrated management of the product lifecycle data and full value chain data;

(2) the product digital twin model is **perfected** by continuous data and information interaction with the physical entity of the product;

(3) the final representation of the product digital twin models is a **complete** and **accurate digital description** of the physical entity of the product; and

(4) product digital twin model can be **used** to **simulate**, **monitor**, **diagnose**, **predict**, and **control** the formation process and status of physical entities in a physical environment.

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Basic features of Product Digital Twin Model

Virtuality

the product digital twin model is a physical product in **digital mapping** model

Image Credit: macs.eu

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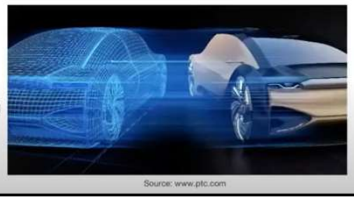
Basic features of Product Digital Twin Model

Uniqueness

a physical product corresponds to a product digital twin model.

product digital twin



physical product

Source: www.ptc.com

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Basic features of Product Digital Twin Model

Multiphysical

- the product digital twin model is based on the physical properties of physical product digital mapping model;
- It is not only necessary to describe the geometric properties of the physical product (such as shape, size, tolerance, etc.),
- but also to describe the various physical properties of the physical product, including
  - structural dynamics models,
  - stress analysis models,
  - thermodynamic models,
  - fatigue damage models, and
- material properties of product composition materials (such as stiffness,

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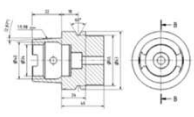
Basic features of Product Digital Twin Model

Multiscale

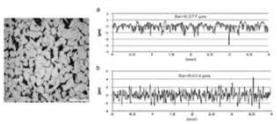
Macroscopic properties

Geometric dimensions



Microscopic properties

Microstructure of the material,
Surface roughness



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Basic features of Product Digital Twin Model

Hierarchical

the different components, parts, etc. that make up the final product can all have their corresponding digital twin models.

Aircraft digital twin model

Rack digital twin model

Propulsion control system digital twin model

Flight control system digital twin model

progressive realization of the product digital twin model.

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Basic features of Product Digital Twin Model

Integrated

the product digital twin model is a multiscale and multilevel integrated model of multiple

- physical structure models,
- geometric models, and
- material models,

which is conducive to the **rapid simulation** and analysis of the product's structural and mechanical properties.

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Basic features of Product Digital Twin Model

Dynamic

the product digital twin model will **constantly change and improve** through the **continuous interaction with the product entity** during various stages of the whole lifecycle;

For example,

- Product manufacturing data (such as test data, the progress data) will be reflected in the digital twin model of the virtual space, and
- At the same time, based on the digital twin model, can realize the real-time, dynamic and visual monitoring of the manufacturing state and process of the product.

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Basic features of Product Digital Twin Model

Super-realistic

the product digital twin model and the physical product are basically **identical** in appearance, content, and nature, with high degree of actuality, and can accurately reflect the real state of the physical product.

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Basic features of Product Digital Twin Model

Computability

based on the product digital twin model, **simulations**, **calculations** and **analysis** can be used to simulate and reflect the status and behavior of the corresponding physical product in real time

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Basic features of Product Digital Twin Model

Probability

the product digital twin model allows **computation** and **simulation** using **probabilistic** statistics

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Basic features of Product Digital Twin Model

Multidisciplinary

the product digital twin model involves the **intersection** and **fusion** of multiple disciplines such as **computational science**, **information science**, **mechanical engineering**, **electronic science**, **physics**, etc., and has multidiscipline.

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A Digital Twin is a _____

A) A virtual entity of a physical product

B) Tightly integrated with its sub-models.

C) Common for all instances of the product

D) Hyper-realistic

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Implementation of Digital Twin

Product design stage

Product digital twin is a **hyperrealistic dynamic model** of physical products in virtual space.

Product definition based on the 3D model

- Process design
- Tooling design
- Production manufacturing process
- product function testing and verification process simulation
- Optimization

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Basic features of Product Digital Twin Model

Product design stage

In order to ensure the **accuracy of simulation** and **optimization** results, at least the following three points must be guaranteed:

1. High accuracy and hyperrealism of product virtual mode
2. Accuracy and instantaneity of simulation
3. Model light-weighting

   lightweight technology of the model greatly **reduces the storage size** of the model, so that the **geometric** information, **feature** information and **attribute** information needed for product process design and simulation can be directly extracted from the 3D model

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Implementation of Digital Twin

Production stage

The evolution and improvement of product digital twin is through constant interaction with product entities.

In the manufacturing phase, the physical real world delivers production test data to virtual products in the virtual world and displays them instantly

Production process monitoring

- comparison of the design value and the measured value,
- comparison of the actual used material characteristics with the design material characteristics,
- comparison of the planned completion schedule and the actual completion schedule, etc.

In addition, based on the production measured data, through the **intelligent forecasting** and **analysis** of logistics and schedules, we can realize the **prediction** and **analysis** of **quality**, manufacturing **resources**, and production **schedules**.

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Implementation of Digital Twin

Production stage

- How to achieve real-time accurate multisource heterogeneous **data collection**, effective **information extraction**, and reliable transmission in a complex and dynamic physical space are **prerequisites** for achieving digital twin

In recent years, the rapid development of technologies, such as

Internet of Things, **Sensor networks**, **Industrial Internet**, and **semantic analysis and identification**, has provided a practical and feasible solution.

In addition, **artificial intelligence**, **machine learning**, and **data** are used to demonstrate the role of digital twin in **product data integration** demonstration, **product production progress monitoring**, **product quality monitoring**, intelligent analysis and decision-making

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Implementation of Digital Twin

Product Service stage

- The actual status, real-time data, use and maintenance of recorded data predict and analyze the **health**, **life**, **function** and **performance** of the product, and provide early warning of product quality issues.
- At the same time, when the product fails and has quality problems, it can realize **rapid positioning of product physical location**, **fault and quality problem records**, **parts replacement**, **product maintenance**, **product upgrade** and even scrapping and decommissioning.

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Implementation Use Case

Digital Twin of Machine Tool

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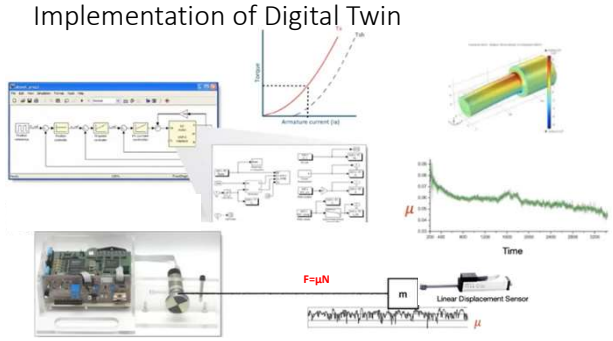
Implementation of Digital Twin



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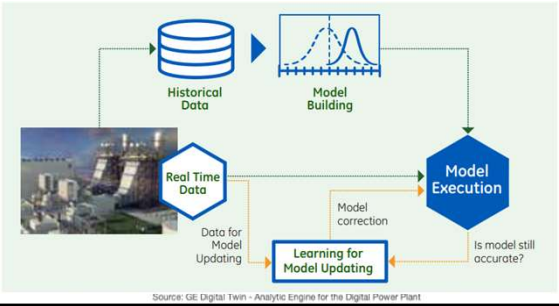
Implementation of Digital Twin



Source: GE Digital Twin - Analytic Engine for the Digital Power Plant

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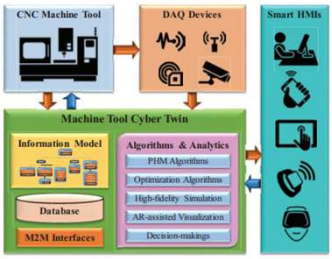
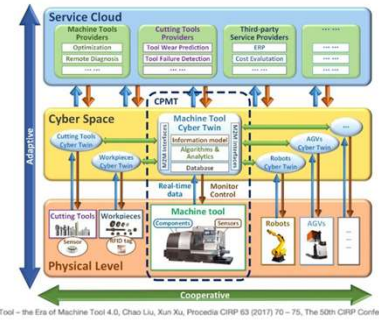
Components and Function of Cyber physical machine tool



Cyber-Physical Machine Tool – the Era of Machine Tool 4.0, Chao Liu, Xun Xu, Procedia CIRP 63 (2017) 70 – 75, The 50th CIRP Conference on Manufacturing Systems

58

System Architecture of CPMT–centered CPPS



Cyber-Physical Machine Tool – the Era of Machine Tool 4.0, Chao Liu, Xun Xu, Procedia CIRP 63 (2017) 70 – 75, The 50th CIRP Conference on Manufacturing Systems

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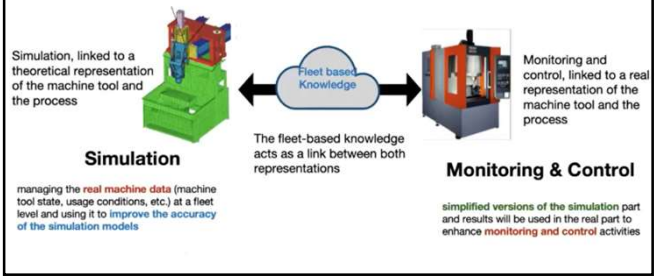
Main Application Environment of Digital Twin



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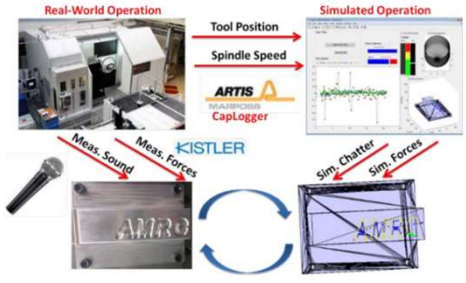
Main Application Environment Digital Twin



Evaluation of Machine Tool Digital Twin for Machining Operation in Industrial Environment 17th CIRP Conference on Modelling of Machining Operations
Mikel Armendia , Frédéric Cugnon , Luke Berglind , Erdem Ozturk

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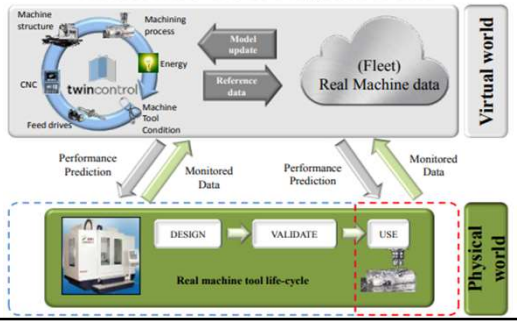
Machine Tool Digital Twin



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Machine tool Digital Twin

Application of combining Real Time Data with Simulation Models

- **Digital twins** can be evaluated with real data by feeding monitored inputs as in the real representation of the machine. This way, models can be tuned to improve their performance
- **Simulation models** can be used for the so-called **virtual commissioning** which consists of the digital twin of a physical system to set-up the **controller**.

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Virtual Machining

- Prediction of cutting forces, torque, power, stability and vibrations
- For **milling** and **turning** processes, surface roughness, dynamic tool position and inclusion of the spindle dynamics nonlinearities in predictions are not available in existing tool path simulation capabilities
- Tool/workpiece engagement evaluation along the tool path
- The accuracy of virtual machining is directly related to the identification of the engagement conditions.

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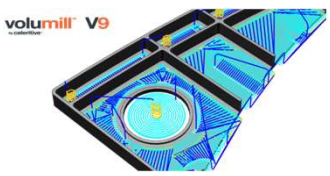
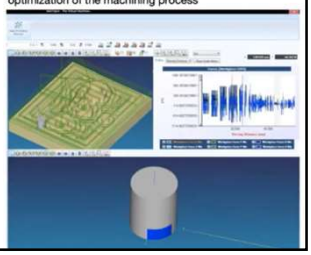
Virtual Machining

Geometry Based
Simulation tools -Volumill



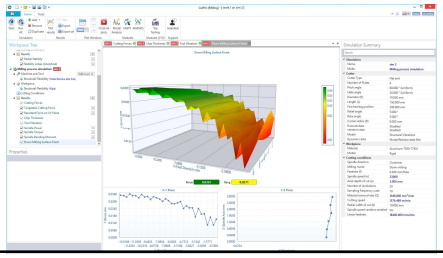
Machpro can let the user know about stability issues in addition to simulation of cutting forces, allowing an optimization of the machining process



65

Virtual Machining

Cutpro software runs analytical model for calculation of cutting forces and stability for a given set of parameters.



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These software packages cannot be used in simulation of the complete tool path for a given part

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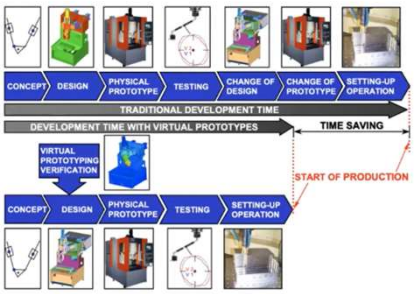
Virtual Machine Tool



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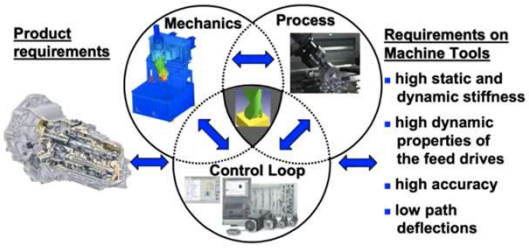
M/C Tool: The Mechatronic System



Requirements on Machine Tools

- high static and dynamic stiffness
- high dynamic properties of the feed drives
- high accuracy
- low path deflections

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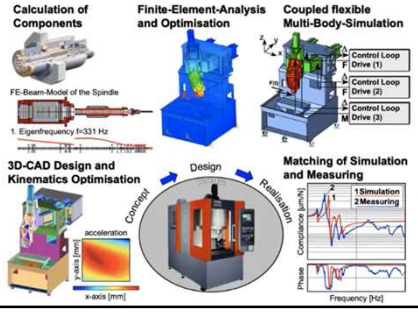
Integrated Development of Modern Machine Tools with Virtual Prototypes



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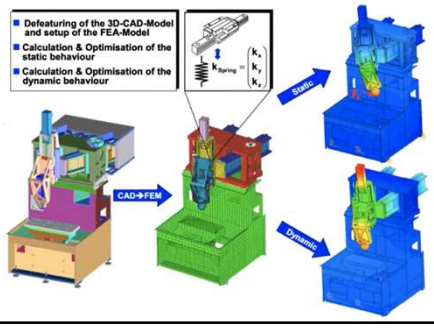
Steps of a FEA-Analysis of a machine tool



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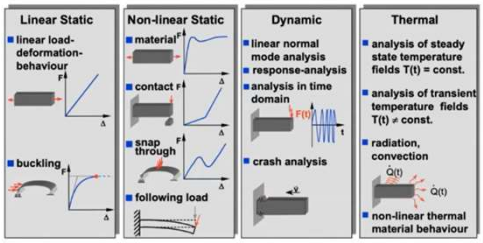
Virtual Machine Tool

Analysis types of the Finite-Element-Analysis



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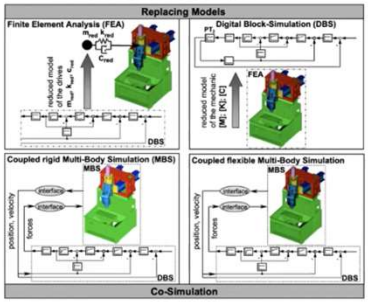
Methods of coupled simulation of structural dynamics and control loops



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There is no commercial package in which machining process is integrated with machine tool structure.

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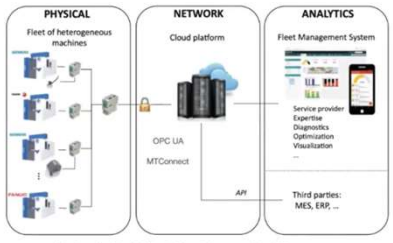
Monitoring and Data Management



Overview of a typical data monitoring and management architecture

Three main sections are observed: (1) the local monitoring of the physical systems (machines and process); (2) the platform (normally cloud-based) where the data will be managed; (3) the network through which the information will be collected and transferred between the previous systems.

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Application of Digital Twin

1. Product design based on digital twin

Synergy of existing physical products and virtual products in the design driven by the digital data generated by the products

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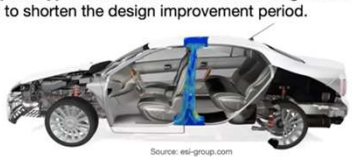
Applications of Digital Twin

2. Virtual prototype based on digital twin

Virtual prototype is a **digital model** built into the **digital world** that reflects the authenticity of a physical prototype, through multi-domain comprehensive simulation and equipment performance simulation, the performance of the equipment can be tested and evaluated **before** the **physical prototype** is manufactured, and the design defects can be improved to shorten the design improvement period.



Source: esi-group.com

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Application of Digital Twin

3. Workshop rapid design based on digital twin

4. Process planning based on digital twin

5. Workshop production scheduling optimization based on digital twin

6. Production logistics accurate distribution based on digital twin

7. Intelligent control of workshop equipment based on digital twin

8. Man-machine interaction based on digital twin

9. Assembly based on digital twin

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Application of Digital Twin

10. Testing/detection based on digital twin
11. Manufacturing energy management based on digital twin
12. Product quality analysis and traceability based on digital twin
13. Fault prediction and health management based on digital twin
14. Product-service system based on digital twin

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Implementation of Digital Twin is directly useful for _____

A) Real-time comparison of desired vs actual metrics

B) Guiding Operator to perform Maintenance

C) Sale of product

D) Implementing Industrial IoT

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Why Digital Twin?

Why Digital Twin so important? | Why should Organizations consider it?

- The digital twin can allow companies to have a complete digital footprint of their products from design and development through the end of the product life cycle.
- With the creation of the digital twin, companies may realize significant value in the areas of speed to market with a new product, improved operations, reduced defects, and emerging new business models to drive revenue
- The digital twin may enable companies to solve physical issues faster by detecting them sooner, predict outcomes to a much higher degree of accuracy, design and build better products, and, ultimately, better serve their customers

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Source https://www.youtube.com/watch?v=CJtvlvIzVT0

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