The Digital Twin: Technologies, Business, and Applications
Adam Drobot, Roberto Minerva, Noel Crespi
April 28, 2021, IEEE SVC Virtual Presentation
“The winner of the 1987 America's Cup competition embodied the results of a concentrated technological effort in sailboat design. Computers played a significant role in the victory!”

By John S. Letcher Jr., John K. Marshall, James C. Oliver III and Nils Salvesen

The Digital Twin – Start of the Journey

Freemantle Australia 1987

Stars & Stripes 1987
Design and Built – Four Different Variations of Stars and Stripes

Developed Multi-Disciplinary Models that included:

- Hydrodynamics
- Aerodynamics
- Structural Dynamics
- Material Properties
- Weather Prediction (Wind Direction and Velocity on actual course)

Over 10,000 Simulations, Sensor Data, Tow Tank Tests, Weather Feeds

VPP – Velocity Prediction Program

Design Changes Based on Numerical Models

Since 1964, the Americas Cup course has been 24.3 nautical miles, consisting of six legs, with the first leg to windward.

The margin of victory seconds to minutes.
The Digital Twin – Start of the Journey

2021
Auckland NZ

2013
San Francisco USA

1851
England
Sometimes things don’t go according to plan. Murphy and mother nature but perseverance pays off!

2013
San Francisco USA
A “Digital Twin” is a tool for capturing the past, understanding the present, and predicting the future.
A “Digital Twin” is a dynamic, virtual digital representation, of an asset or a physical object, a product, a processes, a service, or a system. It digitally models and displays the state, properties, condition, and attributes of the real-world counterpart in context.
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Using data from multiple sources, a “Digital Twin” continuously learns and updates itself to represent the current state or working condition of the asset or object, product, process, service, or system. End-users and decision-makers gain deep understanding, which they apply to improve their knowledge and awareness, or optimize the performance of the modeled asset and the larger systems it interacts with.
Digital Twins are applicable to many human activities and endeavors where modeling and simulation can shed light on how well the actual activities/endeavors are conducted and function in a “real world” context. To be concrete they can help us: (1) understand performance and important attributes; (2) pinpoint where improvements in efficiency or optimization are possible; (3) avoid critical disruption or failures; and (4) can add value in fundamental ways to our capabilities and dramatically affect our experiences.

In broad terms one can bucket the domains where Digital Twins are important as:

- Manufacturing
- Products and Goods
- Services
- Processes
Digital Twin

The Physical World

The World Of Imagination

No Corresponding “real” object

The Digital Twin

Digital Twin

Virtual Digital Twin

The Digital World
Digital Twin

- Technologies, Business Models, and Applications

- Supporting Infrastructure
  - Data History
  - Analysis
  - Tests
  - Resources
  - Controls
  - Reporting
  - Connectivity
  - ………

- Sensors Instrumentation
- Contextual Data
- Actions
- Environment
- Feedback
Digital Twin

Some of what’s under the skin

- Representation
- Interface Controls
- Execution
- Models And Simulations
- Data And Data Feeds
- Testing And Validation

Digital Twin

The Digital Twin
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The Digital Twin – Technologies, Business Models, and Applications
The Digital Twin

The Physical World

Complex/Compound Object

The Digital World

Digital Twins working in concert
The Digital Twin

Technologies, Business Models, and Applications

The Digital Twin

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A System of Objects

Constellation of Digital Twins working in concert
Digital Twin

A Lifecycle View – Different Roles at Different Stages

- Requirements
- Design
- Development
- Deployment
- Maintenance Upgrades
- Retirement Disposal

Capability

Time and Cost

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The Digital Twin – Technologies, Business Models, and Applications
Digital Twin

Digital Twin Execution and Practice

Level of Sophistication

Level -1 Stand Alone DTs
Representational

Level -2 Aggregated DTs
Instrumentation Analytics Models

Level -3 Orchestrated DTs
Predictive Behaviors Data Fusion and Analysis Rudimentary Controls

Level -4 Enterprise wide Use/Reuse Connected and Networked IoT Sensors and Data Feeds Analysis Visibility Prognostics and Diagnostics Basis for Controls

Level -5 High Level of Automation and Autonomy DTs are part of the Ecosystem High Fidelity and Granularity in Models Enterprise wide Infrastructure to Support DTs Fundamentally built into the business

The Digital Twin – Technologies, Business Models, and Applications

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Digital Twin

Ink on Mylar and Slide Rules
Early Calculators
Mainframe Computers
Department Silos

CAD/CAM
Room Size Computers
IT Transformation
Concurrent Engineering

Engineering Workstations
Super Computers, Computing Clusters
Electronic Digital Mockups
Integrated Product Management

Growth of Fast Computing
Edge Computing and Networks
Growth of Digital Twins
Collaborative Enterprise

Quantum Computing
Mature Digital Twins
Autonomy
Process Cognition


The Digital Twin – Technologies, Business Models, and Applications

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In the constructing of a Digital Twins the underlying representation is critical. It can emphasize different aspects of what is important. The orientation can be driven by representations that are oriented towards:

- The Visual Display of Information
- Data Driven
- Logical Relationships
- Domain Specific Physical Model
- Event Driven Dynamics
- Knowledge Driven
- Experience Driven
The Digital Twin

- **Graphical (geometry) oriented** → example airports, smart cities, products, ...... or educational/entertainment
- **Data Oriented** → processes, products, elements producing a large quantity of data that have impacts on humans and other objects, e.g. smart cities, cultural heritage, process control and quality assurance
- **Process Oriented** → manufacturing or services (ships, airplane, complex objects, banking, medical care, ...) capturing procedures and flows in a physical or abstract setting
- **Model Oriented** → representing the object in a specific environment and studying its reactions, ability to keep up to the required functionalities e.g., prototyping and simulation of working
- **Service oriented** → Representing the object focused on the services and functionalities to be released to the final users.
- **Logic oriented** → Representing how objects and artifacts are related to each other (building systems, large capital goods,.....)
The Digital Twin - Technologies

- **Building Blocks and essential Ingredients**
  - Basic Core Technologies
    - Computing
    - Storage
    - Connectivity
    - Sensors
    - Actuators
    - Interfaces – Humans in the Loop
    - Software
    - Power and Energy
The Digital Twin - Technologies

- **Building Blocks and essential Ingredients**
- **Lifecycle Technologies**
  - Domain Technologies and Domain Knowledge
  - Requirements
  - Design
  - Development
  - Deployment
  - Operational
  - Maintenance, Repair, and Upgrades
  - Retirement
The Digital Twin - Technologies

• **Building Blocks and essential Ingredients**

  **Enabling Technologies**

  – *Domain Technologies and Domain Knowledge*
  
  – *Data Science and Engineering*
  
  – *Computational Geometry and Graphics*
  
  – *Modeling and Simulation*
  
  – *Artificial Intelligence and Analysis*
    - Machine Learning (ML, DL, Neural Nets)
    - Machine Vision, Natural Language Processing, Robotics, General Intelligence, ......
  
  – *Augmented/Virtual Reality*
  
  – *Photogrammetry*
  
  – *Internet of Things (IoT)*
  
  – *Additive Manufacturing*
Digital Twin – Business Value
Digital Twin – Business Value

- Making Things More Efficient
  - Conquering Complexity
  - Implementing Optimization
  - Redesigning and Refactoring Processes
- Automation
- Innovation
- Existential - Making Good Decisions
- Avoiding Risks and Hazards, Assuring Safety
- Managing of Assets
- Creating New User Experiences
The Digital Twin – Business Value

From
Larry Schmitt
Inovo Group

Over 50 Business Models

5 That Stand Out

Aggregator
Fractionalization
Twin as a Service
Multi-sided market/platform
Razor and Blades (and reverse)
Digital Twin – Business Value

The Twin Lives Well beyond the life Span of the Physical Object

From
Larry Schmitt
Inovo Group

Digital is the Twin of the Physical
Physical is the Twin of the Digital

Future Paradigm Shift
The Twin Lives Well beyond the life Span of the Physical Object

Laser Scan of Notre Dame before the fire!
Digital Twin – Value

Reconstructed Image

Seeing what the eye can not

Laser Stations

From
Larry Schmitt
Inovo Group

The Twin Lives
Well beyond the life Span of the Physical Object
The Digital Twin – Value

The Twins Lives Forever – Not the Physical Object!

From
Larry Schmitt
Inovo Group

The Twin Lives
Well beyond the life Span of the Physical Object
The Digital Twin – Value

From Larry Schmitt
Inovo Group

The Twin Lives
Well beyond the life
Span of the Physical Object

It can also recreate objects that no longer exist but are important to understand

The Capitoline Hill in Rome - Detail
Reconstruction And Animation of the Growth of Ancient Rome
The Unearthed City of Dvin - Armenia

The Digital Twin
April 28, 2021

The Digital Twin – Technologies, Business Models, and Applications
Digital Twin – Value

Rebuilding Notre Dame Cathedral

The Twin as Template

New Methods New Materials

From Larry Schmitt
Inovo Group

The Twin Lives Well beyond the life Span of the Physical Object
Digital Twin - Applications

- Shipbuilding

Aircraft Carrier > 1Billion Parts

Aircraft 3 – 7Million Parts

Car 20 – 30 Thousand Parts

The Digital Twin – Technologies, Business Models, and Applications
Digital Twin - Applications

- Shipbuilding
  - Carpentry Shop
    - Models and Arrangements
  - Drafting Room
    - Drawings and Engineering
Digital Twin - Applications

- Shipbuilding
Digital Twin - Applications

• Shipbuilding

The Shipyard

Carrier Integration and Design Building

Pipe bending
Digital Twin - Applications

- Shipbuilding
  - Placing the Island
  - Section Assemblies
Digital Twin - Applications

- Shipbuilding

Submarine Section

Joint Manufacturing Assembly Facility

Welder
Digital Twin - Applications

• Shipbuilding

An actual ship and a virtual ship in a virtual ocean

Solving a mystery!
In 2014, nine blue whales were found dead in ice in the Gulf of St. Lawrence. Whales get trapped in these waters sometimes, but never in such high numbers. In anticipation of the Great Whales exhibition, we look at how the blue whale skeleton came to the ROM under extraordinary circumstances.

https://www.rom.on.ca/en/rom-at-home/the-blue-whale-story
Digital Twin - Applications

• Preservation

Royal Ontario Museum

Beached Pod of Whales in Nova Scotia
Digital Twin - Applications

• Preservation

Royal Ontario Museum

Mounting The Whale Bones

Scanning the Whale Bones
Digital Twin - Applications

- Preservation
  Royal Ontario Museum

Printable Digital Twin
Digital Twin - Applications

- Public Health
- Medical Models
- Integrated Diagnostics
- Athletics and Personal Health Training
Digital Twin - Applications

- Oil & Gas Exploration and Production
  - Automation In Exploration
  - Design and Buildout
  - Maintenance and Safety

- Wind Power and Renewables From Design To Maintenance

The Digital Twin
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The Digital Twin – Technologies, Business Models, and Applications
Digital Twin - Applications

- Automation in Manufacturing
- Controls and Quality Monitoring
- Powerplant Design Buildout and Operation
- Predictive Maintenance
- Controls
Thank You!

$172.90 Amazon


$180.59 Amazon
“Digital Twin: A Complete Guide For The Complete Beginner”; Vijay Raghunathan and Santanu Deb Barma - Authors; 56 Pages (2020). **ASIN:** B081CKGR5Q

$2.00 Amazon Kindle Only


$158.78 Amazon

$36.00 Amazon


$89.00 Amazon
The Digital Twin - Bibliography


$183.95 Amazon


$204.97 Amazon

$250.00 Vital Source


$130.00 Amazon

$72.76 Amazon


$9.99 Amazon Kindle Edition (Not a good book)
The Digital Twin - Bibliography


$85.95 Amazon

“Advances and New Trends in Environmental Informatics: Digital Twins for Sustainability”; Andreas Kamlaris (Editor), Volker Wohlgemuth (Editor), Kostas Karatzas (Editor), Ioannis N. Athanasiadis (Editor), Springer; Progress in IS, 1st ed. 279 pages (December 17, 2020) ISBN-13: 978-3030619688

$97.42 Amazon

$70.00 Amazon


$110.15 Amazon
“Artificial Intelligence and Industrial Applications: Artificial Intelligence Techniques for Cyber-Physical, Digital Twin Systems and Engineering Applications”; Tawfik Masrou (Editor), Ibtissam El Hassani (Editor), Anass Cherrafi (Editor), Springer, Lecture Notes in Networks and Systems, Book 144, 344 pages (July 19, 2020)


$167.95 Amazon

“Success with Simulation: A definitive guide to process improvement success using simulation for healthcare, manufacturing, and warehousing”; Hosni I Adra (Author), Publisher: Hosni Adra, 290 pages (December 23, 2018)


$24.00 Amazon

$40.00 Amazon


$34.99 Amazon
$85.95 Amazon

$35.95 Amazon
“Handbook of Research on Developing Smart Cities Based on Digital Twins”; by Matteo Del Giudice (Author, Editor), Anna Osello (Editor), IGI Global, Advances in Civil and Industrial Engineering, 674pages (January 15, 2021)
$295.00 Amazon

$349.99 Amazon

$169.99 Amazon


$4.19 Amazon

$8.99 Amazon


$159.56 Amazon
The Digital Twin and Cultural Heritage
Cultural Heritage - Bibliography


Digital Twin - Applications

Cultural Heritage - Bibliography


Digital Twin - Applications

Cultural Heritage - Bibliography


Digital Twin - Applications

Cultural Heritage - Bibliography


