digi TWIN GLOBAL™ PRESENTS

DIGITAL TWIN SYMPOSIUM

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# The Promise and Applications of Digital Twins

**John Vickers | NASA, Principal Technologist, Advanced Manufacturing**

**FEBRUARY 26 - 28, 2025** | **BATON ROUGE, LA**

# Digital Twin Definitions- A picture is worth a thousand words

*A digital twin is a set of virtual information constructs that mimics the structure, context, and behavior of a natural, engineered, or social system (or system-of-systems), is dynamically updated with data from its physical twin, has a predictive capability, and informs decisions that realize value. The bidirectional interaction between the virtual and the physical is central to the digital twin.*
**National Academies Report 2024**

***Humpty Dumpty:*** *"When I use a word it means just what I choose it to mean, no more nor less."* **Lewis Carroll**

*A digital twin is a digital replica of a physical object, person, system, or process, contextualized in a digital version of its environment.* **McKinsey**

*A Digital Twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning, and reasoning to help decision-making.*
**IBM**

*"A poet would be overcome by sleep and hunger before being able to describe with words what a painter is able to in an instant."*
***Leonardo da Vinci***

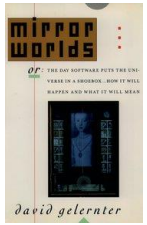
*A digital twin is an integrated data-driven virtual representation of real-world entities and processes, with synchronized interaction at a specified frequency and fidelity.*
**Digital Twin Consortium**

*Virtual twins provide the ability to 3D model everything around you, and then test and simulate to ensure your model is perfected.* **Dassault**

*A digital twin is a complete (holistic) computational (modeling and simulation) replica of a real-world application (purpose) that enables understanding of interconnected relationships(systems) and explores potential future outcomes(prediction).* **John Vickers**

**"Digital Twin" Google Scholar ~190,000 results vs Google ~17,300,000 results (Definition ~800/9000)**

# Origins Story (Vickers/Grieves)






Mirror Worlds: or the Day Software Puts the Universe in a Shoebox, Gelernter, 1993

Next-Generation Manufacturing

NSF A Framework for Action, (Neal et al.) 1997

Intelligent Synthesis Environment (ISE) (Goldin, et al.) 1999

Intelligent and Integrated Manufacturing Systems (IIMS)

National Science and Technology Council, 2004

Manufacturing the Future Intelligent and Integrated Manufacturing Interagency Working Group on Manufacturing R&D, 2008

Radical Innovation in Design and Manufacturing workshop – Disney World, 2009

NASA Materials and Manufacturing Technology Roadmap (National Academies), 2010 **Digital Twin

SME Magazine - Where the 'Digital Universe' Is Going and Where Wild Savings Can Be Had Today, (Kip Hanson) 2021

SME Magazine - The Promise of Digital Twins—and Today's Remarkable Applications, 2024

"Conceptual Ideal for PLM"
Product Lifecycle Management (PLM) Center University of Michigan, 2002 ** Digital Twin

Product Lifecycle Management: Driving the Next Generation of Lean Thinking: 2006

Vickers/Grieves introduction 2007

Product Lifecycle Management and the Quest for Sustainable Space Exploration AIAA SPACE Conference & Exposition, 2010

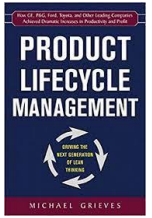
Virtually Perfect: Driving Innovative and Lean Products through Product Lifecycle Management, 2011
** Digital Twin

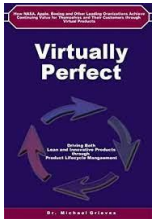
Can the digital twin transform manufacturing, Economist, 2015

Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems, 2017

Holst Memorial Lecture and Award, 2022

Digital Twins, Simulation, and the Metaverse, 2024




# NASA's Digital Transformation Strategic Framework

## How we Synchronize DT Plans & Catalyze DT Progress

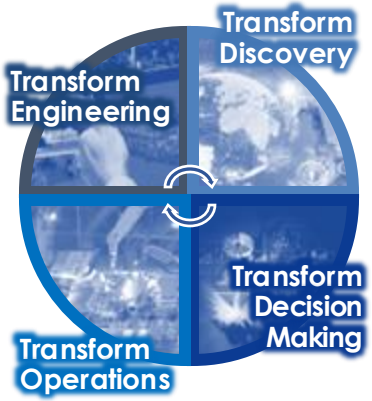
**3** FUTURE STATE GOALS

**4** TRANSFORMATION TARGETS

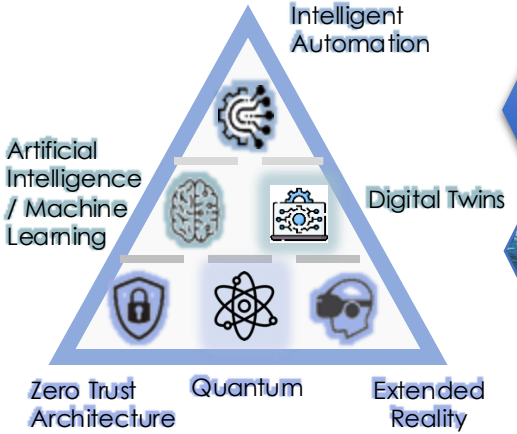
**5** DIGITAL LEVERS

**6** TECHNOLOGY FOUNDATIONS

**7+** MISSION OUTCOMES


- Establish Interoperable *Architectures*
- Transform Critical *Processes*
- Maximize the Impact of our *Data*
- Adopt Common *Tools*
- Strengthen Inclusive[3] *Teaming*



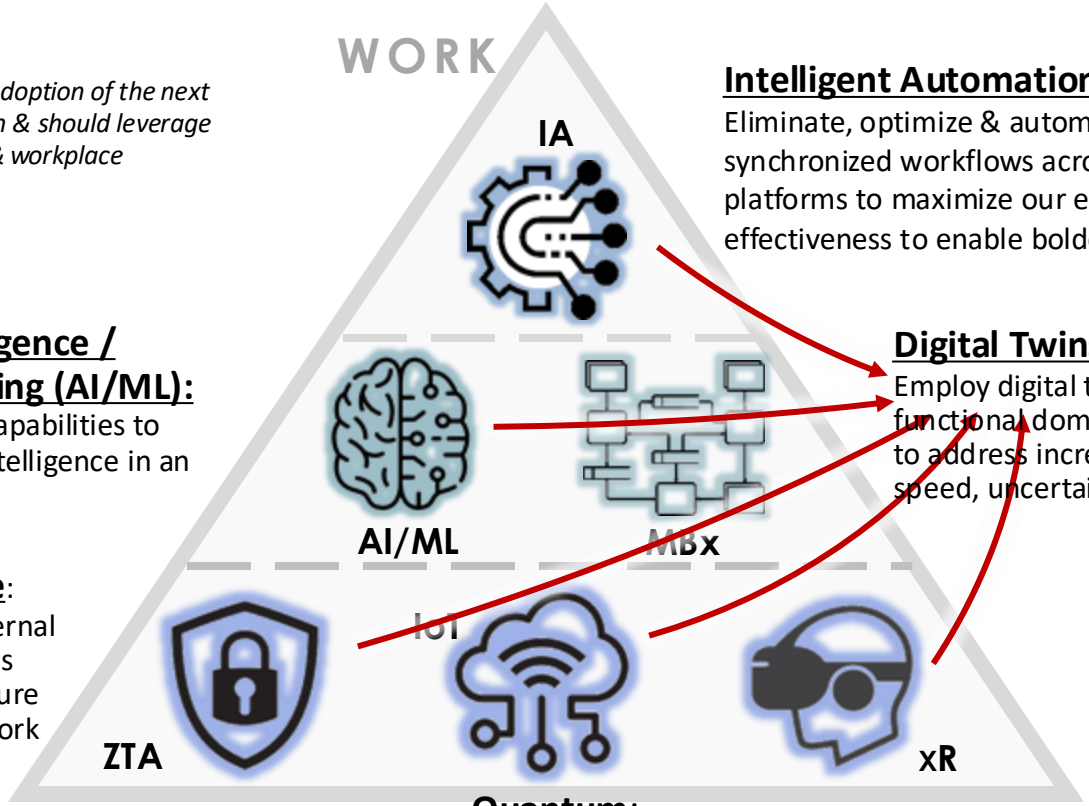


**One Future NASA**

NASA TM 20220018538

# WHICH digital technologies will we use next?
## *6 Technology Foundations*

*DT will catalyze investigation and adoption of the next key digital technologies that we can & should leverage to transform our work, workforce & workplace*




**Intelligent Automation (IA):**
Eliminate, optimize & automate processes into synchronized workflows across enterprise platforms to maximize our efficiency and effectiveness to enable bolder missions faster

**Artificial Intelligence / Machine Learning (AI/ML):**
Harness machine capabilities to augment human intelligence in an era of big data

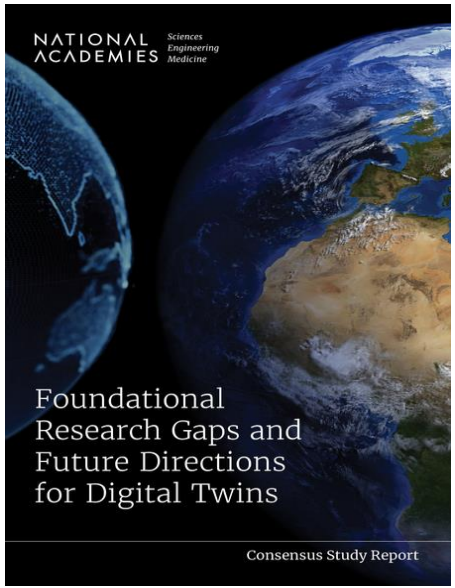
**Digital Twins:**
Employ digital twins across any/all functional domains to enable our people to address increasing complexity, scope, speed, uncertainty & changes

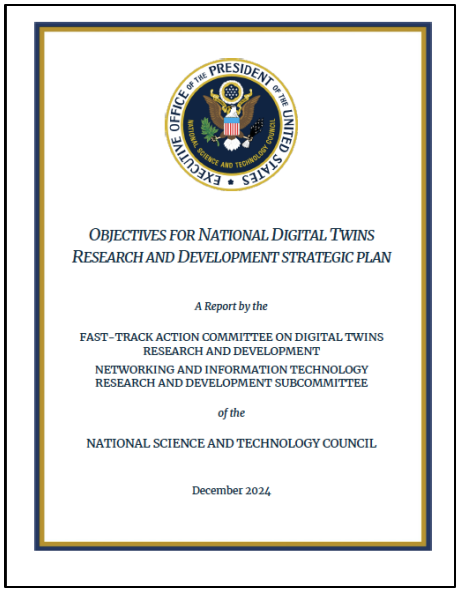
**Zero Trust Architecture**:
Enable dynamic internal/external collaboration wherever teams need to work, leveraging secure infrastructure, identity, network & data architecture

**Extended Reality**:
Enhance agile internal/ external teaming via seamless, immersive, secure visualization & collaboration

**Quantum**:
Leverage its potential for significantly enhanced missions by utilizing quantum computing and communication to solve complex challenges in areas like mission planning, materials science, and deep space travel

# National Deliberation Digital Twins



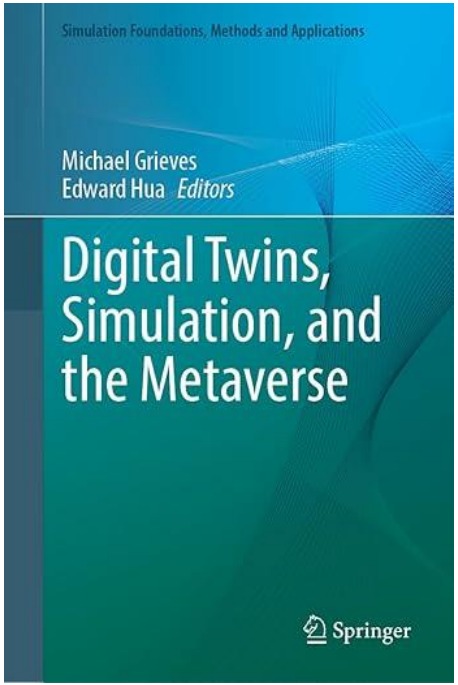

**Summary of the National Academies Report**

- Digital twins hold immense promise for revolutionizing various sectors…
- A digital twin is "a set of virtual information constructs that mimics the structure…
- Fit for Purpose Virtual Representation
- Modeling and Simulation/physical counterpart/Bidirectional Interaction
- Improved Decision-Making/Enhanced Efficiency/Accelerated Scientific Discovery/Knowledge Preservation

**Research Gaps**

- Verification, Validation, and Uncertainty Quantification (VVUQ)
- Mathematical and Computational Gaps
- Data Integration and Management
- Interdisciplinary Collaboration
- Interagency Working Group

# My Reading Digital Twin Books





**Summary of "Twin Systems"**

- Practical applications of digital twins across various stages of infrastructure projects…
- The level of fidelity depends on the purpose
- Not only physical assets but also behaviors and processes
- Emphasis on a systems thinking and more holistic approach to implementation
- Capacity to extrapolate forwards and backwards
- Ability to outlive intended purpose
- Not merely digital replicas but dynamic, living systems
- Digital twin lifecycle, from its origins in design stages to its maturity in the operational phase
- Interconnected forecasting, forensics, AI, and IoT
- Security challenges associated with digital twins, particularly in large-scale infrastructure projects

🚫 More than an expansion of DT concept

# NASA Space Technology Research Institute -- Institute for Model-Based Qualification & Certification of Additive Manufacturing (IMQCAM)

## Vision

Our vision is to deliver a Digital Twin (DT) platform comprising a powerful set of integrated computational models and simulation tools that can be used with confidence by NASA researchers and practitioners for Q&C of AM processes and products. This DT will promote a holistic, cradle-to-grave model-based approach for unraveling complex subtleties in the materials-processes-structure-property performance and life relationships in the metals additive manufacturing domain.

## Mission

The goal of the IMQCAM is to develop an end-to-end model or Digital Twin of the LPBF process, connecting feedstock, 3D printing conditions, and post-print microstructural state to part response and location-specific properties, as well as fatigue life that is crucial to the aerospace community.

$15M/5-year grant

Partner Institutions: Carnegie Mellon University, Johns Hopkins University (JHU), JHU-Applied Physics Laboratory, Vanderbilt University, University of Texas-San Antonio, Southwest Research Institute, University of Virginia, Pratt & Whitney (PW), Case Western Reserve University

Carnegie Mellon University,
Johns Hopkins University


Group photograph from the IMQCAM Continuation Review, Oct 3-4 at CMU. Photo credit: CMU

Major Focus Areas:

- Process Modeling
- Multiscale Modeling &
- Life Prediction
- Digital Twin Assisted Qualification & Certification
- Data & Software Integration

# NASA'S LunaRecycle Centennial Challenge

**"Everything that we do on the moon: we've got to figure out how to dispose of it or it's there forever…"** *Pam Melroy, Deputy NASA Administrator*

**The LunaRecycle Challenge is a $3 million, two track, two-phase competition focused on the design and development of recycling solutions that can reduce solid waste and improve the sustainability of longer-term lunar missions.**

**Digital Twin track, focused on designing a digital twin of a complete system for recycling one or more solid waste categories on the lunar surface and manufacturing one or more end products. Teams in this track must include the manufacturing of one or more finished end products in their design.**

# NASA's Rocket Factory

NASA Michoud Assembly Facility New Orleans, LA

NASA SLS Moon Rocket

*The transformative potential of digital twins is immense. As technologies advance, converge, and adoption grows, digital twins are poised to revolutionize how we work, live, and explore, leading to a more productive, sustainable, and innovative future.*

Photo inside MAF


Digital Twin Image

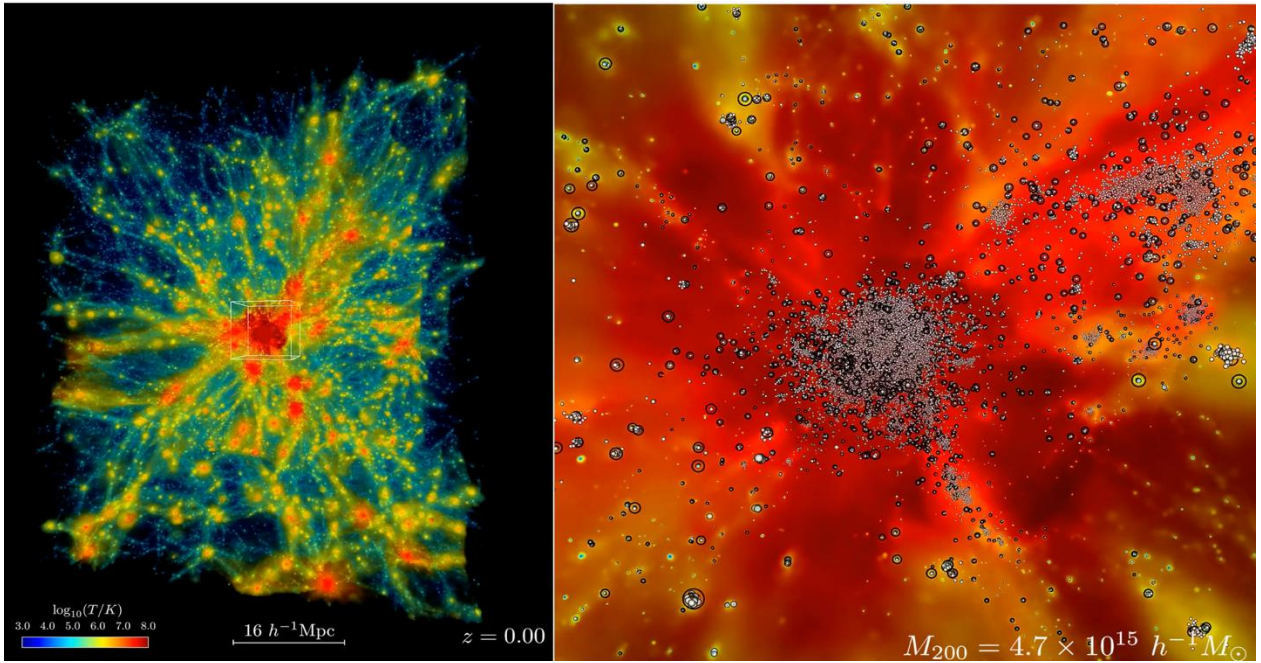
**Smart Factories** today

# Digital twins: Exploring the Unknown, Expanding our Understanding

**“Digital twins hold exciting potential for exploring the unknown. Digital twins can create virtual replicas of unexplored environments. They can push the boundaries of knowledge, unveil the unexplained, and enhance our ability to respond to the unexpected, leading to a more resilient and informed future.”**

https://www.technologyreview.com/2024/06/10/1093417/how-digital-twins-are-helping-scientists/

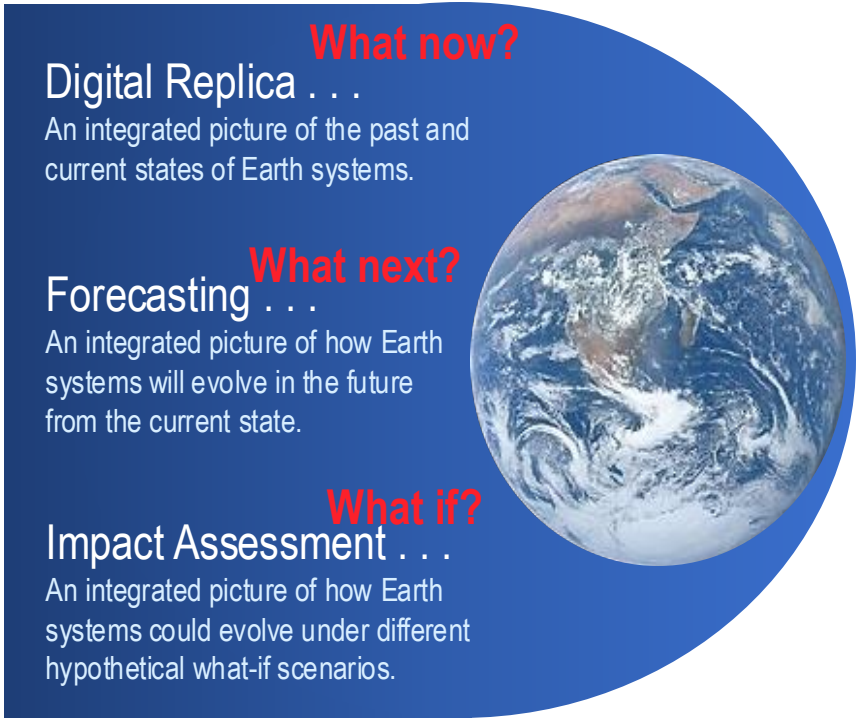
# Digital twins: Exploring the Unknown, Expanding our Understanding




**World's largest simulation of the cosmos lays new computational foundation for simultaneous extreme-scale dark matter and astrophysical investigations. The universe just got a whole lot bigger… or at least in the world of computer simulations. The Department of Energy's Argonne National Laboratory used the fastest supercomputer on the planet to run the largest astrophysical simulation of the universe ever conducted.**

# Earth System Digital Twins Components

**NASA Earth Science Technology Office (ESTO), Advanced Information Systems Technology (AIST)**
**Earth Systems Digital Twins (ESDTs) are an emerging capability for understanding, forecasting, and conjecturing the complex interconnections among Earth systems, including anthropomorphic forcings and impacts to humanity.**




**An Earth System Digital Twin or ESDT** is a dynamic and interactive information system that first provides a digital replica of the past and current states of the Earth or Earth system, as accurately and timely as possible, second allows for computing forecasts of future states under nominal assumptions and based on the current replica, and third offers the capability to investigate many hypothetical scenarios under varying impact assumptions.

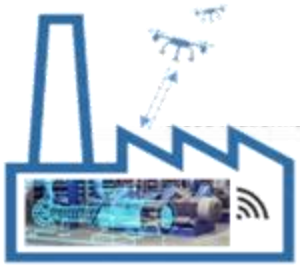
**=> What Now? What Next? What If?**

An ESDT includes:

- Continuous observations of interacting Earth & human systems
- From many disparate sources
- Driving inter-connected models
- At many physical and temporal scales
- With fast, powerful and integrated prediction, analysis & visualization capabilities
- Using Machine Learning, causality and uncertainty quantification
- Running at scale in order to improve our science understanding of those systems, their interactions and their applications

# Digital Twins of our Workplace

## Smart Centers today…

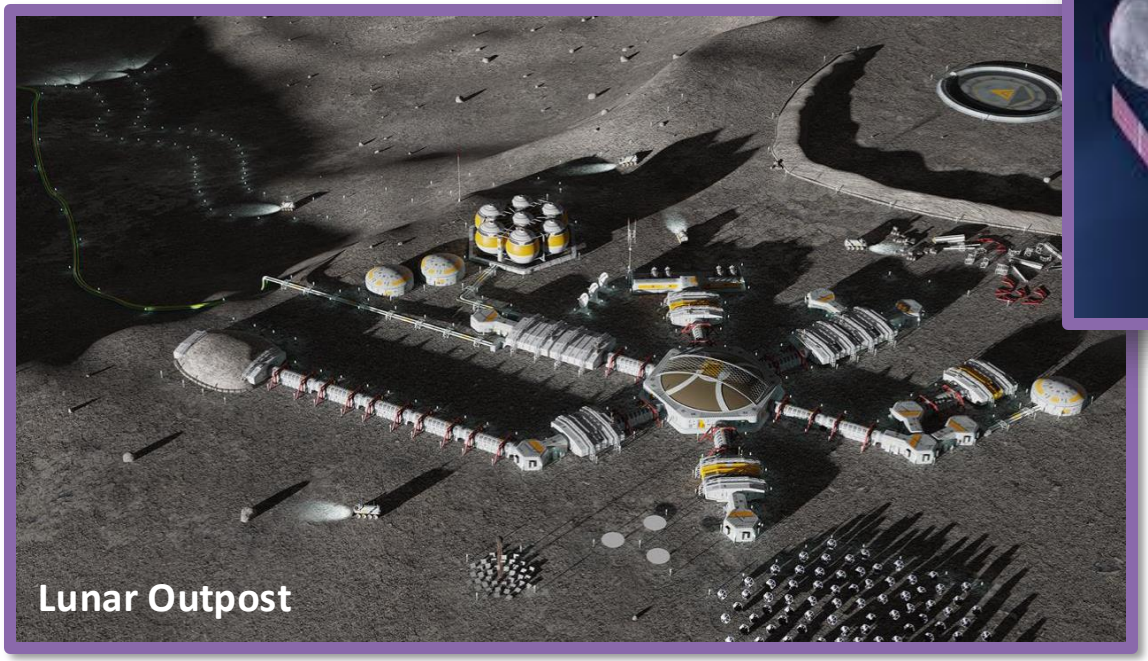





*Integrating Smart Cities technologies to* ***optimize services*** *for our "citizens," "business partners" and "city managers"*

# Cislunar & Lunar Surface Mission Planning

*Leveraging digital twins to design, manufacture, test and operate mission elements from multiple nations >1000x before attempting real missions to* ***speed design cycles & reduce costs***



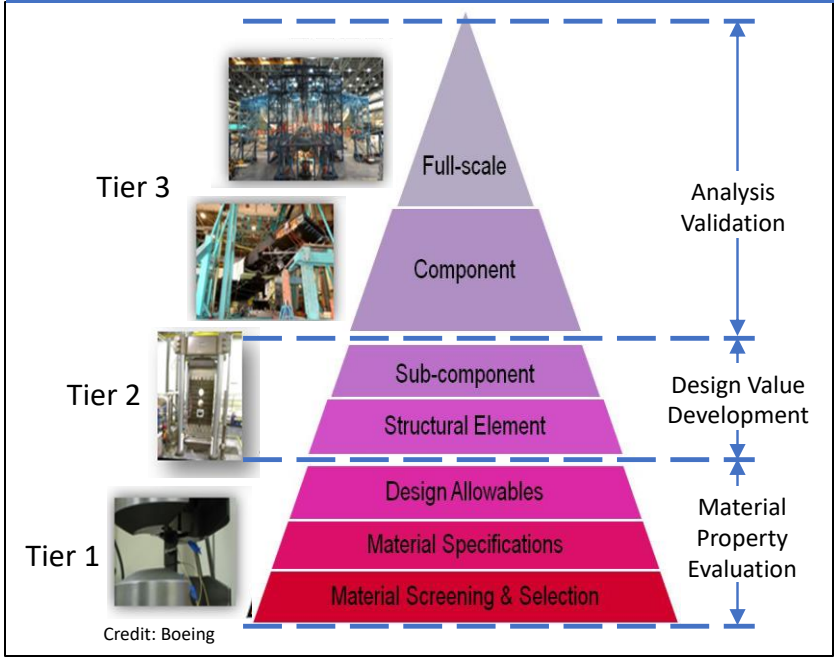

Gateway Lunar Space Station

**Smart Bases** tomorrow

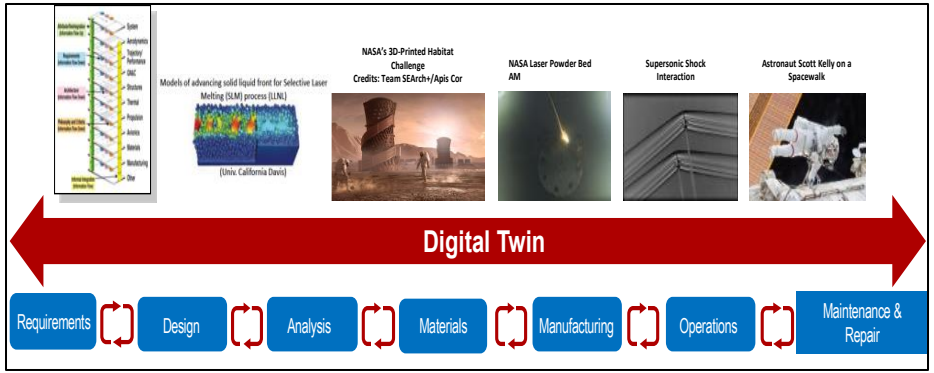

**Award to Semiconductor Research Corporation Manufacturing Consortium Corporation in North Carolina, $285 Million CHIPS Manufacturing USA Institute for Digital Twins. Total investment of over $1 billion, SMART USA (Semiconductor Manufacturing and Advanced Research with Twins USA). Focus on digital twin efforts to more rapidly develop, validate, and improve domestic semiconductor design, manufacturing, advanced packaging, assembly, and test processes.**

# A Little Less Conversation A Little More Action Please

## *Product Development, Testing and Certification Today*

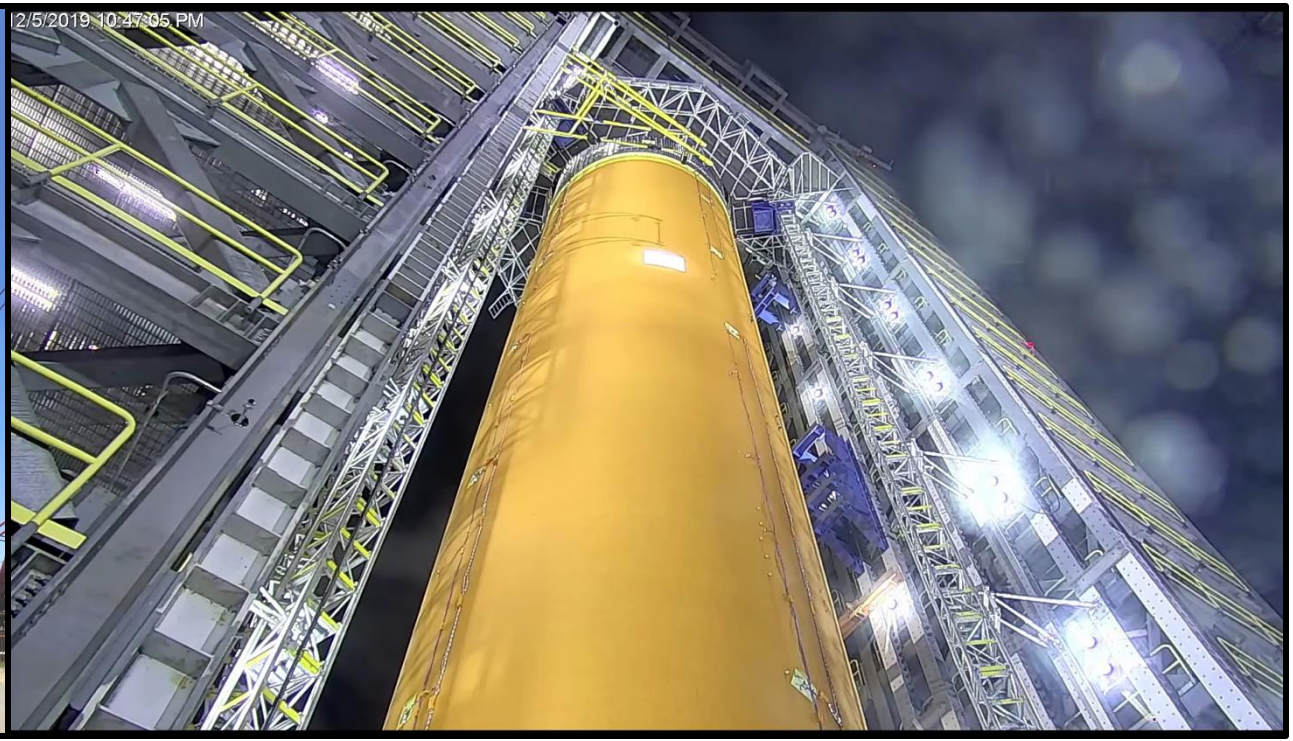



Credit: Boeing




***"It takes too long and costs too much to certify aerospace structures"***
***Exhaustive testing done to support analysis***

# Testing and Certification Today




*"One good test is worth a thousand expert opinions." Wernher Von Braun*

# Legacy vs. Transformation


# QUESTIONS?

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