Digital Engineering Ecosystem for Innovative Nuclear Technologies

22nd NDIA Systems and Mission Engineering Conference

Tampa, Florida

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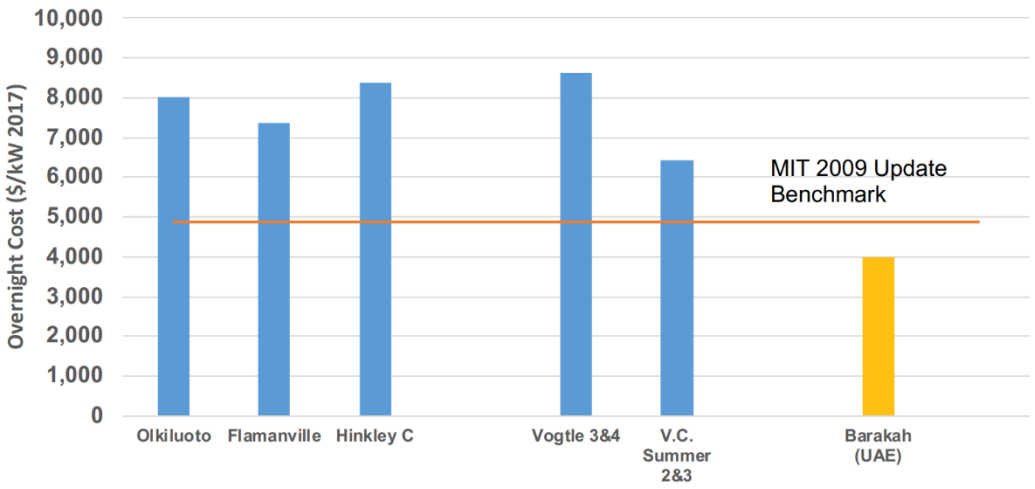
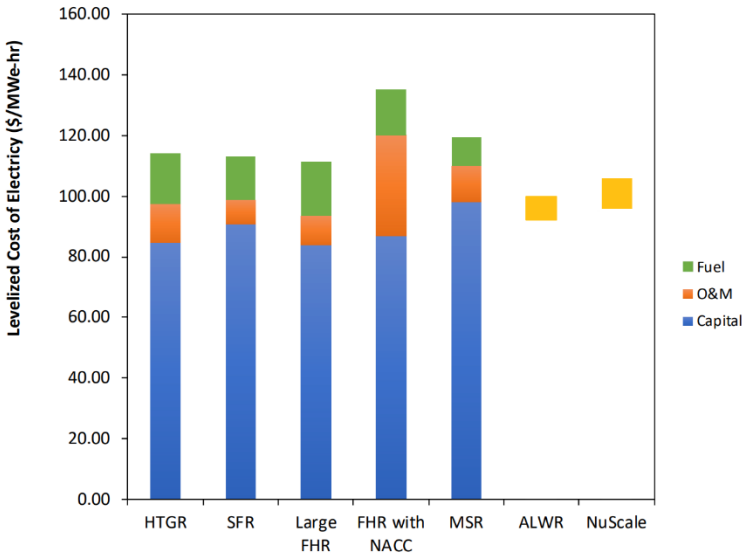
Nuclear Power Economics

Overnight cost of recent Gen-III+ builds versus benchmark



Projected LCOE for different advanced reactor concepts



The Future of Nuclear Energy in a Carbon-Constrained World

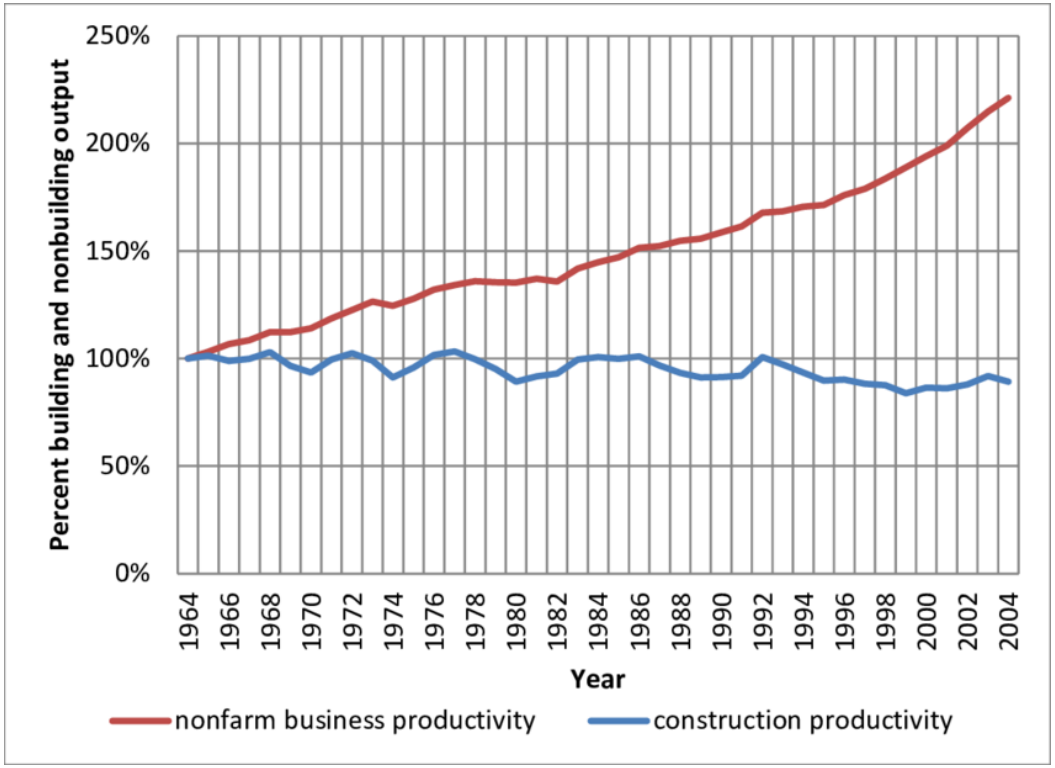
New nuclear plant construction is of **high capital cost** and new nuclear construction has only become **costlier**

Source: https://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf

Factors contributing to overruns

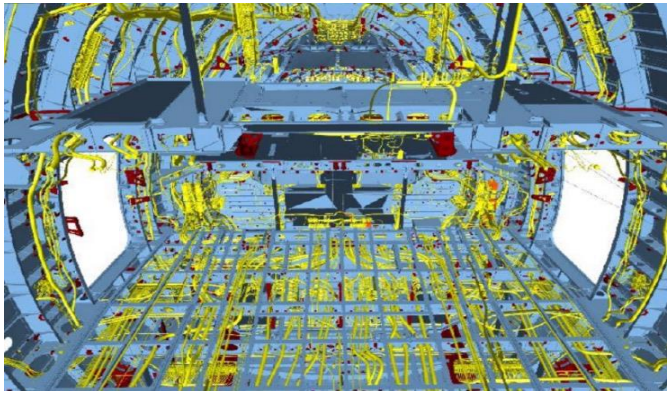
- First of a Kind: **30% more expensive** than subsequent plants of the same design
- Construction factors:
  - Delays
  - **Rework**
  - Supply chain issues
- Construction productivity **lags** all other industries

Labor Productivity index for the US Construction

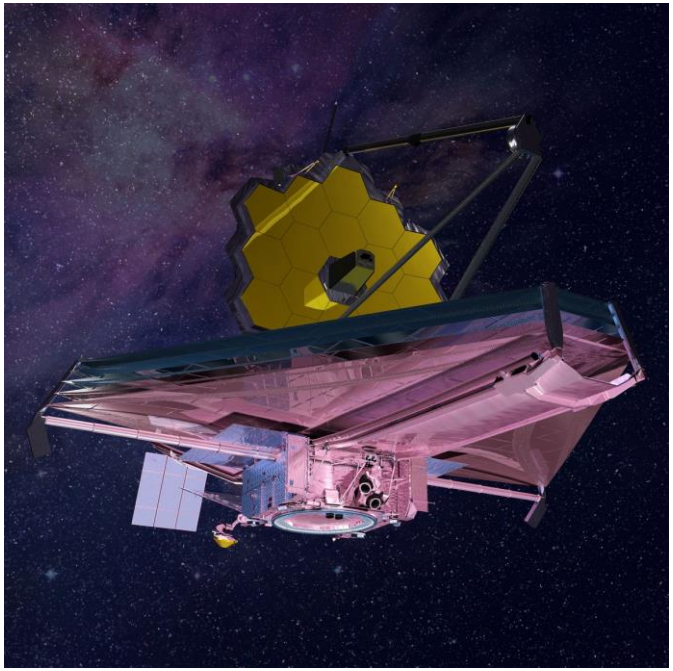


Characterization of the US Construction Labor Supply (Gilbert, 2012)

Complex Systems Development is Challenging



Airbus A380 Wiring Design Flaw **(~$1B)**

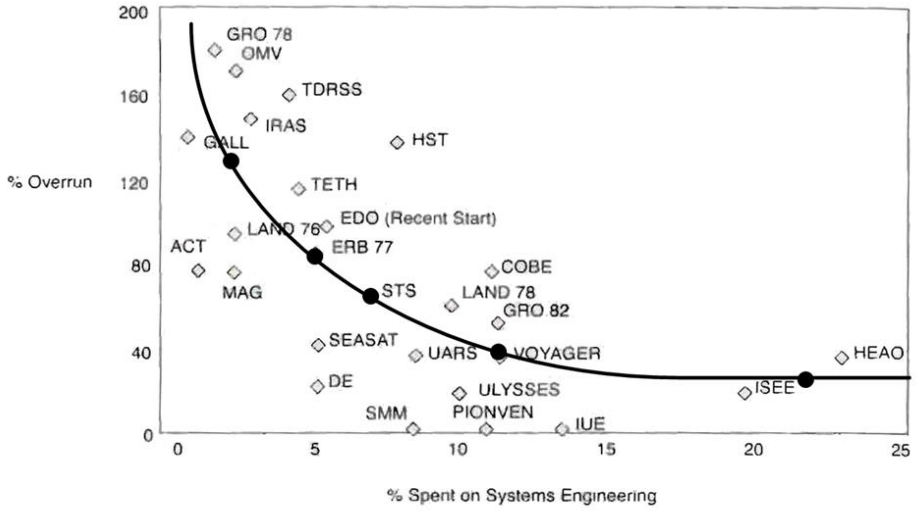


JWST **(~$9B)**

Vogtle Project **(~$14 billion)**

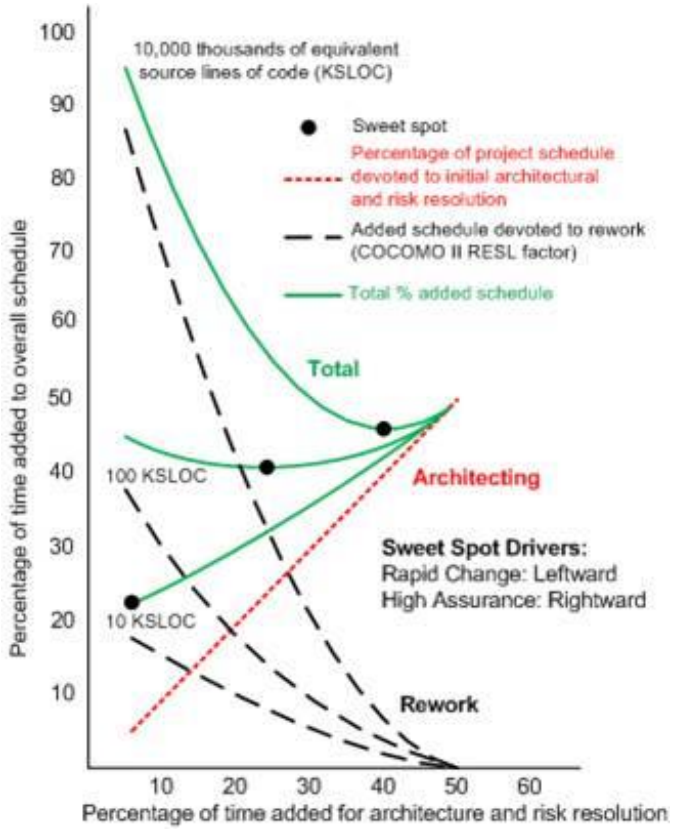
Sources: http://beyondplm.com/2016/05/05/will-cloud-software-prevent-future-design-catastrophes-similar-a380/, https://cleanenergy.org/blog/georgia-regulators-kick-multi-billion-dollar-plant-vogtle-nuclear-can-down-the-road/, https://www.theverge.com/2018/8/1/17627560/james-webb-space-telescope-cost-estimate-nasa-northrop-grumman

Historical solutions outside Nuclear



*Source: Werner M. Gruhl, Chief Cost & Economics Analysis Branch, NASA Headquarters

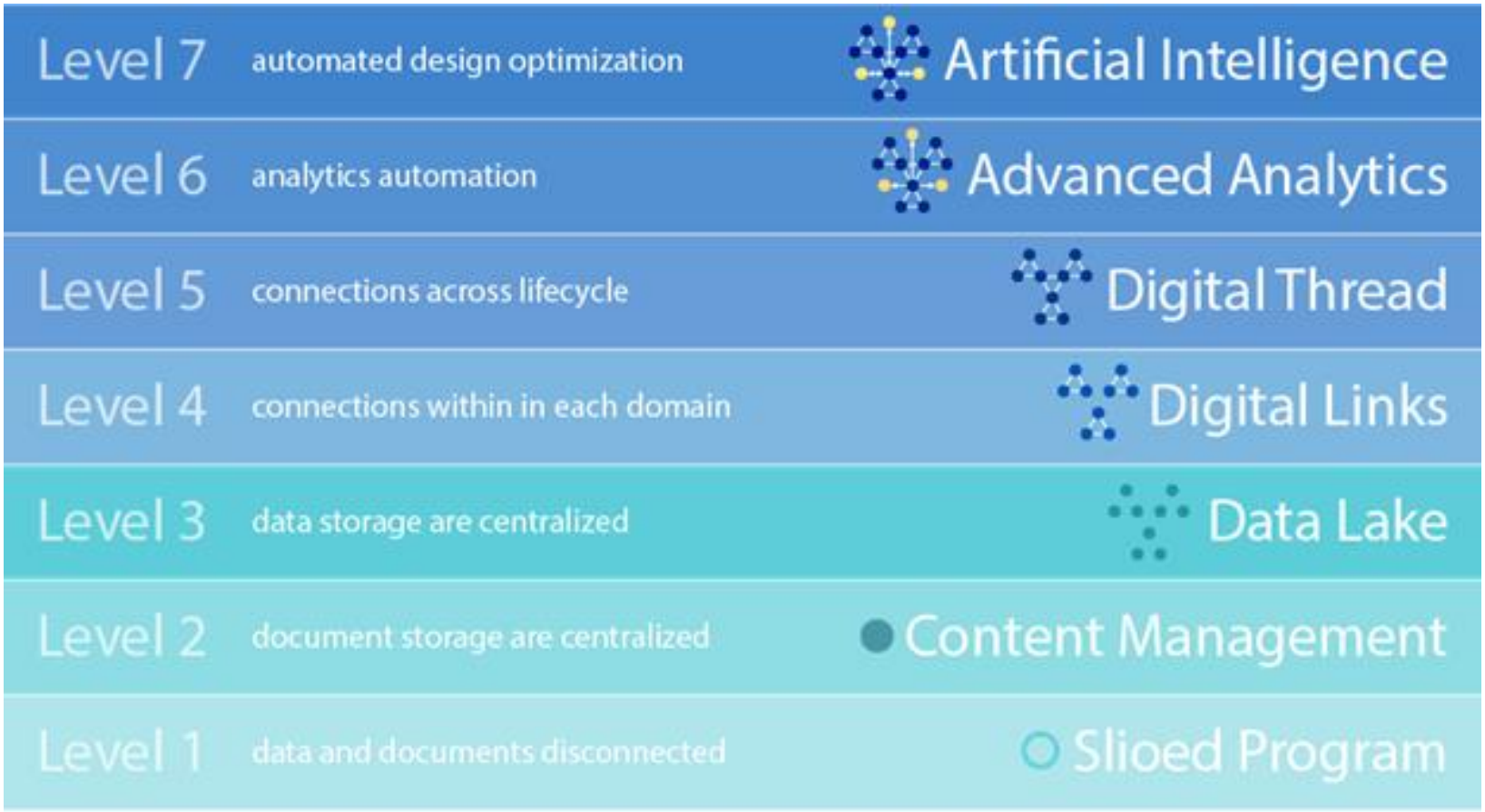
NASA: General correlation between the **amount invested in systems engineering** within a program and **cost overruns**



Risk-Balanced "How Much SE Is Enough" (Boehm, Valerdi, and Honour 2008)

Software: Averages of 18% rework for ten-thousand-SLOC projects and **91% rework** for ten-million-SLOC projects

Evolution of Design: **Digital Engineering**

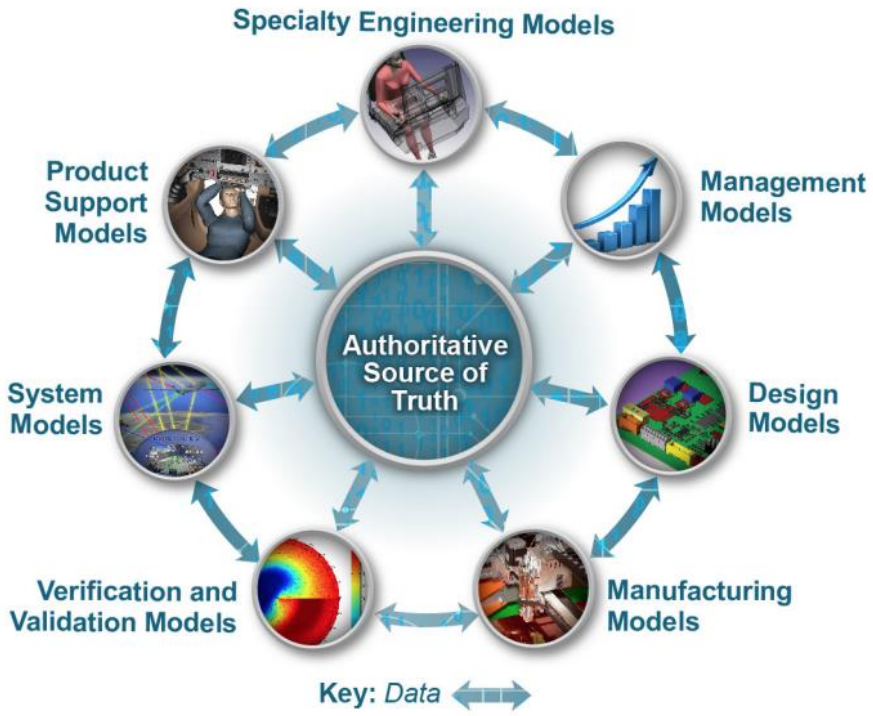


Digital Engineering

Current State of the Art

- Example: A excel file of sheets with hardcoded values (attributes) with no understanding of their connections (relationships)
- Problem 1: **A change in one cell does not propagate to other cells**
- Problem 2: A team working on sheet 1 does not communicate to teams working on sheet 2
- Root Cause: No formal ontology is defined to allow propagations across data silos to occur

Future: Connected Data



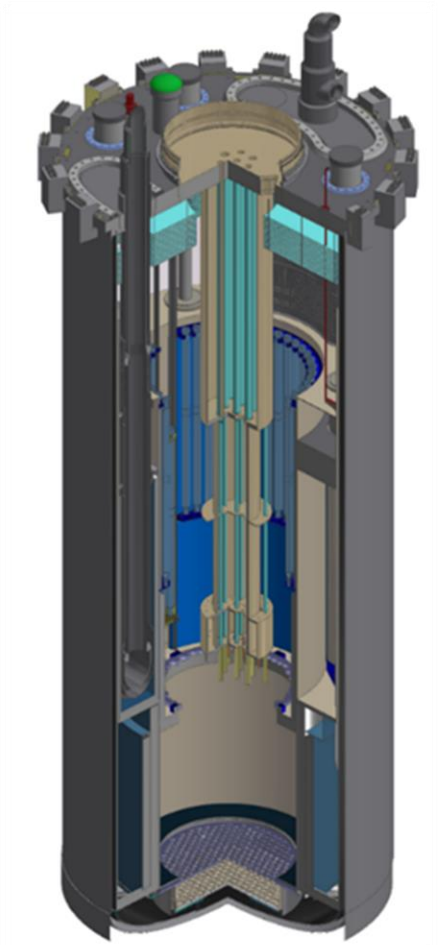
Zimmerman, Phil, Tracee Gilbert, and Frank Salvatore. "**Digital engineering** transformation across the **Department of Defense**." *The Journal of Defense Modeling and Simulation* (2017): 1548512917747050.

Digital Engineering Value Proposition

- Significant program impacts, for example published impacts at Mortenson Construction demonstrate
  - **600 day** direct **schedule reductions**
  - **25% productivity increase**
  - Use across 416 VDC programs
- **40% improvement** in first-time quality through use of digital twins (Boeing)
- Concept of digital twins is proven across engineering domains: Construction (Mortenson VDC), Aerospace (Boeing 777), Automotive (Bugatti)

Versatile Test Reactor (VTR)

- A VTR multi-laboratory, university, and subcontractor team was established with a total of ~ 350 members from 6 laboratories, 20 universities, and 6 industry partners:
  - Core, fuel, safety analysis, safety basis, and PRA (DOE Laboratories)
  - Experiment concept development (DOE Laboratories, Industry, and Universities)
  - Reactor conceptual design and cost estimate (GEH/Bechtel team)
- Digital Engineering Key Activities:
  - Central Integrated Datastore (Ontology, Integration API)
  - Building Information Management
  - Systems Engineering (Requirements / Test / Risk Management)
  - Cloud Deployment (INL)



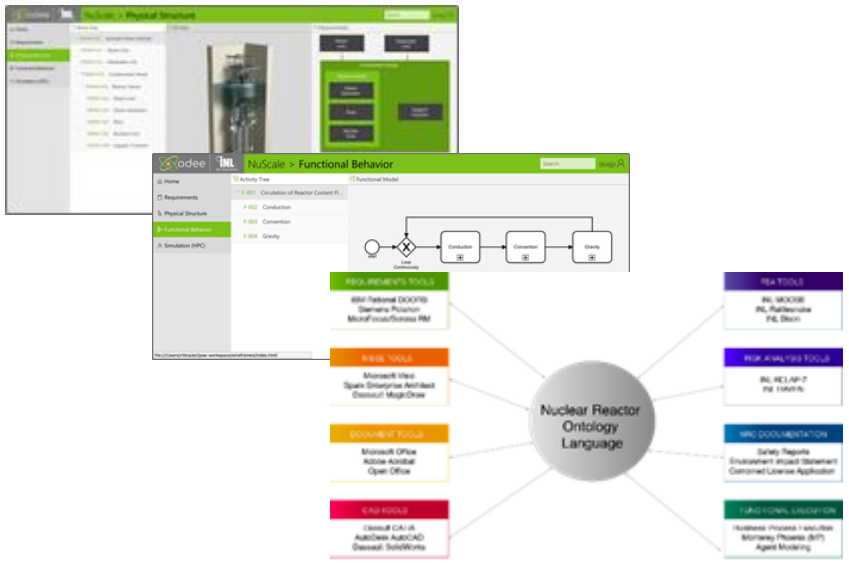
VTR: Central Integrated Datastore

Key Components

Ontology: Utilizes ontology for a standardized, common data model to enable a generic framework independent of tool/solution

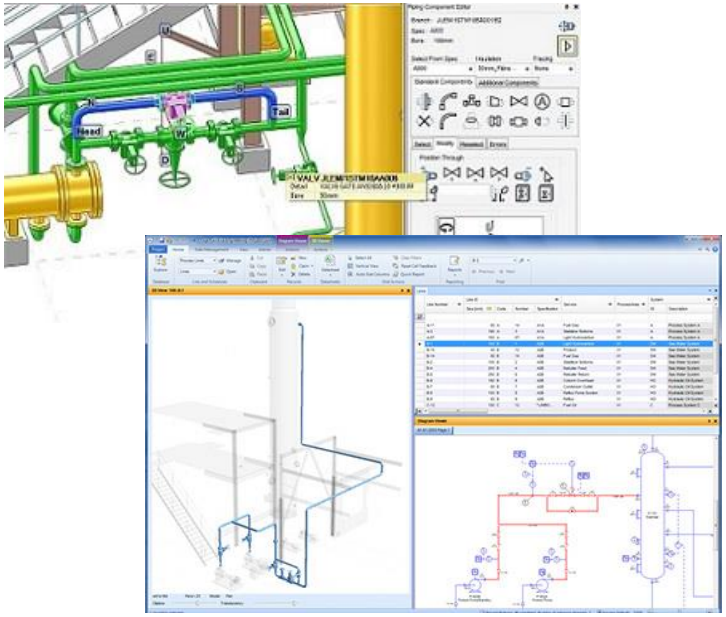
Central Software Framework: This allows for a common software framework to be shared, allowing for code re-use and minimal point-to-point integrations

Central Datastore: This will utilize the Microsoft Azure Cosmos Graph Database which allows real-time replication across geographic regions and storage of "big data" (petabytes)



VTR: Building Information Management

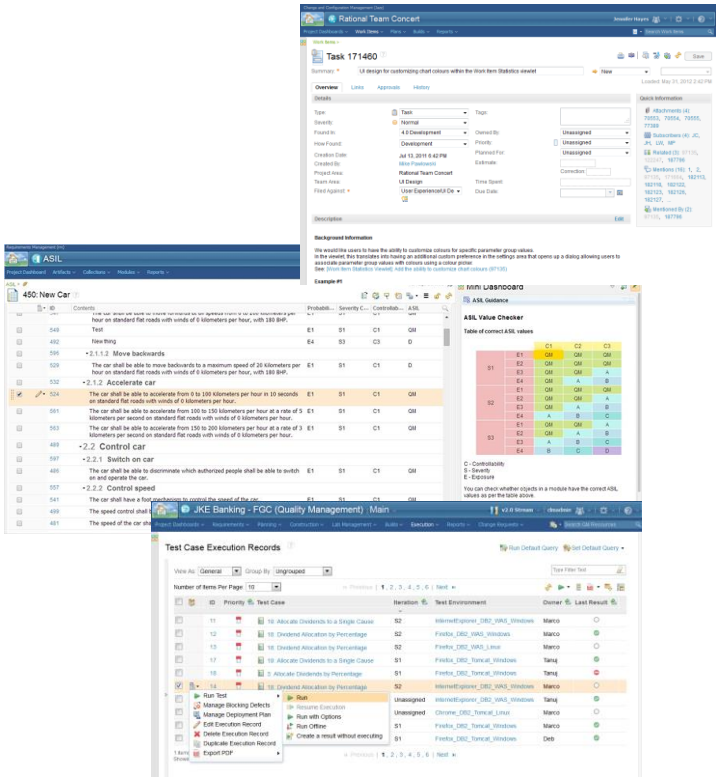
- **Accomplishments**
  - Bechtel and INL teams trained on AVEVA BIM
  - AVEVA E3D deployed across Bechtel VDC team with 3D models now issued from AVEVA
  - AVEVA BIM deployed on Microsoft Azure and on INL public network
  - Regular 4D models and Fly throughs
  - MCNP decks automated with reduced parameter set for Fuels Analysis
  - NC State led IFC (independent BIM file) and Exodus conversion for seismic automation
  - NC State led virtual reality capability
  - Interconnection with Bechtel to provide daily model updates
  - Automated export from AVEVA BIM (IFC)



- **Look Ahead**
  - Integration of AVEVA Material Parts List and Geometry into central-store
  - Batching of AVEVA BIM export
  - Incremental team roll out of engineering and requirements system

VTR: Systems Engineering

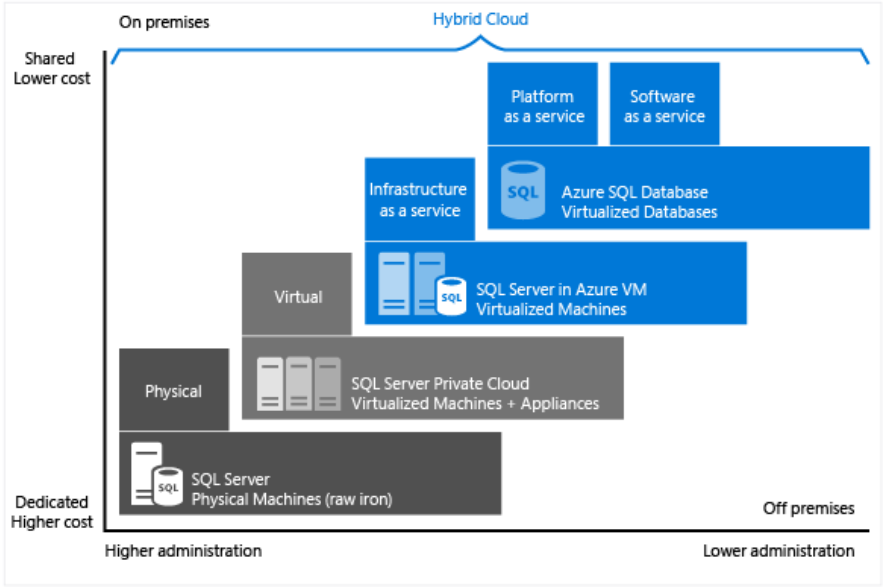
- **Accomplishments**
  - Initial Requirements Management Plan issued for the VTR program (GEH)
  - Requirements Management data model / ontology developed (GEH/Bechtel/IBM/INL)
  - Systems Engineering Suite (IBM Jazz Platform) deployed for team (INL)
  - Automation of requirements management reporting (INL)
  - Overall Requirements Management document issued from systems engineering database (GEH)



- **Look Ahead**
  - Test management data model / process development
  - Risk integrated into systems engineering system
  - Further roll-out of requirements management system
  - VCU led Research into automation of traceability and type identification

VTR: Cloud Deployment & Automation

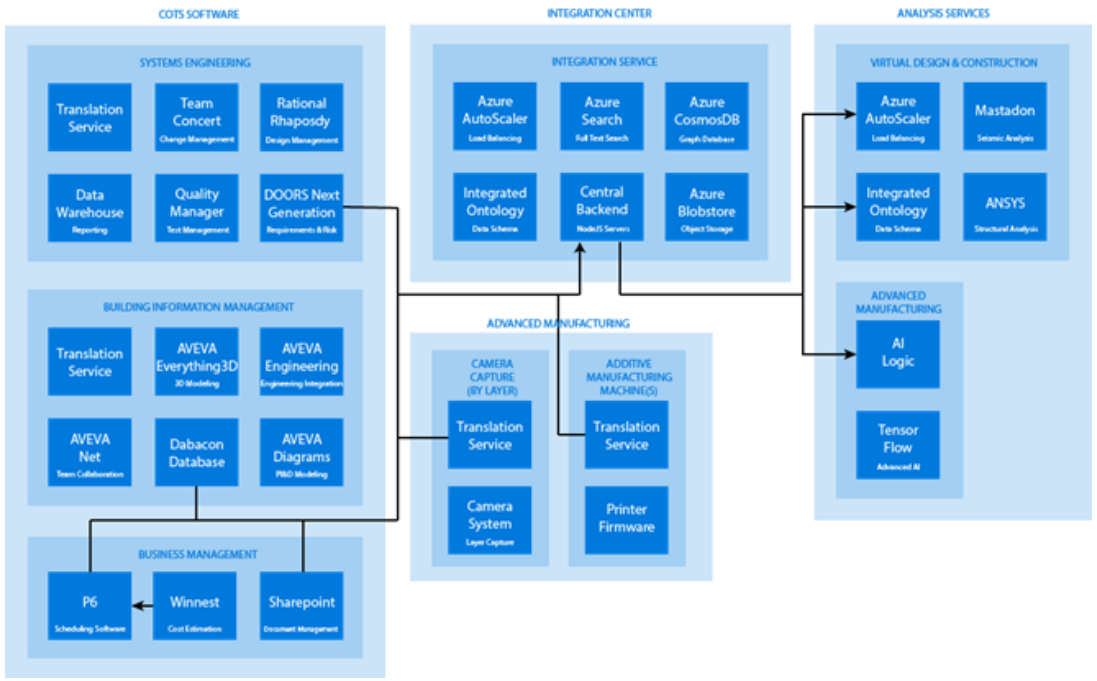
- **Accomplishments**
  - Interim Authority to Test Versatile Test Reactor system on Microsoft Azure for Government Cloud Granted (INL first)
  - AVEVA Building Information Management, IBM Jazz Platform (Requirements Management [RM], Risk Management [RSKM], Test Management [TM) Acquired
  - Requirements Management, Risk Management, Test Management servers deployed to INL public network to GEH and Bechtel contractors (DMZ)
  - AVEVA BIM 3D server deployed to INL public network (DMZ)

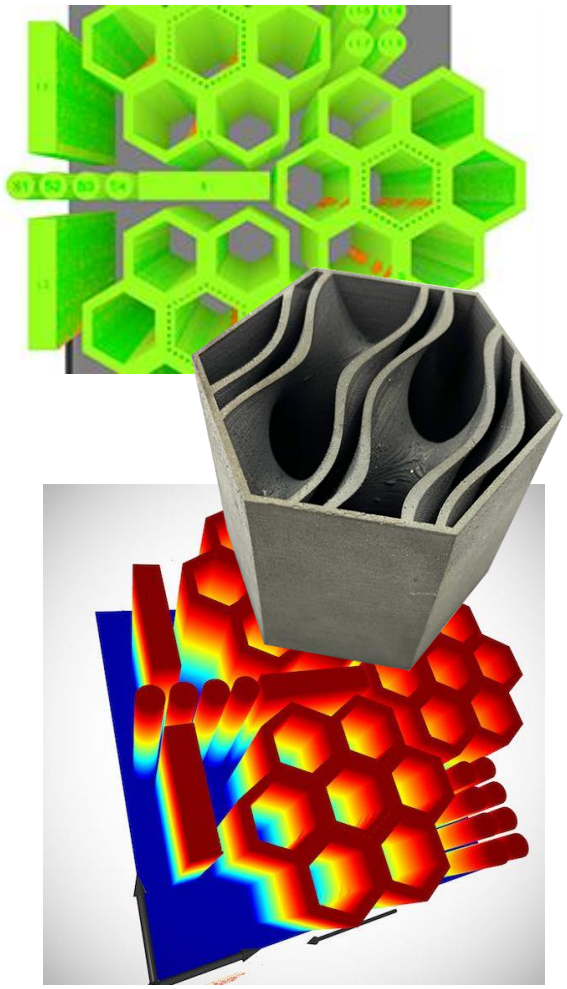


- **Look Ahead**
  - Automation (Code as Infrastructure) of engineering applications deployment and maintenance using Azure Automation stack
  - ATO in Microsoft Azure Cloud (Q4, 2019)

Transformational Challenge Reactor

- Transformational Challenge Reactor (TCR): An Additively manufactured microreactor (ORNL)
- TCR Digital Engineering: Integrates with VTR digital engineering system and will support advanced manufacturing use cases



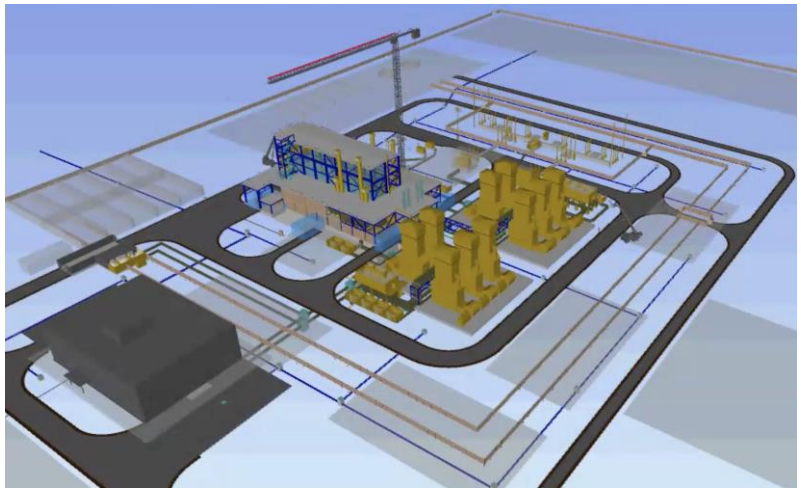
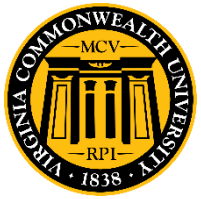


International Collaboration

- American Society of Mechanical Engineers (ASME) Plant Systems Design Standard
  - Purpose: Develop, review and maintain technology neutral processes and procedures for design organizations to incorporate and integrate existing systems engineering processes, practices and tools with traditional architect engineer design development processes, practices and tools for design of nuclear, fossil and petrochemical plants
  - INL: Managing requirements development and supporting tasks through all design phases
- SysML v2 Submission Team (SST) Team Member: Developing the Next Generation Systems Modeling Language
- Plan to Open Source Key Software and Data Models

Conclusion: Digital Engineering

- Significant program impacts:
  - **600 day** direct **schedule reductions** (Mortenson VDC)
  - **25% productivity increase** (Mortenson VDC)
  - **40% improvement** in first-time quality through use of digital twins (Boeing)
- Integration of engineering, software, IT, and culture change
- Major implementation ongoing at Idaho National Laboratory for DOE across VTR, TCR, and microreactors



PARTNERSHIPS