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The New York Academy of Sciences

Infrastructure Architecture Framework

An Enterprise Architecture and Systems Engineering Approach to Transforming Infrastructure 4.0

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Infrastructure Architecture Framework

New York Academy of Sciences

Opening comments

Jerry Hultin, Former Under Secretary Chair of the Navy; Current New York Academy of Sciences, Chair, Board of Governors; and Chair and Co-Founder, Global Futures Group, LLC

Presentation of the New York Academy of Sciences Infrastructure Architecture Framework

Michael Salvato, Enterprise, Investments & Transformation, Infrastructure Advisory Services, Mott MacDonald

Panel Discussion (Facilitated by Michael Salvato)

Mildred Chua-Ulger, ALN Board of Directors; IAM Knowledge Leadership Group Chair; Vice President & Advisory Growth Leader at Mott MacDonald; She also held numerous top-level management NY Metropolitan Transportation Authority

Rashmi Jain, Professor, Doctoral Faculty and Graduate Council Chair at Montclair State University

David Totman, ALN Senior Fellow; American Society of Civil Engineers liaison to ISO 55001; Innovyze Thought Leader Strategy; 2019 President, Utility Engineering and Surveying Institute

Panel Discussion

Questions

- The Fourth Industrial Revolution is said to be blurring of boundaries between the physical, digital, and biological worlds. What does that mean for infrastructure systems such as water, energy, and transportation? (David)
- Equity, net zero, sustainability & resilience are fundamental to a culture of value. How can operators incorporate these values in their asset management system and importantly the culture of their organizations? (Mildred)
- How does enterprise architecture and systems engineering help an organizations leveraging asset information management systems to create value? What do mature organizations have to manage asset information over the asset life cycle to achieve organizational objectives and outcomes that less mature organizations do not? (Rasmi)
- The Global Forum of Maintenance & Asset Management conceptual model includes 39 core subjects to whole life asset management. How does enterprise architecture & systems engineering help an organization develop these foundational capabilities for "the coordinated activity of an organization to realize value from assets”? (Mildred)
- IoT, Big data, AI, augmented reality, and robotics are just a few of the rapidly emerging technologies of the fourth industrial revolution. What must owner operators do to accelerate the adoption technologies at enterprise scale to provides *high-quality environmental, economic, and social outcomes, and functions as a system within broader human and natural systems”* from the Infrastructure 4.0. (David)

Infrastructure Architecture Framework

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Context: Re-envisioning Infrastructure 4.0

Stakeholders: Systems-of-Interest and Practices

Approach: Enterprise System Architecture & Engineering

Application: Lessons Learned, Benefits and Next Steps

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Context:
Re-envisioning Infrastructure 4.0

The complexity of today's information intensive and interdependent infrastructure systems creates the need for new tools, methods, and understandings. A systems approach and robust architecture framework is needed which recognizes the interaction between the technical, human and ecological dimensions of infrastructure as the defining factor in a system's make-up, functioning, and performance.

Re-envisioning Infrastructure 4.0 – for people and planet

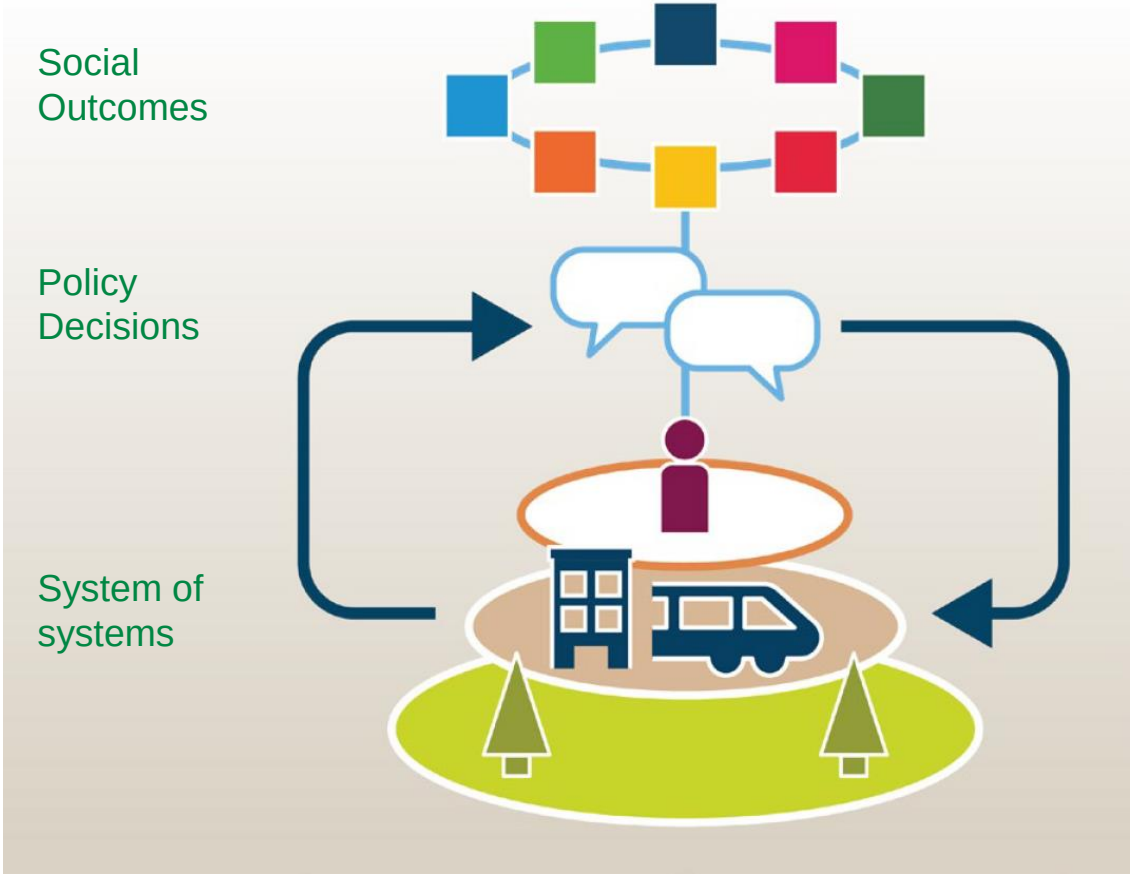
Infrastructure 4.0 drawing a direct line between service outcomes we need as a society and the decisions we make to build, maintain and renew our built environment in harmony with the natural environment

Infrastructure 4.0 is defined by the World Economic Forum as:

"forward-looking infrastructure that leverages technology and information to provide high-quality environmental, economic, and social outcomes, and functions as a system within broader human and natural systems."

To realize it full potential, Infrastructure 4.0 needs to be re-envisioned as a complex, socio-technical system

- Social, economic and environmental outcomes
- Realized from organizational processes, technologies & data
- Derived from Nested systems of systems at various levels
- Comprised of interconnected and intelligent assets
- Managed over a lifecycle within a circular economy

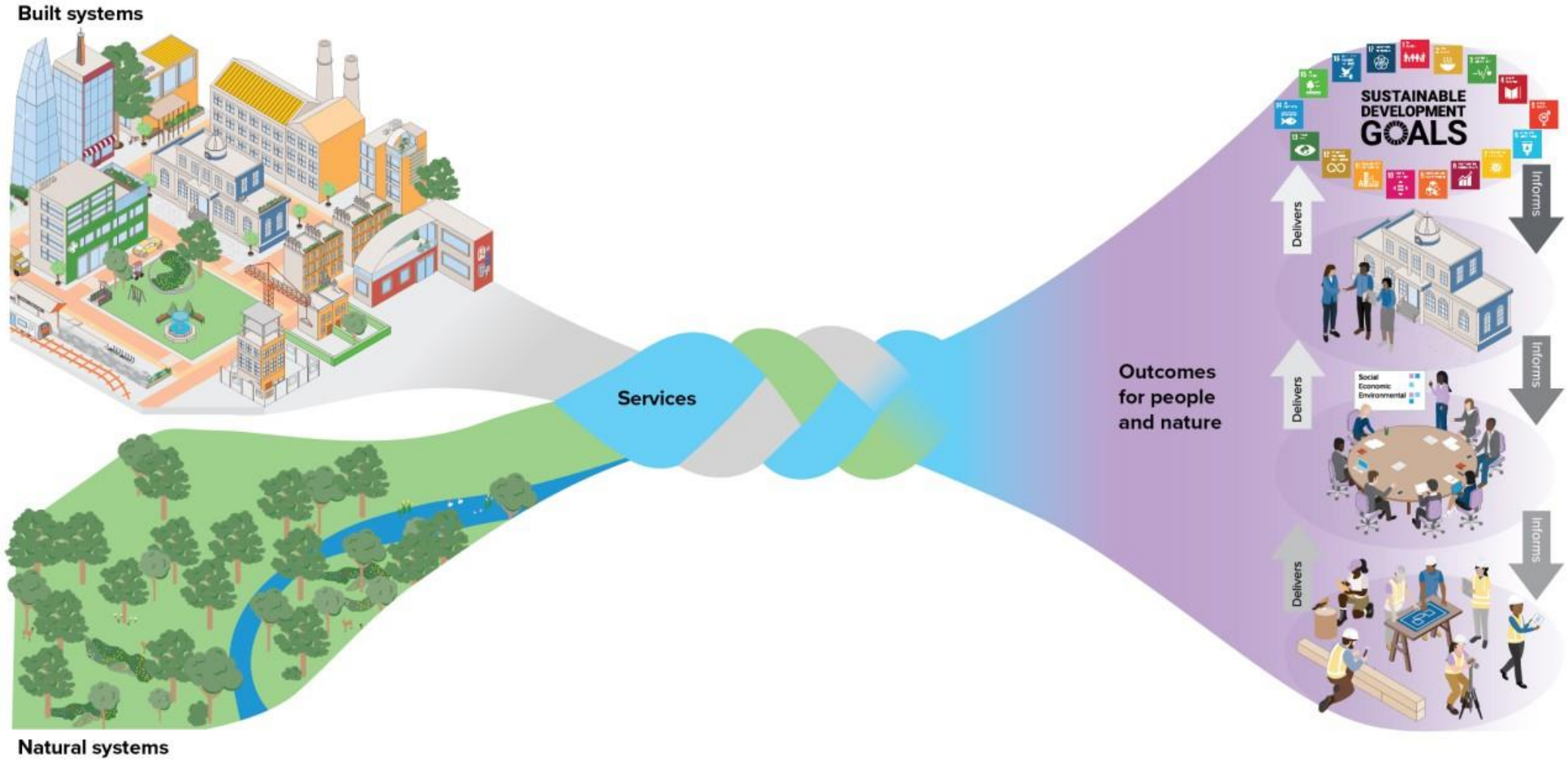


Infrastructure 4.0 (weforum.org)

TIP 2030 Roadmap 2030 (gov.uk)

Re-envisioning Infrastructure 4.0 – as a platform for flourishing

Our vision for the built environment explicit purpose is to enable people and nature to flourish together



http://www.visionforbuiltenvironment.com/

Re-envisioning Infrastructure 4.0 – as a socio-technical system

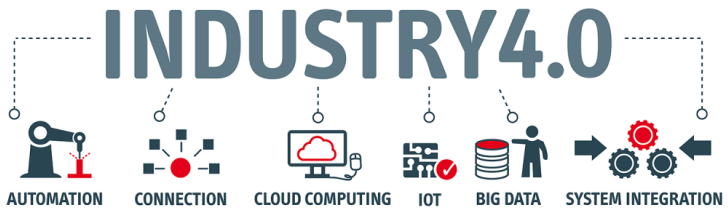
Our vision for the built environment can only be achieved through a whole system approach

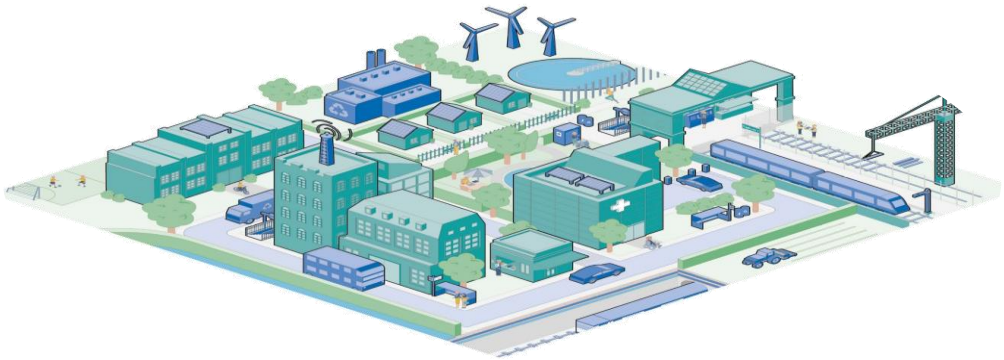
A systems view of infrastructure is incredibly powerful. Even more so when we add **Industry 4.0** thinking and technologies. Combining **Industry 4.0** with system-based approaches, we can transform how we envision, engineer and manage **Infrastructure 4.0**

Enterprise architecture and systems engineering are proven approaches for developing and managing complex, socio-technical systems to realized the enterprise purpose.

This approach is really the only way to master the complexity of cyber-physical systems brought about by the 4th Industrial Revolution and transition to the sustainable forms of development needed to avoid a climate disaster

SUSTAINABLE DEVELOPMENT GOALS





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Stakeholders: Systems-of-Interest and Practices

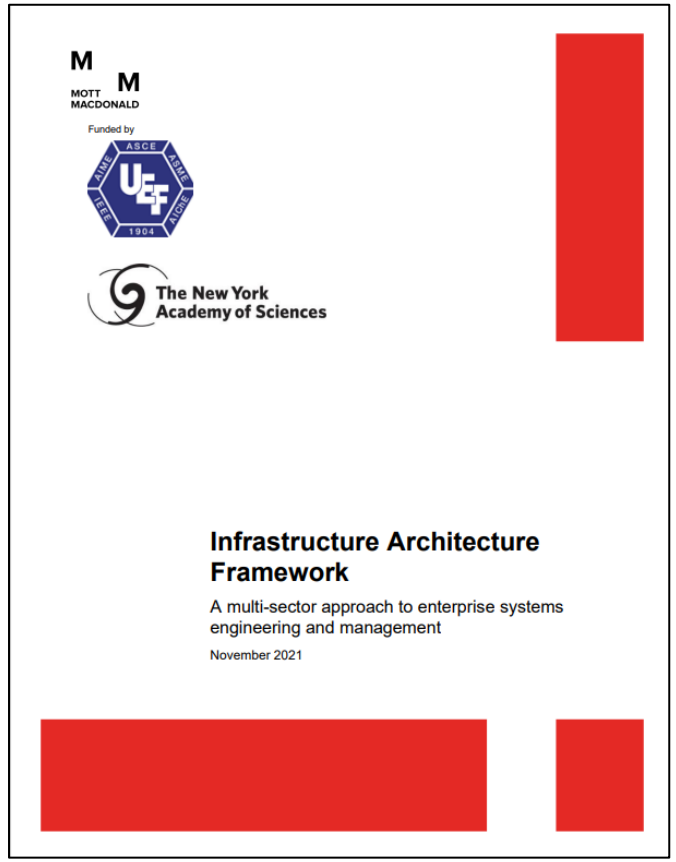
A working group of experts researched and identified standards, bodies of knowledge, and reference models for an integrative architecture framework

The Infrastructure Architecture Framework (IAF)

Using systems thinking, we developed an enterprise model that reveals the interconnections between system hierarchy levels, disciplines, and standards to create a blueprint for Infrastructure 4.0

- We wanted to bring to water, energy and transportation the type of enterprise architecture and systems engineering approaches that have succeeded in e-commerce, aviation, and defense
- The goal was to develop common approaches to engineering and managing infrastructure as a complex socio-technical system for infrastructure owners, operators, suppliers and regulatory agencies

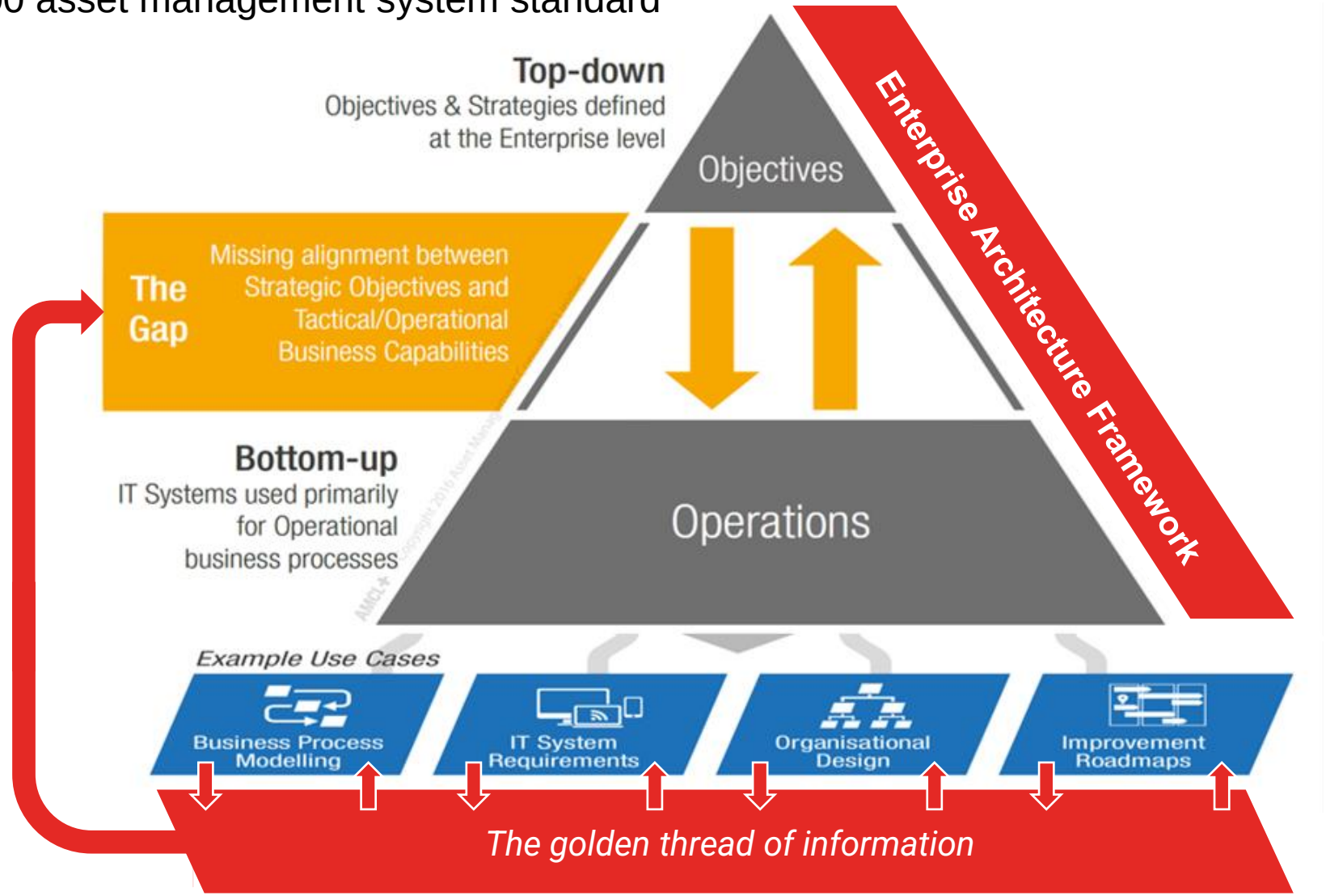
"This work is an important extension of research on systems and digital engineering at the Department of Defense, aerospace and space exploration to civil infrastructure."
Stephen Welby, *Executive Director and COO, IEEE, and former Assistant Secretary for Research & Engineering for the US DOD*



Creating a ‘line of sight’ between operations and objectives

Following the ISO 55000 asset management system standard

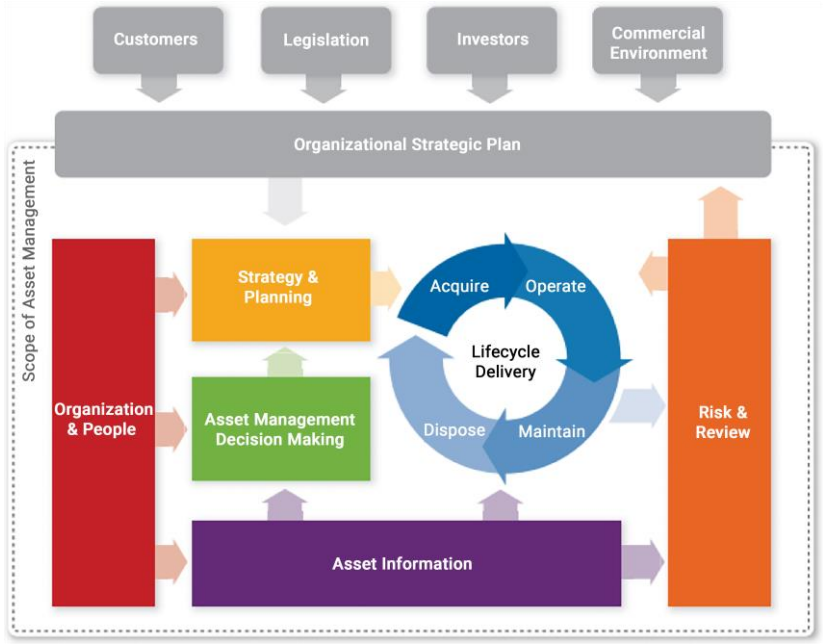
NY Infrastructure Owner/Operator Enterprise Architecture Framework



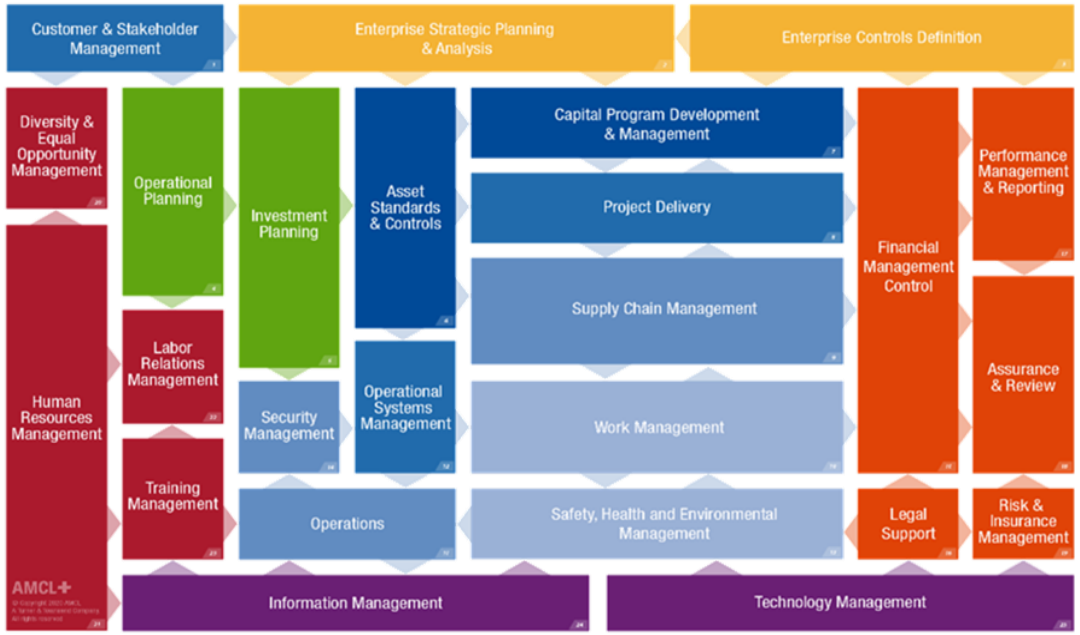
Defining functional capabilities for infrastructure management

Based on the Institute of Asset Management model

Institute of Asset Management Asset Management Standard Model



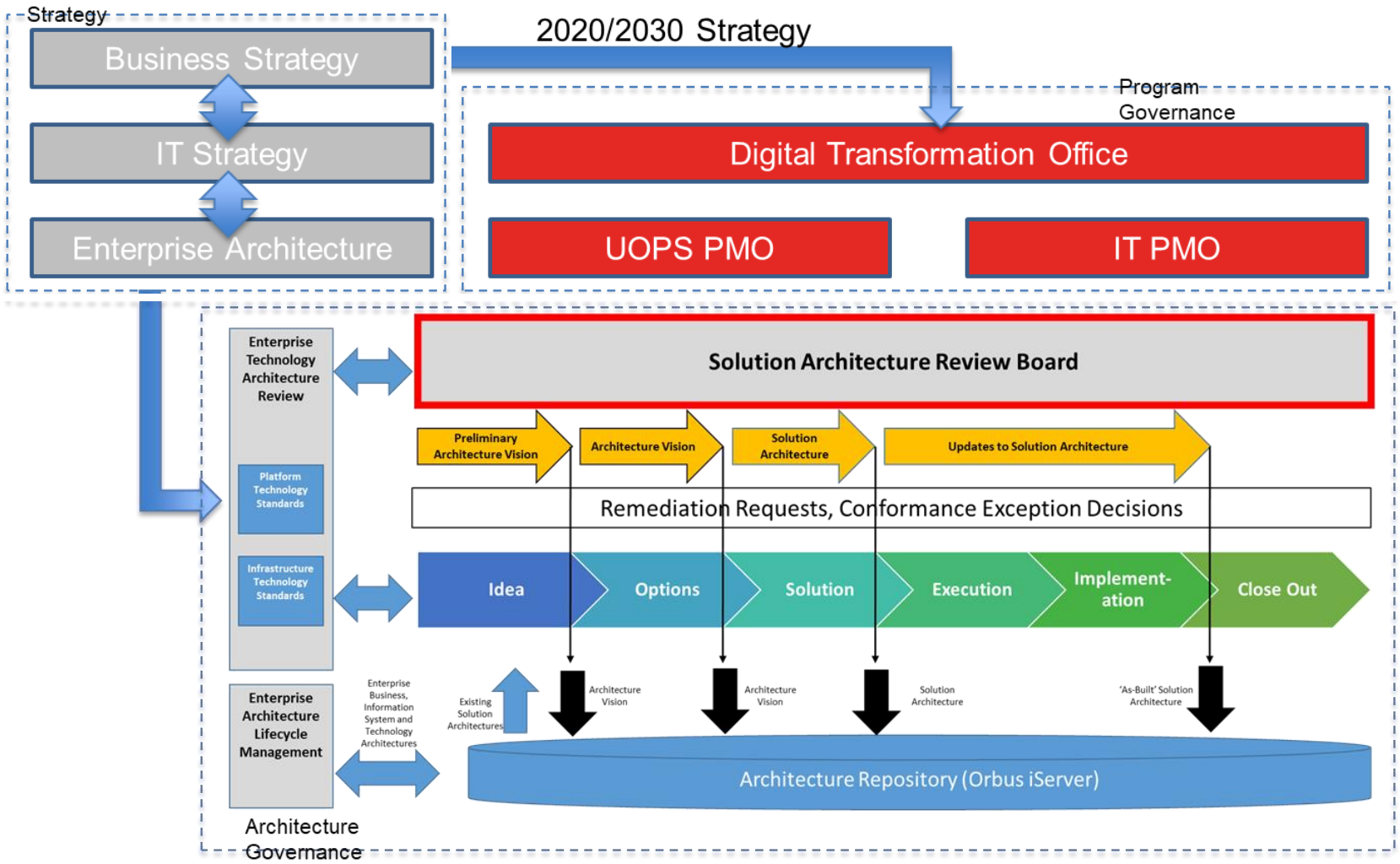
NY Infrastructure Owner/ Operator Capabilities Model



Enabling the business strategy

Following The Open Group Architecture Framework (TOGAF)

NY Infrastructure Owner/Operator Digital Transformation Model



Enterprise Architecture include:

- Business alignment
- Business Capabilities
- Information Technologies
- Management of Change

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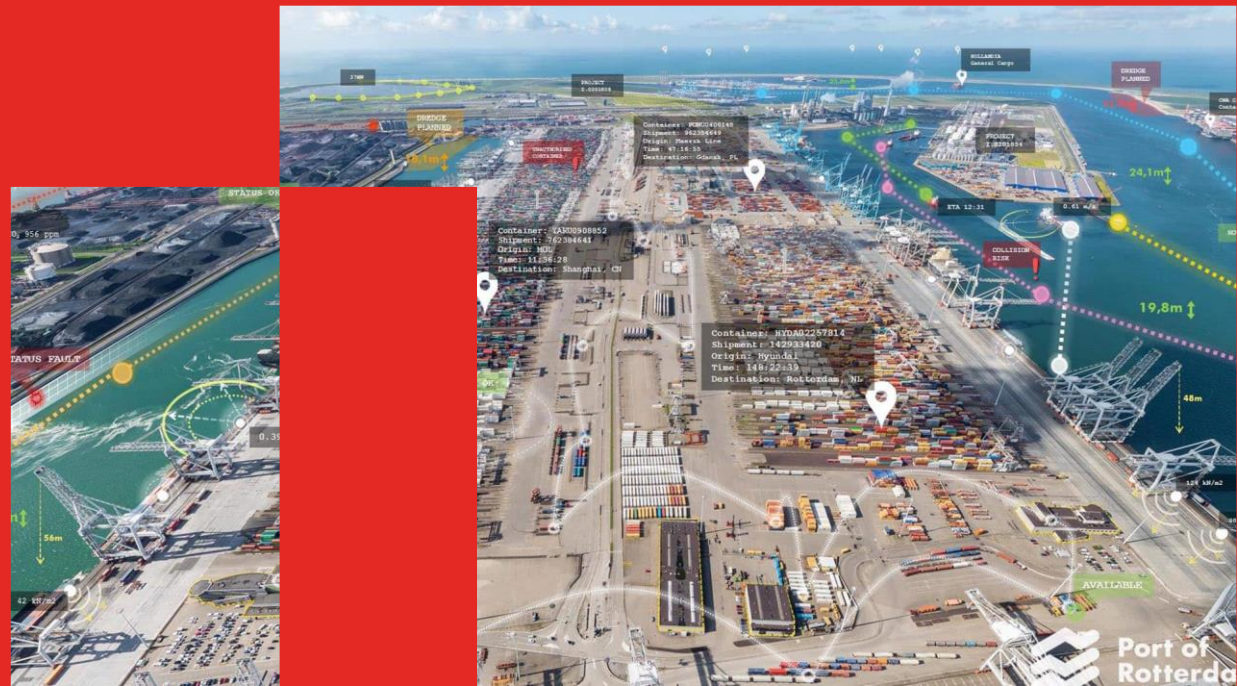
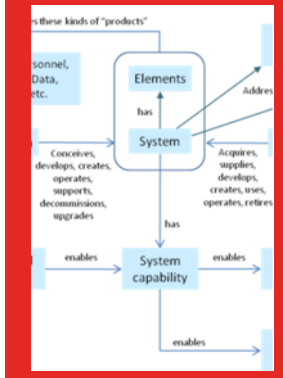
Approach: Enterprise System Architecture & Engineering

The IAF provides common architecture descriptions for the civil infrastructure community



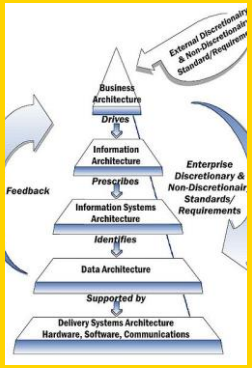
A framework to enable enterprise transformation

This project took an architecture approach to define the structure, rule sets, and their relationships bringing a coherent view of the whole infrastructure enterprise.



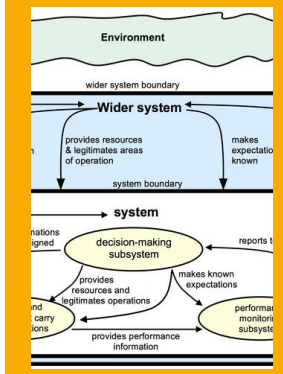
Enterprise systems engineering

An emerging discipline using frameworks, tools, and problem-solving to deal with the inherent complexities of an enterprise, in which people are an inherent part (SEBoK)



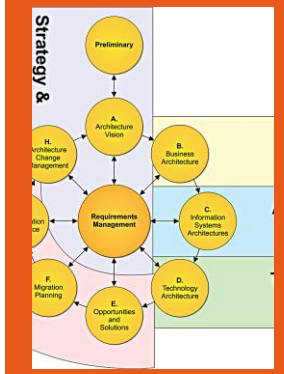
Enterprise architecture

A conceptual blueprint that defines the structure and operation of organizations with the intent to determine how an organization can effectively achieve its current and future objectives. (TechTarget)



Architecture

The structure of a system: its components, relationships, environment, and the principles maintaining its design and evolution. (IEEE)



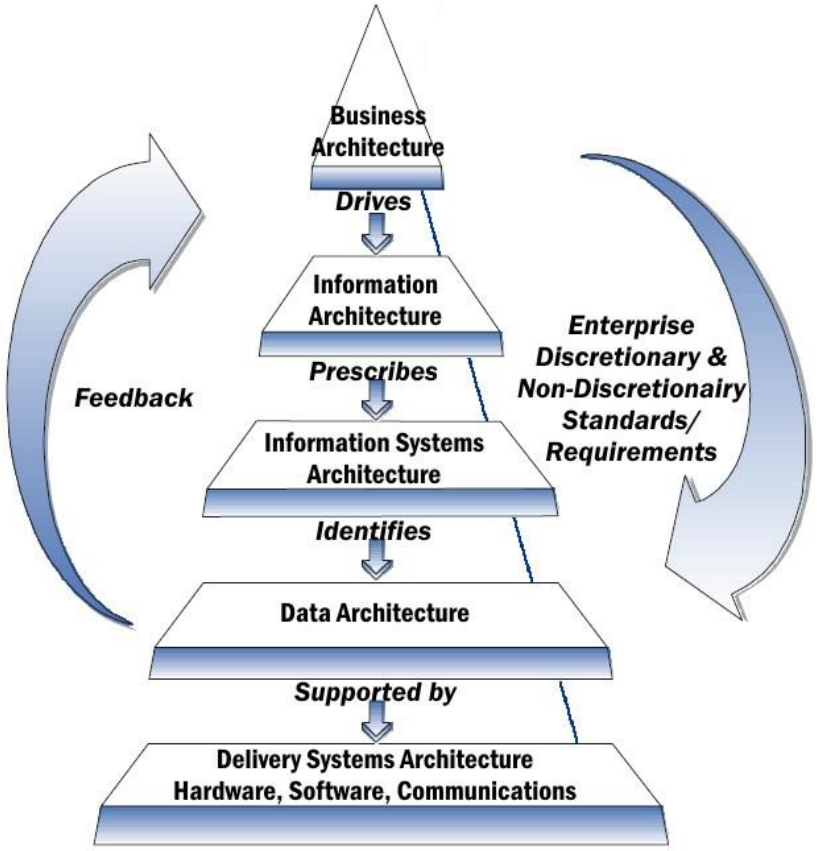
Architecture framework

The minimum set of principles, practices, and requirements for creating and using artifacts describing the systems architecture (Wikipedia)

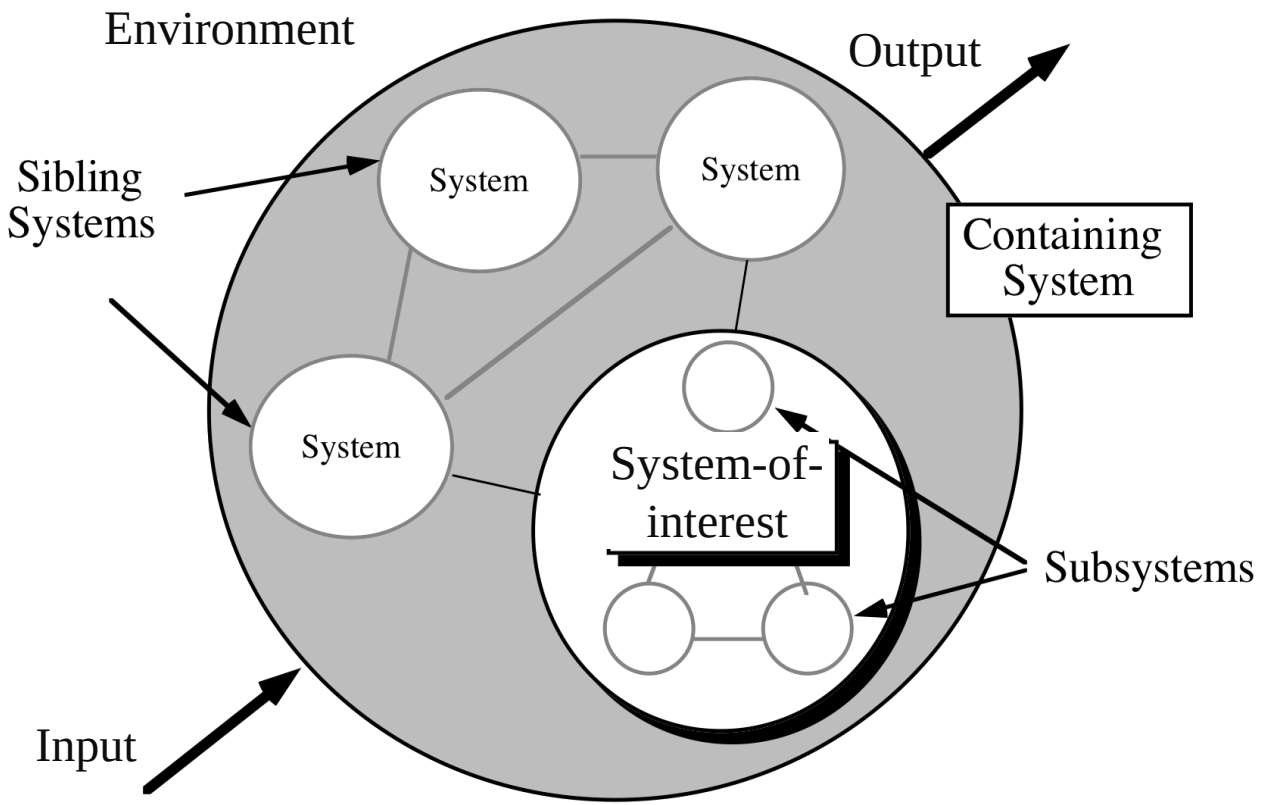
Enterprise architecture and systems engineering

A blueprint and problem-solving approach to deal with the inherent complexities of an enterprise,

Enterprise Architecture View
(A Layered Blueprint)

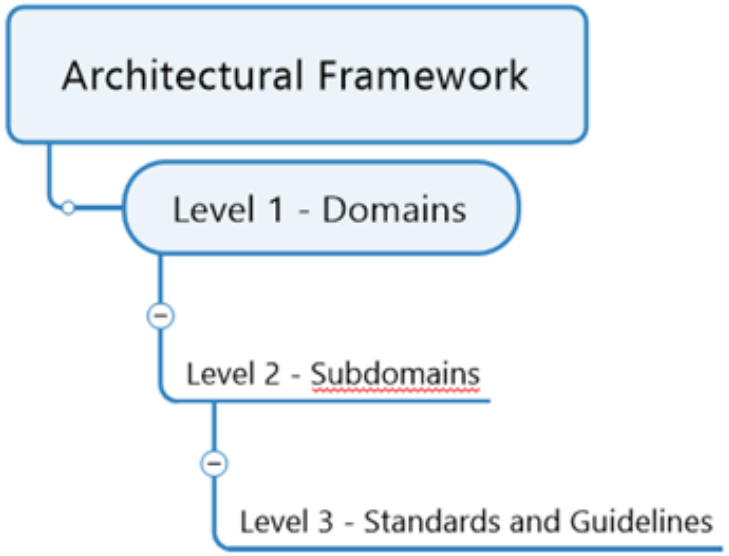


Enterprise Systems Engineering View
(A model based problem-solving approach)



Architecture concept hierarchy

The first step in developing the IAF was to produce an ontology describing the four main domains and their underlying subdomains, standards and guidelines in a hierarchical format



Architecture Concept Hierarchy

Level 1 – Domains

Aligned with the IAF project's mission, they represent international best-practice for engineering, management, and information technology. They are:

- **Enterprise Management Systems**
- **Enterprise Architecture**
- **Information and Knowledge Management**
- **Engineering Systems and Models**

Level 2 – Subdomains

The subdomains of each discipline establish uniform engineering/technical criteria, methods, or processes. Each subdomain is broken down into the standards and guidelines that are relevant to the specifications for the IAF.

Level 3 – Standards & guidelines

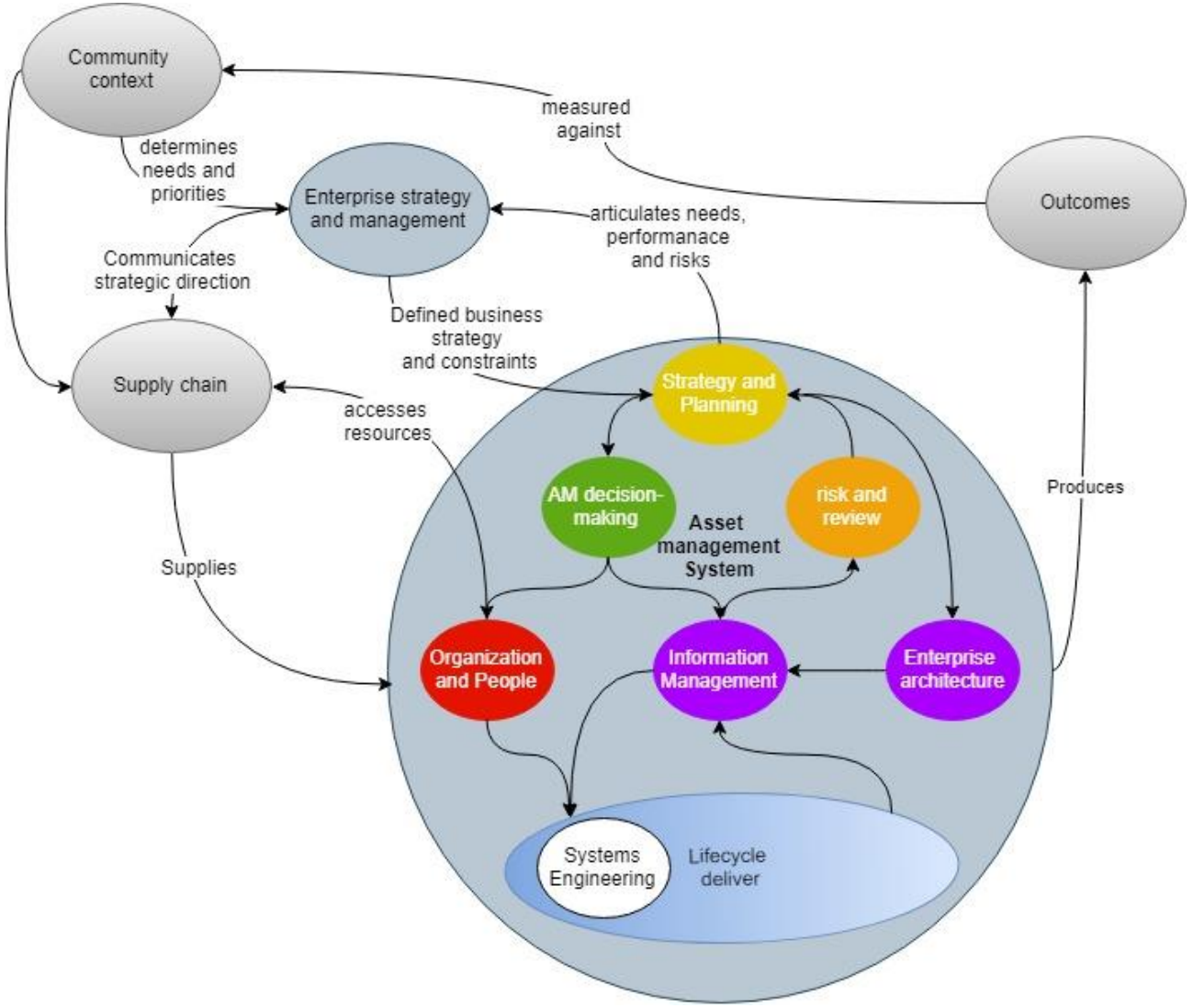
A group of standards, best-practices, and/or bodies of knowledge that comprise each of the subdomains, providing specific structure to the IAF.

Value is created through connections between components

The interconnections between domains and subdomains were identified through connecting elements

The project applied systems thinking to move from the initial ontology of individual disciplines to an enterprise system model, which unveiled and enriched the interconnections between system hierarchy levels, disciplines, and standards.

A Systemigram of the IAF was constructed using the SERC SystemiTool to visualize the domain and subdomain elements and depict the flow of information, resources, and actions



Boardman, J. & Sauser, Brian. (2013).

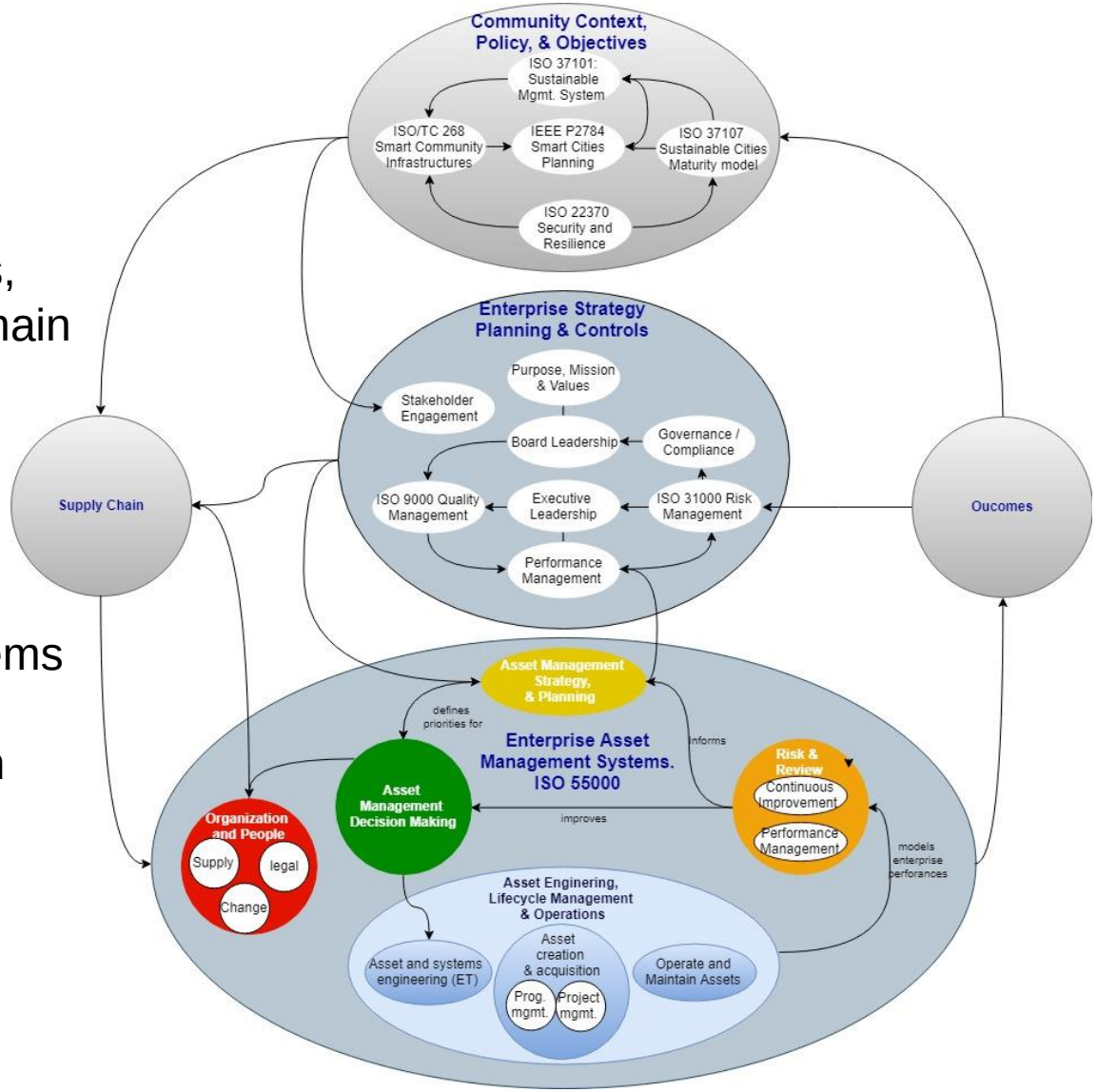
Enterprise management systems

For managing asset-intensive civil infrastructure enterprises

The management domain describes the context, objectives, strategy, management systems, interfaces with the supply chain and performance for the enterprise.

Subdomains include:

- Community context, policy, objectives
- Enterprise strategic planning and management controls
- Asset management, capabilities, operations & control systems
- Portfolio, program and project management
- Legal and procurement framework for enterprise innovation
- Organizational change management, organizational design
- Supply chain management



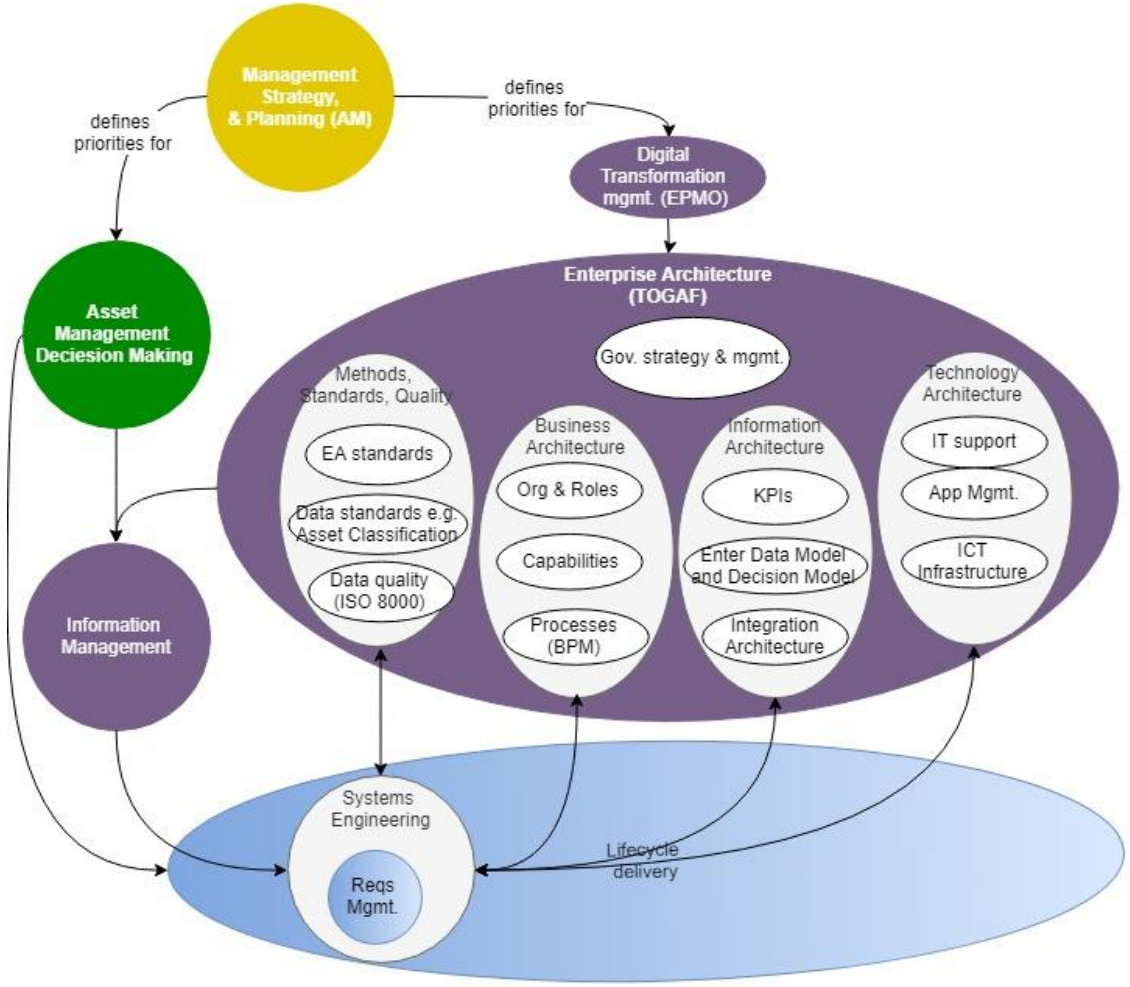
Enterprise architecture

To create a blueprint of the business, information and technology services required by the enterprise

The enterprise architecture domain describes the structure of an enterprise, its businesses capabilities and information requirements, how they are coordinated with each other, and the technology that supports them

Subdomains include:

- ArchiMate (Motivations, Outcomes, Drivers)
- Requirements Management (SE V-Model)
- TOGAF (The Open Group Architecture Framework)
- Business Process Management (BPMN)



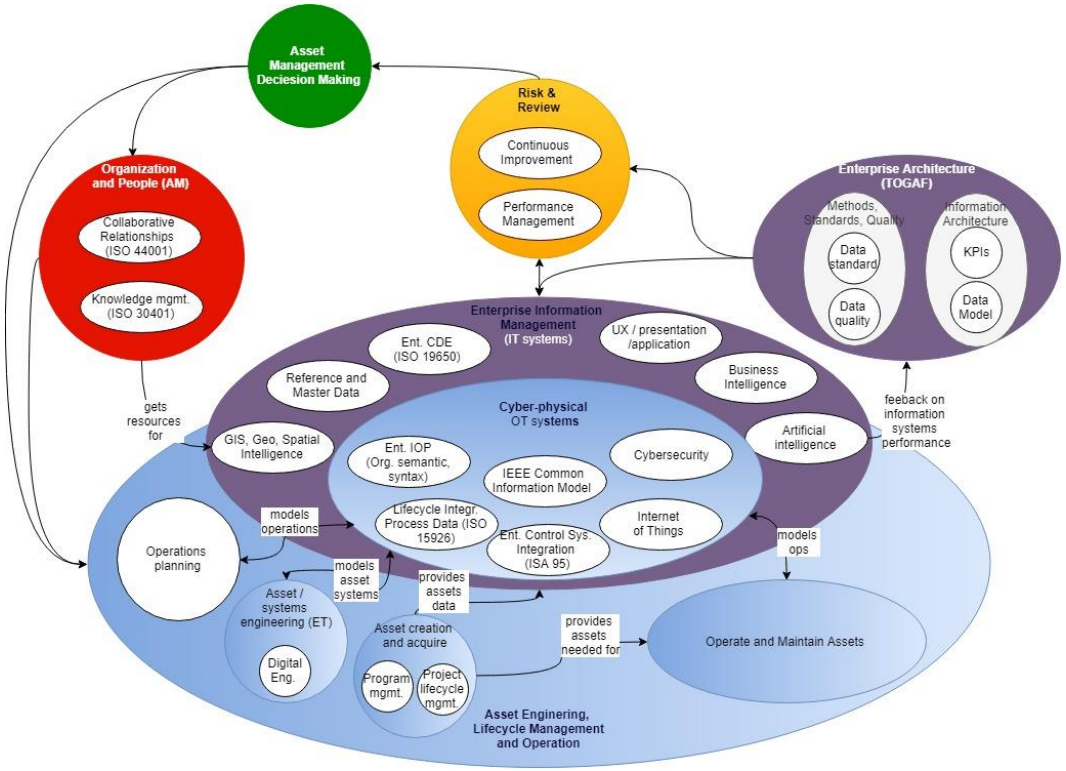
Information and knowledge management

Required to process information that support planning, operations and decision making

Information and knowledge domain describes the functions and activities of an enterprise for transforming raw data, processing information into actionable knowledge. This includes assuring interoperability, integrity and cybersecurity from sensors to system of systems.

Subdomains include:

- Business intelligence
- Knowledge management
- Information management & standards
- Ontologies, interoperability and integration
- Internet of Things (IoT))
- Data and information quality
- Cybersecurity



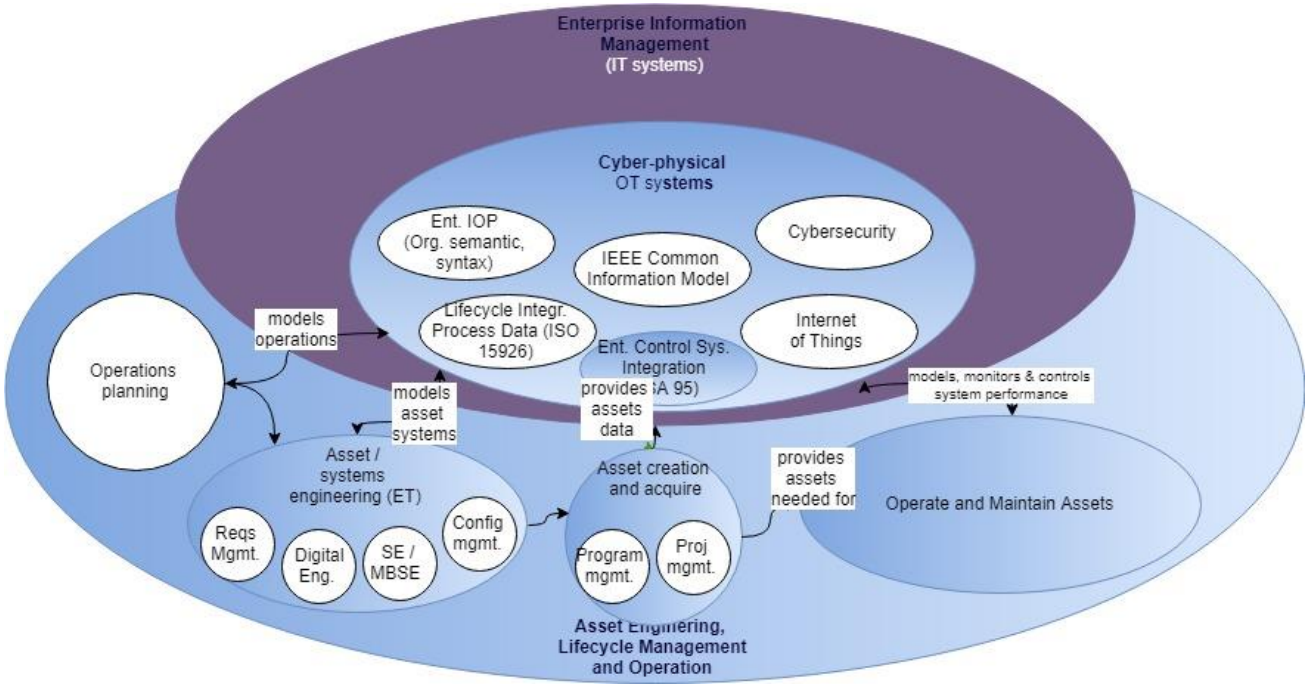
Engineering systems and modeling

To manage the lifecycle of assets & systems to deliver the enterprise purpose within applicable constraints

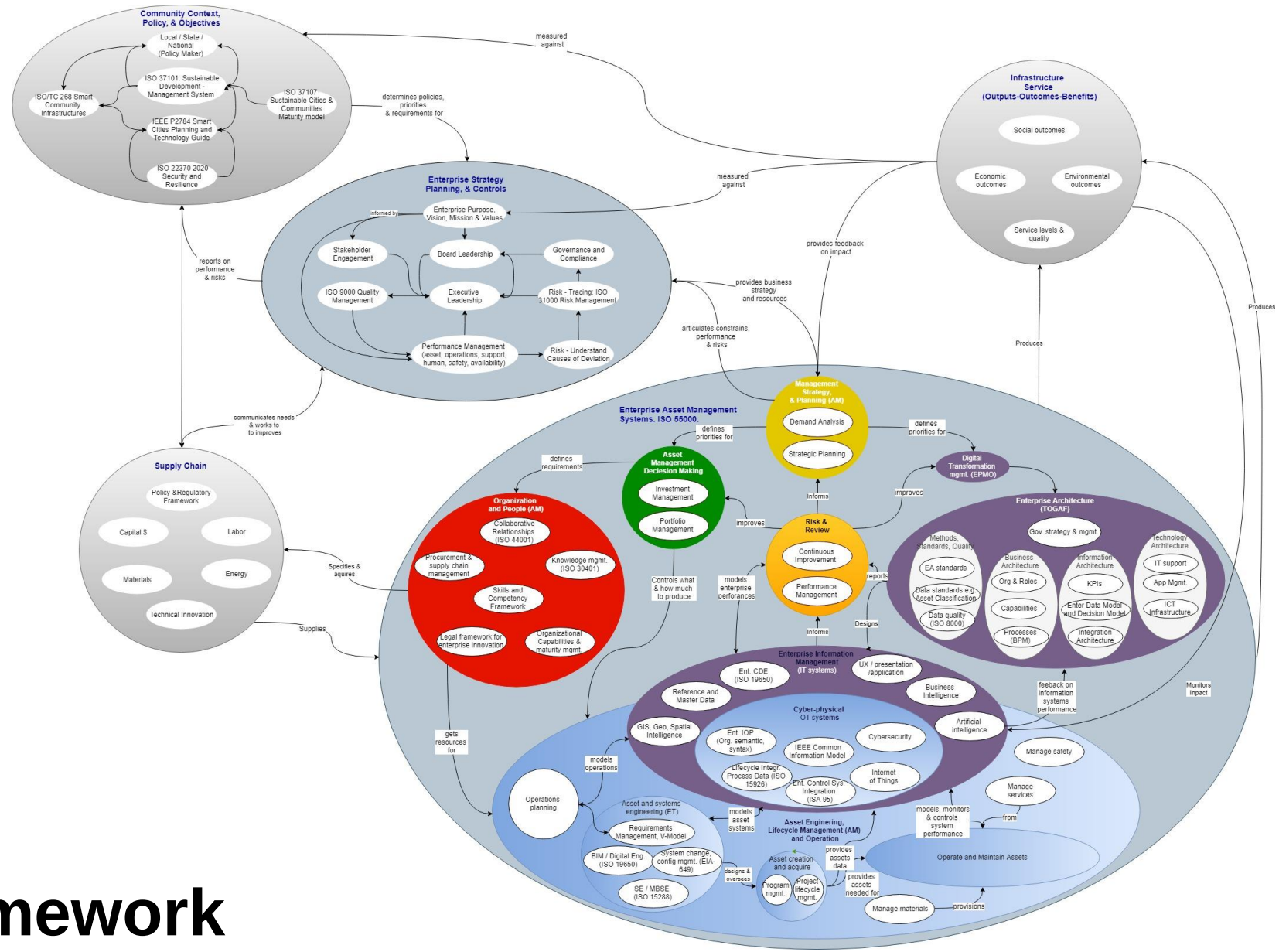
Engineering systems and modeling domain describes the technical and managerial activities that transform stakeholder requirements into viable solutions for the target asset, system, or system of systems throughout its lifecycle including organization, processes, technology, information, and possibly natural components of socio-technical systems.

Subdomains include:

- Systems engineering
- Digital engineering
- Systems modeling
- Enterprise control
- Systems integration



Systemigram of Infrastructure Architecture Framework



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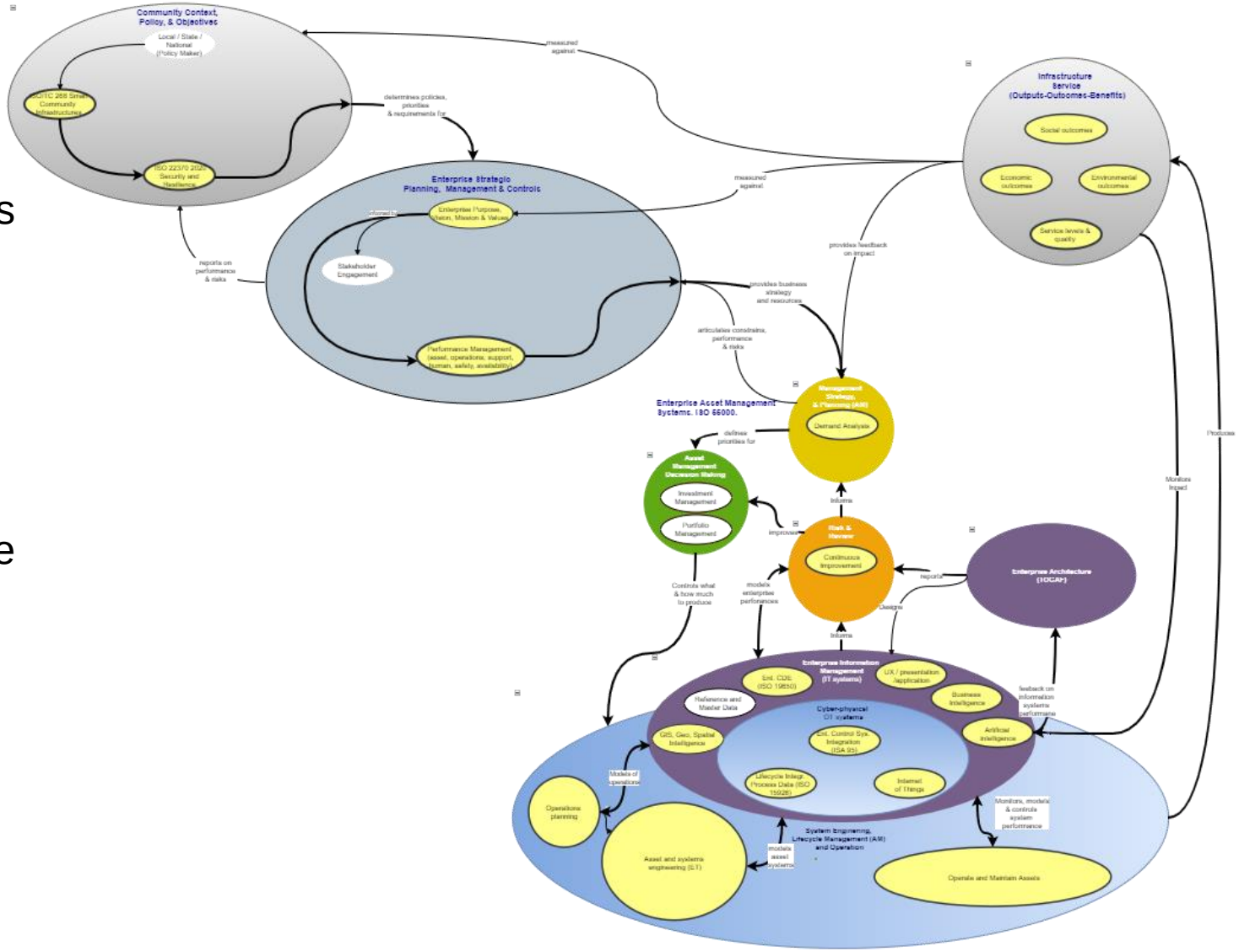
Application: Lessons Learned, Benefits, and Next Steps

Infrastructure Architecture Framework

Water - Digital Twin

Use case

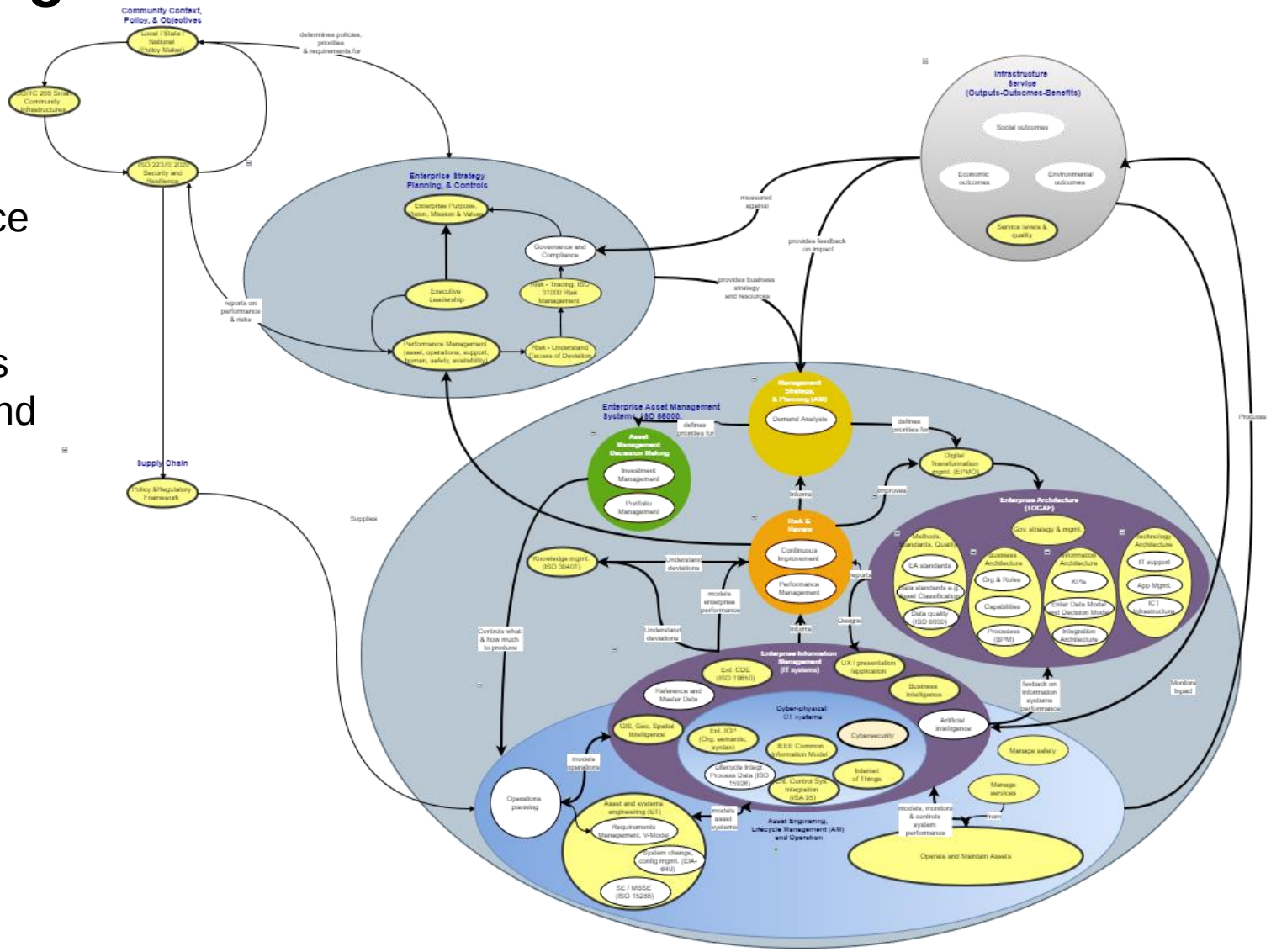
Water Utility (WatU) wants to build a digital twin to integrate information across systems with the goal of promoting a culture of Smart Water Management and the efficient usage of resources among all stakeholders. The envisioned digital twins would be used to forecast flooding and water quality issues, improve city services and responsiveness, and ensure resilience of water infrastructure.



Power - Asset monitoring

Use case

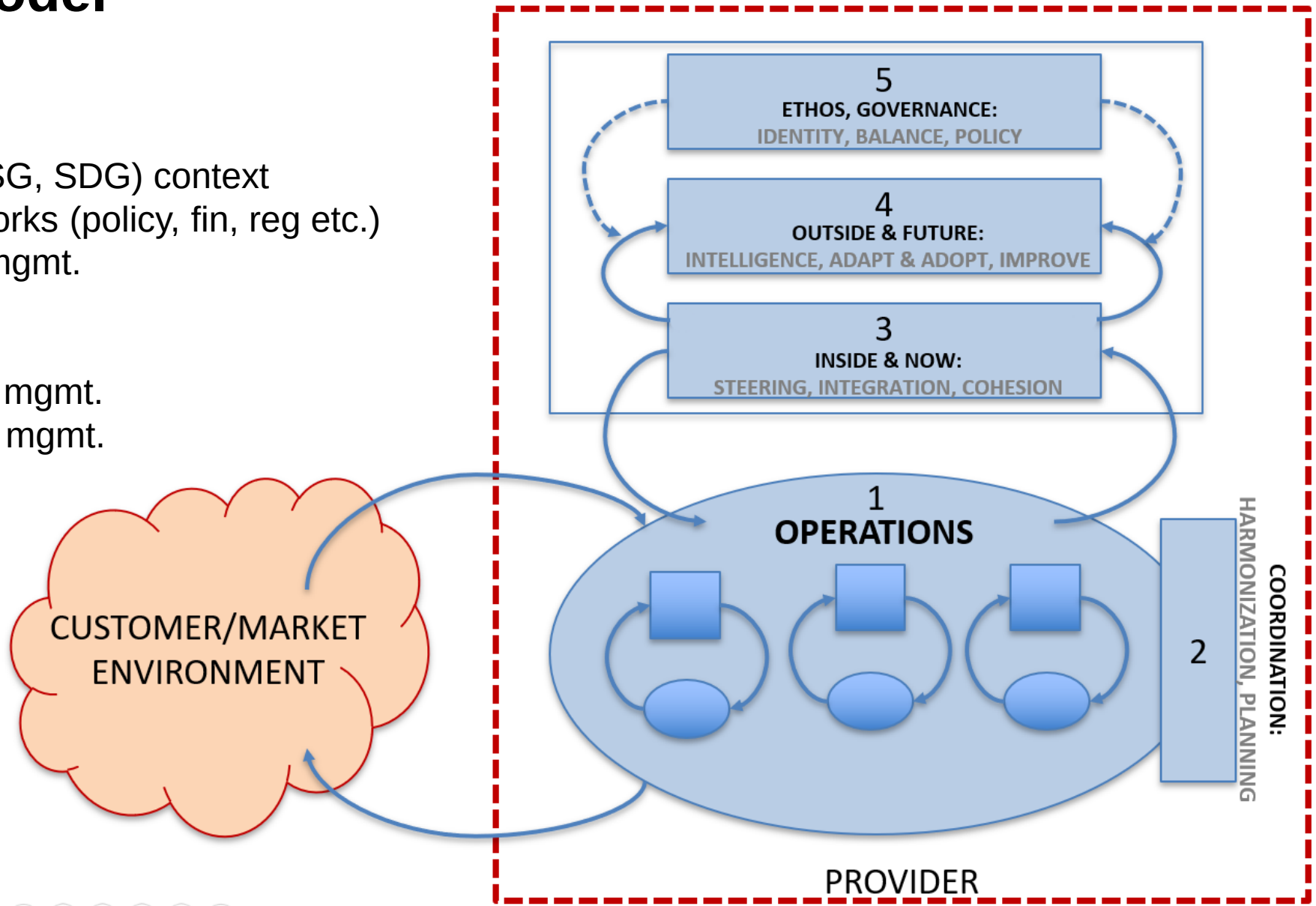
The Power Company (PCo) vision includes being a digital utility to enhance productivity, reliability, safety, customer experience, compliance, and revenue management outcomes. PCo envisions leveraging connectivity, big data, IoT and business analytics to drive actionable business insight to better serve their customers, employees, and other key stakeholders.



Viable System Model

Viable system test

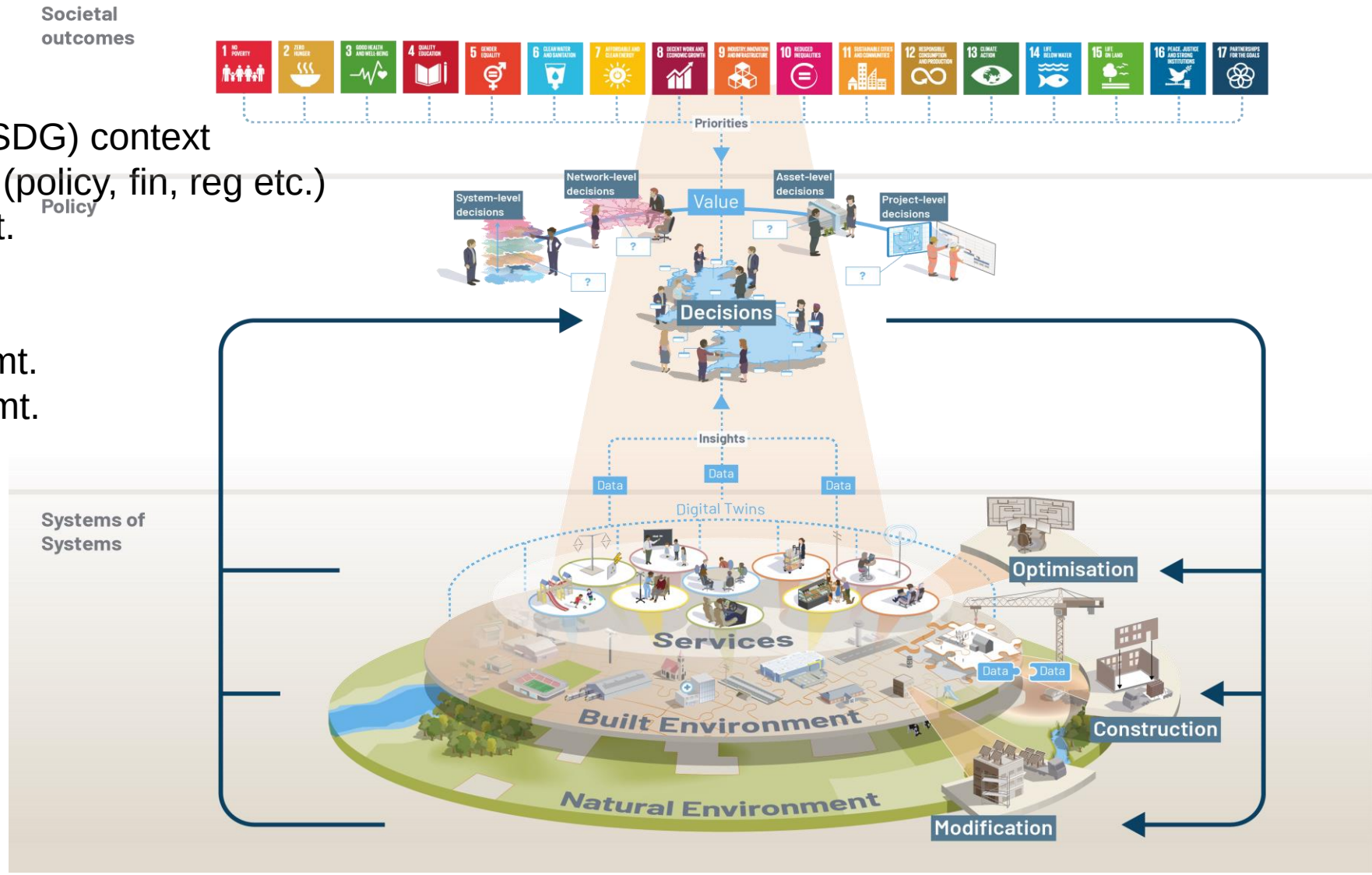
S5 Socio-environmental (ESG, SDG) context
S4 Socio-economic frameworks (policy, fin, reg etc.)
S3 Infrastructure business mgmt.
S2 Enterprise asset mgmt.
S1a System services mgmt.
S1b Project/assets lifecycle mgmt.
S1c Natural assets lifecycle mgmt.



Built Environment Model

Application

S5 Socio-environmental (ESG, SDG) context
S4 Socio-economic frameworks (policy, fin, reg etc.)
S3 Infrastructure business mgmt.
S2 Enterprise asset mgmt.
S1a System services mgmt.
S1b Project/assets lifecycle mgmt.
S1c Natural assets lifecycle mgmt.



[TIP 2030 Roadmap 2030 (gov.uk)]

The benefits for civil infrastructure

The IAF supported the integration of people, process, technology, information, and physical assets aligned to organizational strategy and outcomes.

All infrastructure organizations, such as NY Power and NYC Transit, are defining data to drive what they do, but there's a lack of standardization. The goal of IAF is to create and link common standards for data among organizations.

Thomas A. McDermott Jr.,
Deputy Director, Systems Engineering Research Center

The IAF will jump start cross-service collaboration to address both disaster relief and to meet our needs for the production and distribution of renewable and sustainable energy, and to speed up decarbonization.

John Palmer,
Chief Architect, NY Power Authority

Transforming Infrastructure 4.0 for a sustainable & resilient future

System architecture & engineering offers infrastructure owners/operators a powerful integrative approach to engineering and managing change in complex sociotechnical infrastructure systems

Equitable Infrastructure

Carbon Neutral Infrastructure

Sustainable Infrastructure

Resilient Infrastructure

Infrastructure Architecture Framework

Thank you

Michael A. Salvato

Enterprise, Investment & Transformation

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