National Scale Digital Twin for Infrastructures: Challenges and Opportunities

Berardo Naticchia
Head of Digital Management for Construction Centre
Department of Civil and Building Engineering, and Architecture
Polytechnic University of Marche
via Brecce Bianche
60131 Ancona, Italy
email: **b.naticchia@univpm.it**

Team and expertise

Building Information Modeling

Digital Twin Modeling

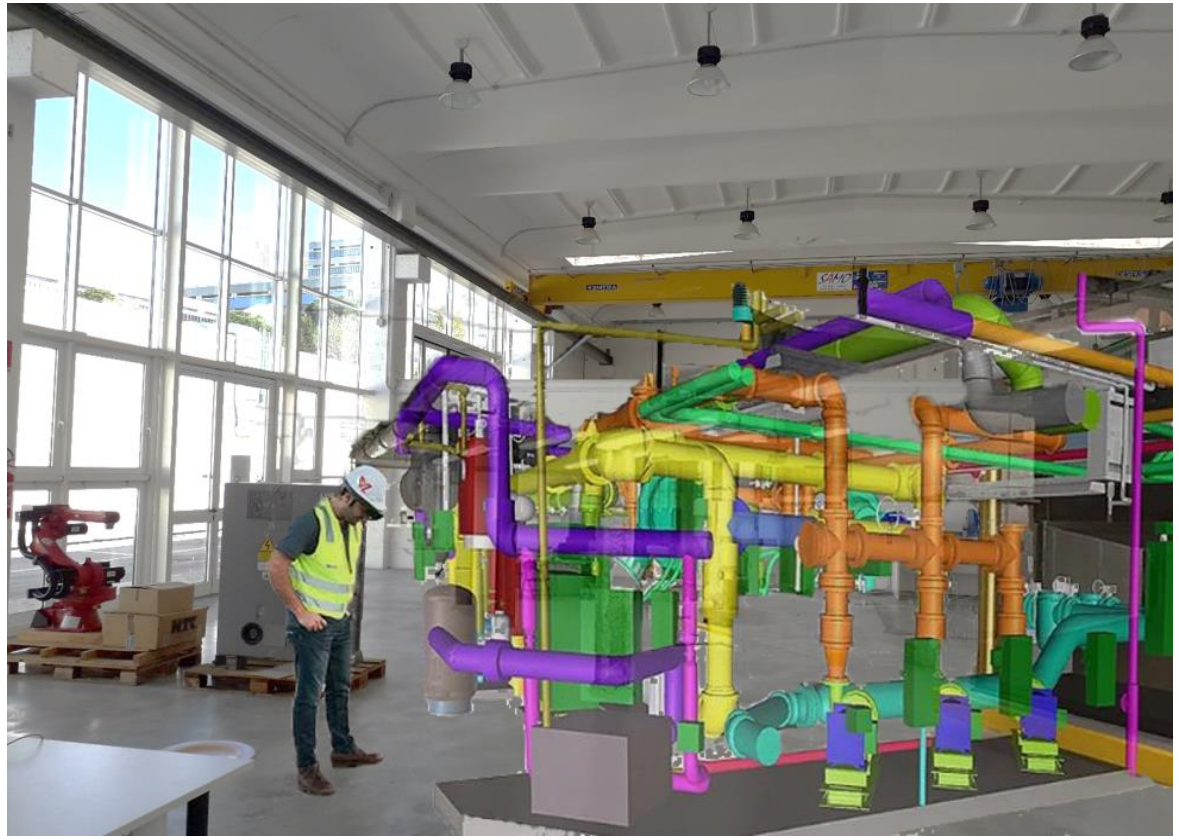
Mixed Reality

Artificial Intelligence

Advanced Digitization Technologies

Internet of Things

Blockchain & Smart Contracts



prof. ing. Berardo Naticchia

prof. ing. Massimo Lemma

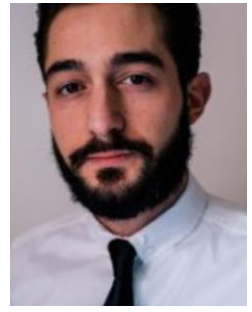
prof. ing. Alberto Giretti

prof. ing. Alessandro Carbonari

dott. ing. Alessandra Corneli

dott. ing. Massimo Vaccarini

dott. ing. Francesco Spegni

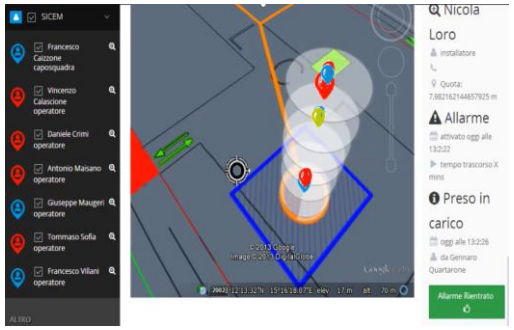


dott. ing. Leonardo Messi

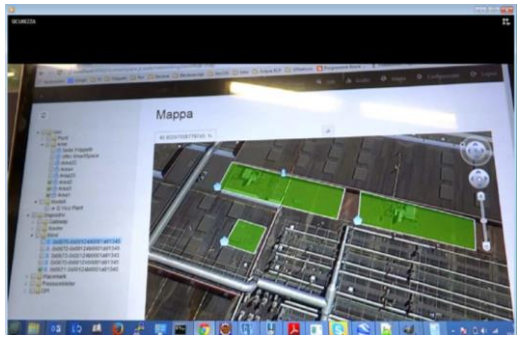
Past experiences in large-scale DT development

Construction

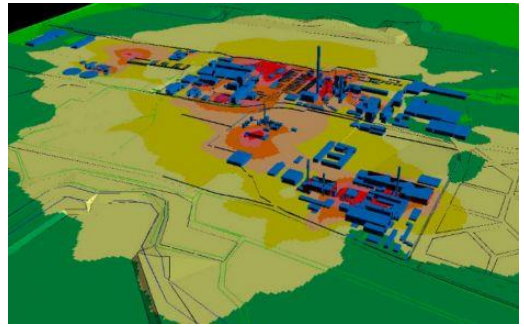
Oil & Gas operations



Manufacturing

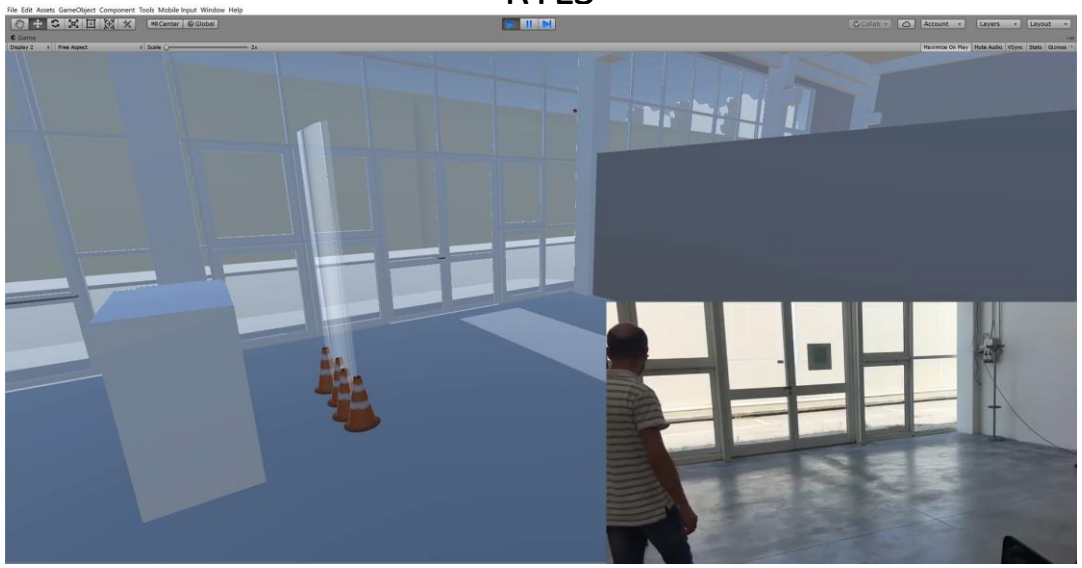


Waste management



Past experiences in development of DT Enabling Technologies

RTLS



MR & AI Technologies

Pervasive IoT & AI for scene understanding

Supervisory Control And Data Acquisition platforms

Current involvement in large-scale DT development programs

National Centre for Sustainable Mobility

Spoke 7: WP 1 - Integration layer

aimed at developing a technology platform for the management of an ecosystem of ICT tools and digital twins of infrastructures to support cooperative, connected and automated mobility (CCAM).

Digital Facility Management and Operations for italian universities

aimed at developing a platform for the implementation of an ecosystem of digital twins for smart buildings to support facility management and operations.

Digital Smart Structures

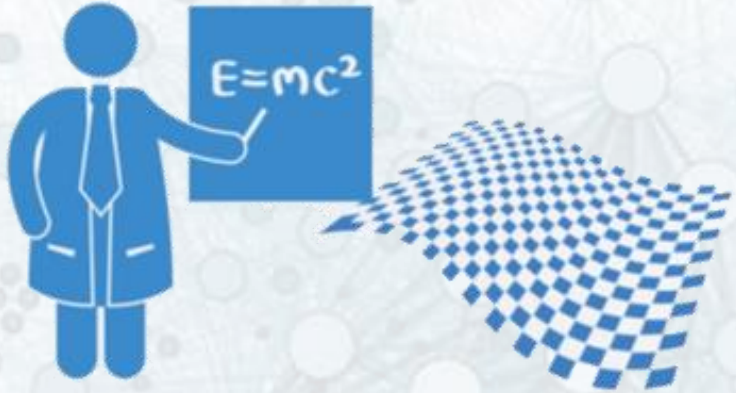
aimed at developing a platform for the management of an ecosystem of digital twins of bridges to support structural health management.

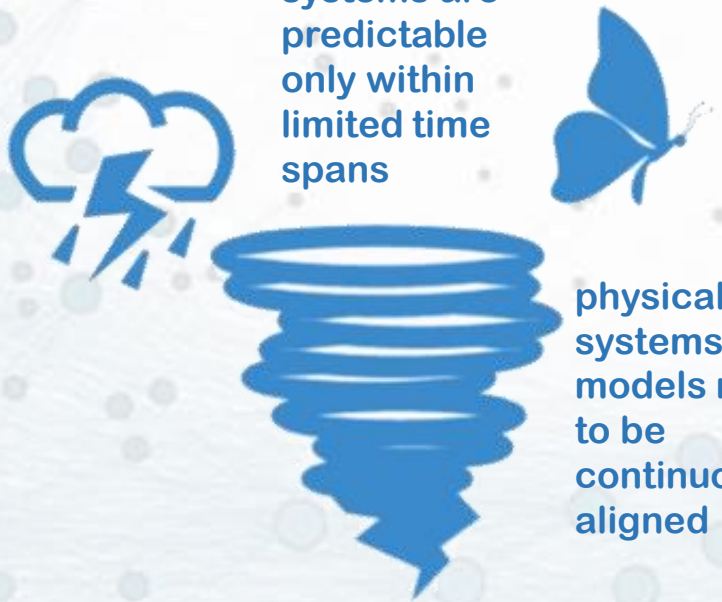
Why do we really need Digital Twins?

What is new that cannot be addressed by classical simulation modeling?

Complex Systems and Complexity Science

Scientific basis of civil engineering dates back to the 18th century





Newtonian mechanics

1700

Relativistic mechanics

1930

Complexity science

1970

The age of complexity

2021 Nobel prize

Complex Systems

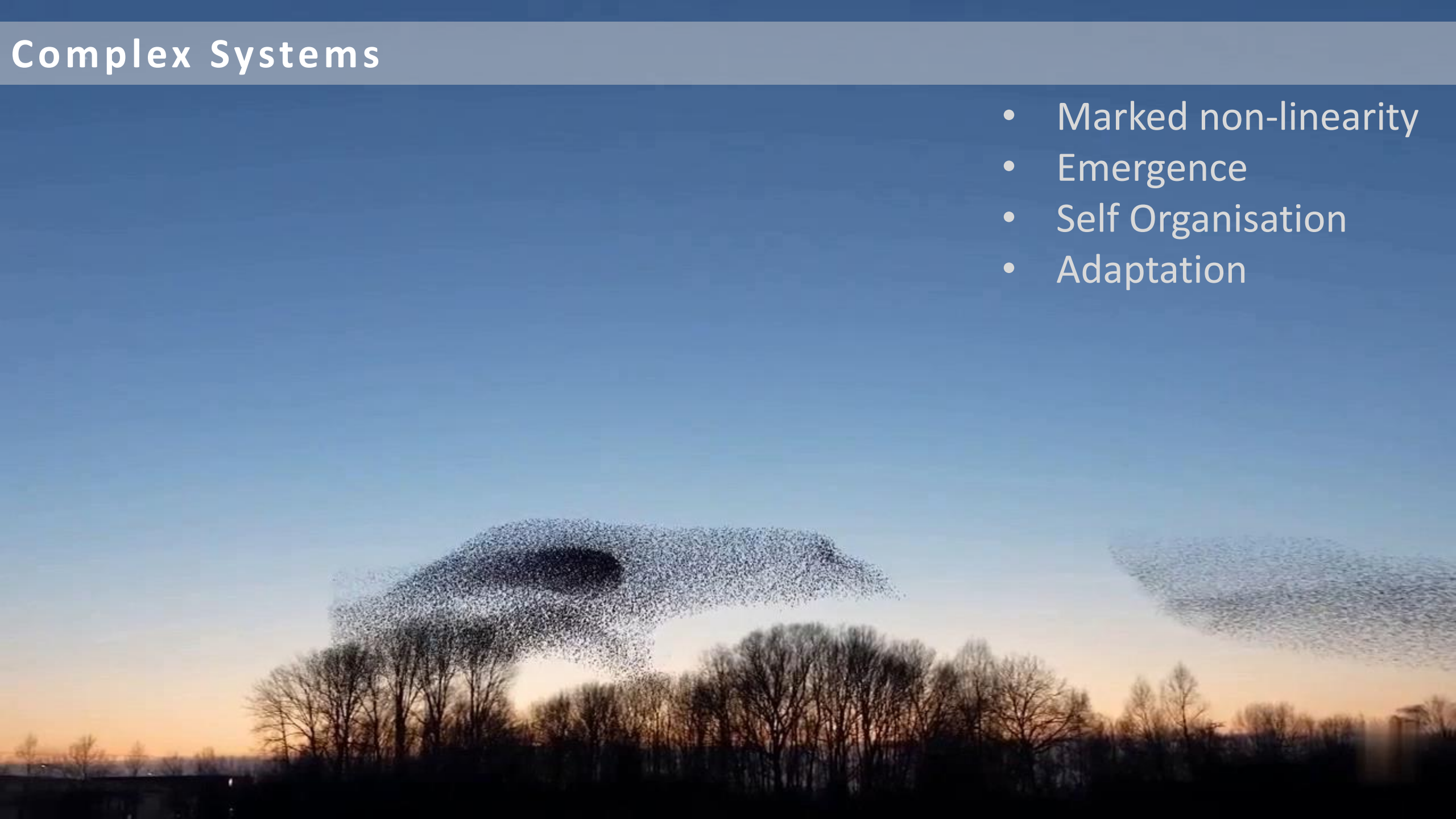
There is no agreed definition of complex systems.

A working approach to defining complex systems is to highlight some of distinctive characteristics they exhibit.

- Marked non-linearity
  (the future is unwritten)
- Emergent behaviours
  (some regularity in the chaos)
- Self Organization
  (no chance to centralize the management)
- Adaptation
- (historical memory)

Complex Systems

- Marked non-linearity
- Emergence
- Self Organisation
- Adaptation

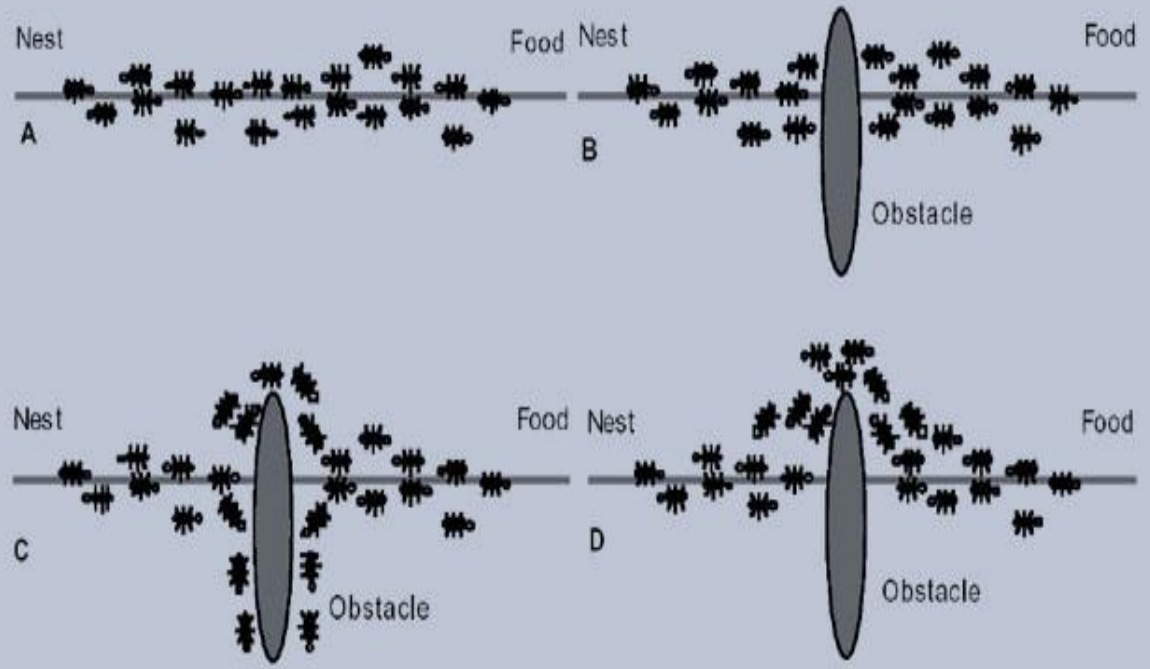


Management of Complex Systems

Participated objective
Synchronization

COLLECTIVE INTELLIGENCE

Swarm Intelligence

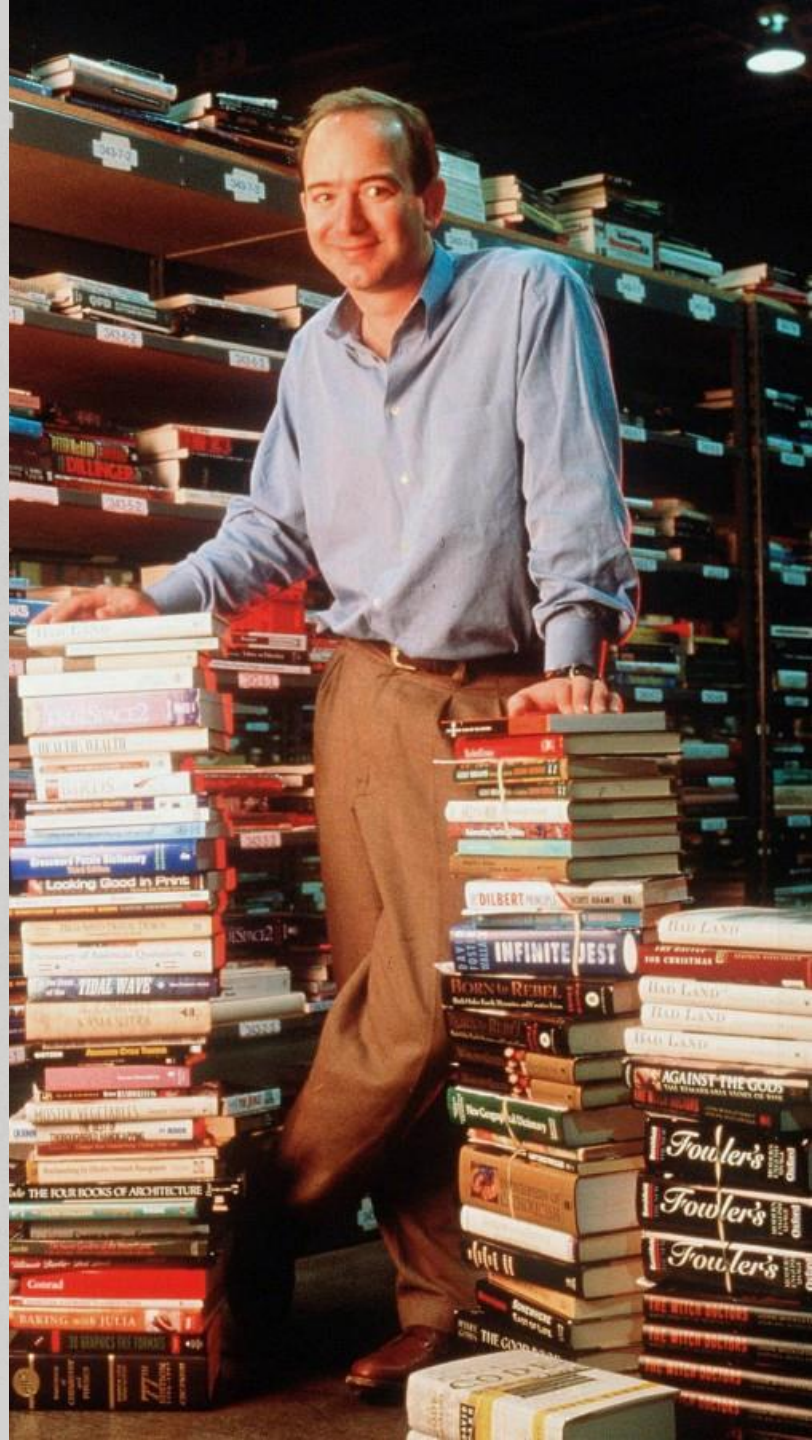


Chemical Twin

AMAZON

This company built one of the world's most efficient warehouses by embracing chaos

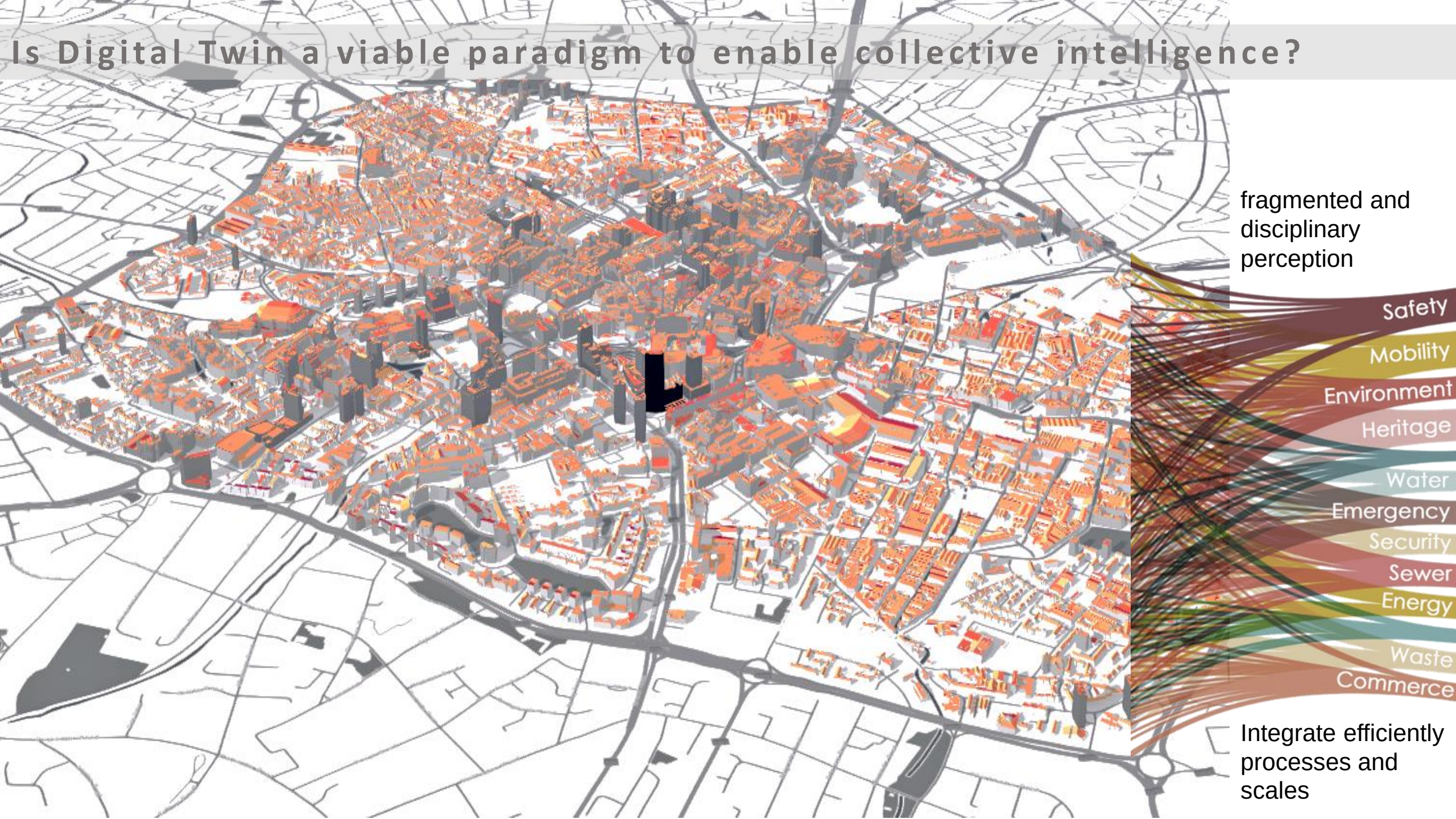
By Sarah Kessler | Illustrations by Justine Shirin



Jeff Bezos founded Amazon in 1997. Today the company is valued at $1.7tn and Bezos himself is worth almost $200bn © Paul Souders/Getty


COLLECTIVE
INTELLIGENCE

Is Digital Twin a viable paradigm to enable collective intelligence?



Digital Twins

enabling collective intelligence

A Chronology of the Digital Twin

Copy of the Apollo 13 Module

This copy, which was on Earth and called "the twin," was used by engineers to determine how to get the astronauts back to Earth safely.

New Term: Digital Twin

Michael Grieves (University of Michigan) first introduced the term "digital twin" in the context of PLM.

Digitalization of an Engine Block

Mackevision developed a digital twin of an engine block to simulate the behavior of engine parts at different speeds.

Digital Twin of a Port

The port's digital twin was used to develop the networked control technology.

Digital Twin at Maserati

Digital twins are used to reduce the product development costs of new models

Other Developments

According to Gartner, there will be more than 20 billion digitally connected sensors and endpoints in 2020. By 2021, half of all the largest industrial companies will be using digital twins

1970 — 2003 — 2016 2017 2018 — 2021 — 20xx — t

2D CAD — 3D CAD

3. Industrial Revolution — Industrie 4.0

Increased use of the Digital Twin

What is a Digital Twin?

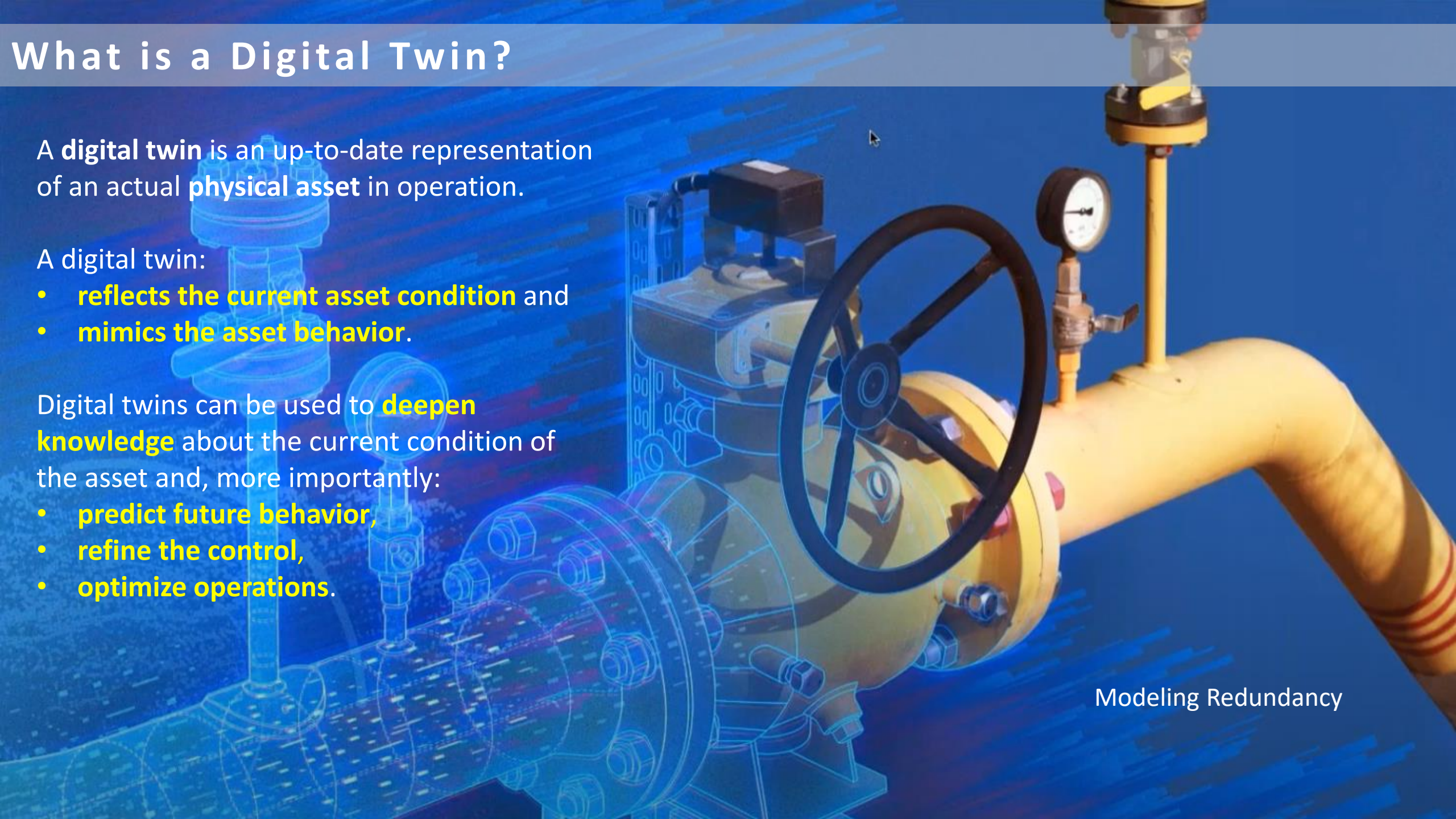
A **digital twin** is an up-to-date representation of an actual **physical asset** in operation.

A digital twin:

- **reflects the current asset condition** and
- **mimics the asset behavior**.

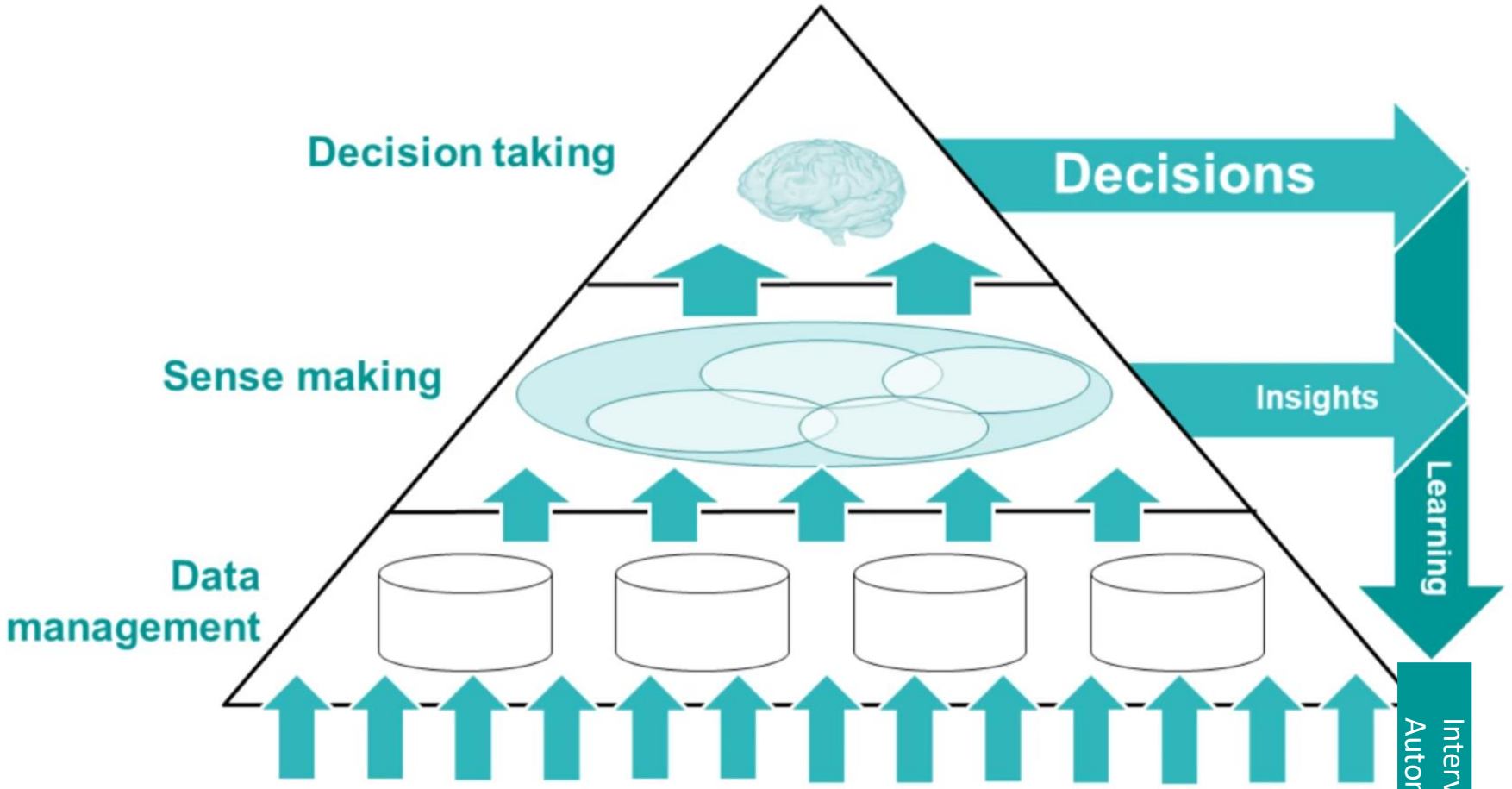
Digital twins can be used to **deepen knowledge** about the current condition of the asset and, more importantly:

- **predict future behavior**,
- **refine the control**,
- **optimize operations**.

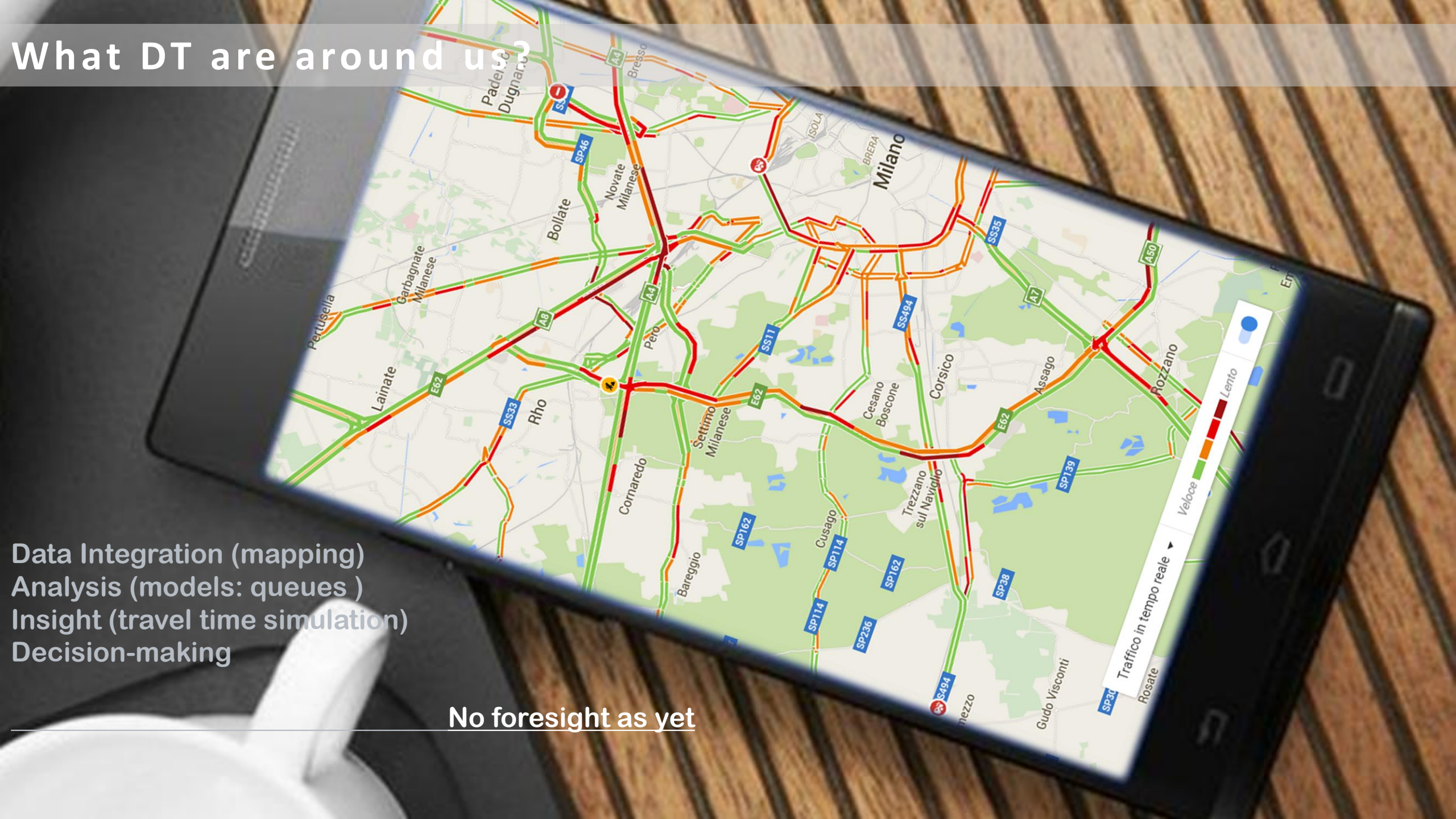


Modeling Redundancy

Information Value Chain in DT

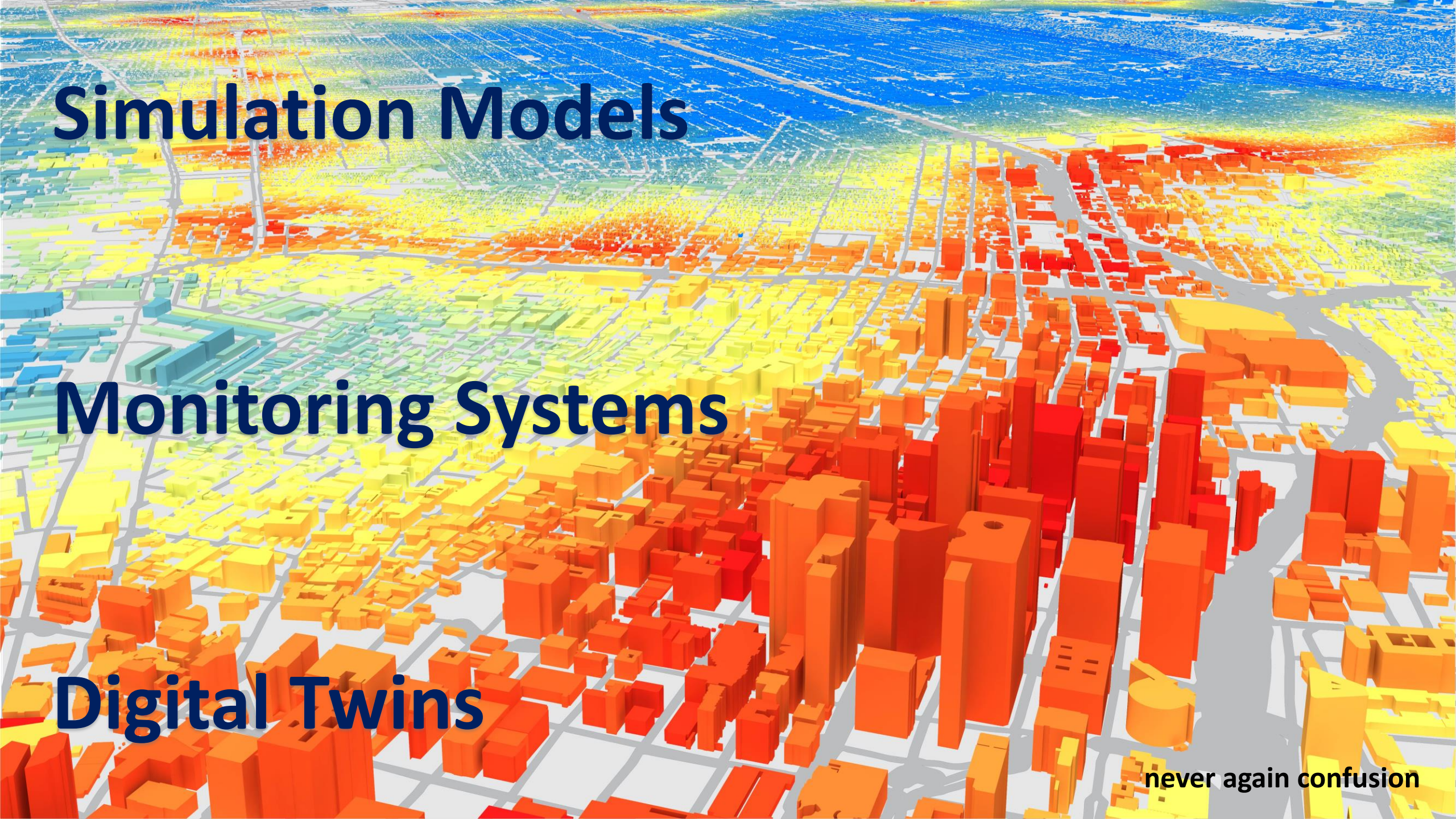


What DT are around us?

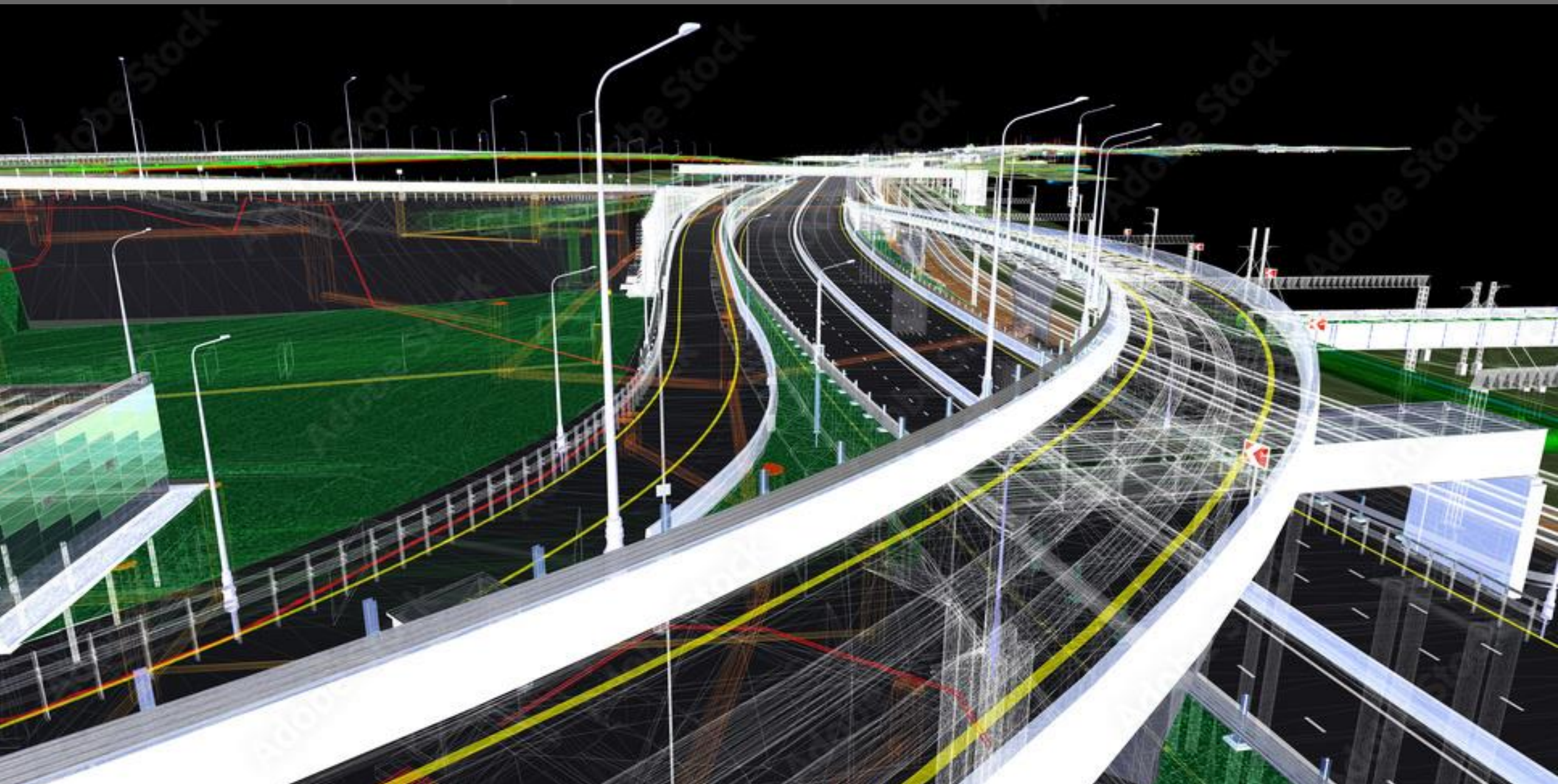


Data Integration (mapping)
Analysis (models: queues)
Insight (travel time simulation)
Decision-making

No foresight as yet


Simulation Models
Monitoring Systems
Digital Twins
never again confusion

Is BIM Model a DT?



Is 3D Map or GIS Model a DT?

Is Monitoring System a DT?

Is Supervisory Control And Data Acquisition (SCADA) a DT?

Is Digital Twin a mature approach to manage infrastructures?

Is DT approach ripe enough to manage infrastructures?

Digital twins in infrastructure: definitions, current practices, challenges and strategies

Didem Gürdür Broo & Jennifer Schooling

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To link to this article: https://doi.org/10.1080/15623599.2021.1966980

sustainability MDPI

Article

Digital Twins in Civil Infrastructure Systems

Matthew Callcut [1], Jean-Paul Cerceau Agliozzo [1], Liz Varga [2,*] and Lauren McMillan [2]

[1] Department of Civil, Environmental and Geomatic Engineering, University College London, UCL Gower Street, London WC1E 6BT, UK; matthew.callcut.19@alumni.ucl.ac.uk (M.C.); jpcerceau@gmail.com (J.-P.C.A.)
[2] Infrastructure Systems Institute, University College London, UCL Gower Street, London WC1E 6BT, UK; lauren.mcmillan.19@ucl.ac.uk
* Correspondence: l.varga@ucl.ac.uk

Sustainability **2021**, *13*, 11549. https://doi.org/10.3390/su132011549

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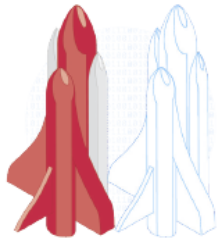
Review

Towards Resilient and Sustainable Rail and Road Networks: A Systematic Literature Review on Digital Twins

João Vieira [1,2,*], João Poças Martins [3], Nuno Marques de Almeida [1], Hugo Patrício [2] and João Gomes Morgado [2]

Sustainability **2022**, *14*, 7060. https://doi.org/10.3390/su14127060

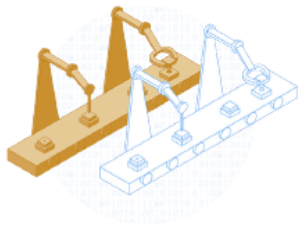


While the concept of accurately modelling the physical world dates back to the first attempts at accurate mapping, NASA were pioneers of digital twins for remote monitoring, controlling and running simulations of their spacecraft from Earth.

The aerospace and defence sectors are frequently cited as the next most advanced in digital twin use, using them to manage highly complex assets, though data sharing between organisational silos remains a barrier.

Offshore oil & gas use digital twins to monitor and predict maintenance schedules for their structures in the interest of safety and efficiency. Data security is a major concern in this sector.

Digital twins are prevalent in manufacturing literature and practice at various scales – from component to factory to wider logistics level – in order to manage efficiency, control, safety and logistics. Interoperability along the supply chain is one of the chief barriers in this sector.

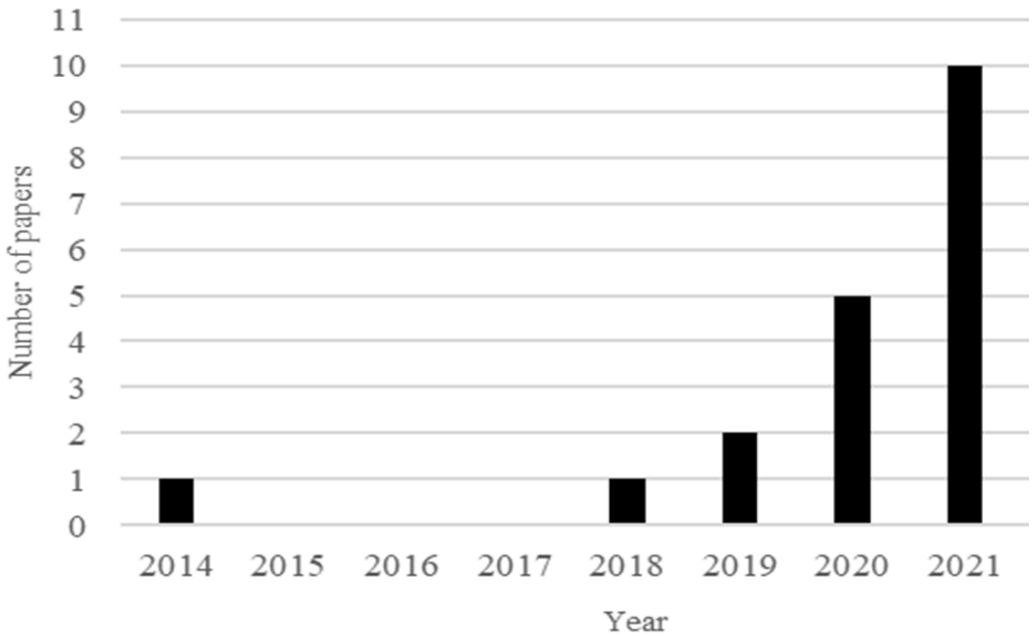


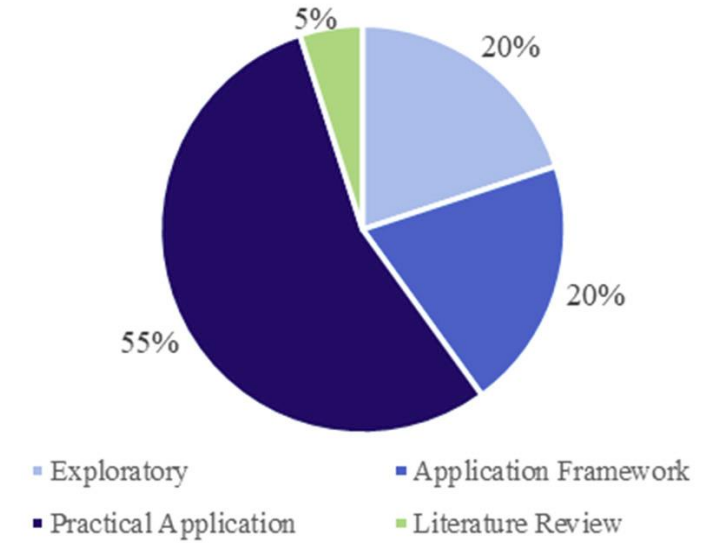
In the built environment, the use of digital twins is just beginning to take off. Fully realised examples are rare, even at the level of individual assets. A great deal more technological and organisational maturity is needed for a National Digital Twin of built assets and services.

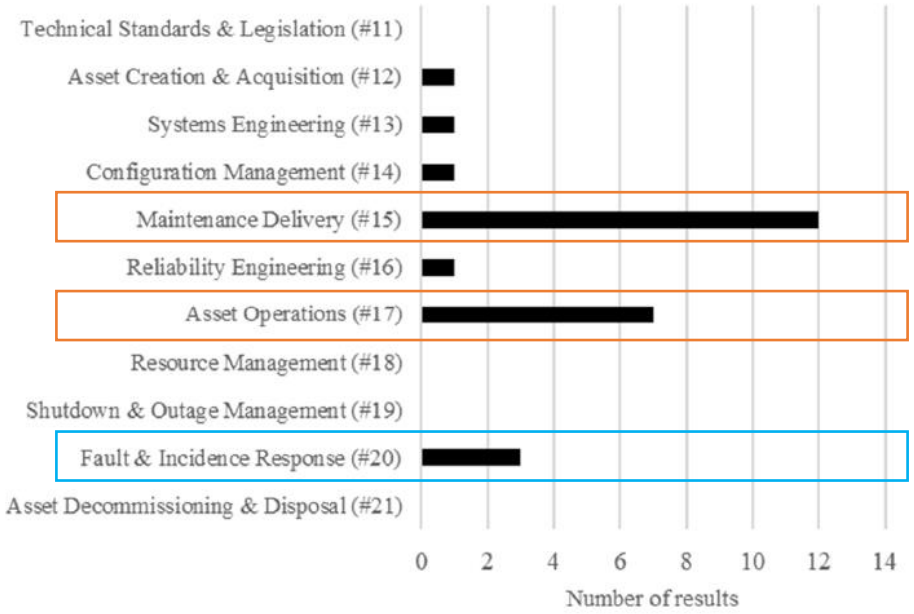
Maturity

DT research in the road and rail sector

Sector	Infrastructure	No. of Papers
Buildings	Building	48
Transportation	Railway	16
	Bridge	15
	Roadway	10
	Tunnel	9
General	General	6
Energy	Electricity	3
Telecommunication	Telecommunication	1
	Total	**108**







DT research in the road and rail sector

Digital Twin for Mobility Infrastructure oriented to services for CCAM.

PROJECTS

RESIST SAFEWAY PANOPTIS

Summary from: Thierry GOGER (FEHRL)

Three great R&D&I Projects were presented at the #H2020RTR21 – 5th edition during the "**Building Resilience-proof infrastructure**" session.

The projects, entitled **RESIST**, **PANOPTIS** and **SAFEWAY** addressed the whole cycle of resilience, from the preparation phase to the recovery phase.

The projects encompassed not only the linear transport infrastructures but also the critical transport infrastructures, such as the bridges and tunnels, as well as the assets and the network level.

They offered solutions, whether they were technical solutions using drones or robots, but also more strategic solutions having a look at monetarisation and economic aspects of the resilience.

The projects covered the whole lifecycle of the infrastructure, starting from the design, the maintenance, and the decommissioning and recycling.

So we can thank the European Commission, 2Zero and ERTRAC for this excellent #H2020RTR21 – 5th edition, and these four great projects for their great input about the Resilience of Transport Infrastructure.

Follow-up promotional activities are planned at the Connecting Europe Days 2022 and TRA 2022.

Follow-up exploitations are envisaged within Horizon Europe and CEF upcoming calls.

Opportunities offered by a National Scale DT of roads

two points of view

(both refer to the management of complex systems):

The Service Level (smartness in day-to-day operations)

The Resilience (behavior under exceptional events)

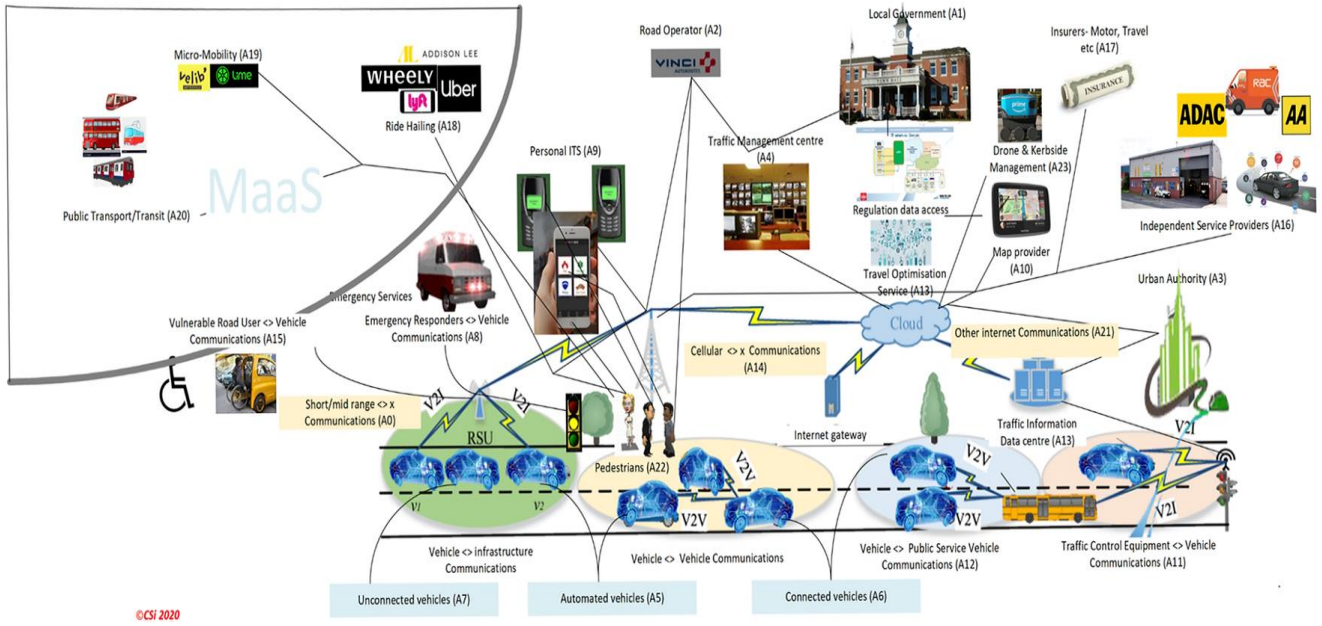
The Service Level Point of View

Maintenance delivery

Asset operations

CCAM scenario

Beyond ego-car towards a collective intelligence



Cooperative, Connected and Automated Mobility (CCAM) is one of the next big trends in the automotive industry.

The exchange of information between infrastructure, service delivery and vehicles, requires a digital twin capable of processing insights for each actor.

LEVEL 0
The driver is responsible for all driving tasks.

LEVEL 1
An Advanced Driver Assistance System (ADAS) assists the driver, who is still required to monitor and coordinate the situation.

LEVEL 2
The ADAS assists steering and braking. In case of an emergency, the vehicle supplements the driver's braking or steering manoeuvres. The driver is still in charge of monitoring and controlling the vehicle.

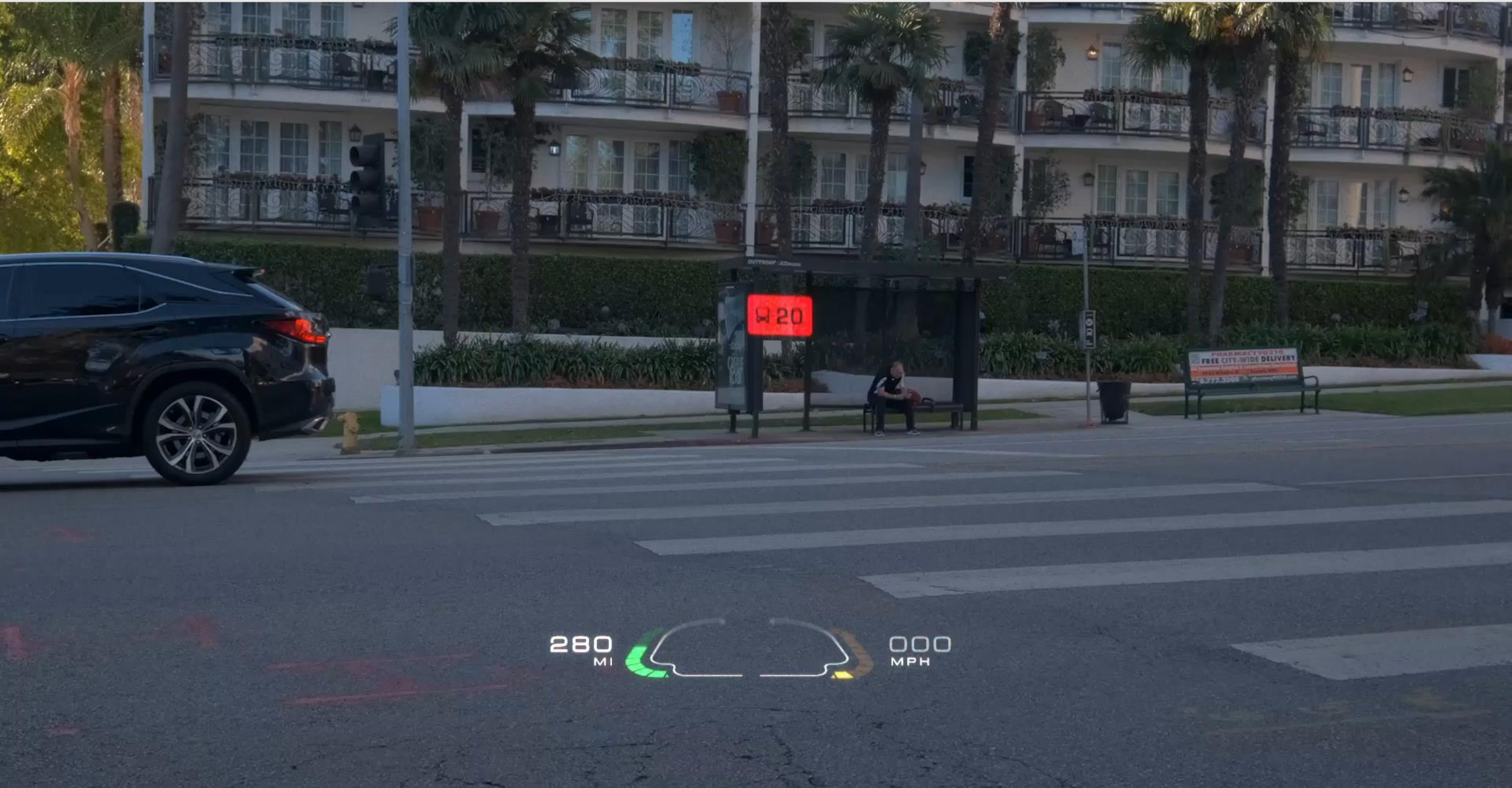
LEVEL 3
Under certain circumstances, an Automated Driving System (ADS) takes over the driving. The driver hands over the driving to the vehicle or takes it back.

LEVEL 4
Under certain circumstances, the ADS is in charge of all driving functions as well as environmental monitoring. The driver decides when the vehicle drives itself.

LEVEL 5
The ADS is in charge of all driving and monitoring systems.

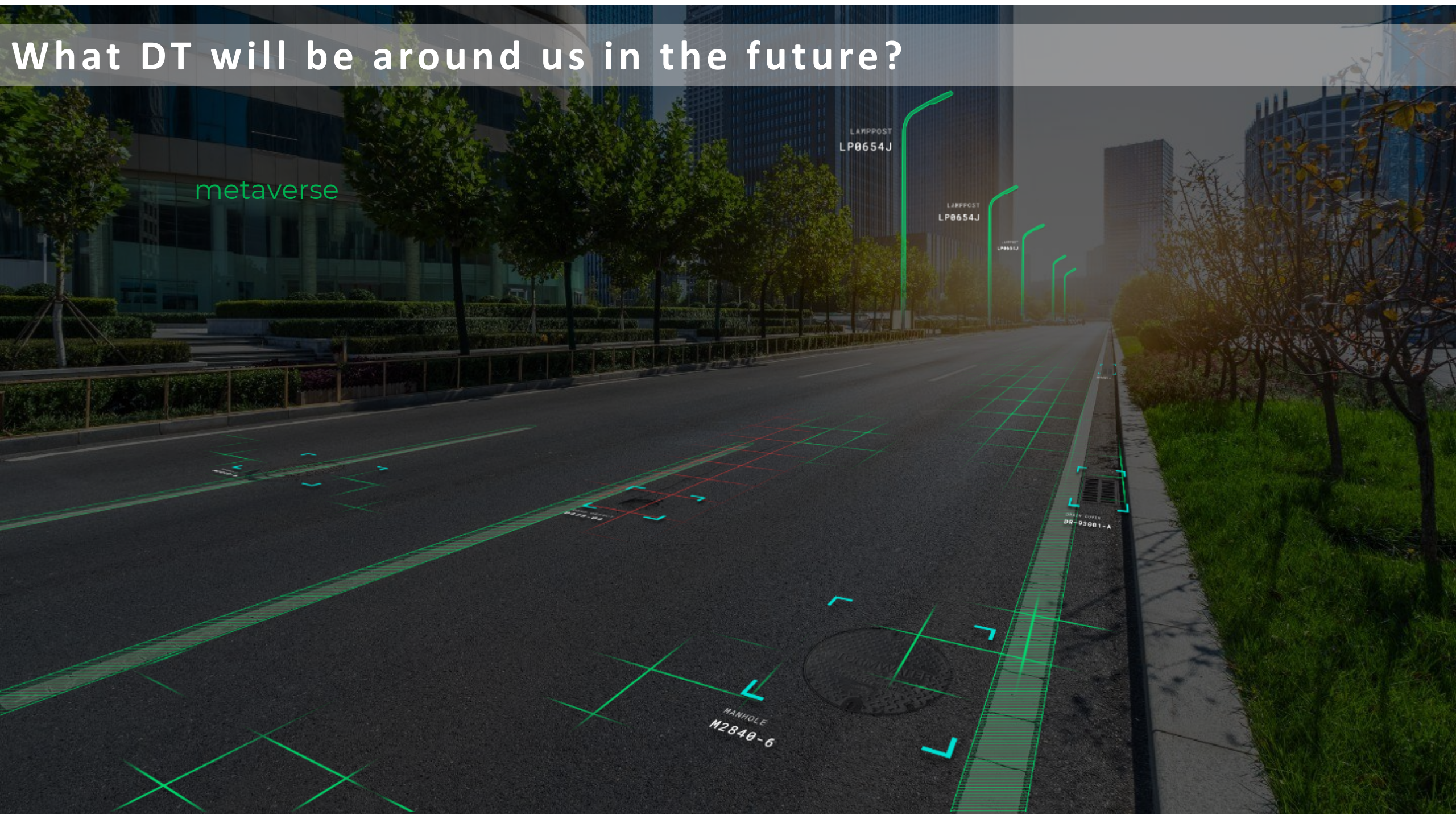
SAE levels of driving automation

What DT will be around us in the future?



What DT will be around us in the future?

metaverse

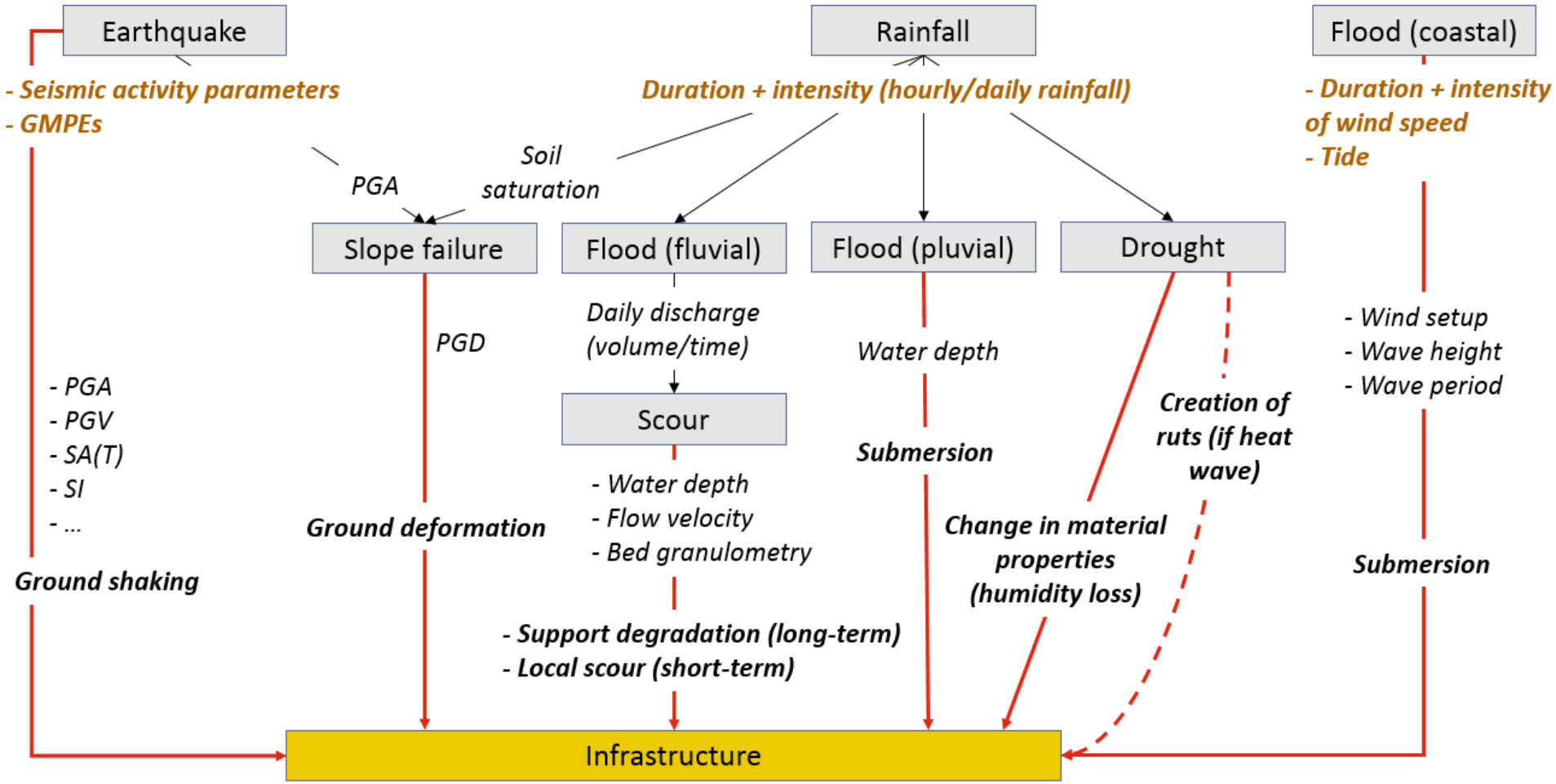


The Resilience Point of View

The fragility of interdependency

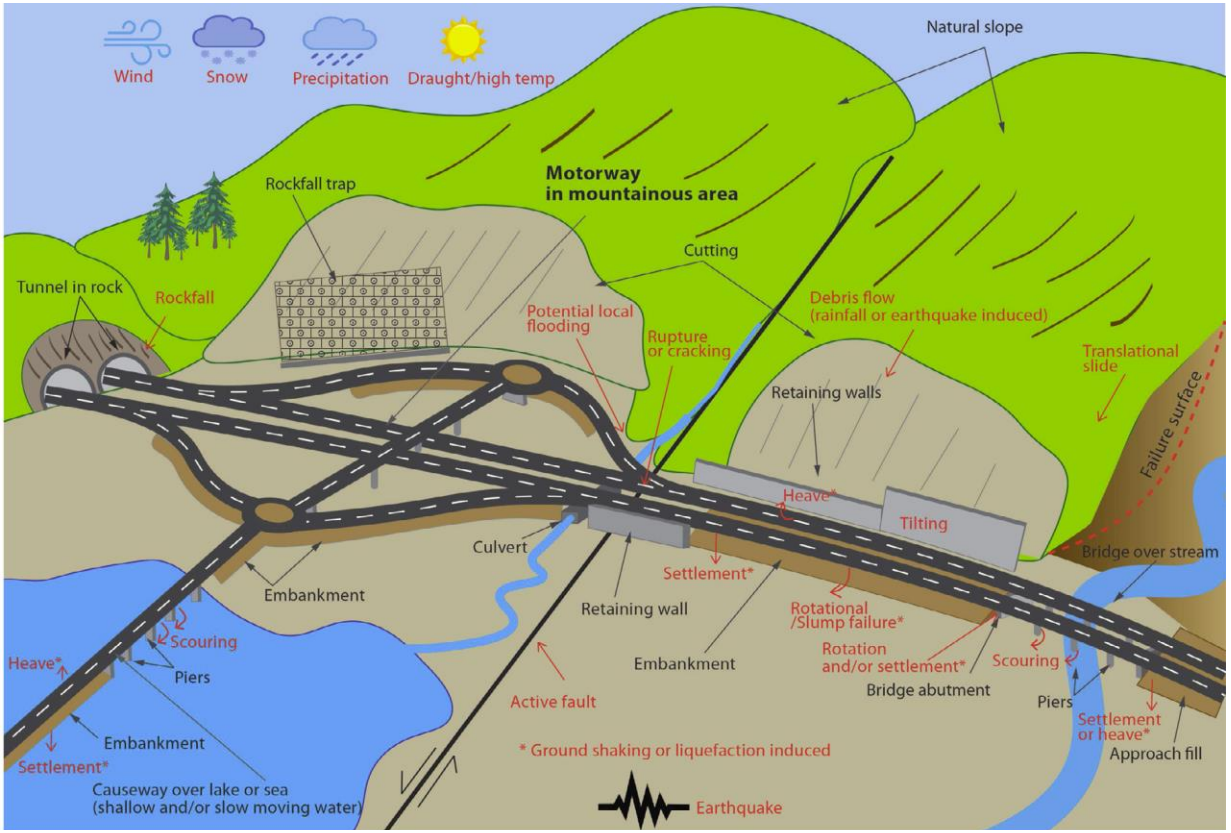
Multi-hazard management

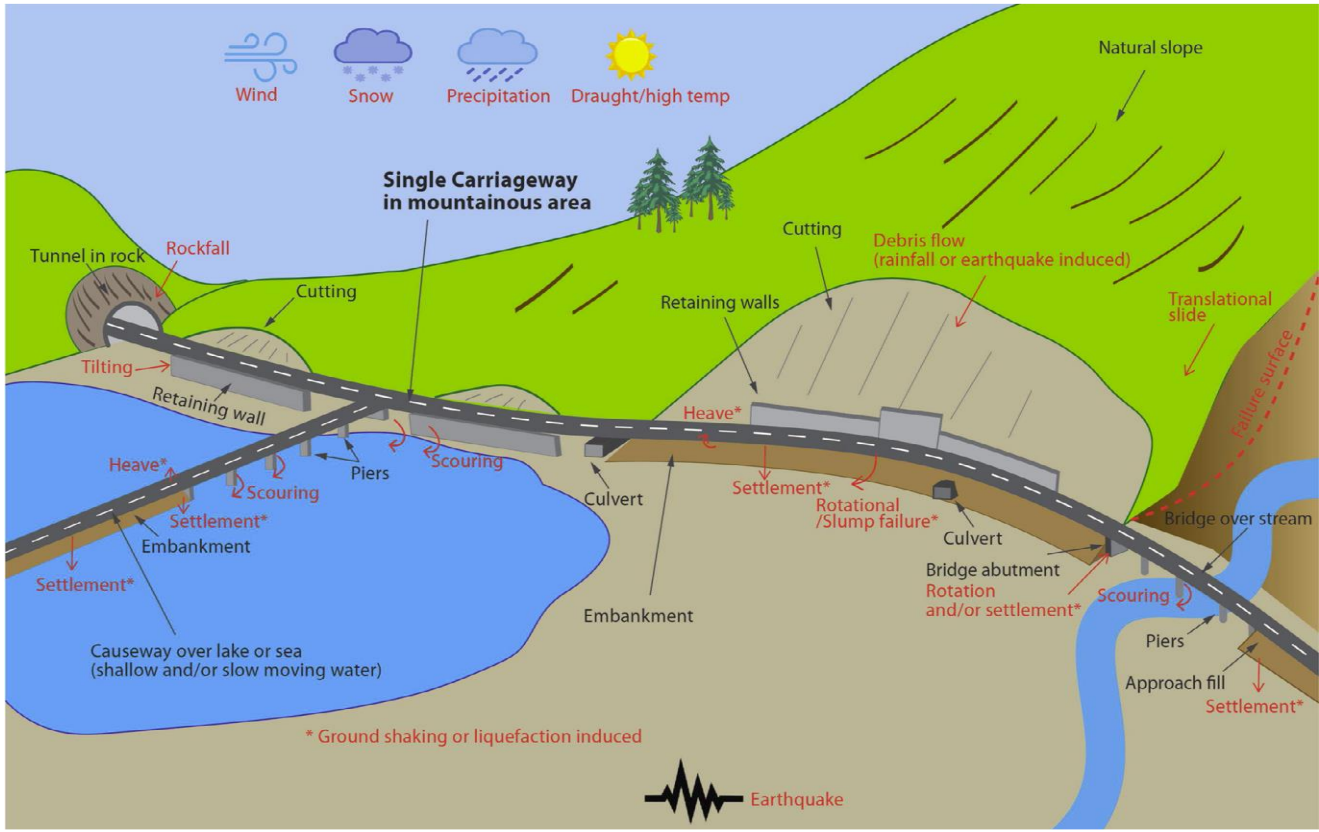
Existing infrastructure systems and the services they provide are increasingly being affected by disasters with a natural hazard origin as well as man-made hazards, and from the impacts of climate change.



Natural hazards and their effects on transport infrastructure

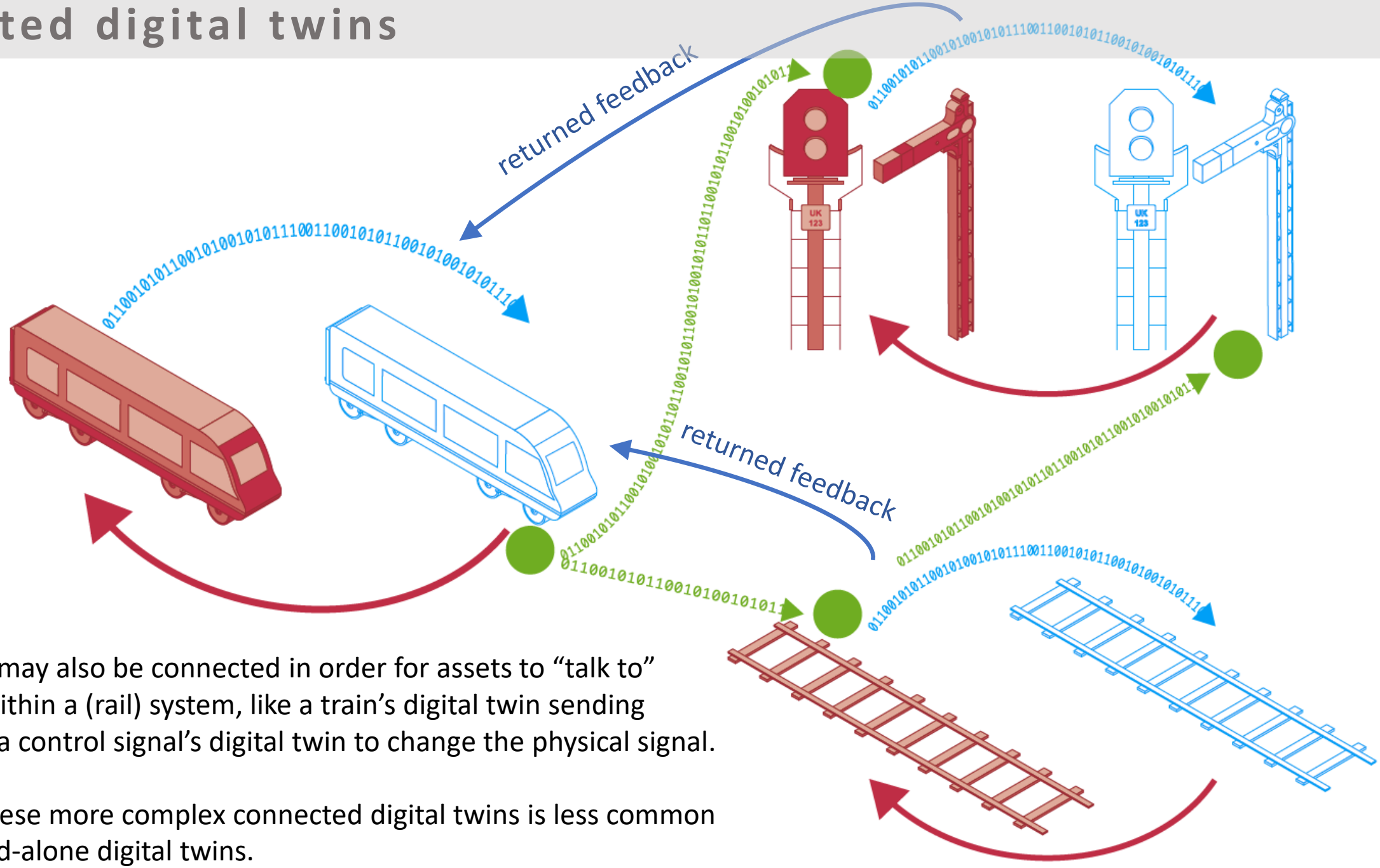
To manage proactively the infrastructure resilience, you need to integrate large-scale multi-domain DTs connecting them to get systemic insights





mountainous areas

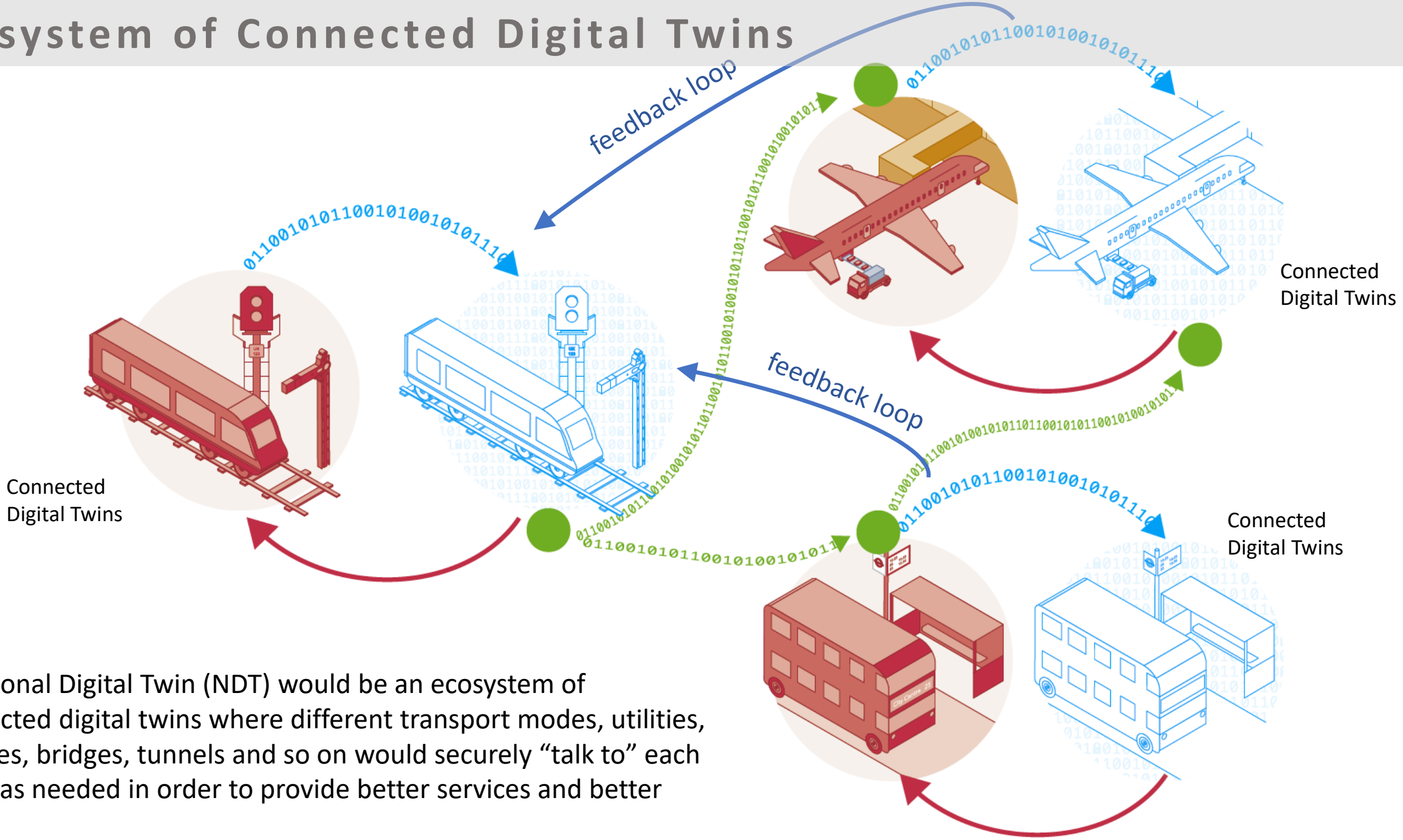
Connected digital twins



Digital twins may also be connected in order for assets to “talk to” each other within a (rail) system, like a train’s digital twin sending messages to a control signal’s digital twin to change the physical signal.

The use of these more complex connected digital twins is less common than for stand-alone digital twins.

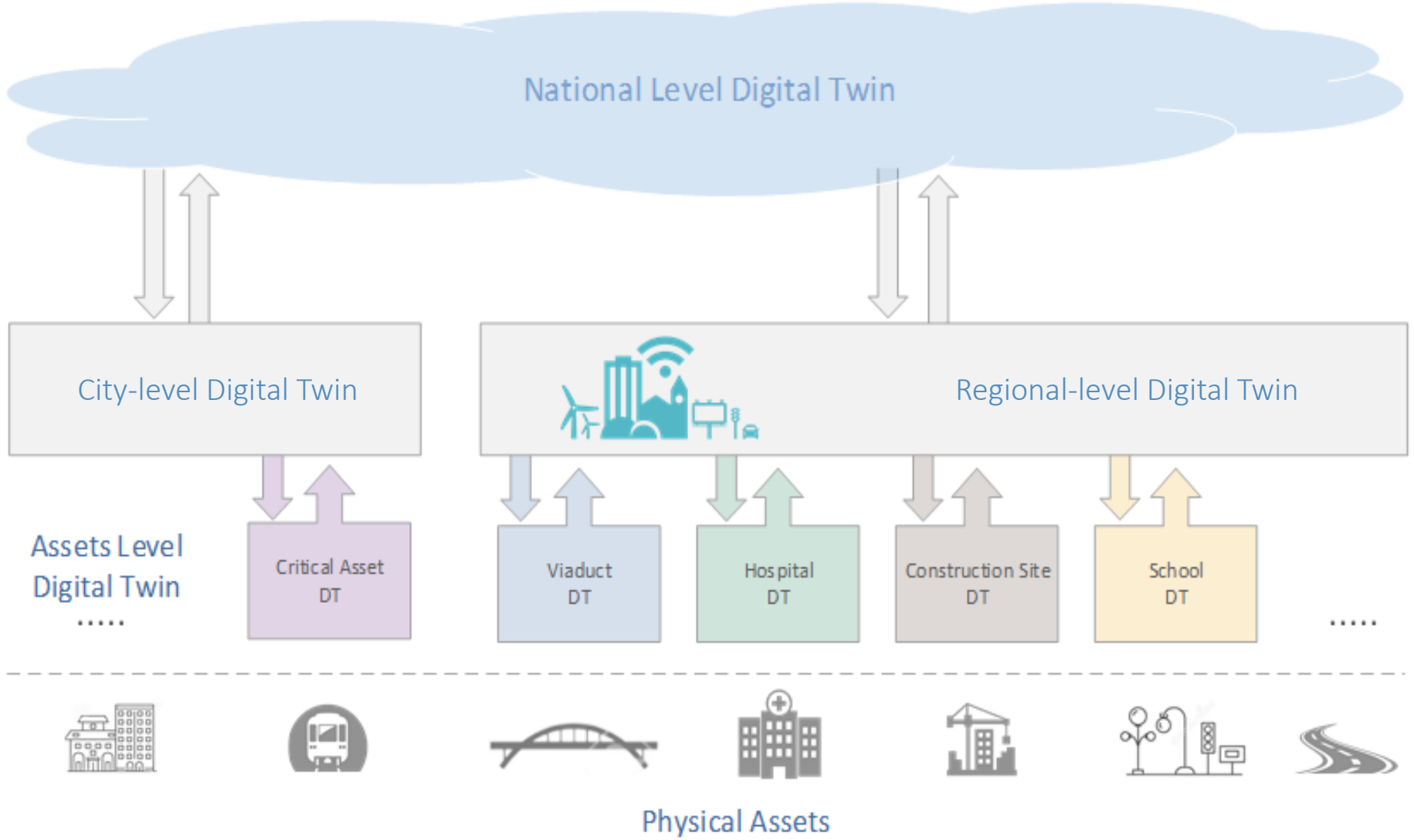
Ecosystem of Connected Digital Twins



A National Digital Twin (NDT) would be an ecosystem of connected digital twins where different transport modes, utilities, services, bridges, tunnels and so on would securely “talk to” each other as needed in order to provide better services and better value.

A reference architecture

Not a global DT but an ecosystem of interconnected DT for managing critical interdependent infrastructures



Challenges to face developing large-scale DTs

Openness and Social involvement

Integrating Data, Semantics, multi-scale and multi-domain data models

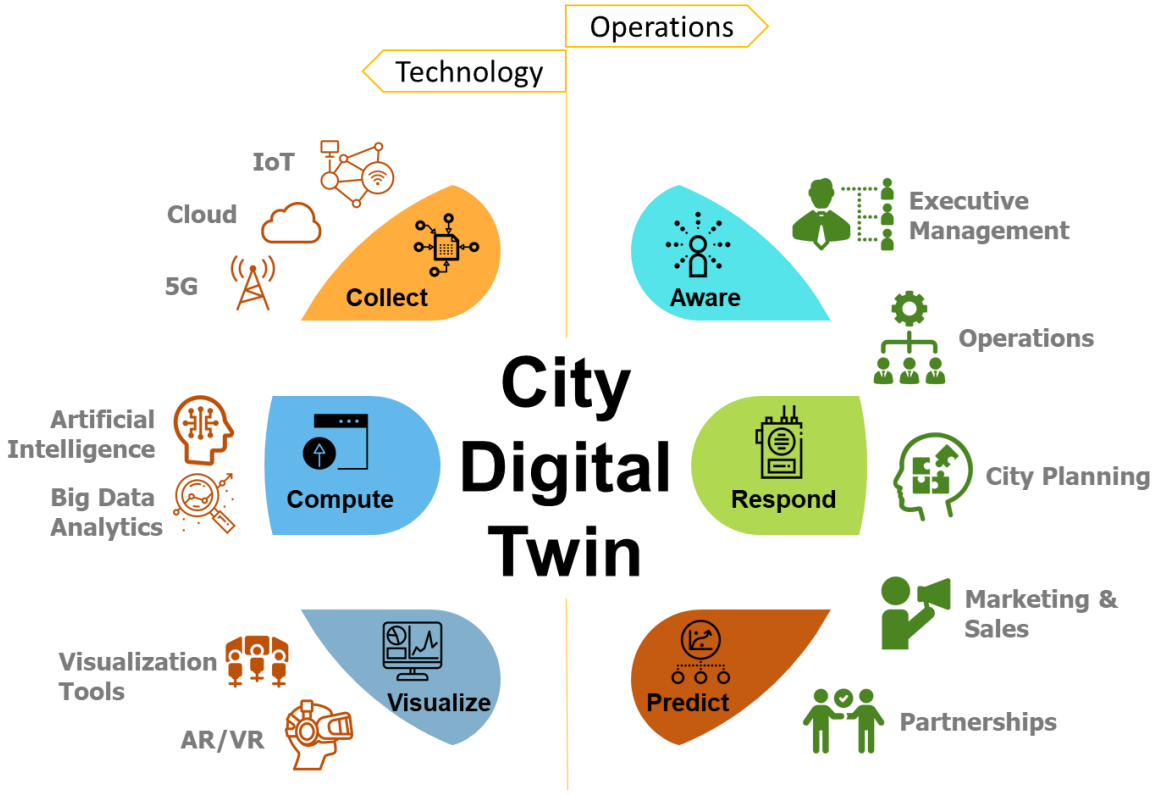
Integrating and synchronizing multi-scale multi-domain analysis

Huge Data: Real-world digitization with scalability, sensing, quality and security

Openness and Social involvement: Information Management Framework

In the implementation of **bespoke digital twins**, **integration of knowledge representation is implicit**.
Data and models are correlated in a predefined way and there is usually no functional scalability

Instead, implementing a large-scale, open and functionally scalable digital twin requires an Information Management Framework that defines the **rules and mechanisms for managing the ways in which knowledge and digital twins can be structured**, combined and accessed.



Foundation Data Model (FDM) structures of relationships to be held within and between digital twins
Reference Data Library (RDL) ontologies from disciplinary sectors
Integration Architecture (IA) that will enable the managed integration of models

Integrating data and analysis: Climbing the wisdom hierarchy

DT supports in approaching different levels of awareness

Insight

Meaning

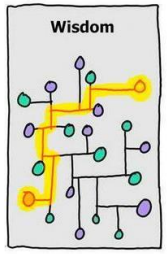
Context

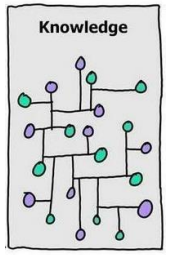
(**Operational view**) Is a human state and relates to the consciousness of human programming. It is related to our human judgment and our mental **decision** related to the knowledge through experience gained. It can with that relate to decisions making.

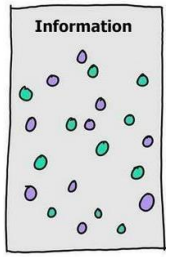
(**Systemic view**) Appropriate information, understanding it, and having **the capability to use it for specific purposes**. It is related to understanding patterns through cognitive and analytical experience.

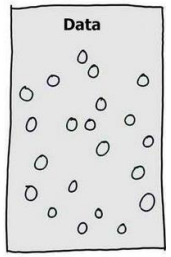
(**Semantic view**) Data that is structured and analyzed in a meaningful format.

(**Raw data**) Quantities, characters or symbols that are available in **raw format**
Data is with that the fundamental criterion for **shaping context**.

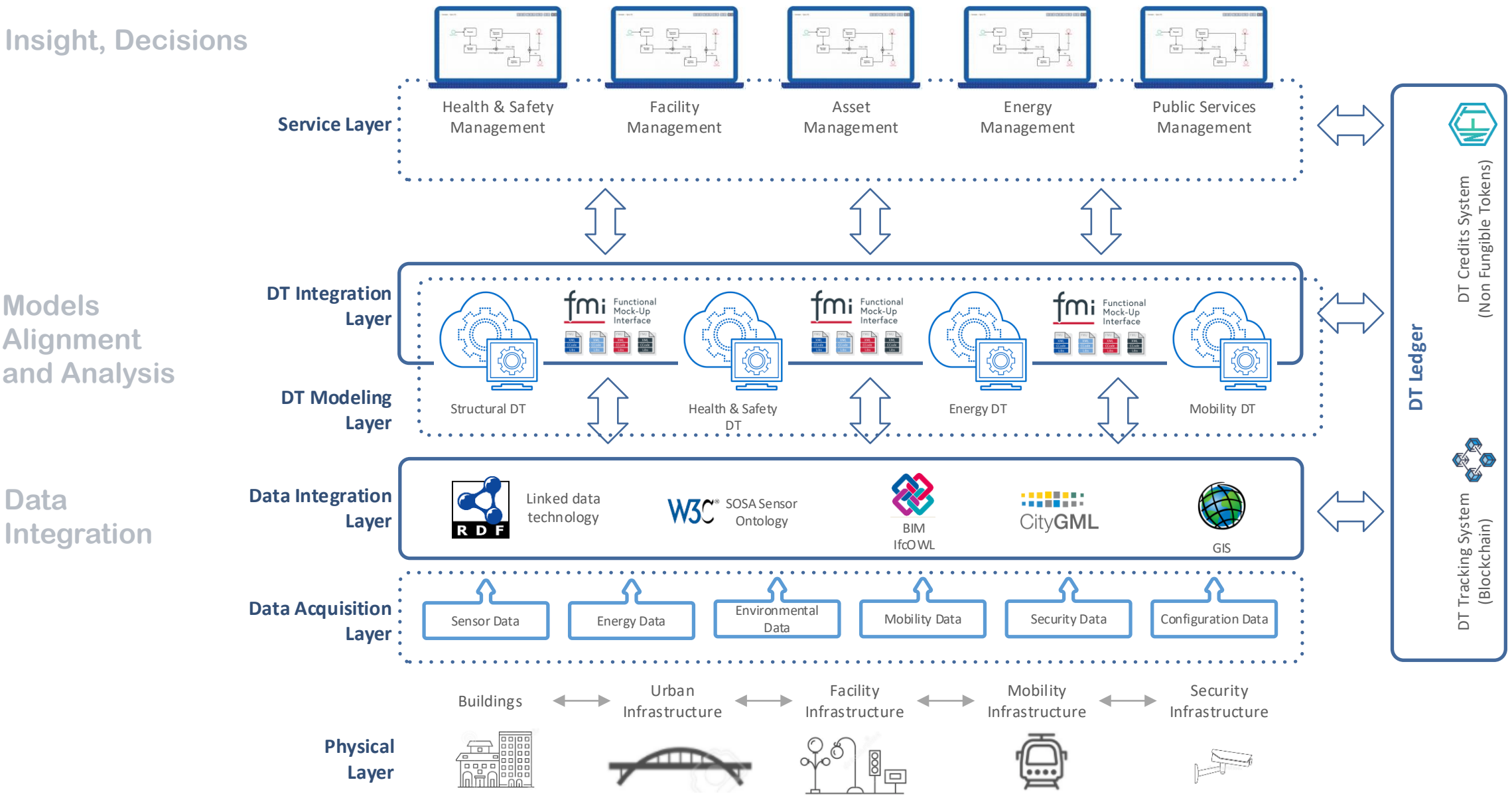




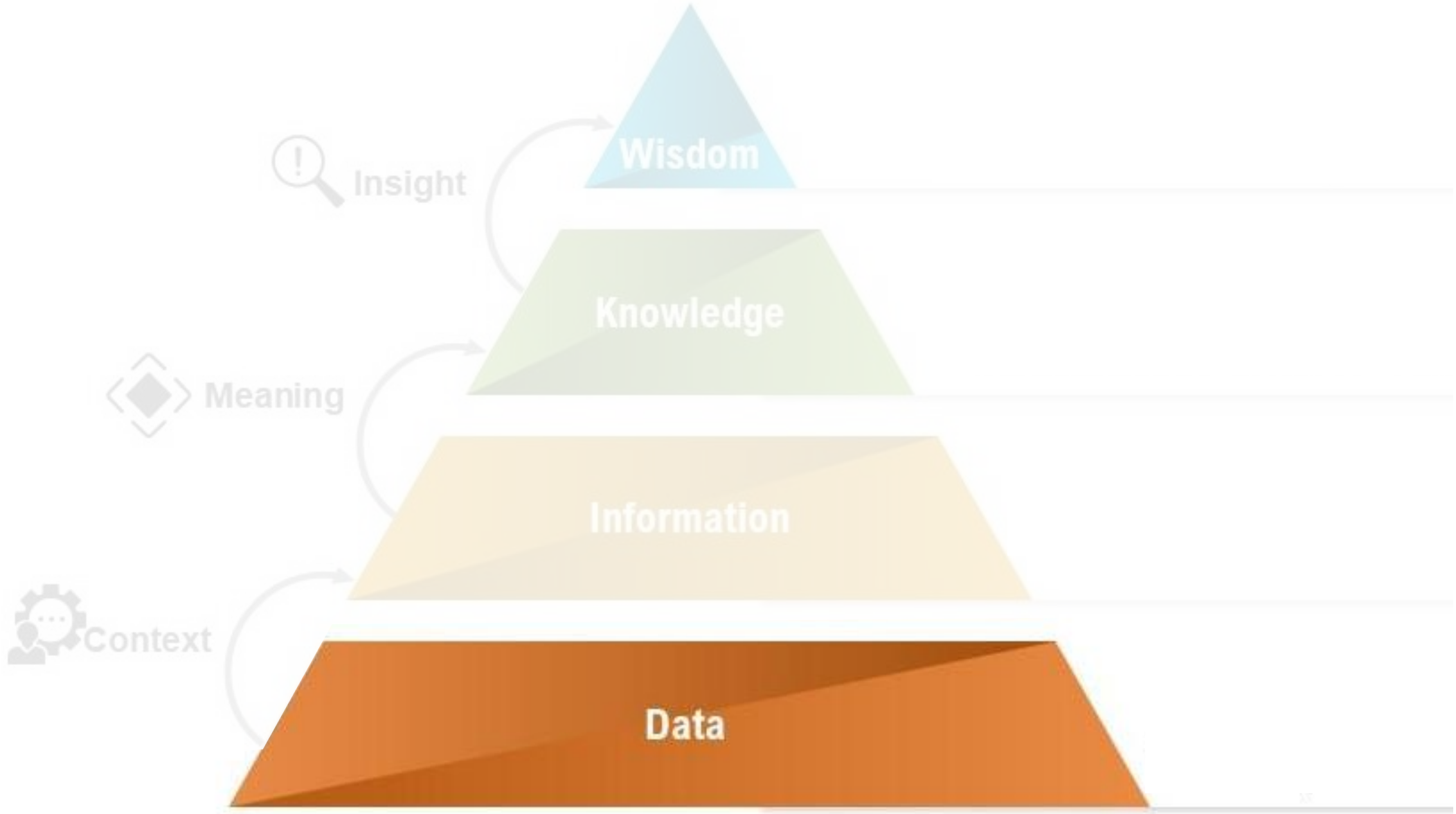


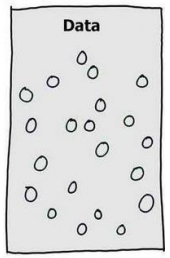


National-scale Digital Twin Architecture

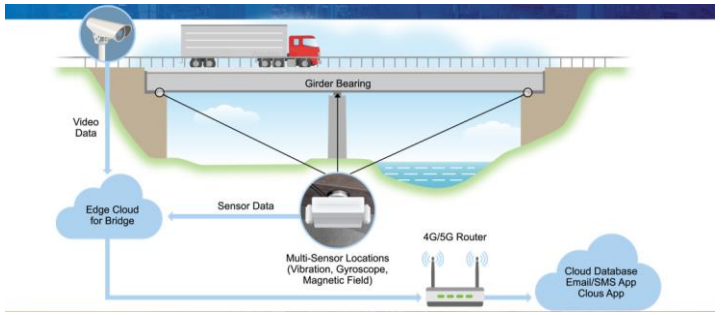


Integrating data and analysis: Climbing the wisdom hierarchy





Integrating Semantics: Data Lake

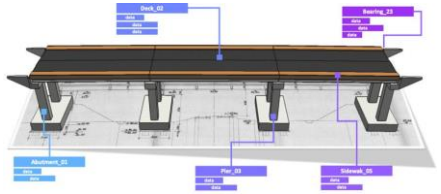


DATA FROM SENSORS

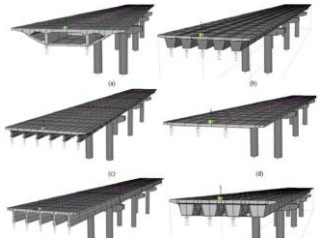
PICTURES

POINT CLOUDS

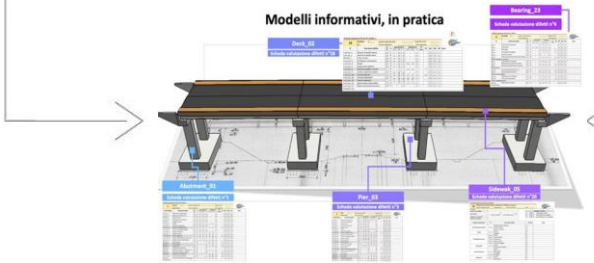
2D - 3D GIS



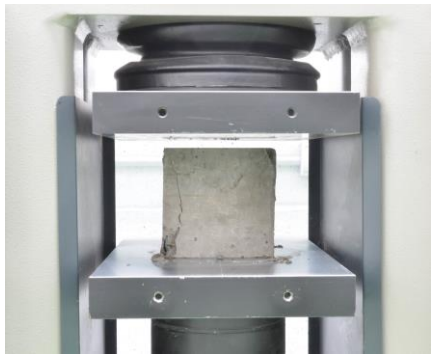
GEOMETRY

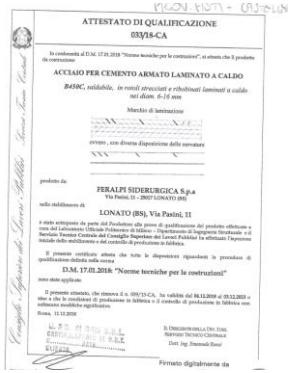


STRUCTURAL MODEL

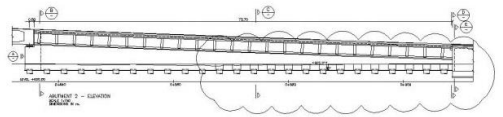


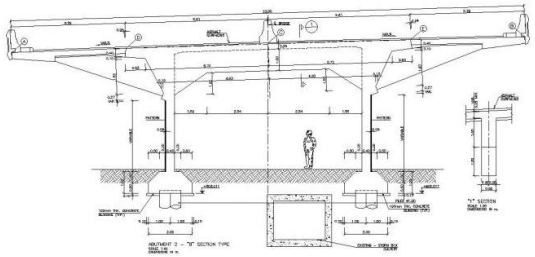
BIM





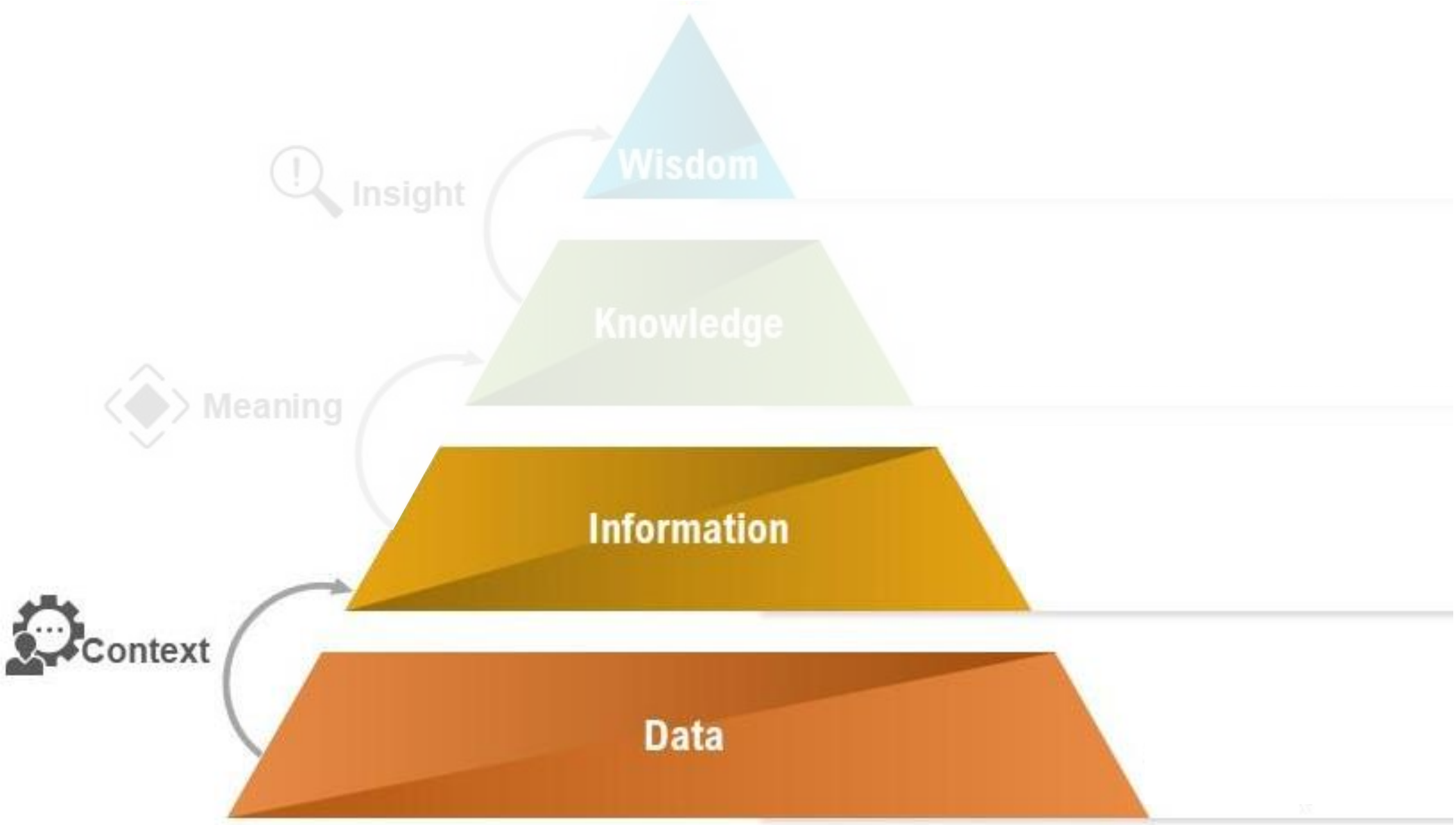
TECHNICAL DATA

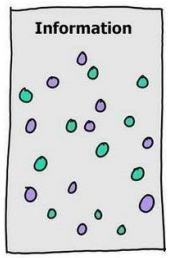


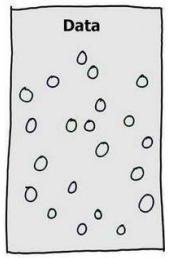


CAD

Integrating data and analysis: Climbing the wisdom hierarchy

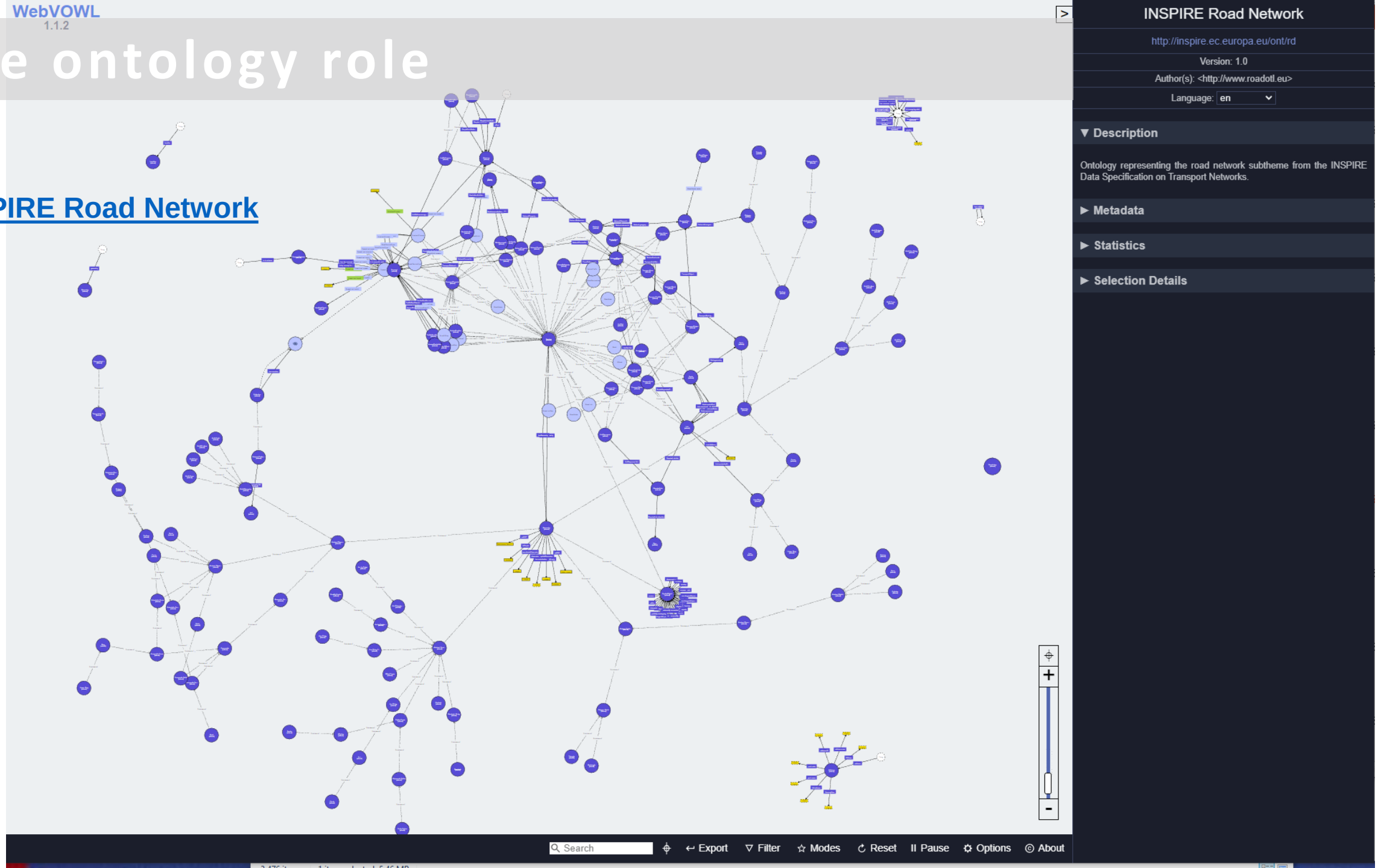




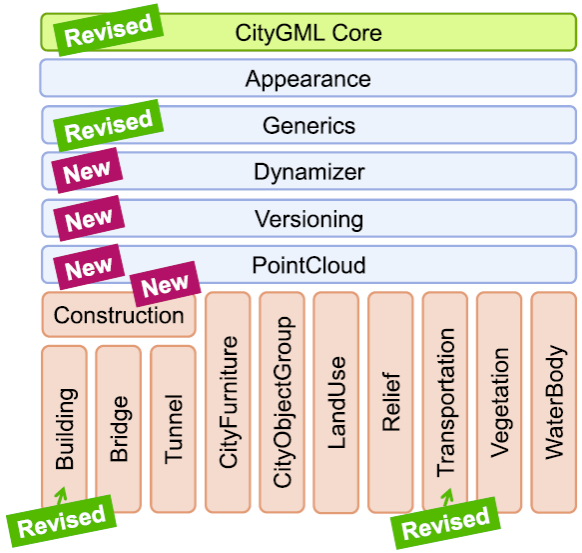


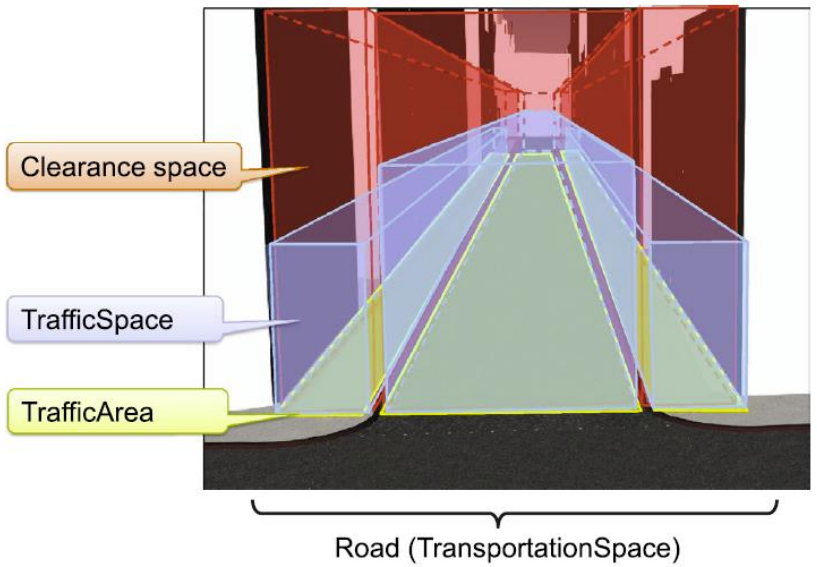
The ontology role

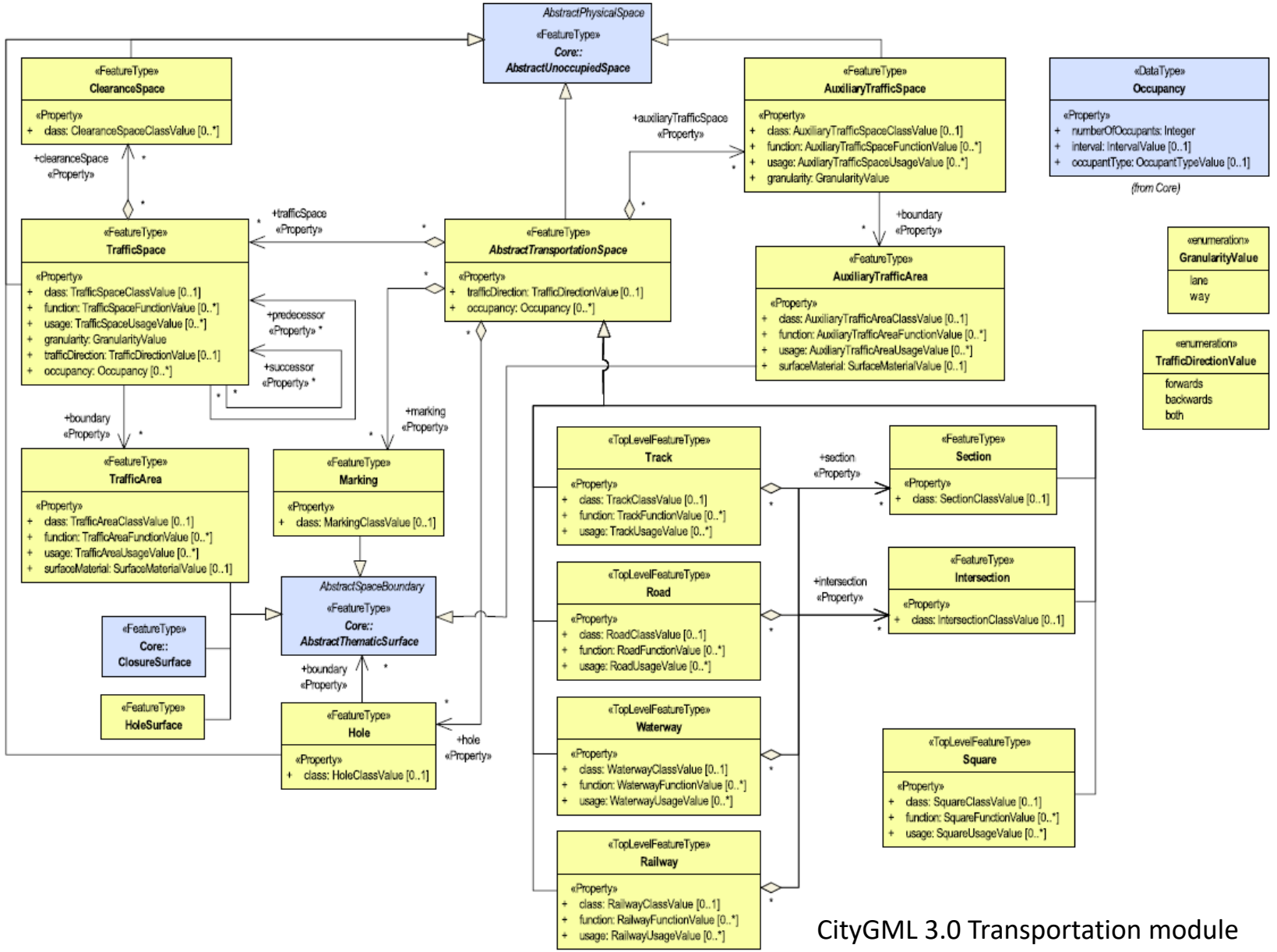
INSPIRE Road Network



The CityGML (Geography Markup Language) Ontology

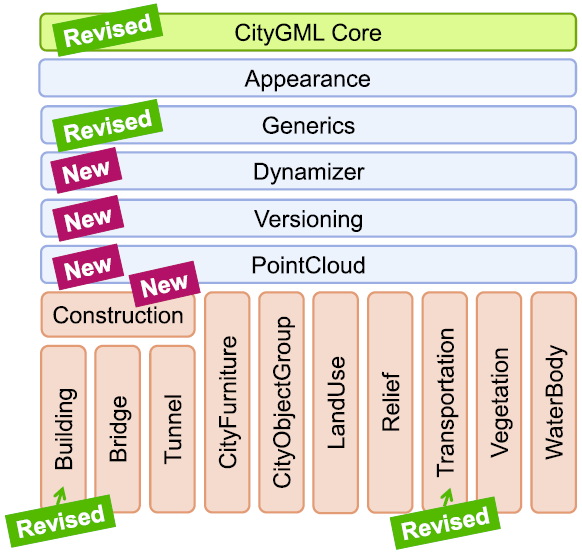




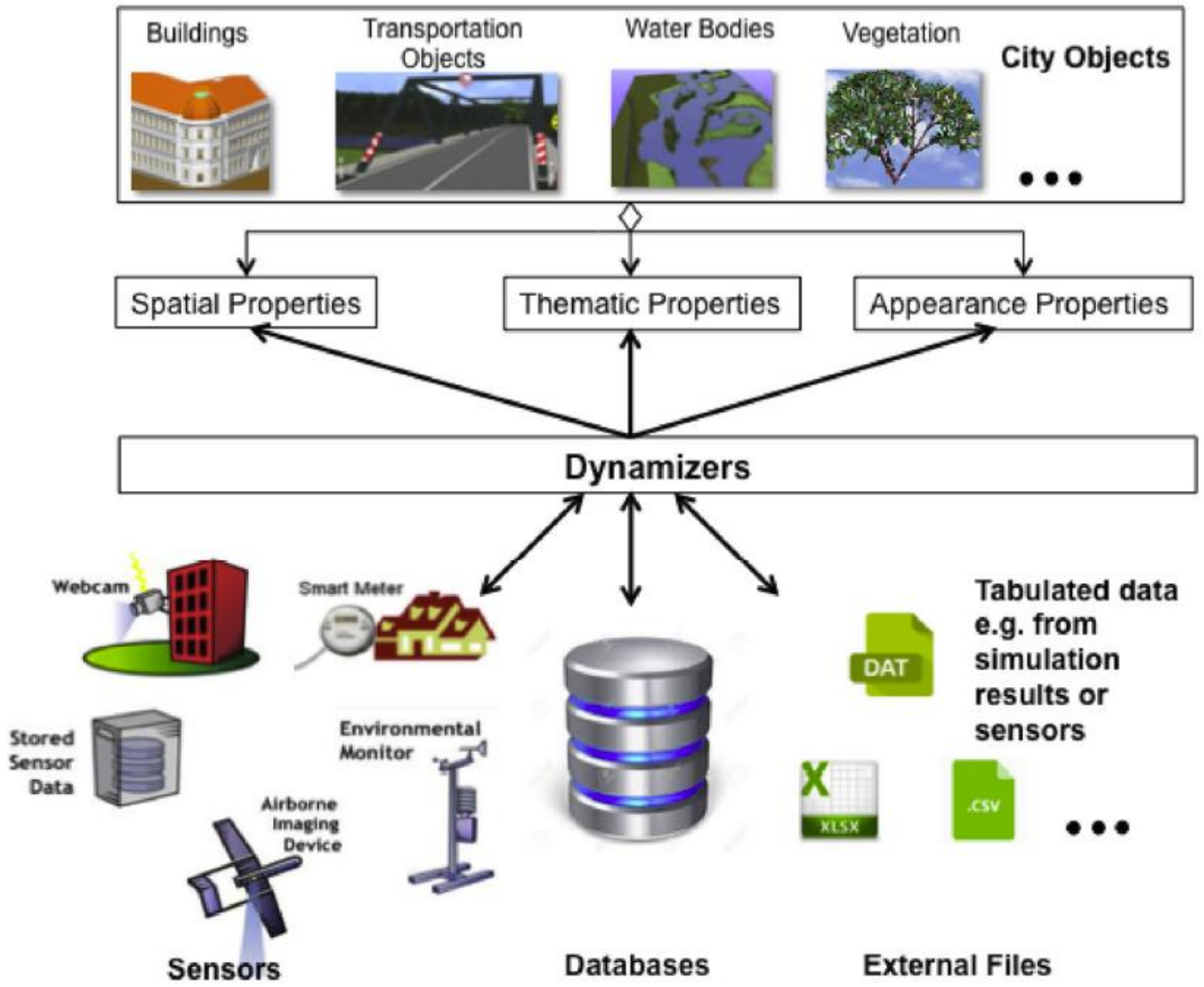


CityGML 3.0 Transportation module

The CityGML Ontology



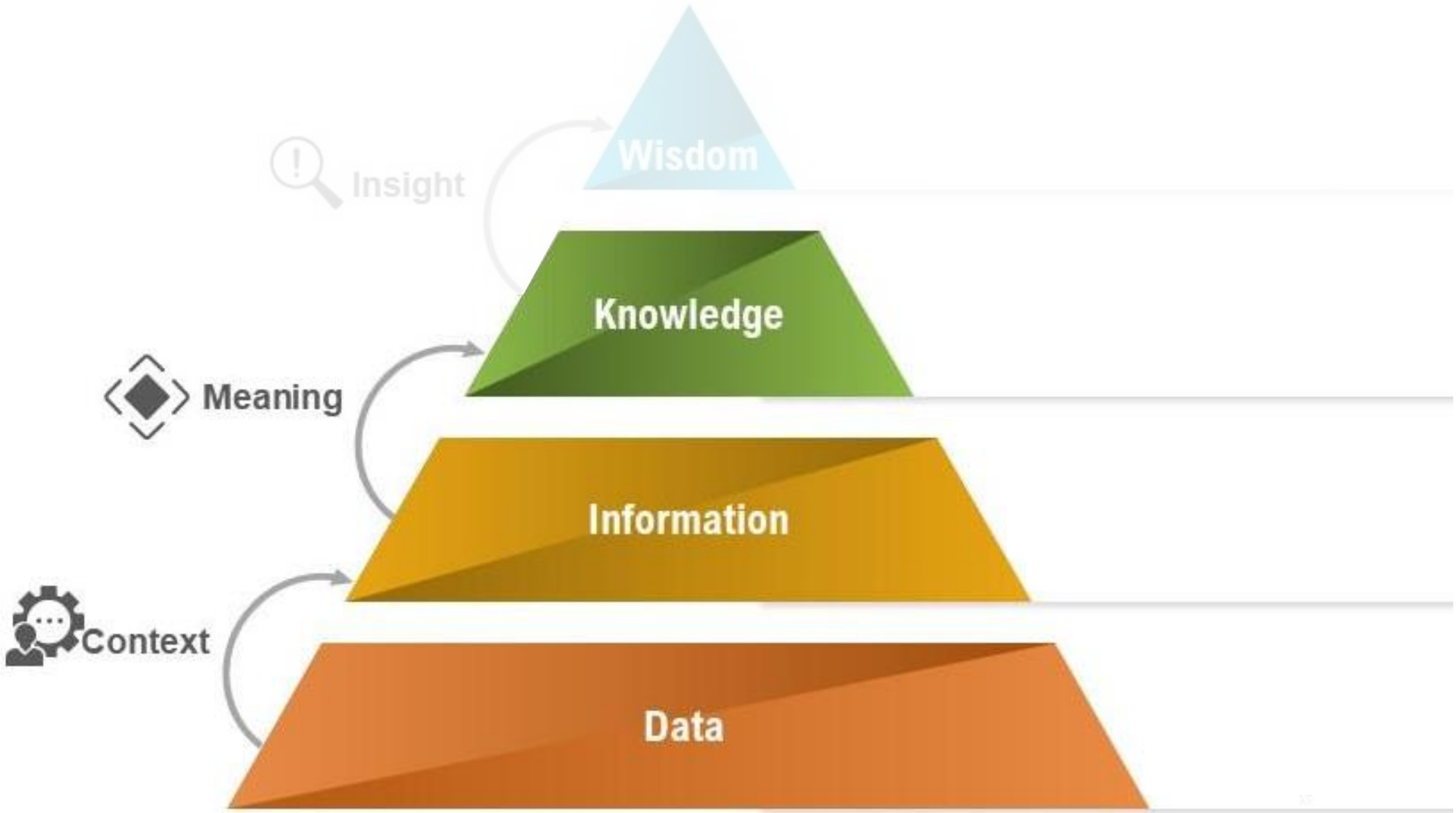
Dynamizers

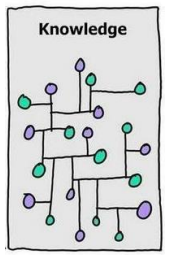


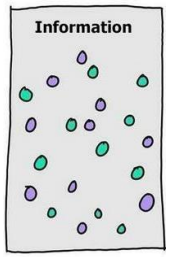
Conceptual representation of Dynamizers allowing:

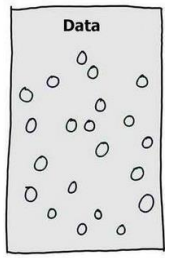
- enhancing the properties of city objects by overriding their static values
- the representation of time-variant values from sensors, simulation specific databases, and external files.

Integrating data and analysis: Climbing the wisdom hierarchy

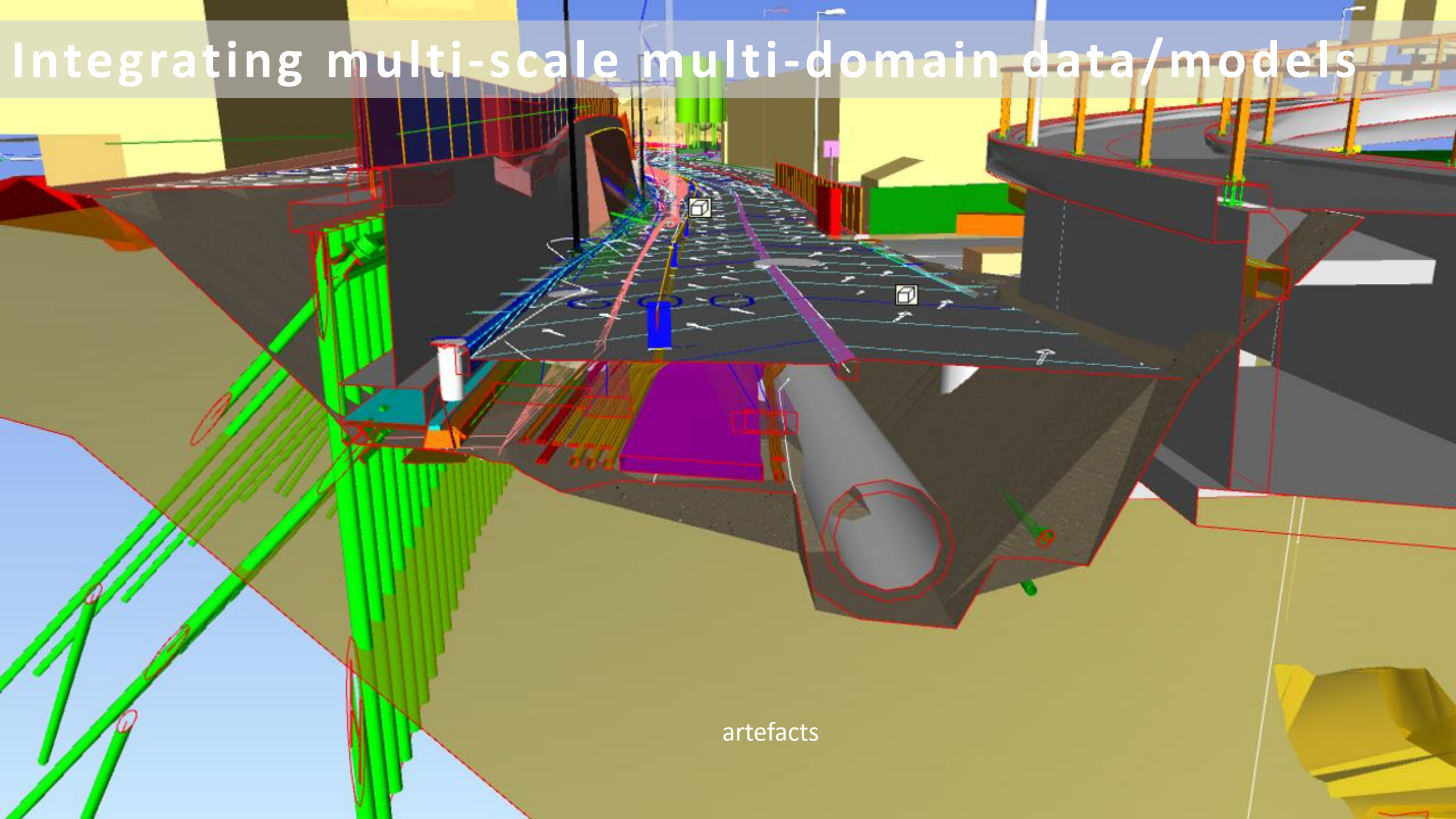






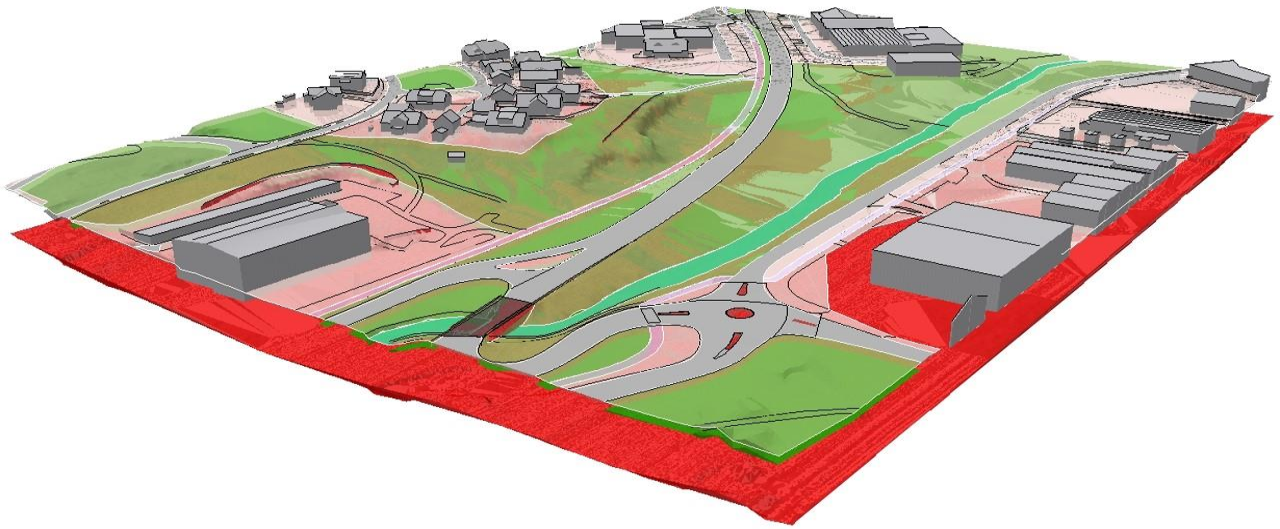


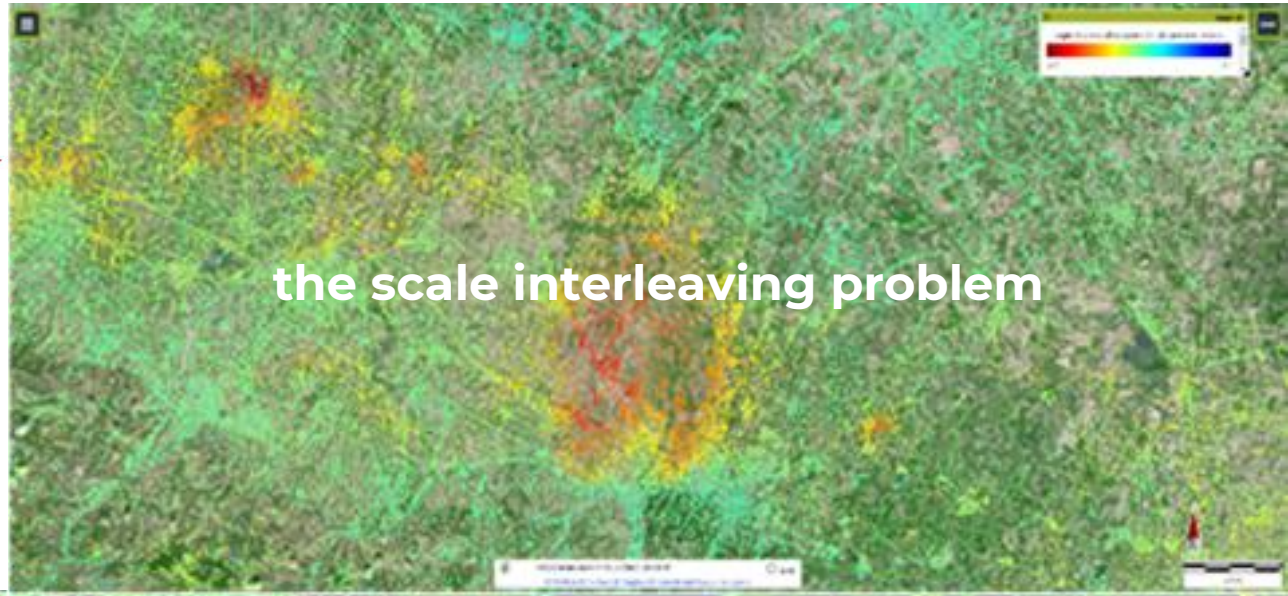
Integrating multi-scale multi-domain data/models

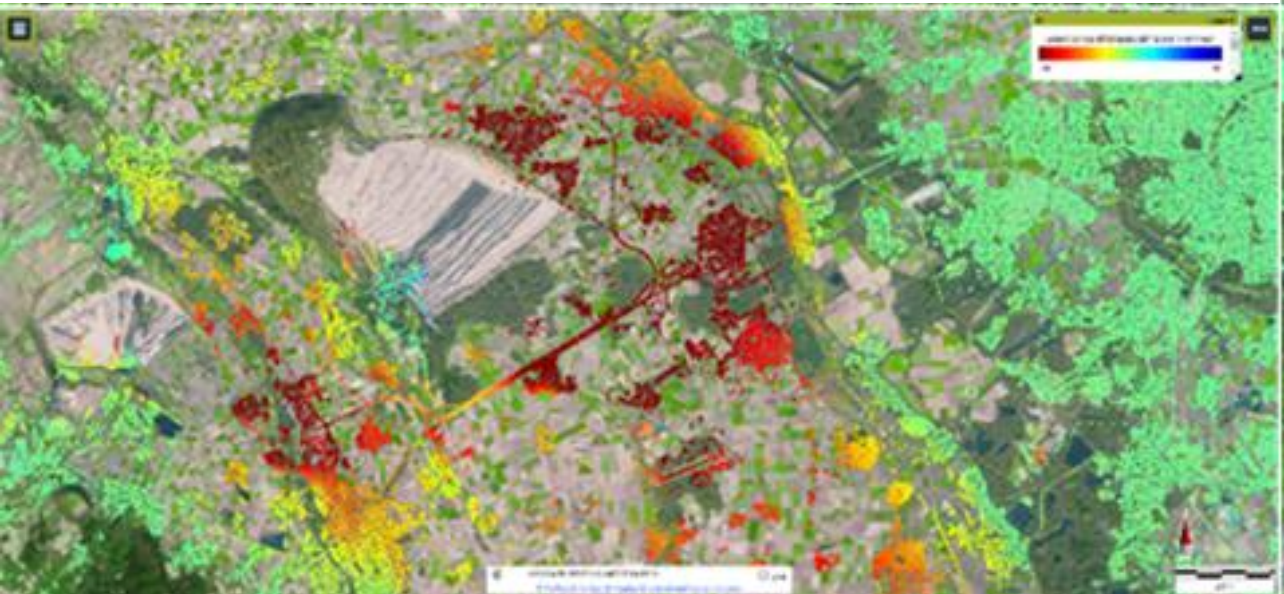


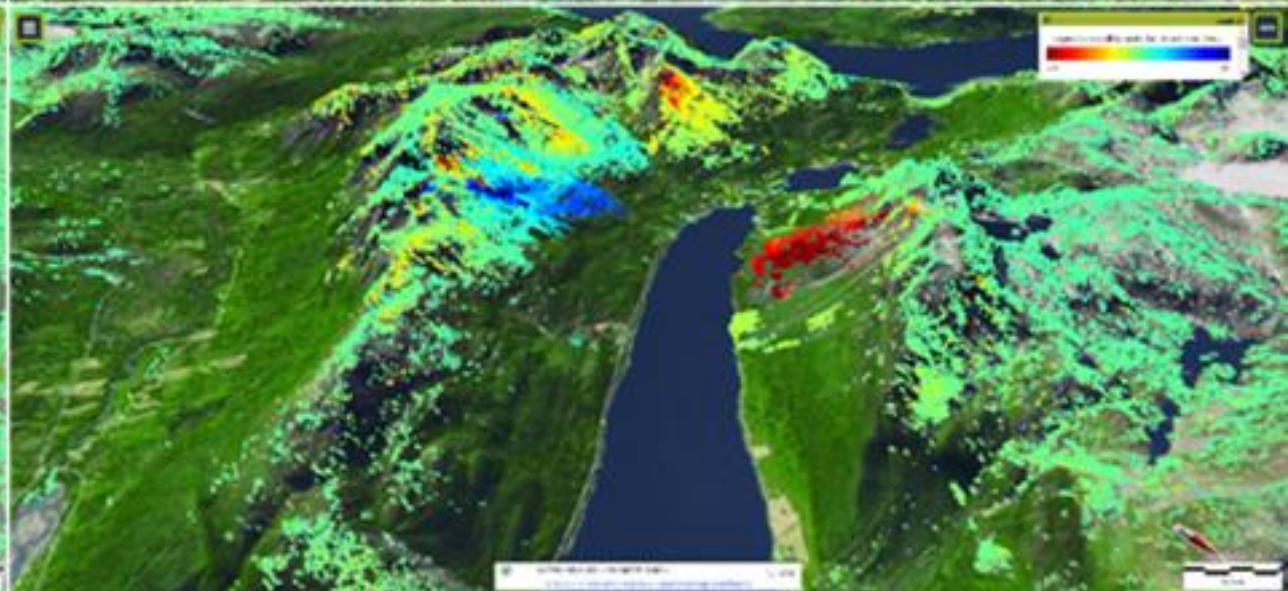
Connecting ontologies: Semantic Web Technologies

European Ground Motion Service (EGMS)

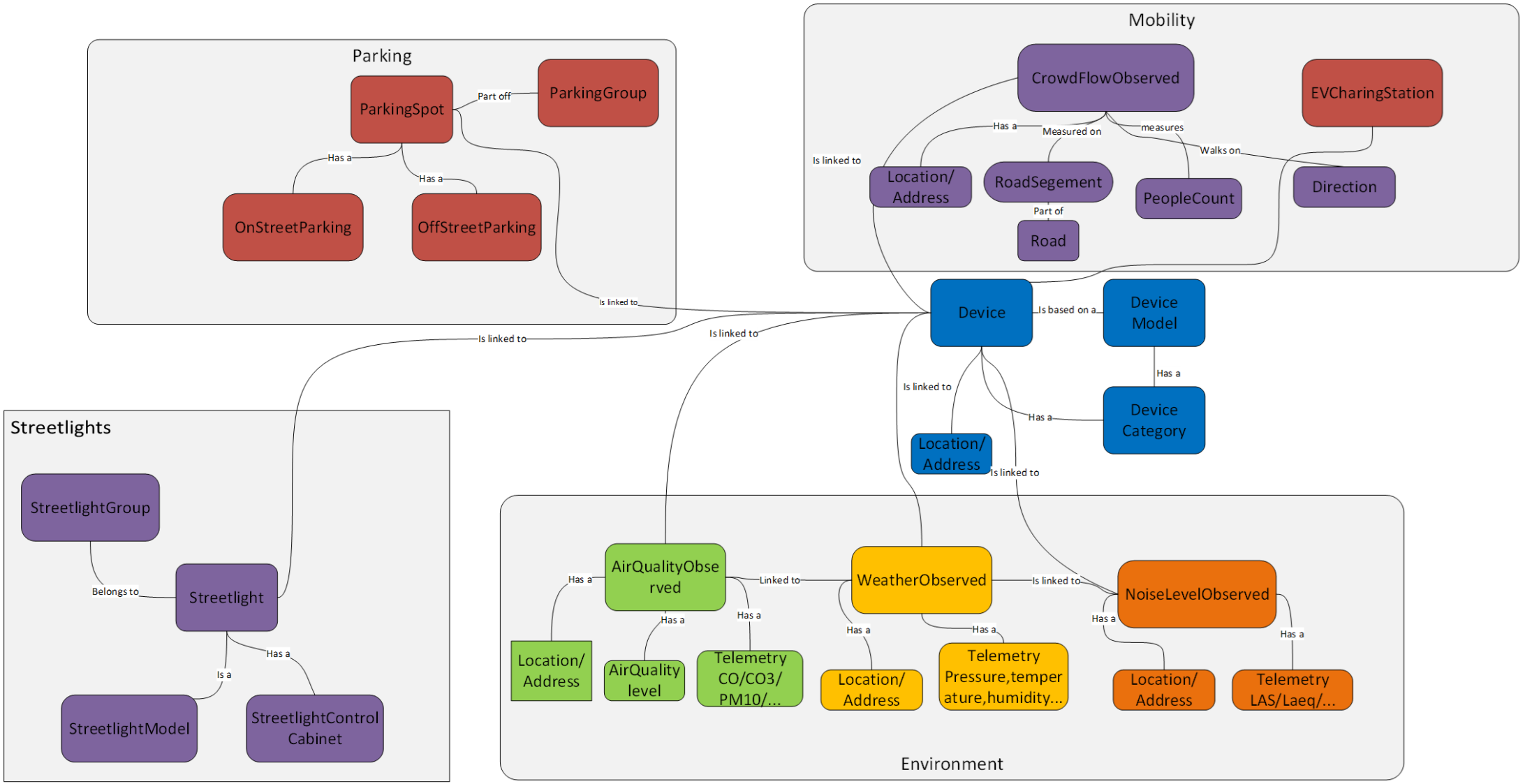




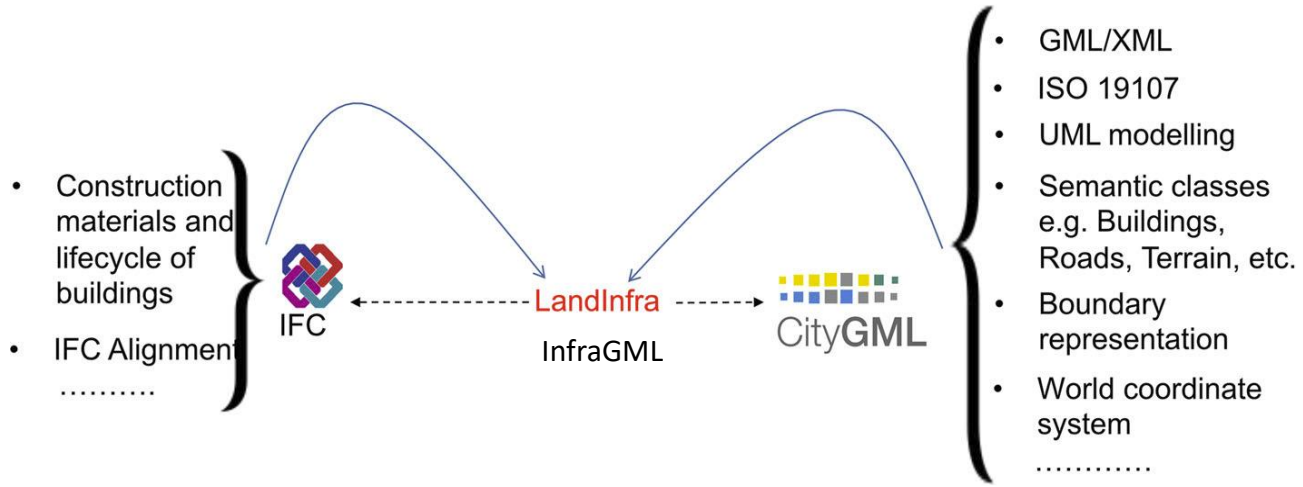




Connecting ontologies: Semantic Web Technologies

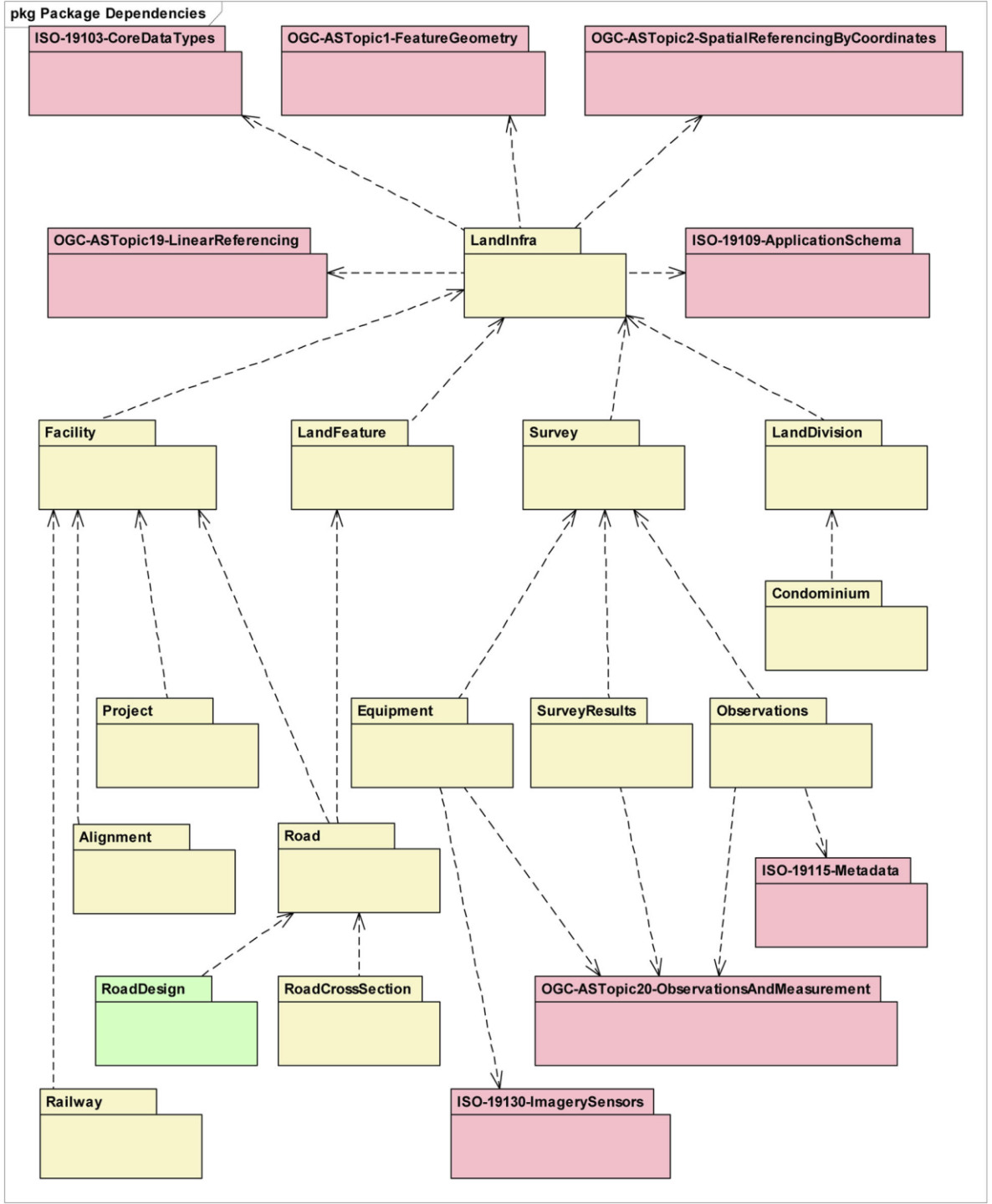


IFC-CityGML alignment



Geography Markup Language (GML)

XML grammar defined by the Open Geospatial Consortium (OGC) to express geographical features.

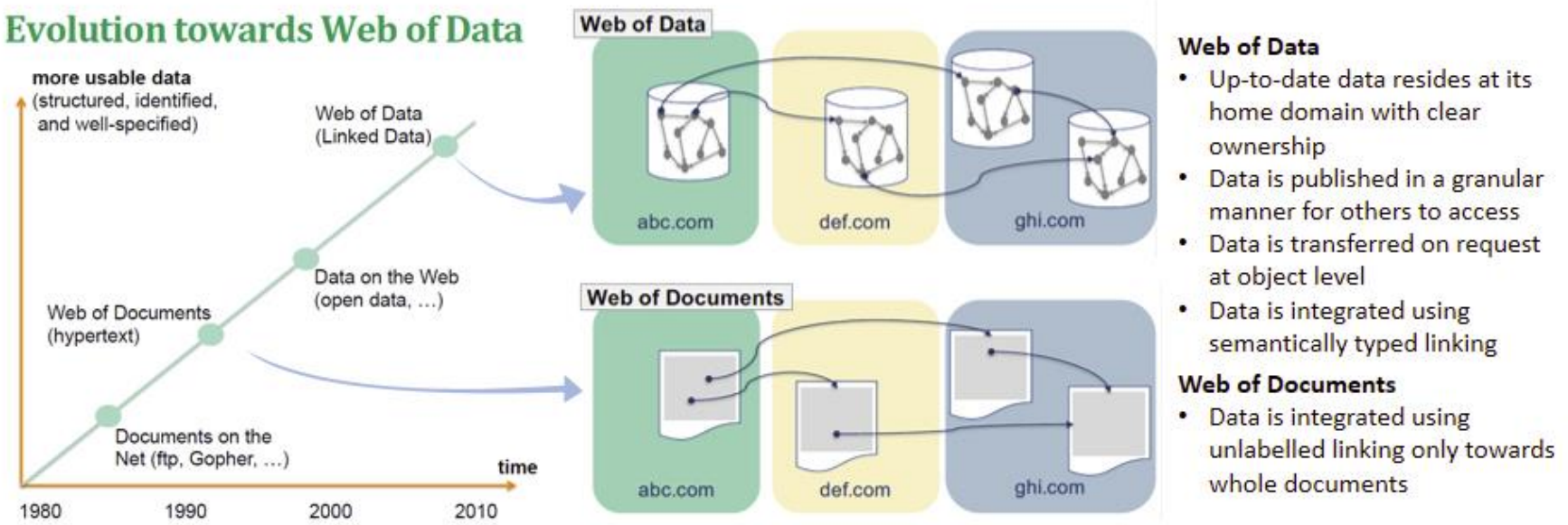


Connecting ontologies: Semantic Web Technologies

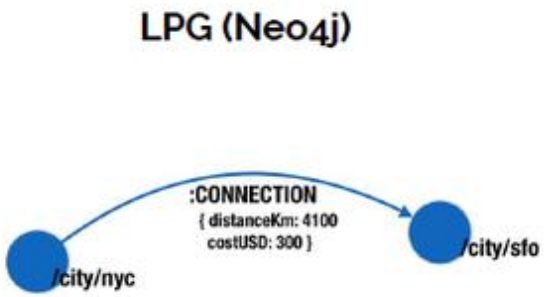
According to the W3C, the **Semantic Web** is a web of data to provide a common framework that allows data to be shared and reused across applications, enterprises, and community boundaries.

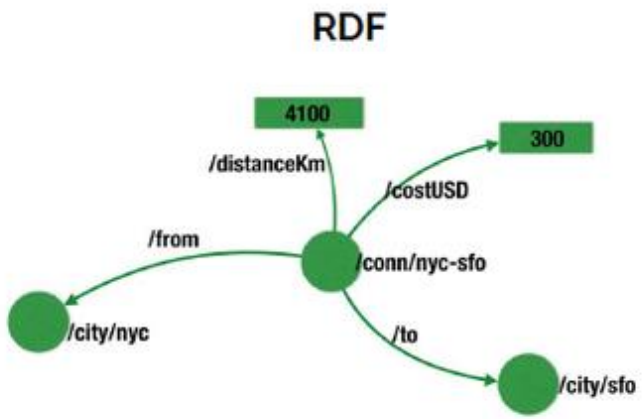
Linked Data is defined to describe a recommended best practice for publishing and connecting structured data as **Knowledge Graphs**

Traversal



Connection between NYC and SF: 300 USD / 4100 in Km.





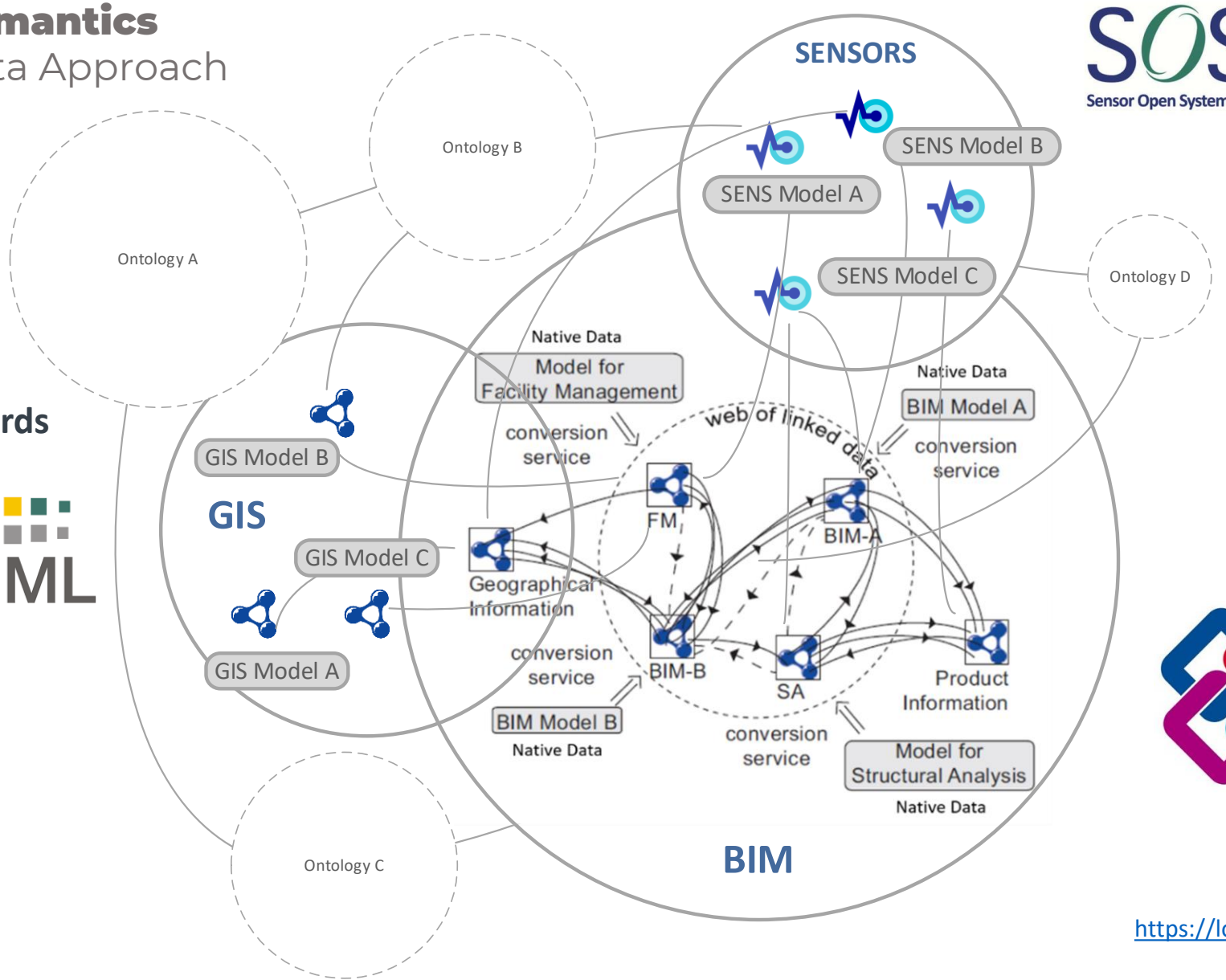
Knowledge graphs

Resource Description Framework (RDF)

Labelled Property Graphs (LPG)

Connecting ontologies: Semantic Web Technologies

Integrating Semantics
W3C Linked Data Approach



OGC Standards

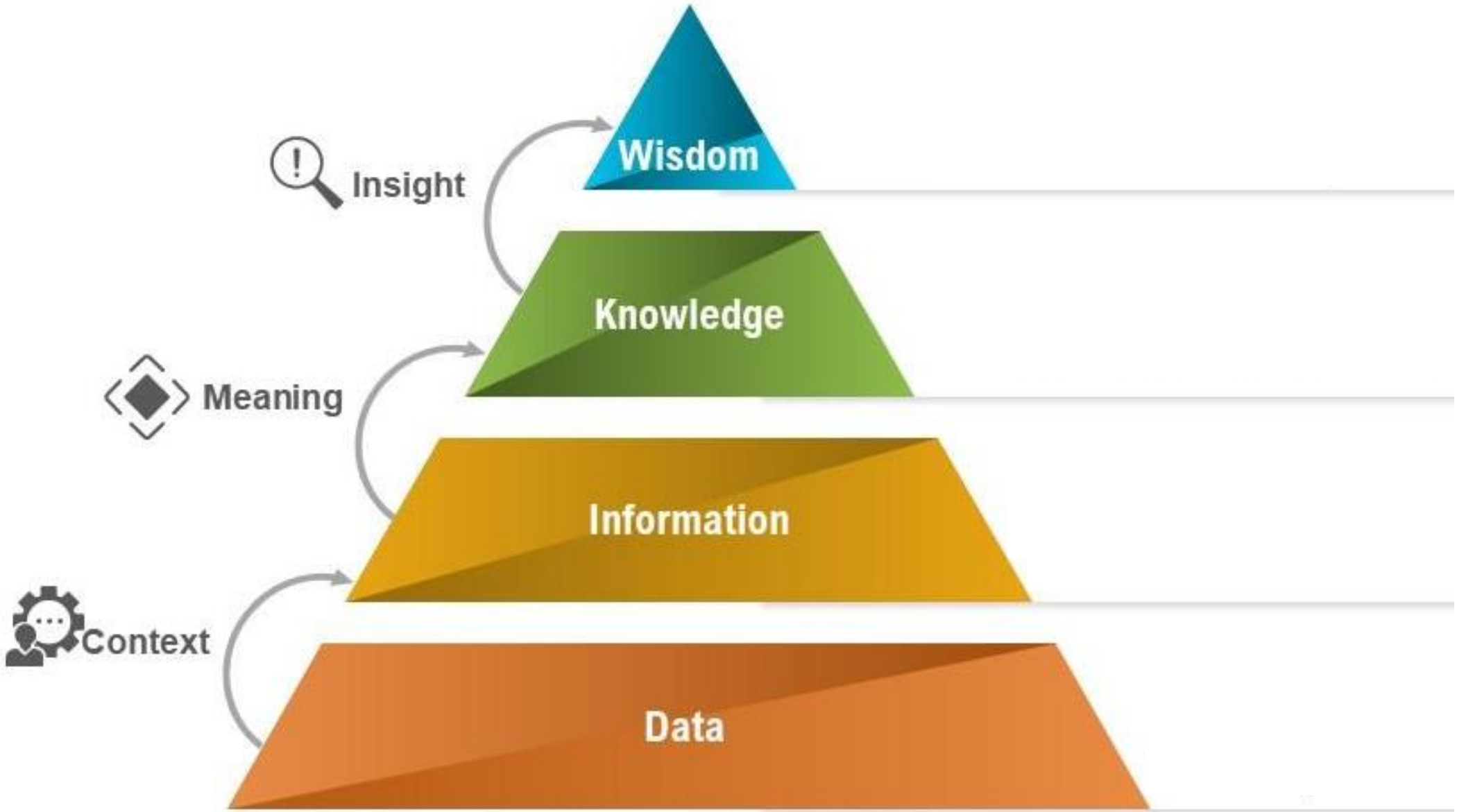
CityGML

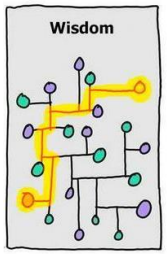
SOSA
Sensor Open Systems Architecture

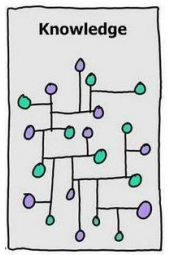
ifcOWL

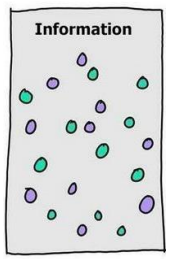
https://lod-cloud.net/clouds/lod-cloud.svg

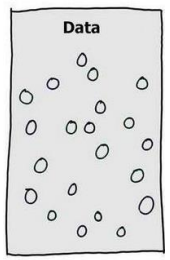
Integrating data and analysis: Climbing the wisdom hierarchy











Integrating data and analysis: Climbing the wisdom hierarchy

Inductive

Specific observation

General conclusion (may be true)

Deductive

General rule

Specific conclusion (always true)

Abductive

Incomplete observation

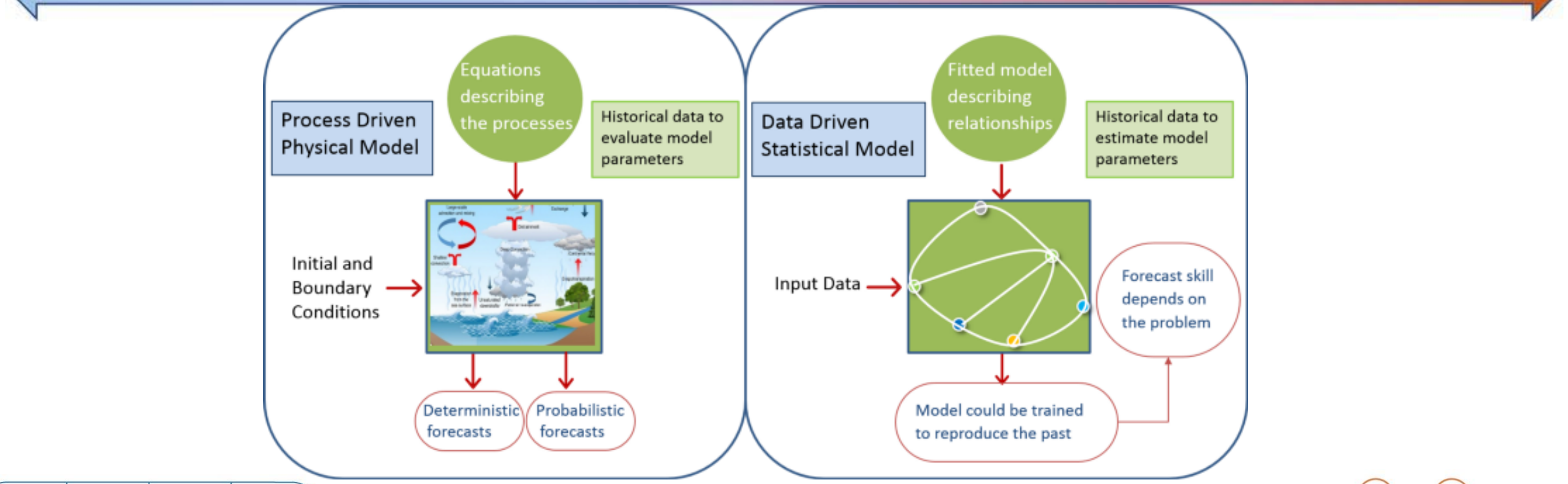
Best prediction (may be true)

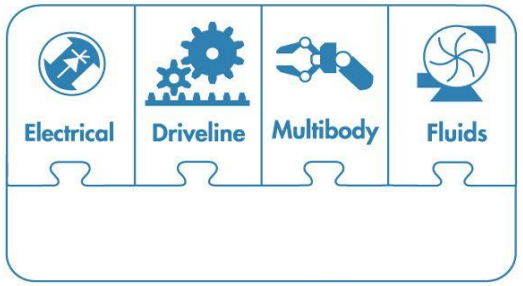
Integrating multi-scale multi-domain analysis

The decision on what to model, and subsequently how to model it, rests on system knowledge and application need.

Process-Driven Inference

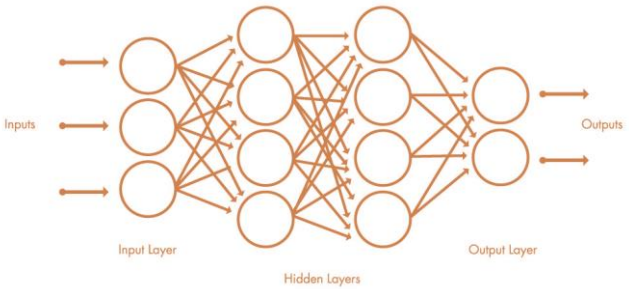
Data-Driven Inference





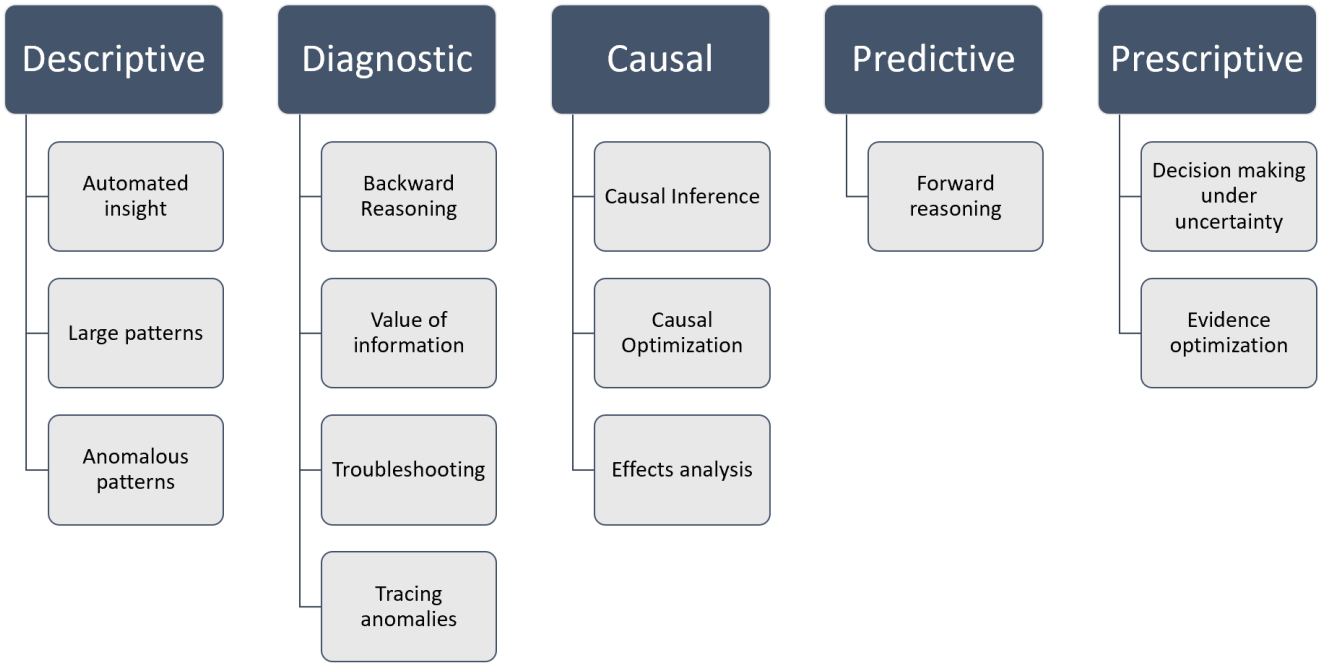
Inference based on explicit causal process simulation

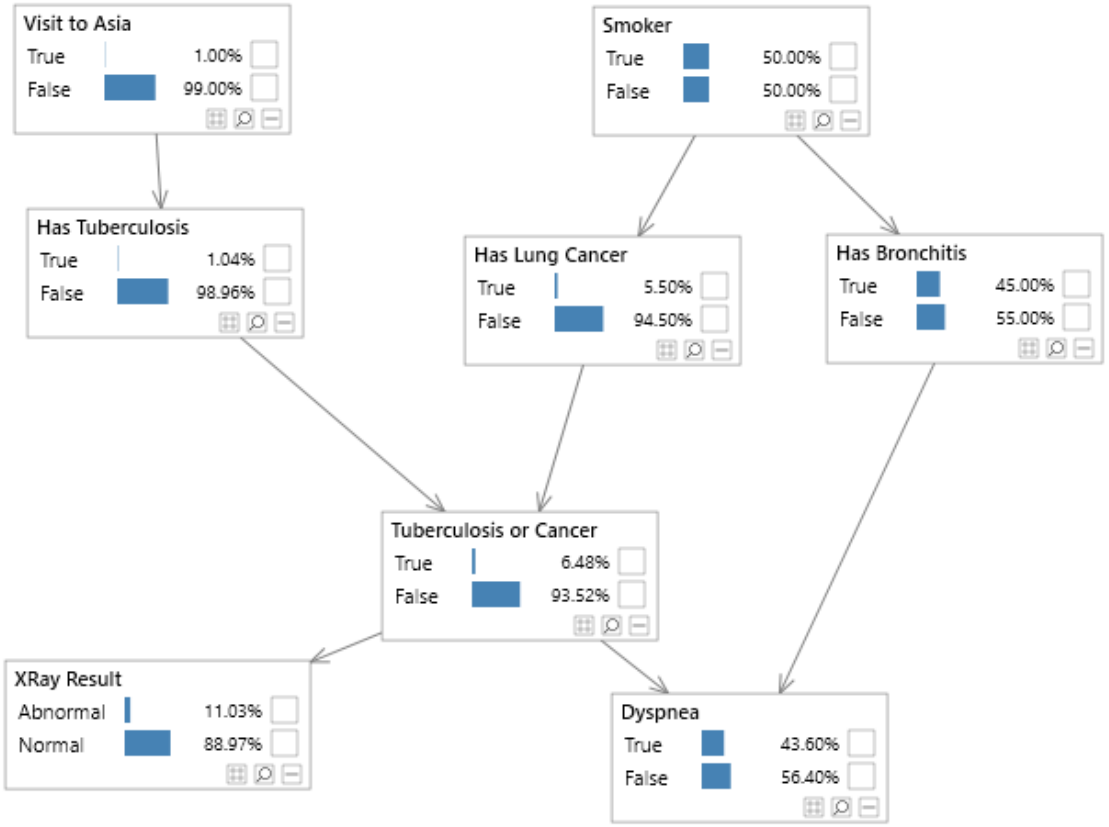
find hidden relationships between data (the cause-effect is difficult to understand)



Bayesian Networks: Data and Process Combined

Bayesian networks are a type of **Probabilistic Graphical Model** that can be used to build models from data and/or expert opinion.



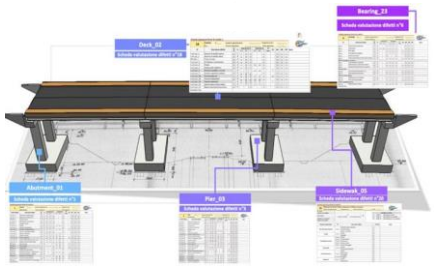


In the Bayesian networks, each node represents a **Variable**

Links are added between nodes to indicate that one node directly influences the other. This is expressed via conditional probabilities

Integrating multi-scale multi-domain models

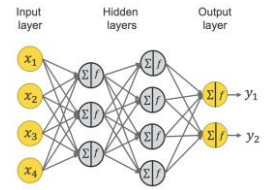
- IfcGeometricRepresentationSubContext
- IfcExtrudedAreaSolid
- IfcRelAggregates
- IfcGeometricRepresentationContext
- IfcShapeRepresentation
- IfcWall
- IfcRelDeclares
- IfcOwnerHistory
- IfcRelDefinesByType
- IfcLocalPlacement
- IfcSIUnit
- IfcBuilding
- IfcWallType

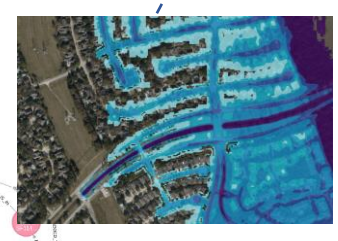


BIM

Pictures

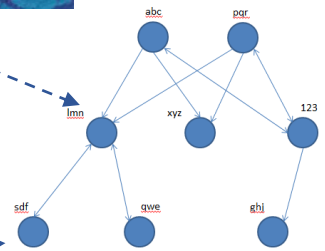
Data-driven inference





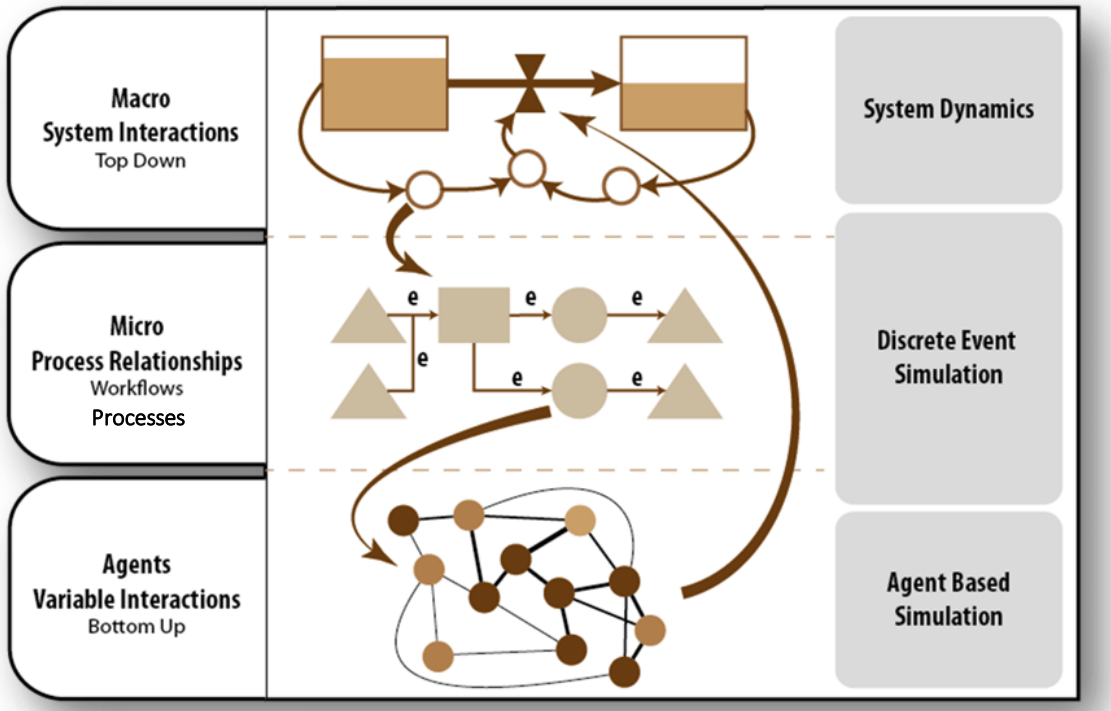
Sensors

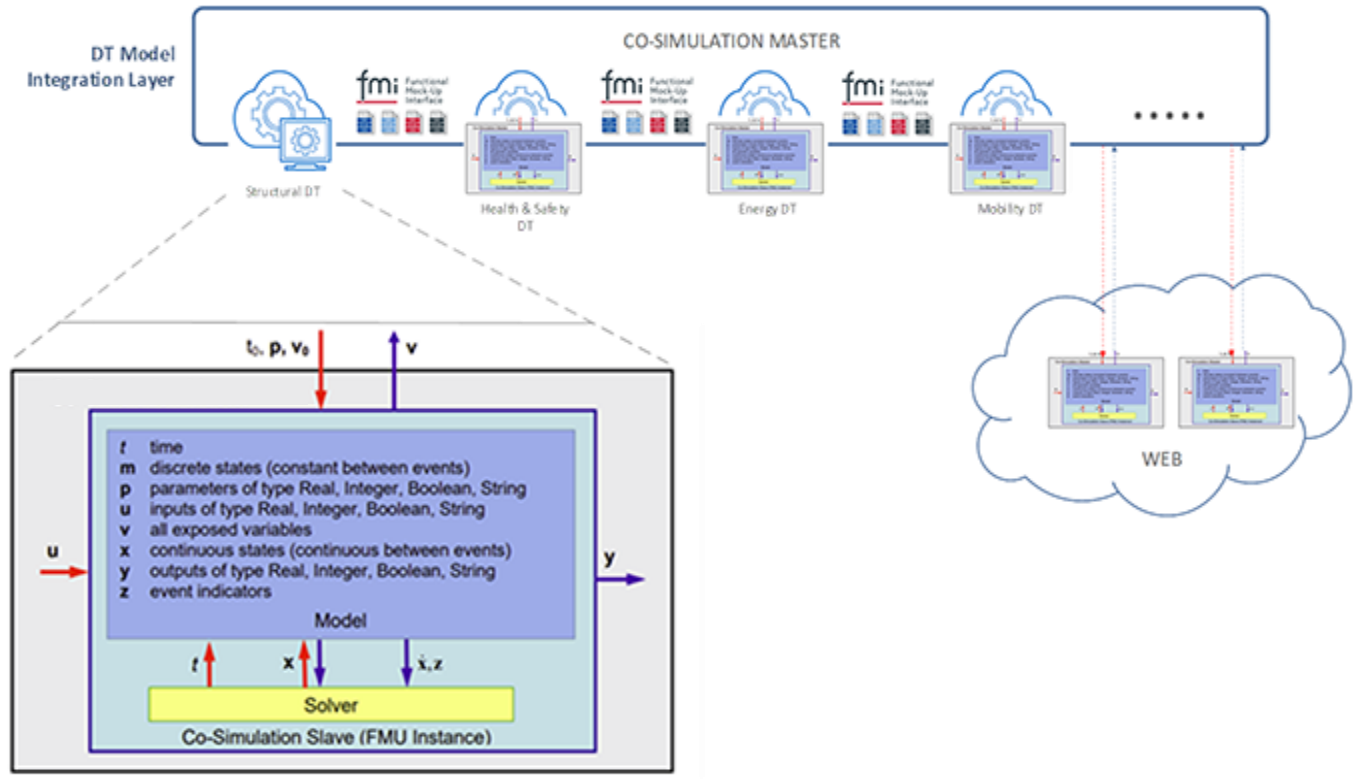
The digital toolchain



Process-driven inference

Integrating multi-scale multi-domain analysis





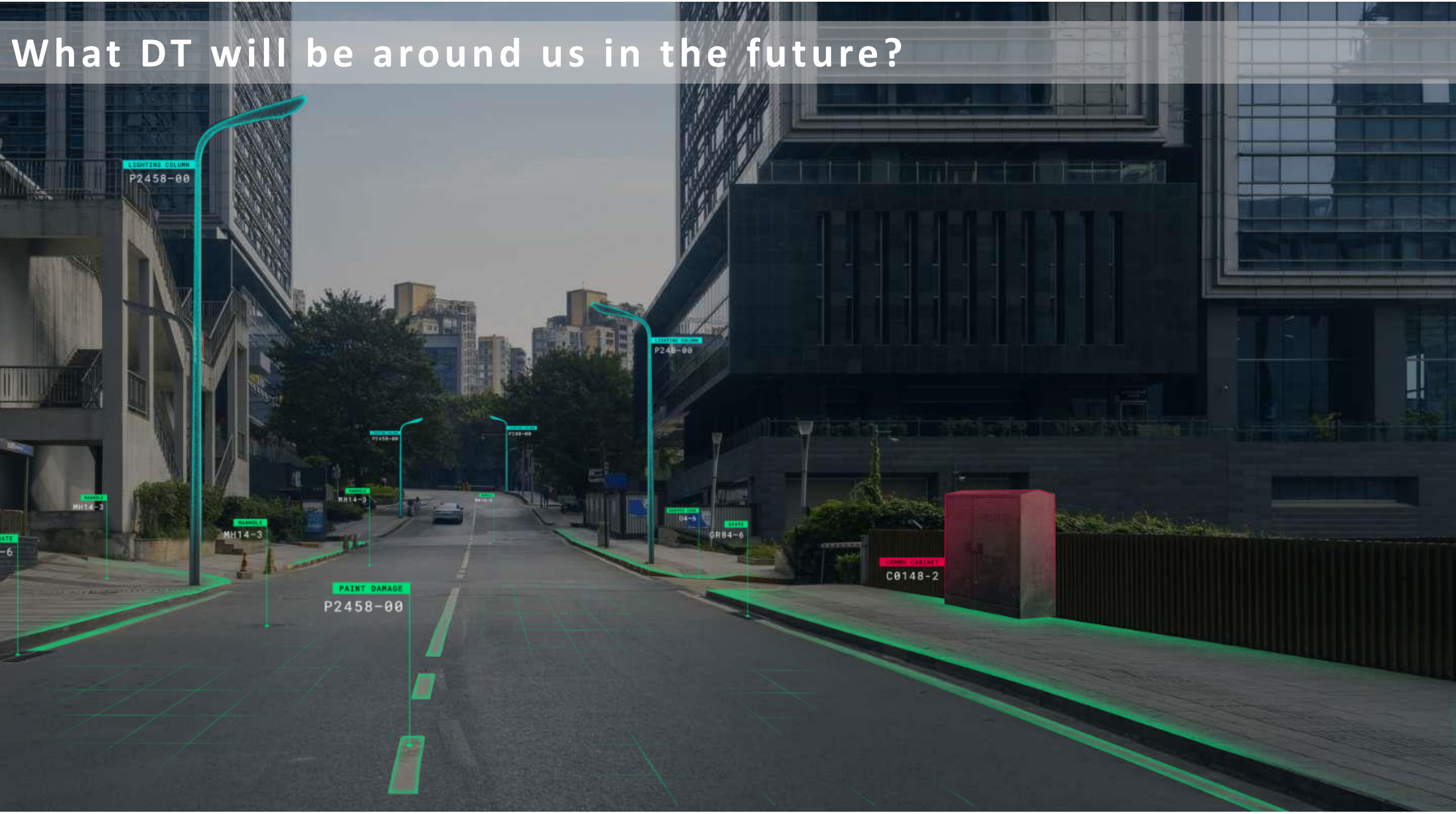
Normalized structure of a generic digital twin

Distributed coupling of Digital Twin Models orchestrated by a co-simulator master

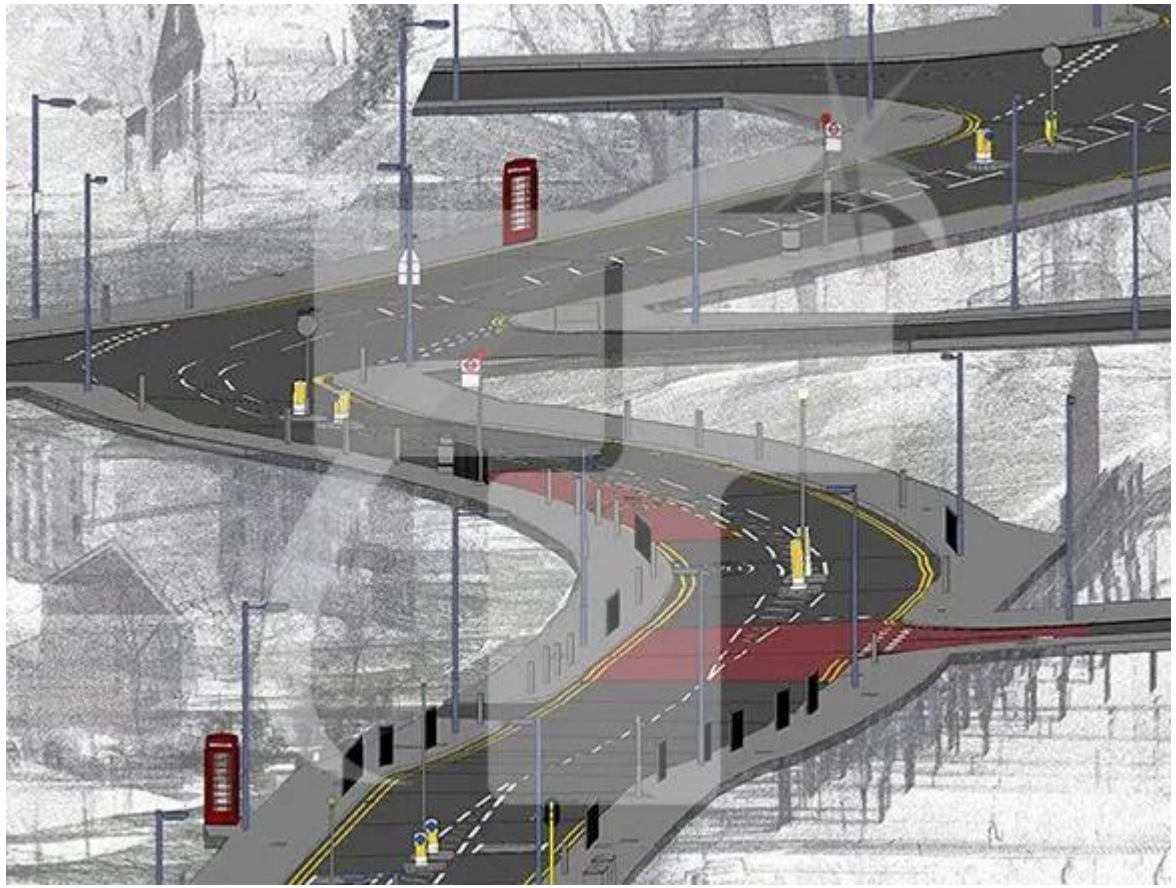
Huge Data: Real-world digitization with scalability

The problem of populating the database on every step of the wisdom hierarchy

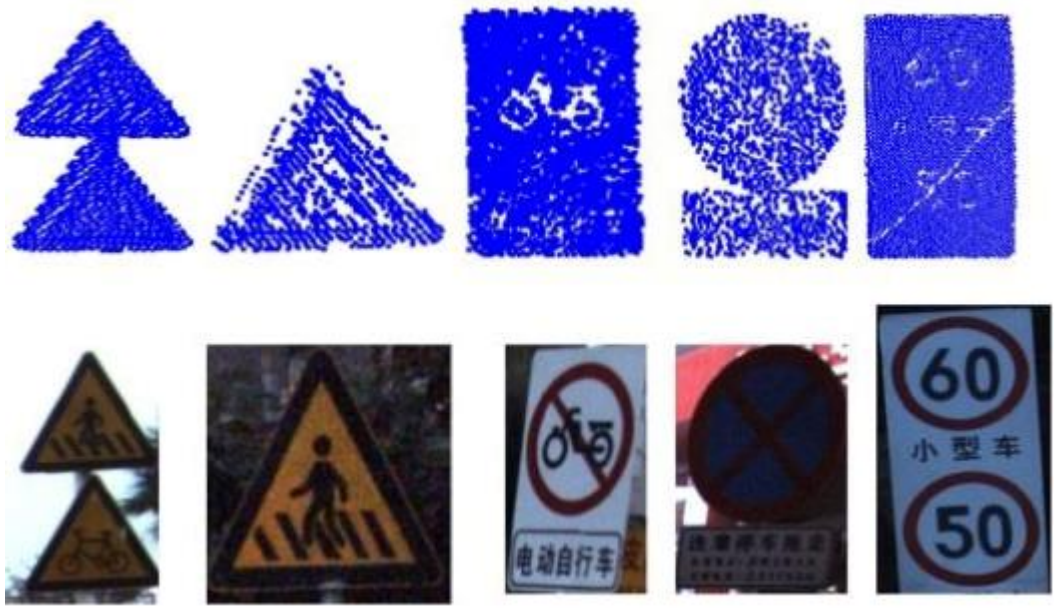
What DT will be around us in the future?

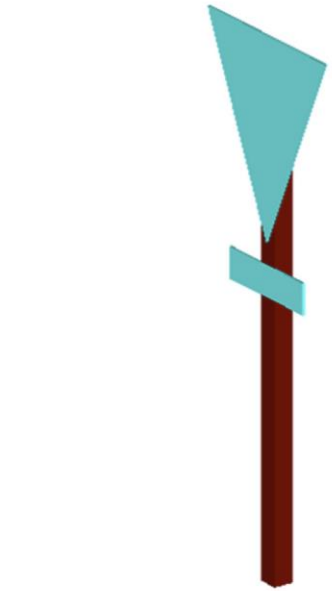


Real-world digitization with scalability

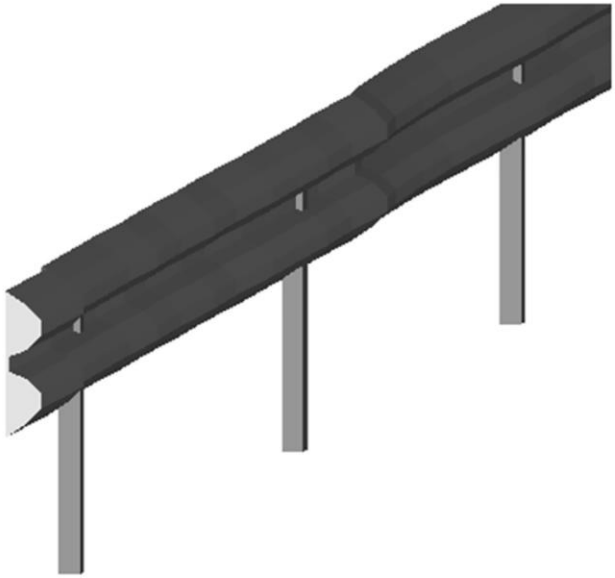


Real-world digitization with scalability





- TrafficSign-Element Assembly
  - 200MetersSign -Plate
  - YieldSign -Plate
  - TrafficSign -Pole



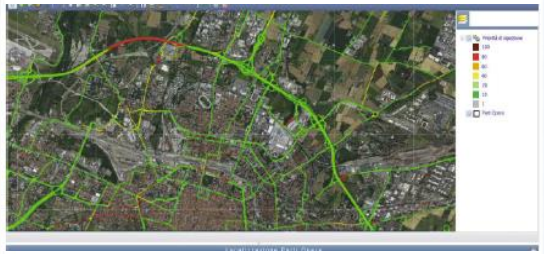
- Guardrail2 - Assembly
  - Guardrail2 - Railing
  - Guardrail2 - Shoe1
  - Guardrail2 - Shoe2
  - Guardrail2 - Shoe3

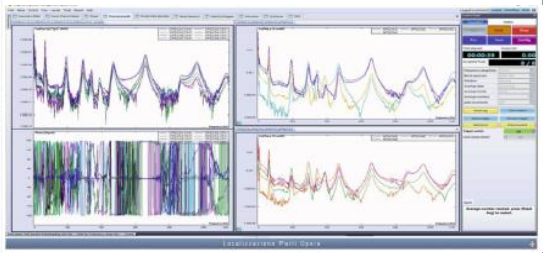
Guardrail and Traffic sign panels identification

localhost:8081/gisPage.html

Models
Objects
Geo
Query
Utilities
View
Helpers
Markups
Reports
Configuration
Test

Select a node...
▼ Webim Objects {0}
(empty object)





GESTIRE MODELLI A SCALA TERRITORIALE

model | object | coords | long.: | lat.: | alt.:

THANK YOU
FOR YOUR
ATTENTION