UNIVERSITY OF CAMBRIDGE
Department of Engineering

LAING O'ROURKE CENTRE for CONSTRUCTION ENGINEERING and TECHNOLOGY

Digital Twinning the Built Environment

Ioannis Brilakis, PhD

Laing O'Rourke Professor @ University of Cambridge

The University of Cambridge

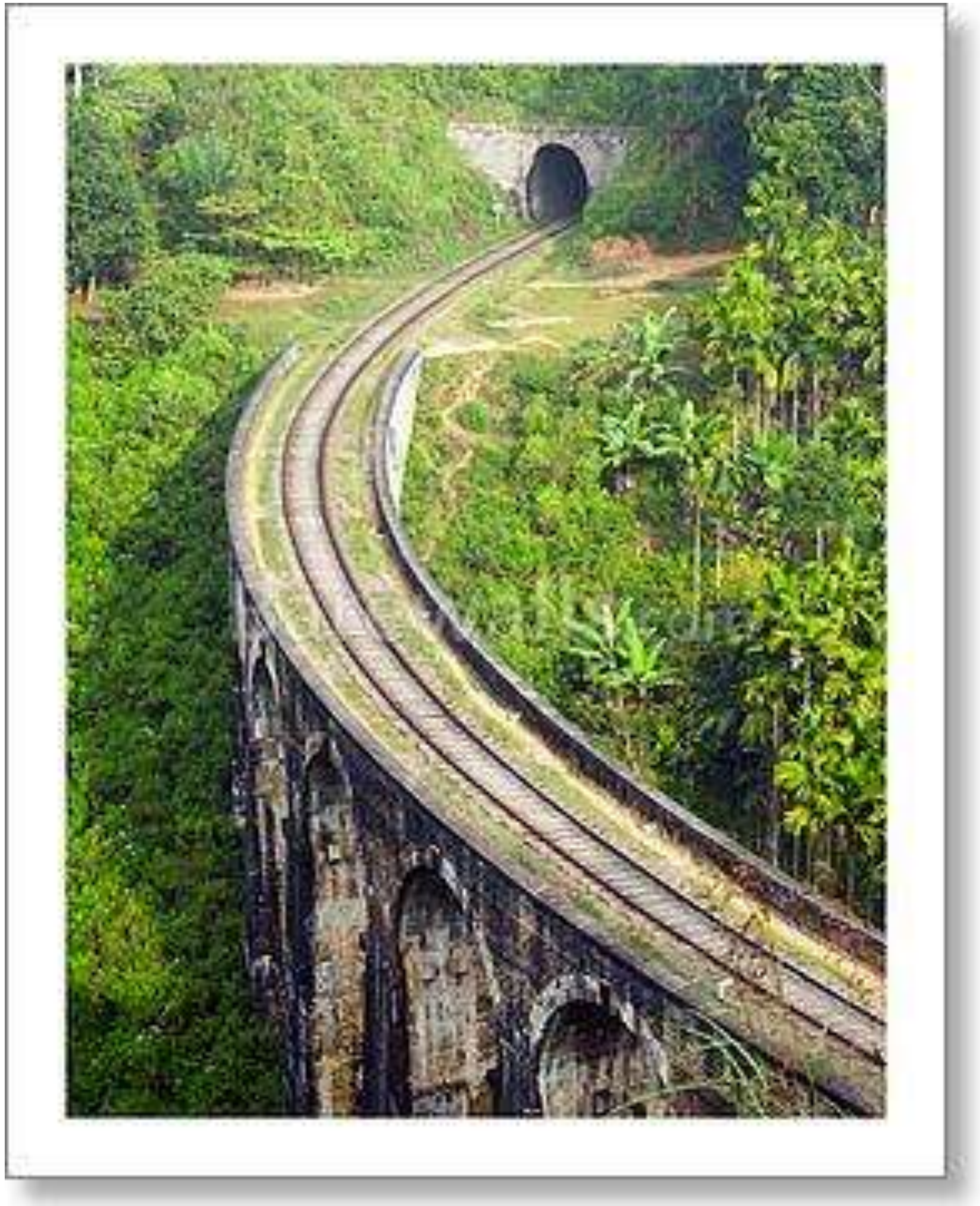
Trinity

King’s

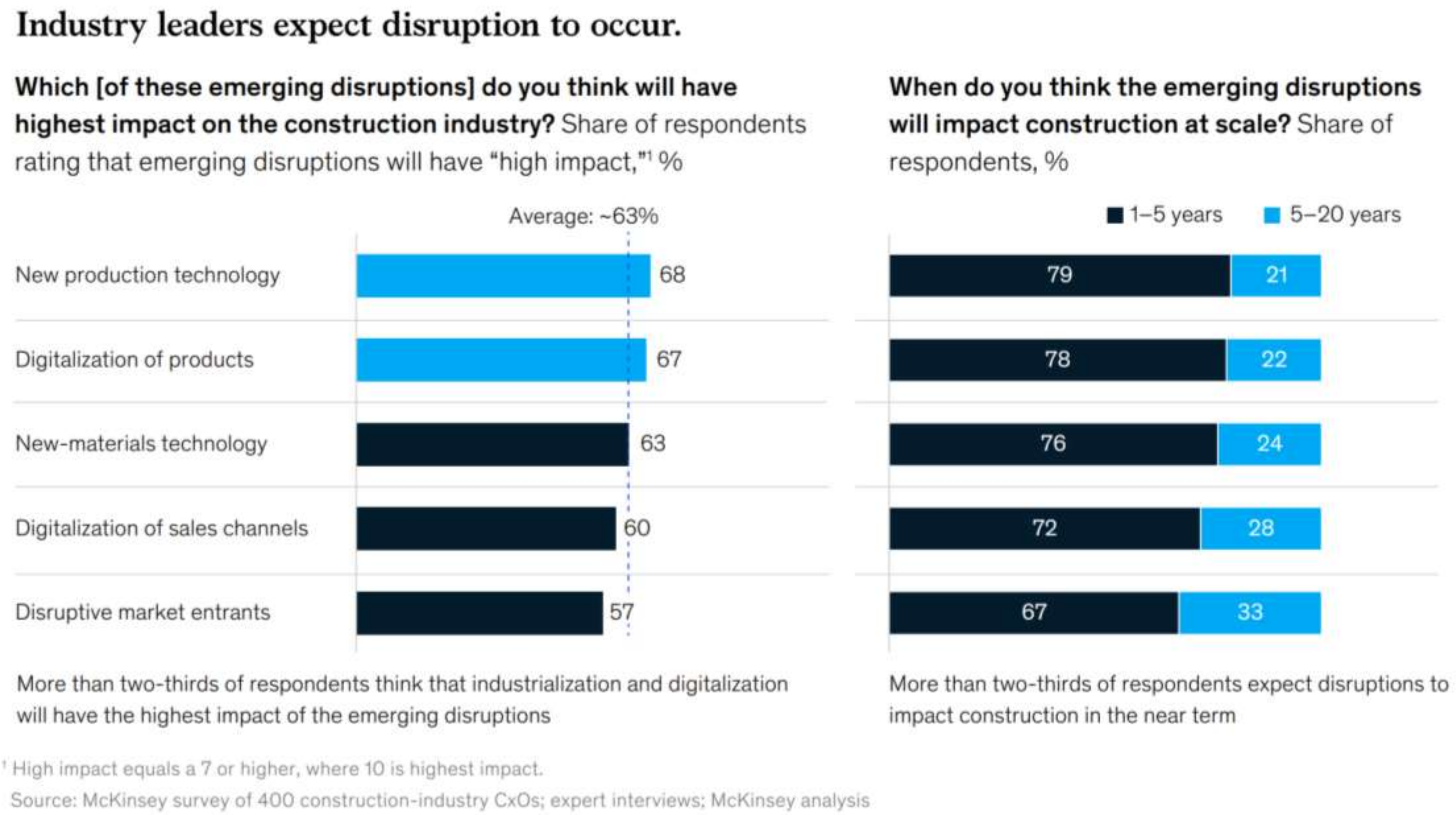
The Civil Engineering Building

Built Environment

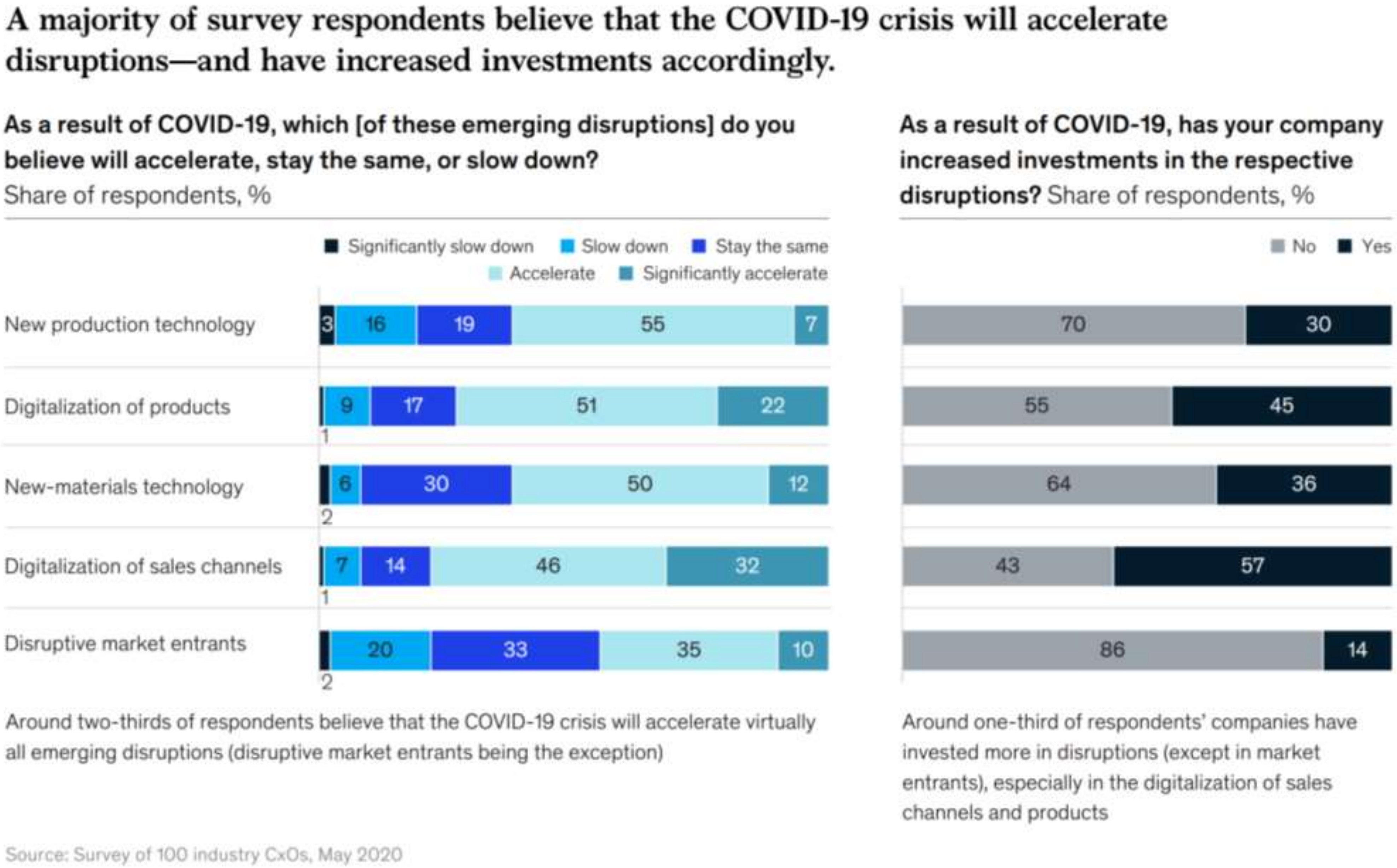
- Economic Infrastructure
  - *Roads, tunnels, bridges, rail, dams, etc.*
- Social Infrastructure
  - *Housing, hospitals, schools, prisons, etc.*
- Interface with natural environment



Digital transformation is taking centre stage



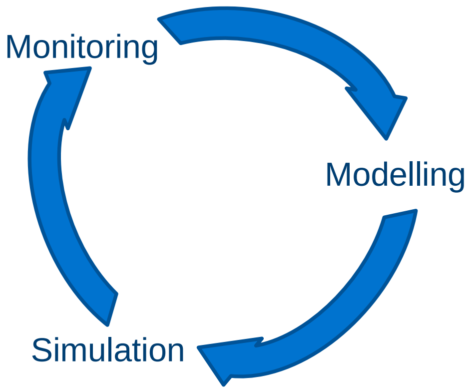
COVID19 crisis = digital transformation catalyst



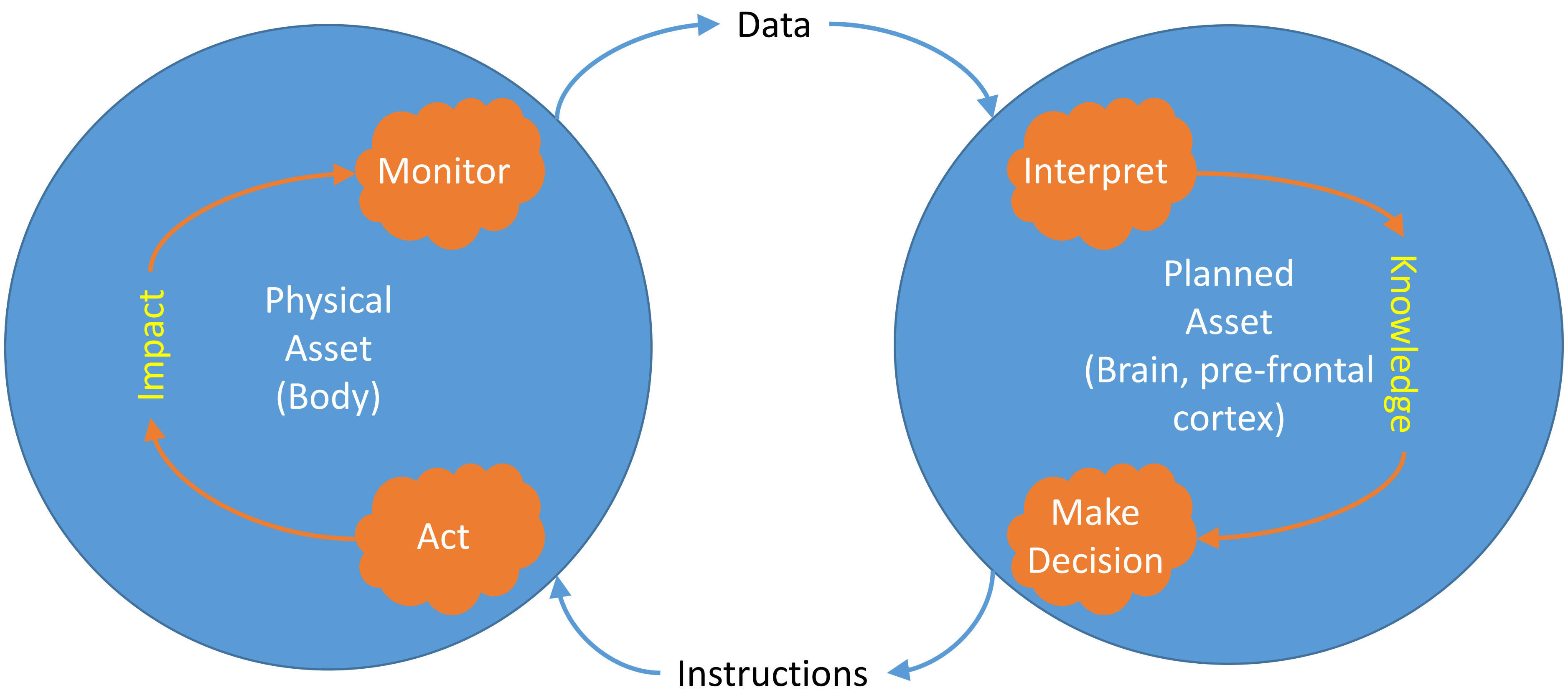
Digital Twins at the core of digital transformation

Role of Digital Twins - Introduction

- “When you walk or drive, you subconsciously plan your actions in your mind, let the bad options die, then act the most viable one” Jordan Peterson



Engineering sequence

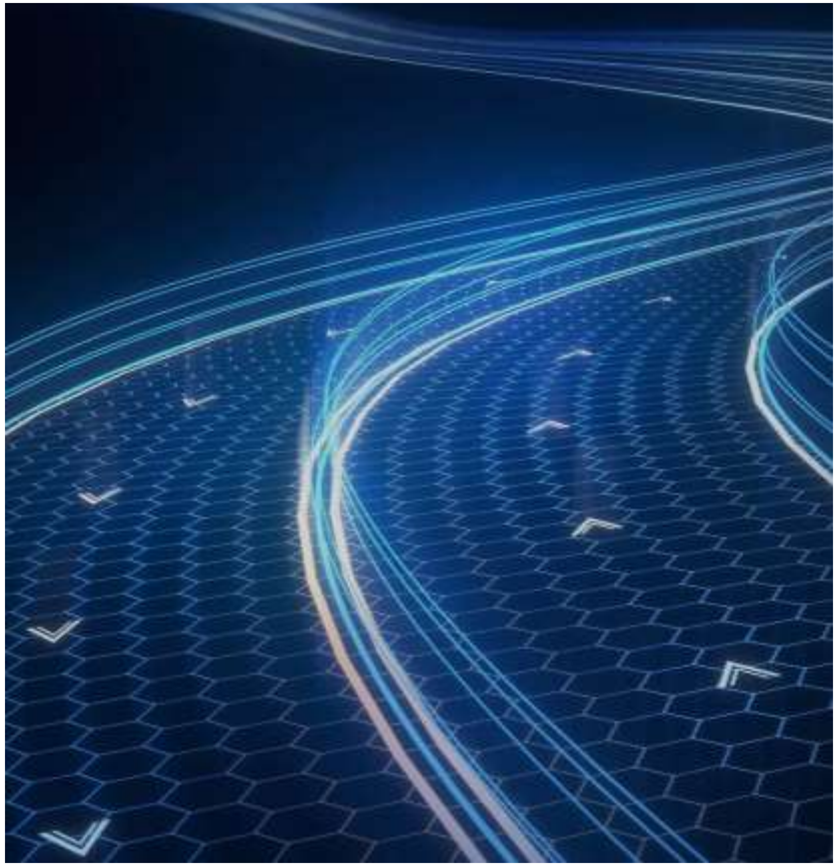


Why Digital Twins?

- Increase automation to manage increasing asset complexity
- Combine product & process; modelling, simulation & monitoring in same platform. As a result they are:
  - *Complex => Expensive*
    - To design / construct / maintain / operate
  - *Rich => Valuable*
    - Flexible, serve multiple purposes
- Federated
  - *Too complex to stay as single model*
- Extensible, futureproofed
- Scalable

DT value

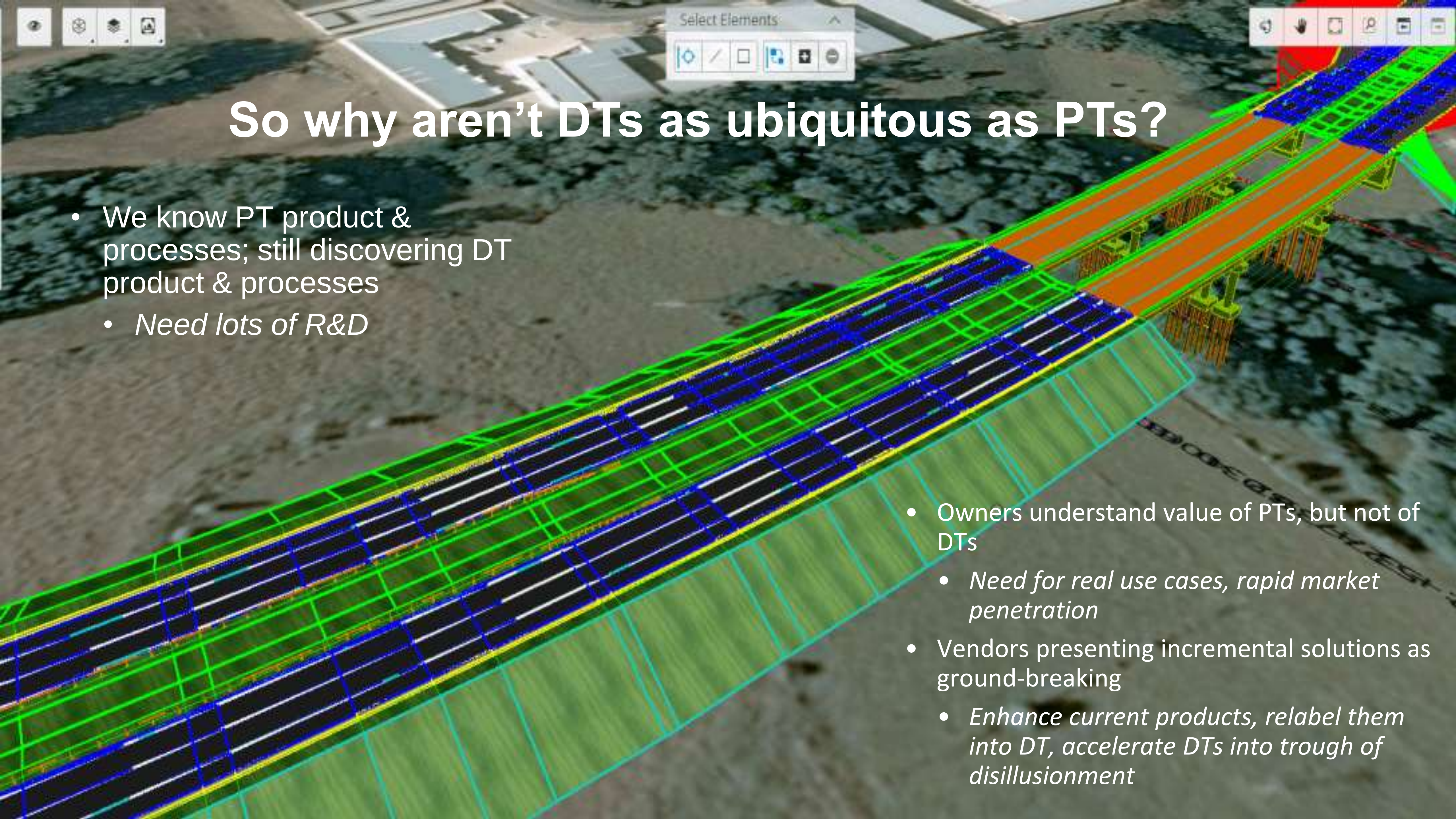
- Better decisions, faster
- Faster refresh rate, more trust in the information
- Serve multiple processes
- More automation
  - *Leave high level decisions to humans*
  - *Push low level decisions to "subconscious"*

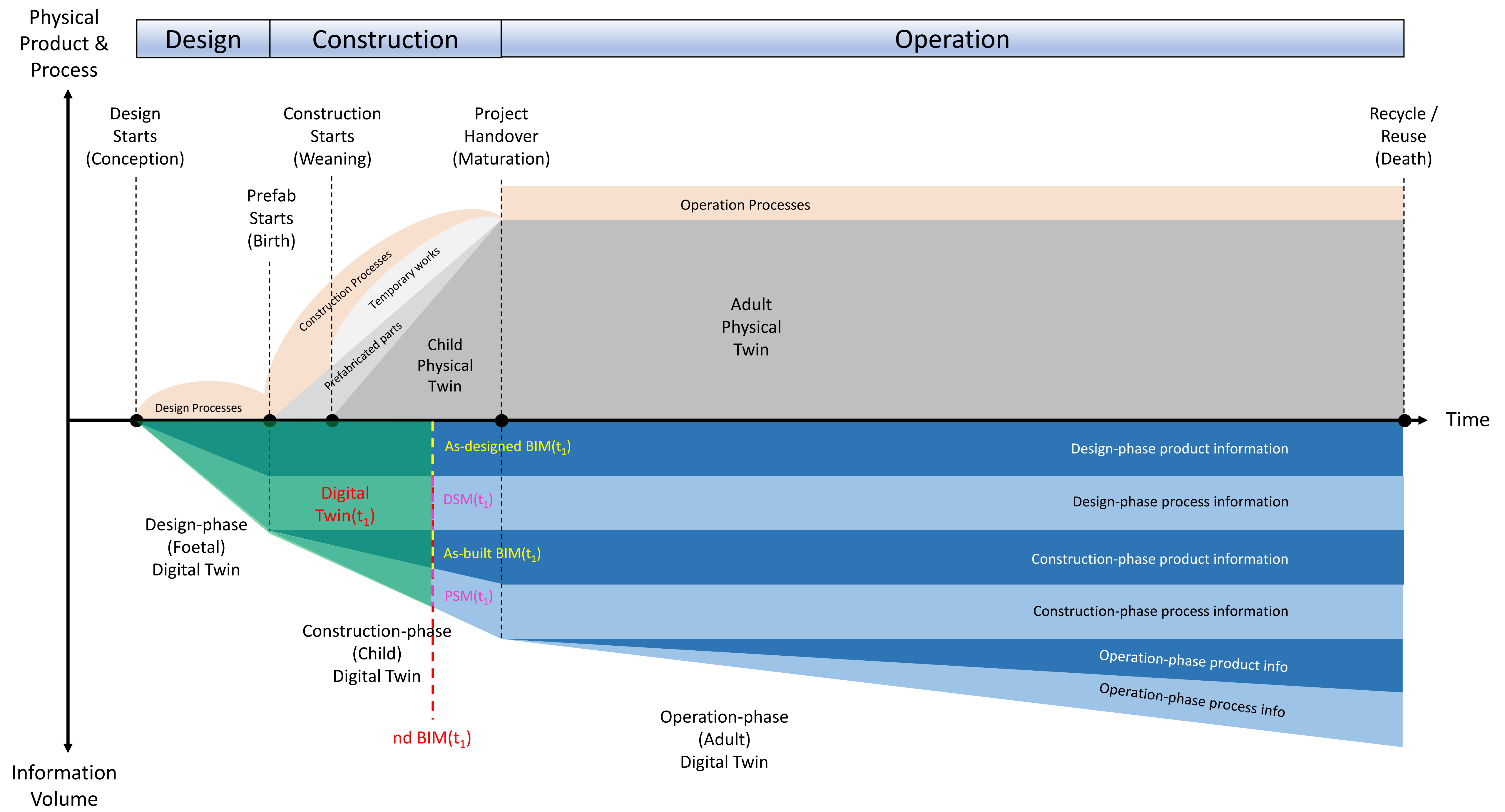


So why aren't DTs as ubiquitous as PTs?

- We know PT product & processes; still discovering DT product & processes
  - *Need lots of R&D*

- Owners understand value of PTs, but not of DTs
  - *Need for real use cases, rapid market penetration*
- Vendors presenting incremental solutions as ground-breaking
  - *Enhance current products, relabel them into DT, accelerate DTs into trough of disillusionment*

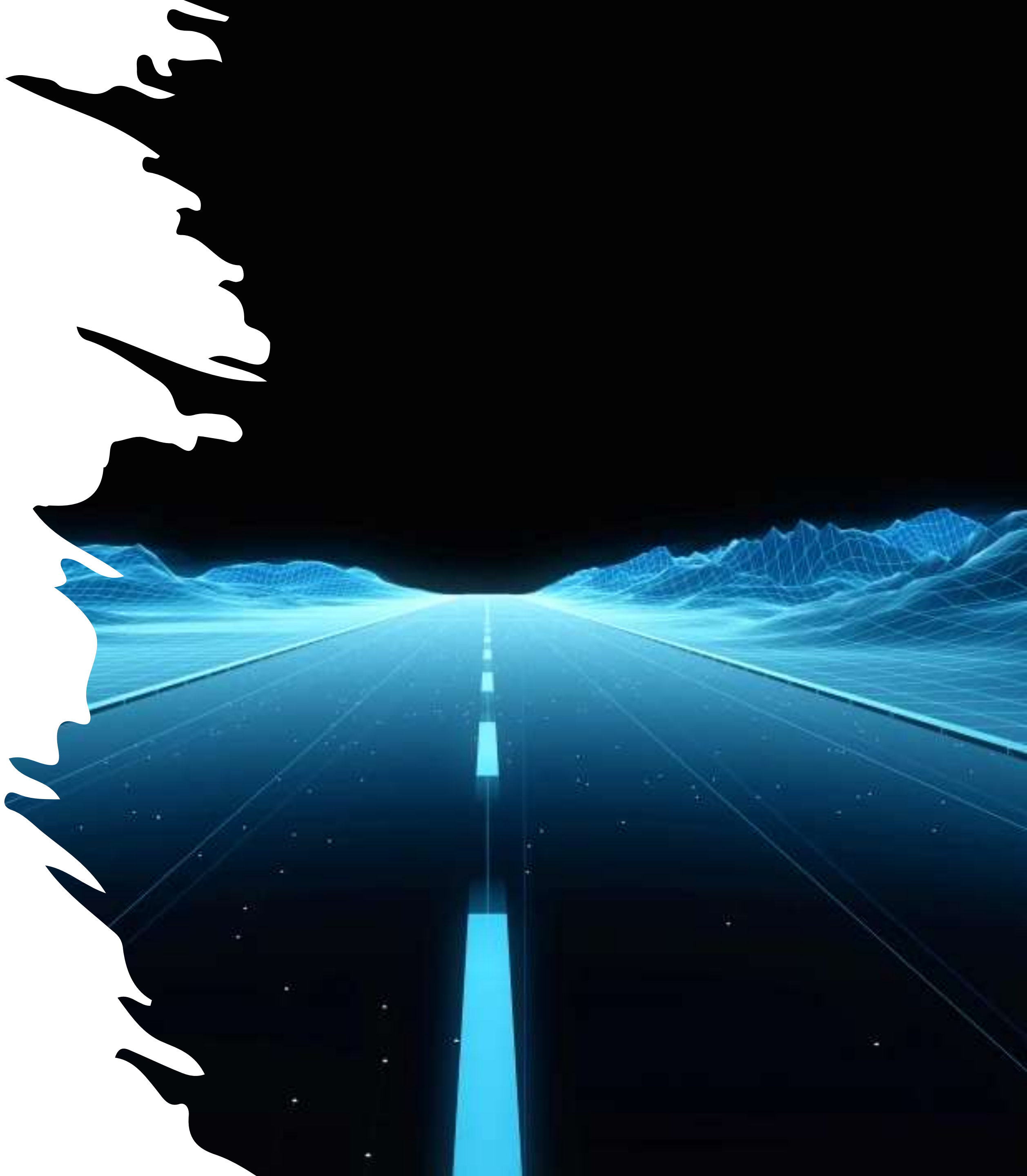




Physical Product & Process
Design
Construction
Operation
Design Starts (Conception)
Construction Starts (Weaning)
Project Handover (Maturation)
Recycle / Reuse (Death)
Prefab Starts (Birth)
Operation Processes
Construction Processes
Temporary works
Prefabricated parts
Child Physical Twin
Adult Physical Twin
Design Processes
Time
As-designed BIM(t_1)
Design-phase product information
Digital Twin(t_1)
DSM(t_1)
Design-phase process information
Design-phase (Foetal) Digital Twin
As-built BIM(t_1)
Construction-phase product information
PSM(t_1)
Construction-phase process information
Construction-phase (Child) Digital Twin
Operation-phase product info
Operation-phase process info
nd BIM(t_1)
Operation-phase (Adult) Digital Twin
Information Volume

DT fundamentals

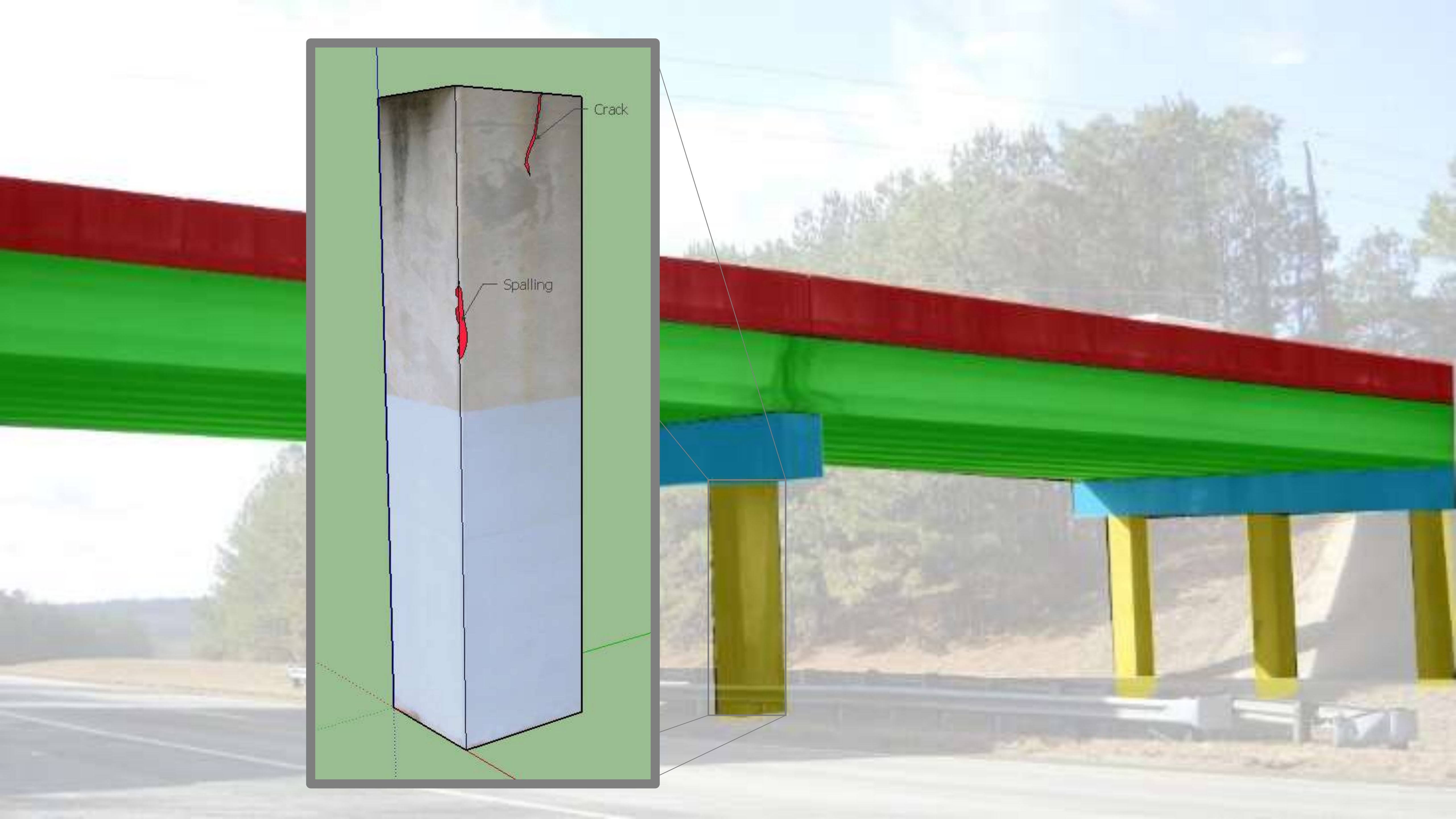
- DTs made of
  - *Information*
    - Derived from data held separately & deleted after use
  - *Knowledge (information patterns via interpolation)*
    - Derived from information
  - *Insight (knowledge patterns via extrapolation)*
    - Derived from knowledge & information
- All derivations above are perfect AI use cases
  - *Hence the importance of AI for DTs*



DT processes

DT planning	• *Understand DT scope, feasibility, costs*	Occurs before PT planning
DT design	• *Derive the DT asset class* • *Design data structures, cloud architecture*	Starts before PT planning
DT construction	• *Populate class, derive asset DT instance*	Occur throughout PT lifecycle
DT maintenance	• *Update instance @varying sampling rates/attribute*	
DT operation	• *Use DT instance*	

Digital Twins Construction

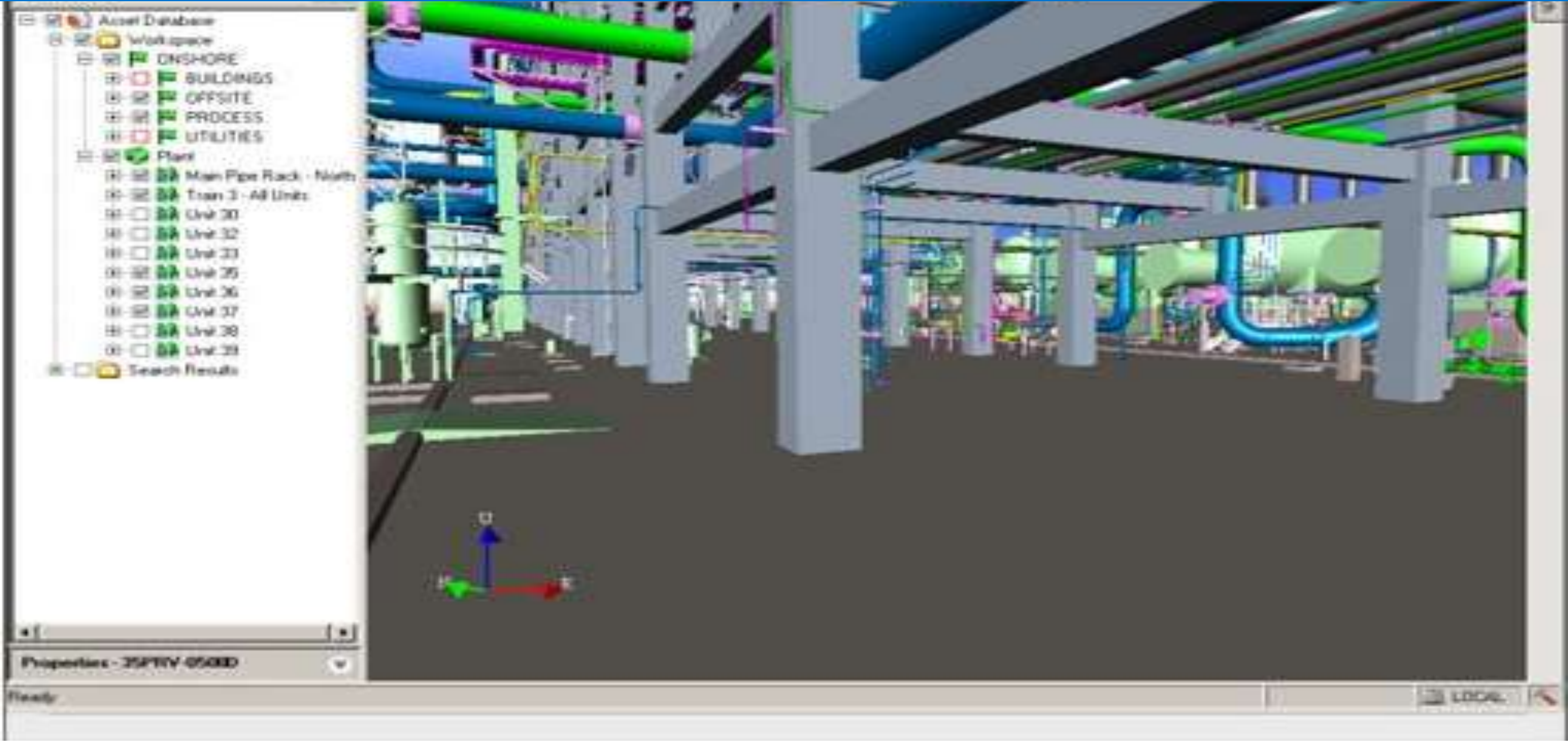

Crack
Spalling

Large-scale real-time 3D reconstruction with accuracy predictions

Maciej Trzeciak, Ioannis Brilakis

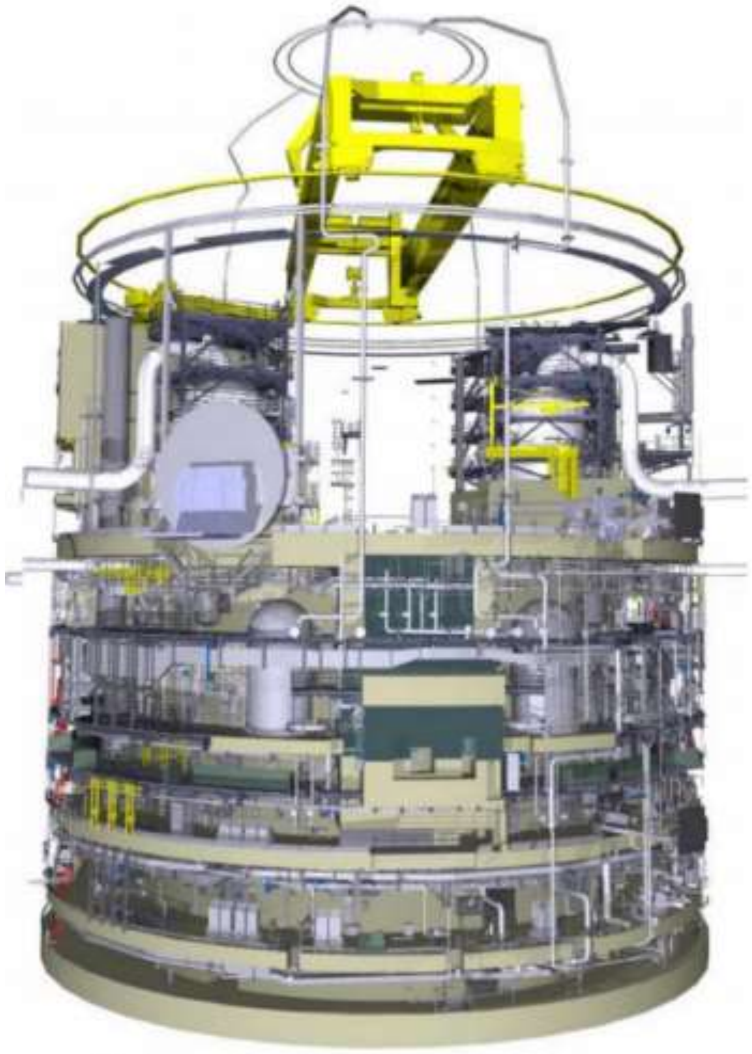
Step 2: Generating Geometric Digital Twin

ASCE Collingwood Prize



Challenges

- Massive datasets and modelling labour costs
  - *10 days modelling per 1 day of laser scanning*
  - *Point clouds with 30+ billion points*
  - *Modeller fatigue: its boring!*



c.first reactor building

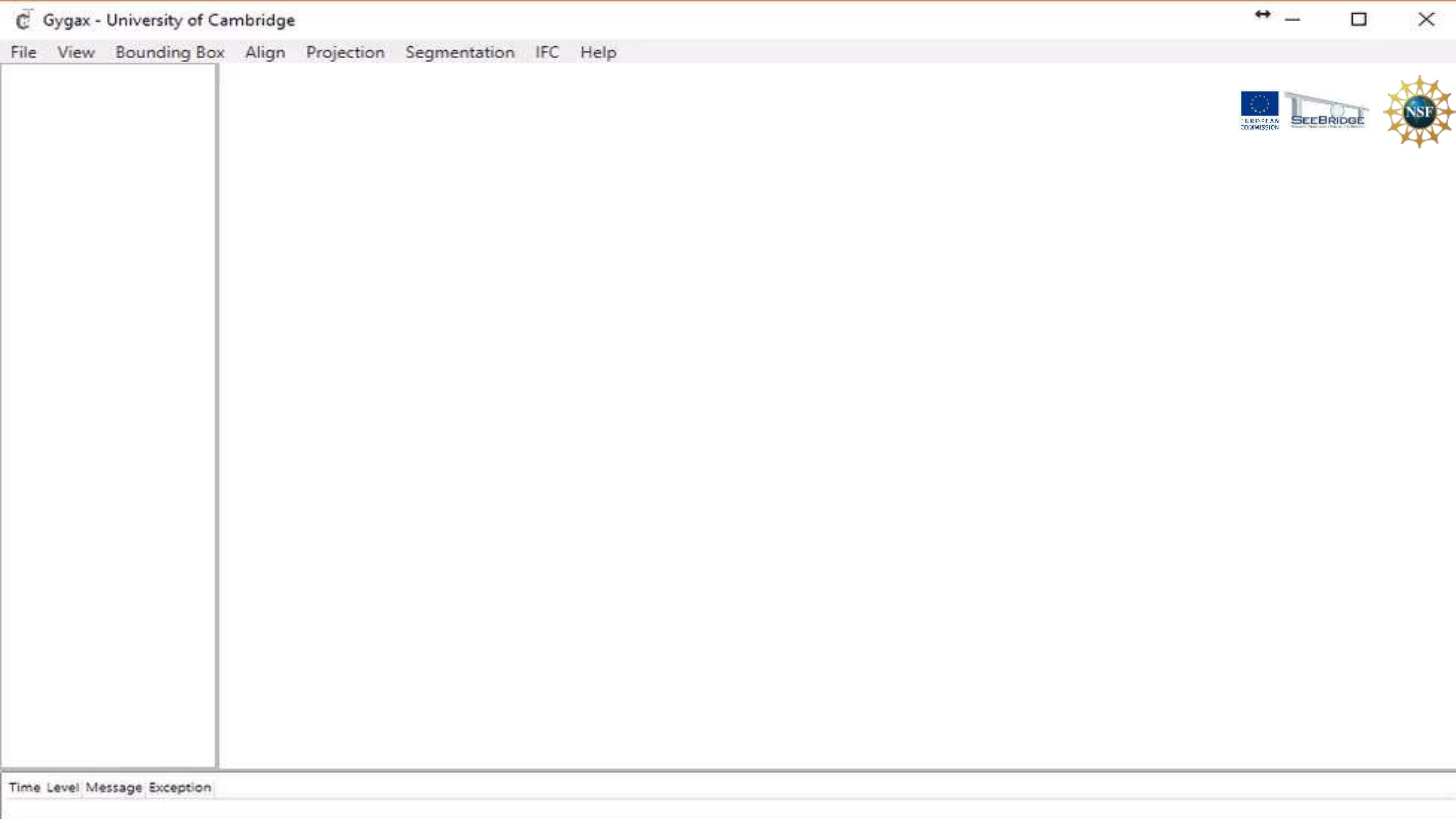
40,000,000,000 points
1084 stations

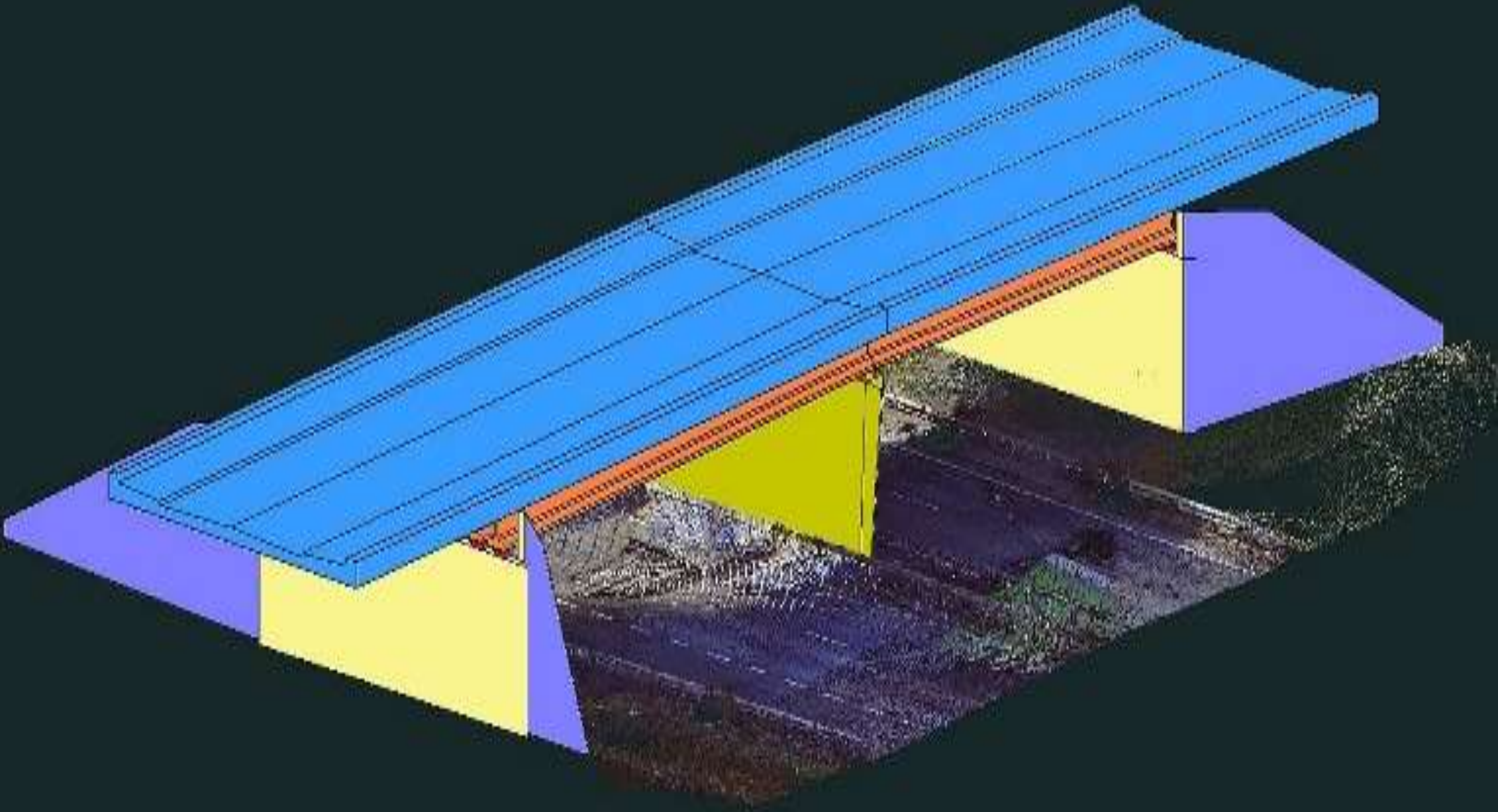
10 operators
~ 6 months

Columns Detection

reseach_1.png - Photos

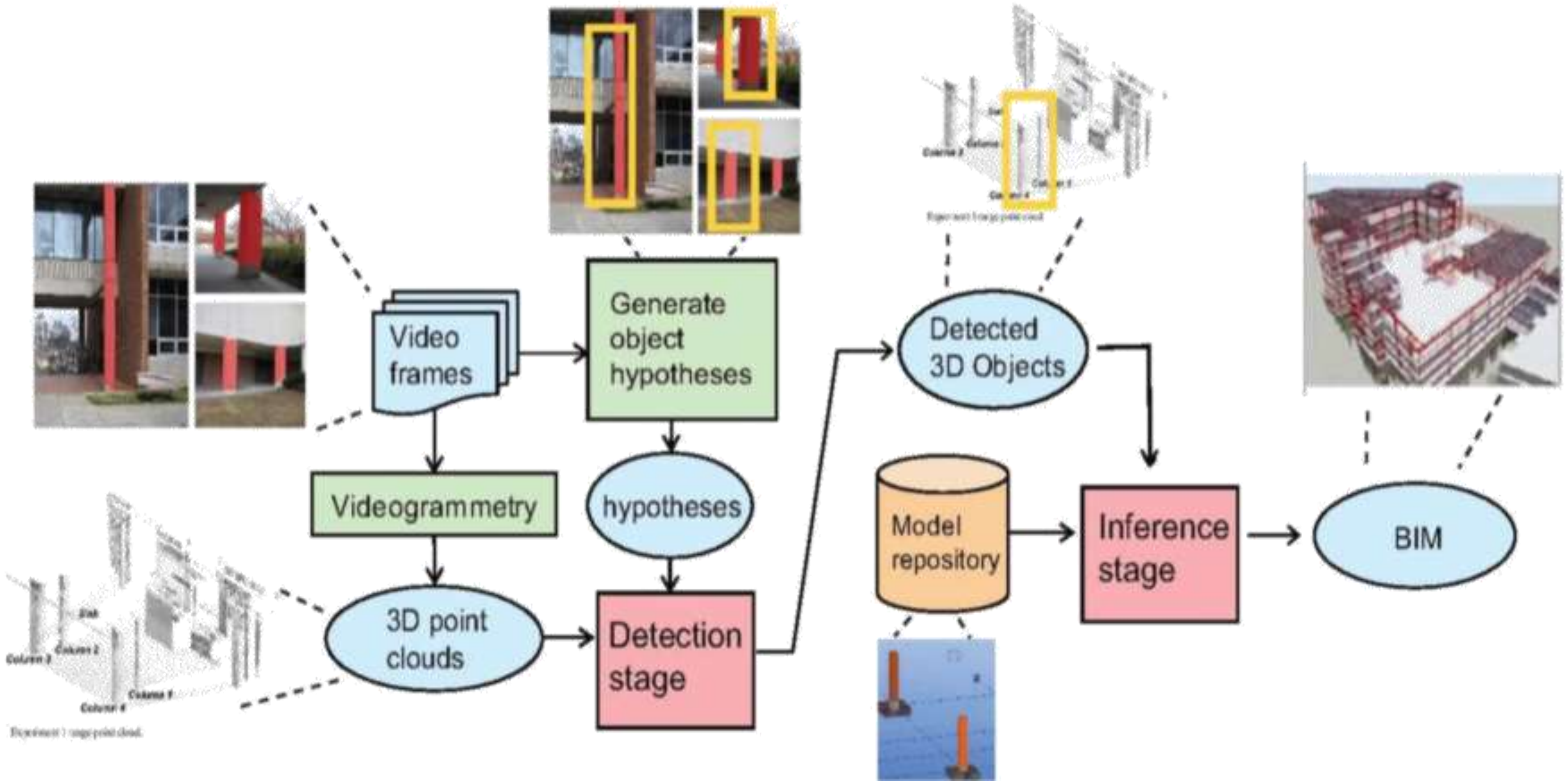
View all photos


Gygax - University of Cambridge
File
View
Bounding Box
Align
Projection
Segmentation
IFC
Help
SEEBRIDGE
NSF
Time
Level
Message
Exception

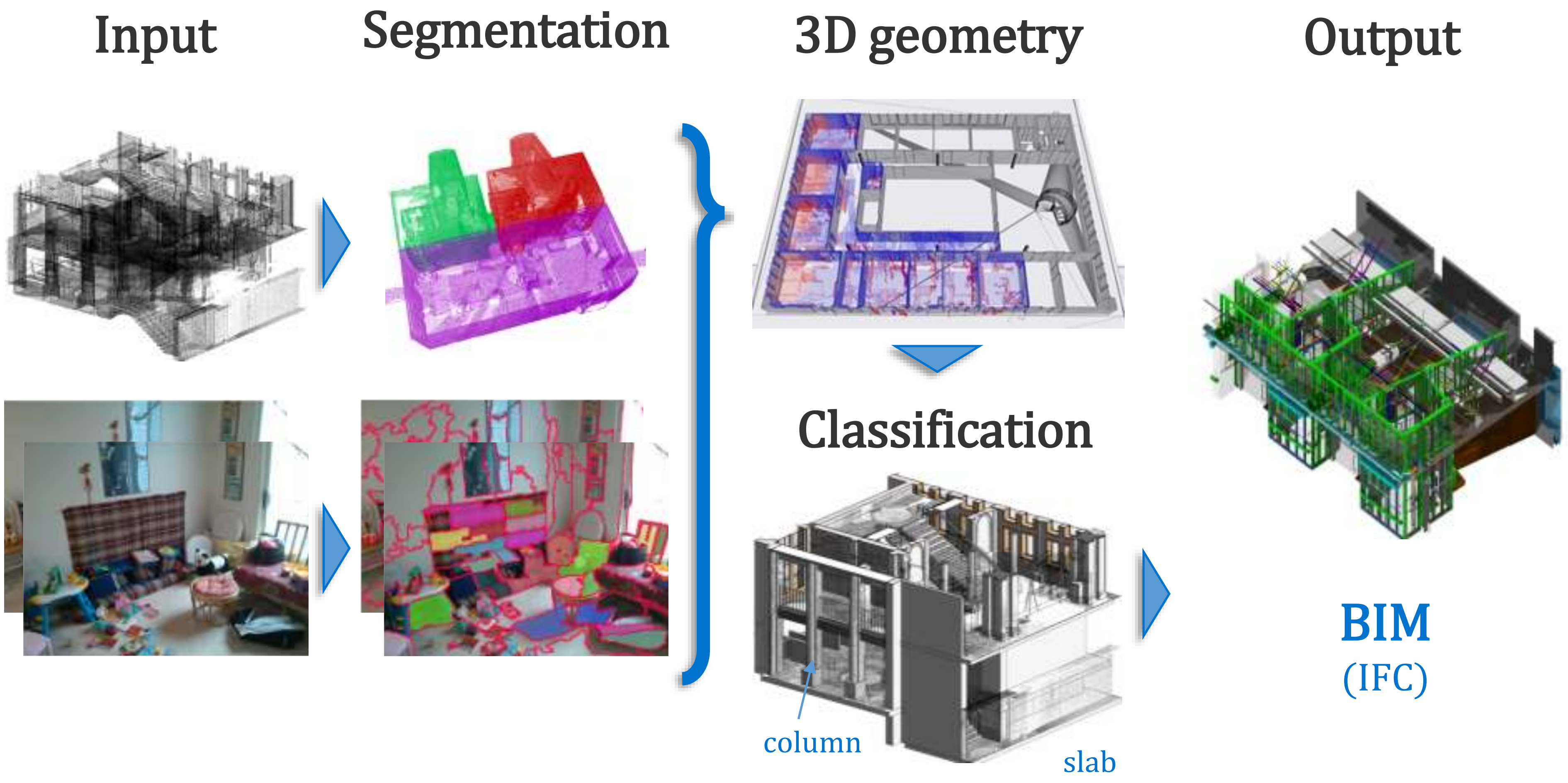


DT Generation - Buildings

- Formalize Digital Twin generation process (video to BIM)

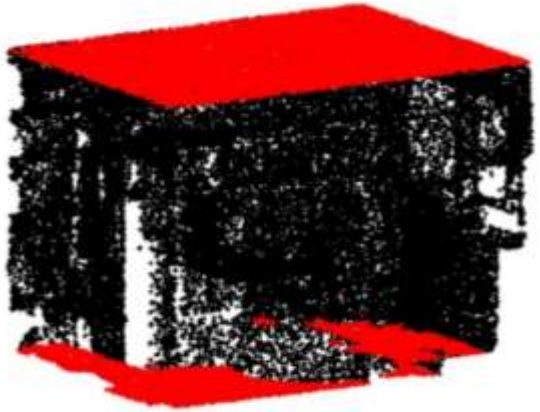


Deep Structured Digital Twin

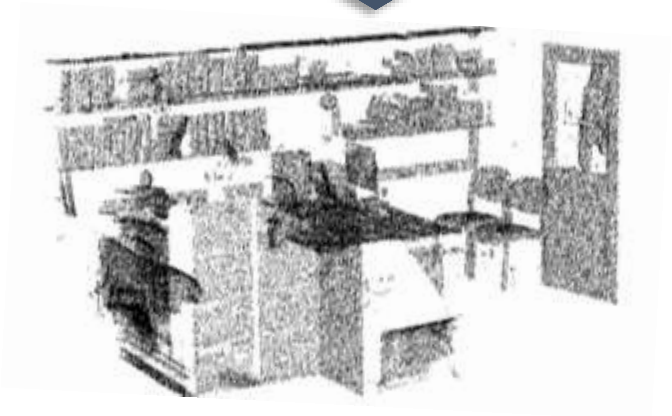


Results – Slabs Detection

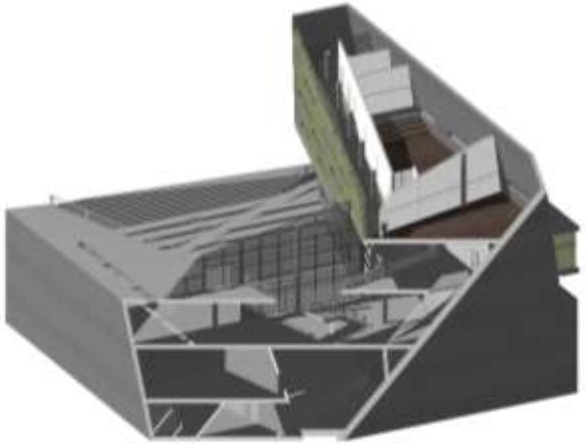
1. Building's PC



2. Coarse Space Localisation

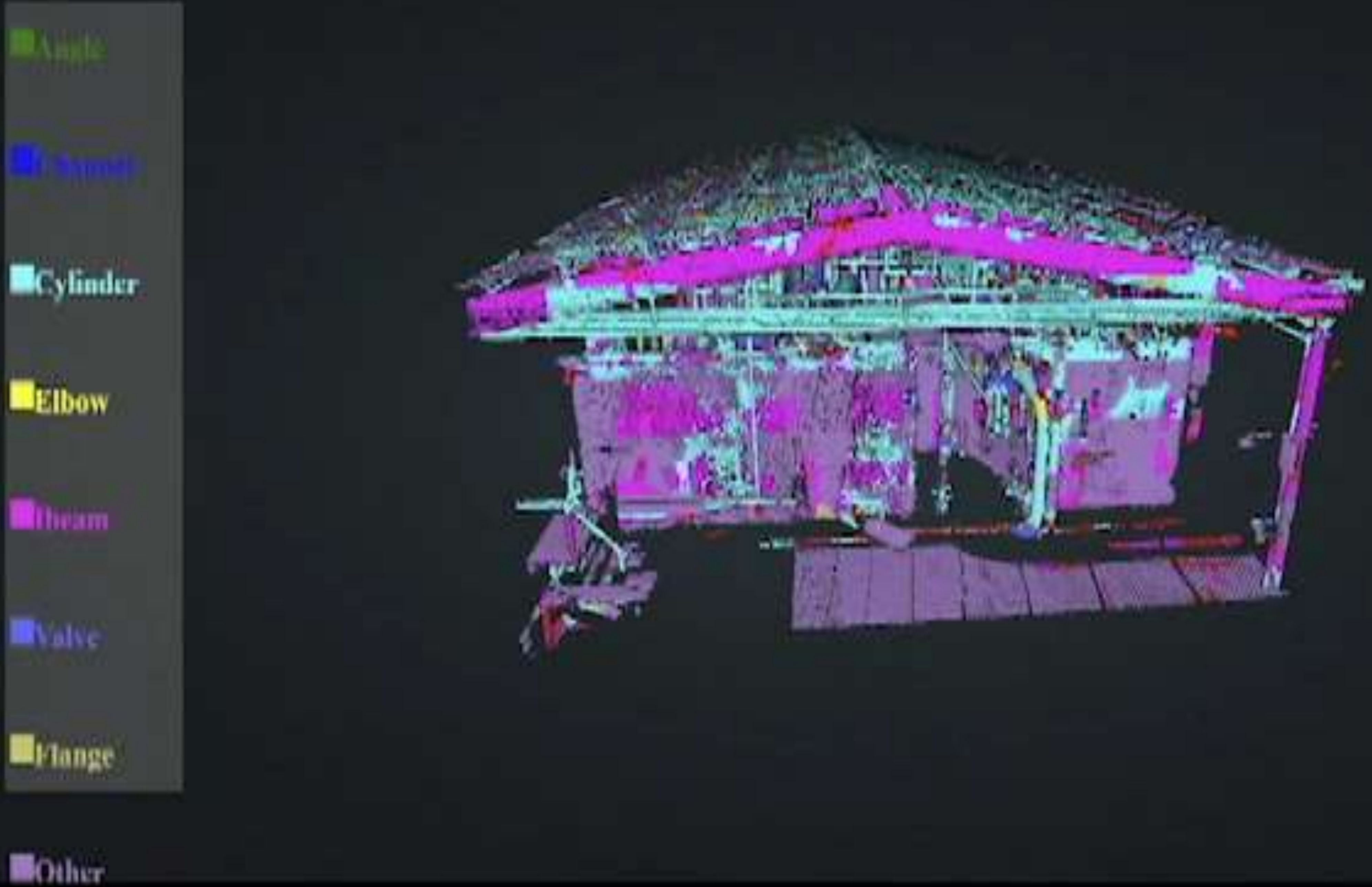


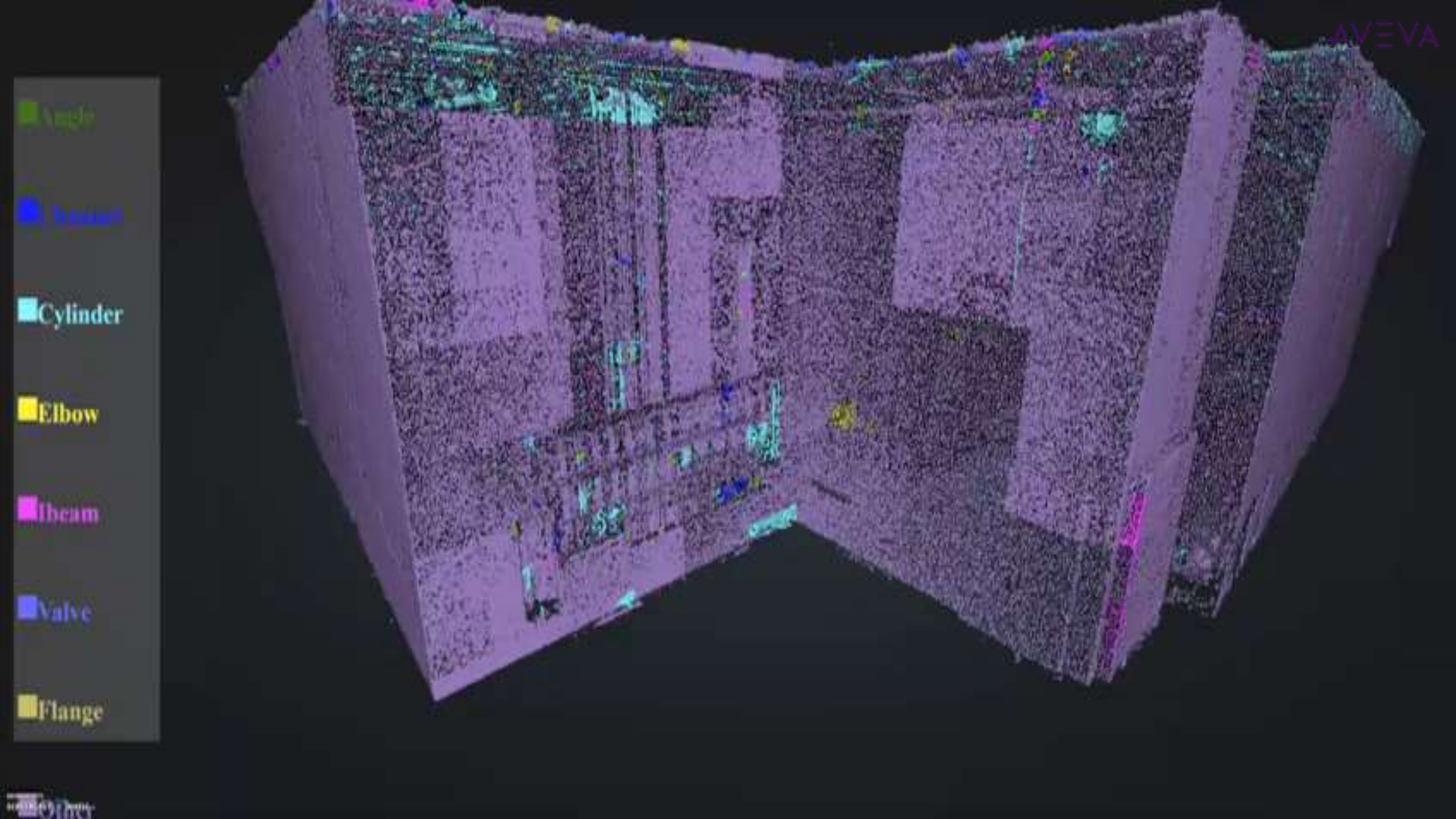
3. Distinguish Clutter



4. BIM

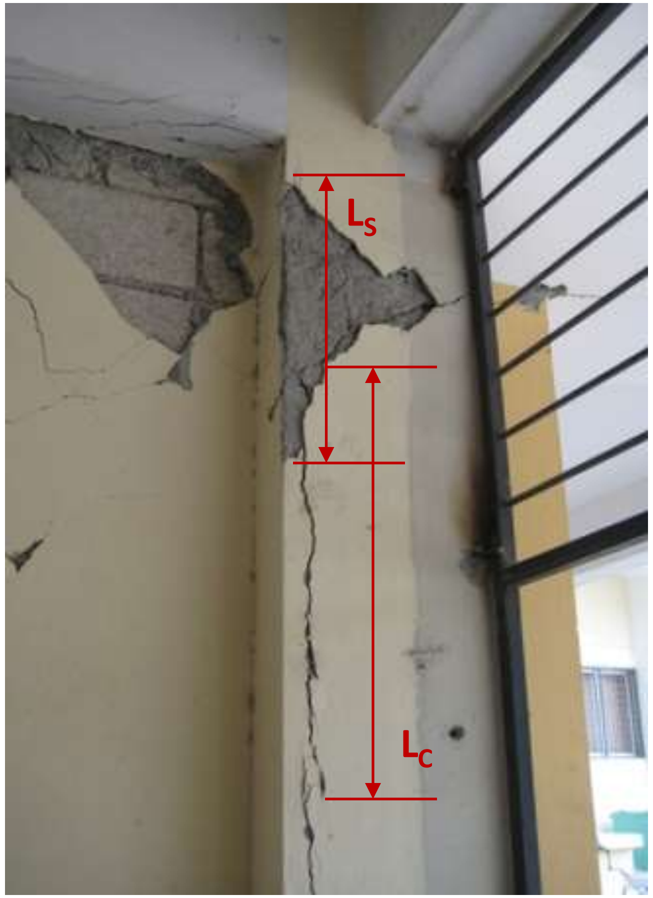
Results –Walls & Spaces Detection

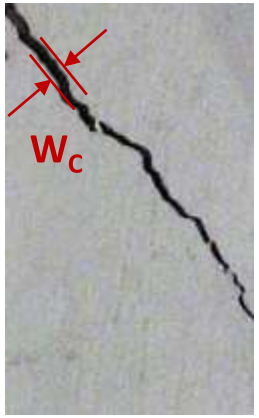

Angle
Cylinder
Elbow
Beam
Valve
Flange
Other

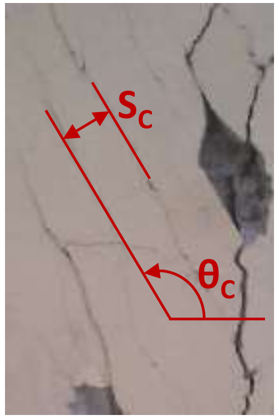


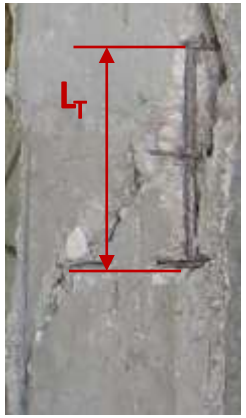
Angle
Cylinder
Elbow
Ibeam
Valve
Flange

Step 3: Enriching the DT









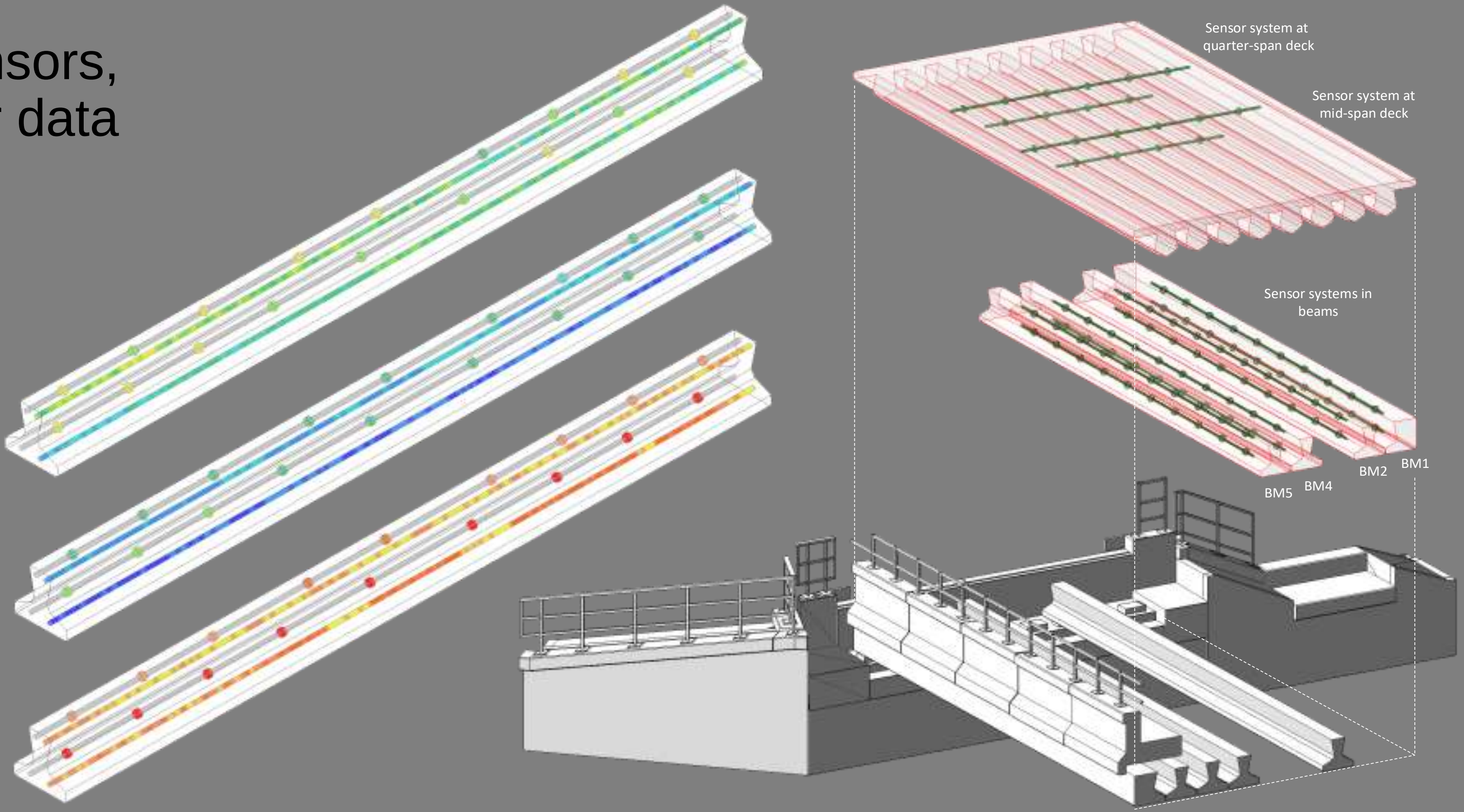
DT Enrichment – Condition Data

Flexural crack
Length 59.3 mm
Width 0.81 mm
Flexural zone yes
Detection date 8/11/16

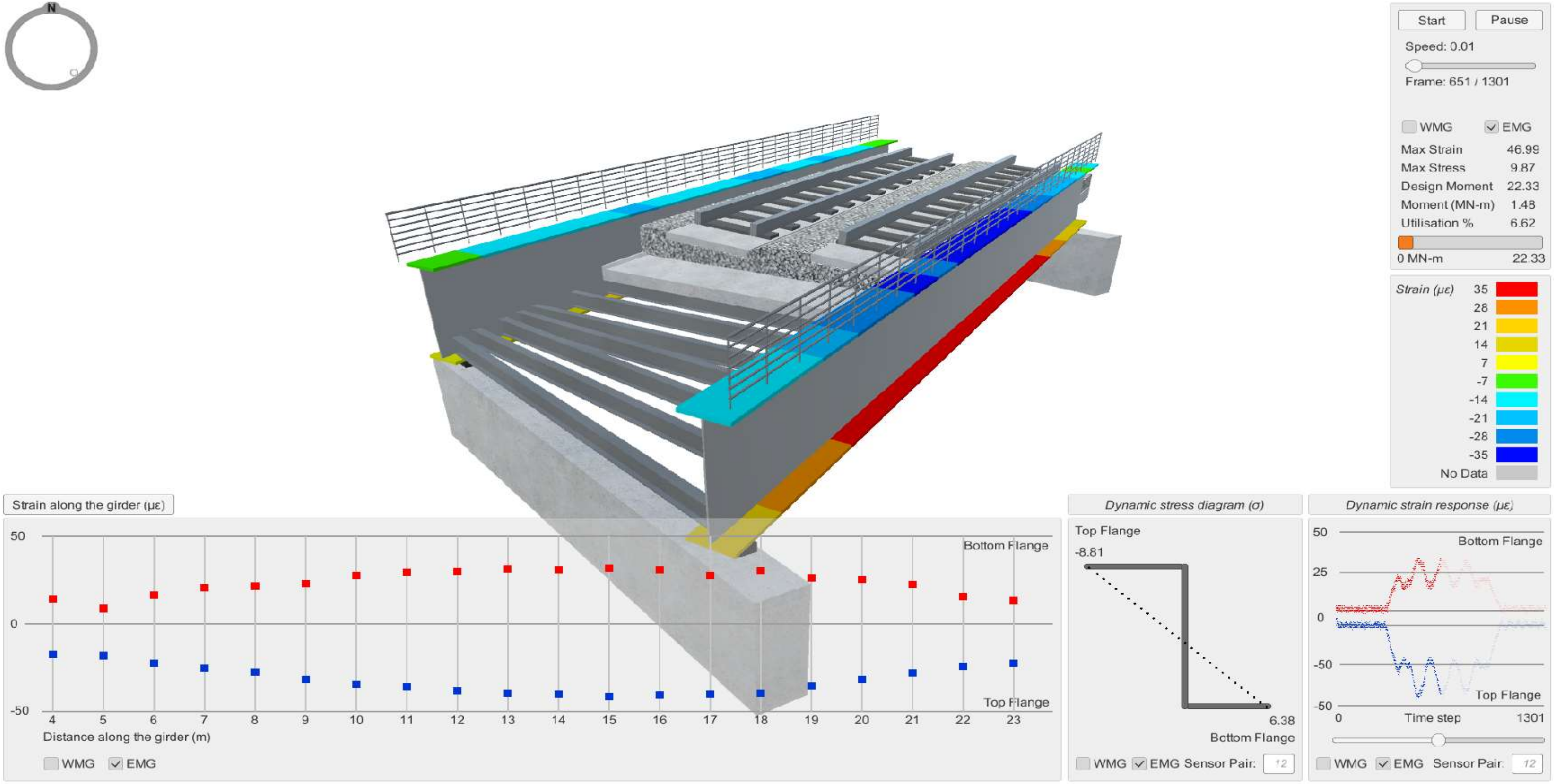
- Structural cracks
- Non-structural cracks
- Spalling
- Scaling
- Efflorescence
- Corrosion
- Other defects

DT Enrichment – Sensor Data

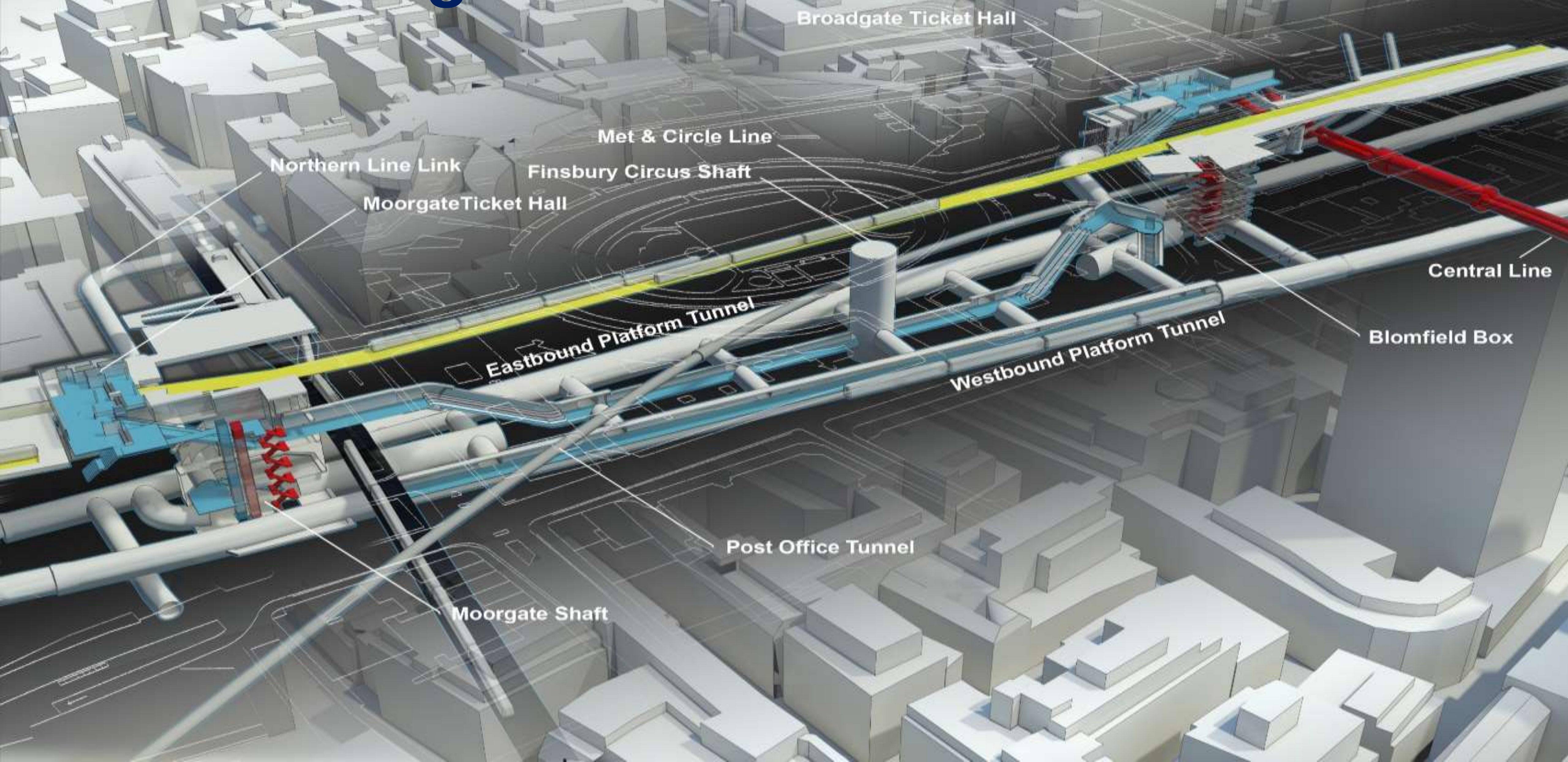
- Modelling sensors, linking sensor data



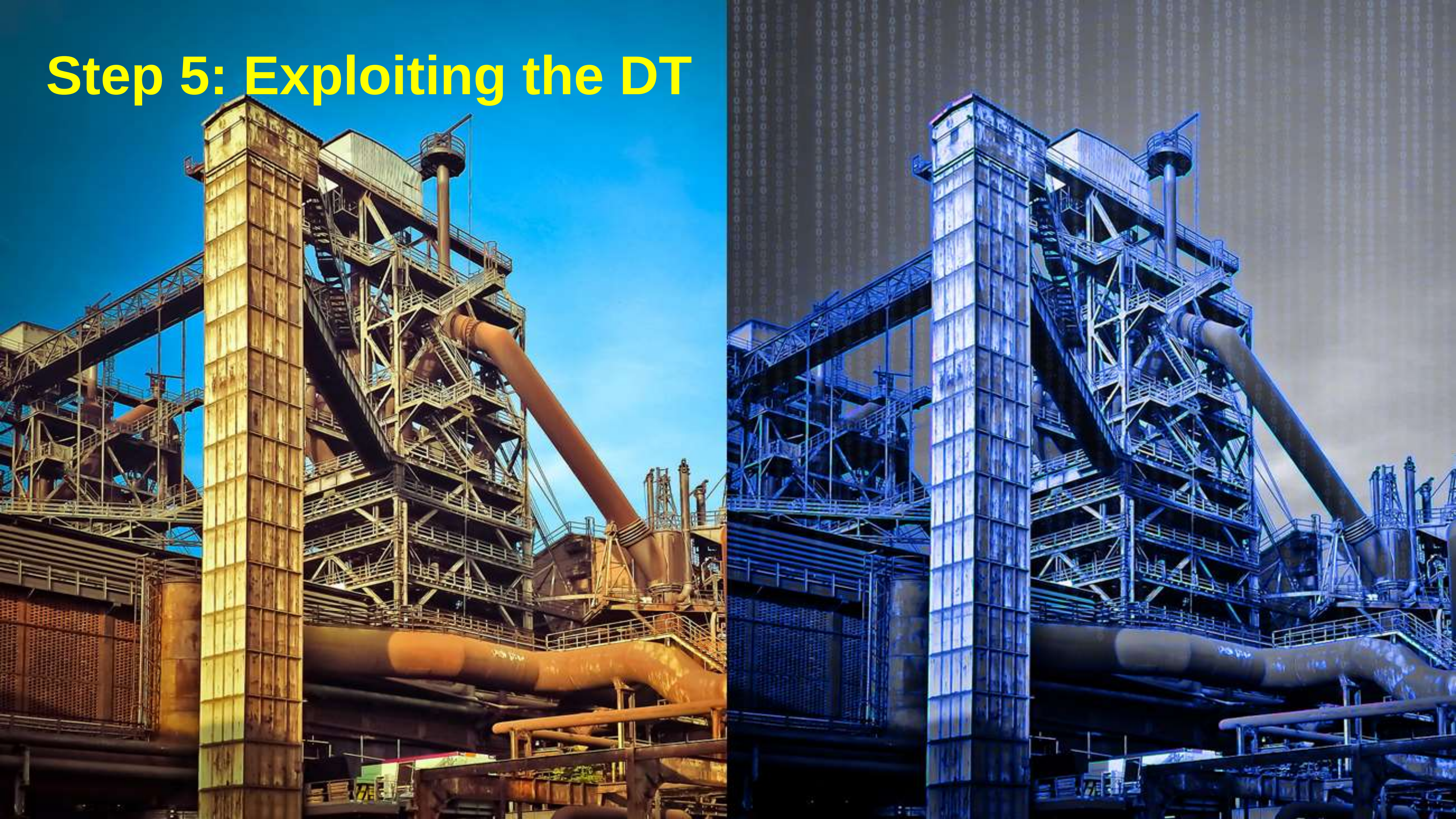
Step 4: Connecting the DT – Tethering, Monitoring



National Digital Twin



Step 5: Exploiting the DT



Innovate UK

DT exploitation: Design Phase

Digitally Enabling the Design For Manufacture, Assembly, and Maintenance of Bridges

Use case – HS2
156 overbridges, 144 underbridges, 65 viaducts

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TGP

Integrate Process, Decisions and Data…

Route / Alignment → Bridge Concept Design → Bridge Detailed Design → Bridge Contracted → Bridge Components Manufactured → Bridge Assembled → Bridge Delivered

Design Constraints and Captured Data

Route / Alignment
- Sector
- Span
- Skew
- Clearance
- Client
- Site constraints

Bridge Concept Design
- Bridge Type
- Bridge Concept
- BOM estimate
- Cost estimate
- Time estimate

Bridge Detailed Design
- Accurate BOM
- Accurate detailing
- Structural design assurance
- Detailed cost estimate
- Detailed time estimate

Bridge Contracted
- Assembly methodology
- Accurate cost
- Accurate time
- Accurate risk

Bridge Components Manufactured
- Accurate schedule
- Accurate component cost
- Accurate component time
- Component QA records

Bridge Assembled
- Installation QA records
- Commissioning QA records
- Final component cost

Bridge Delivered
- Final cost
- Final time
- Final QA records

Define Route / Alignment

Confirm that bridge concept works for route alignment

Bridge Concept

Confirm that detailed design works for manufacturing / assembly

Bridge Detailed Design

Confirm that the bridge is built to the design specification

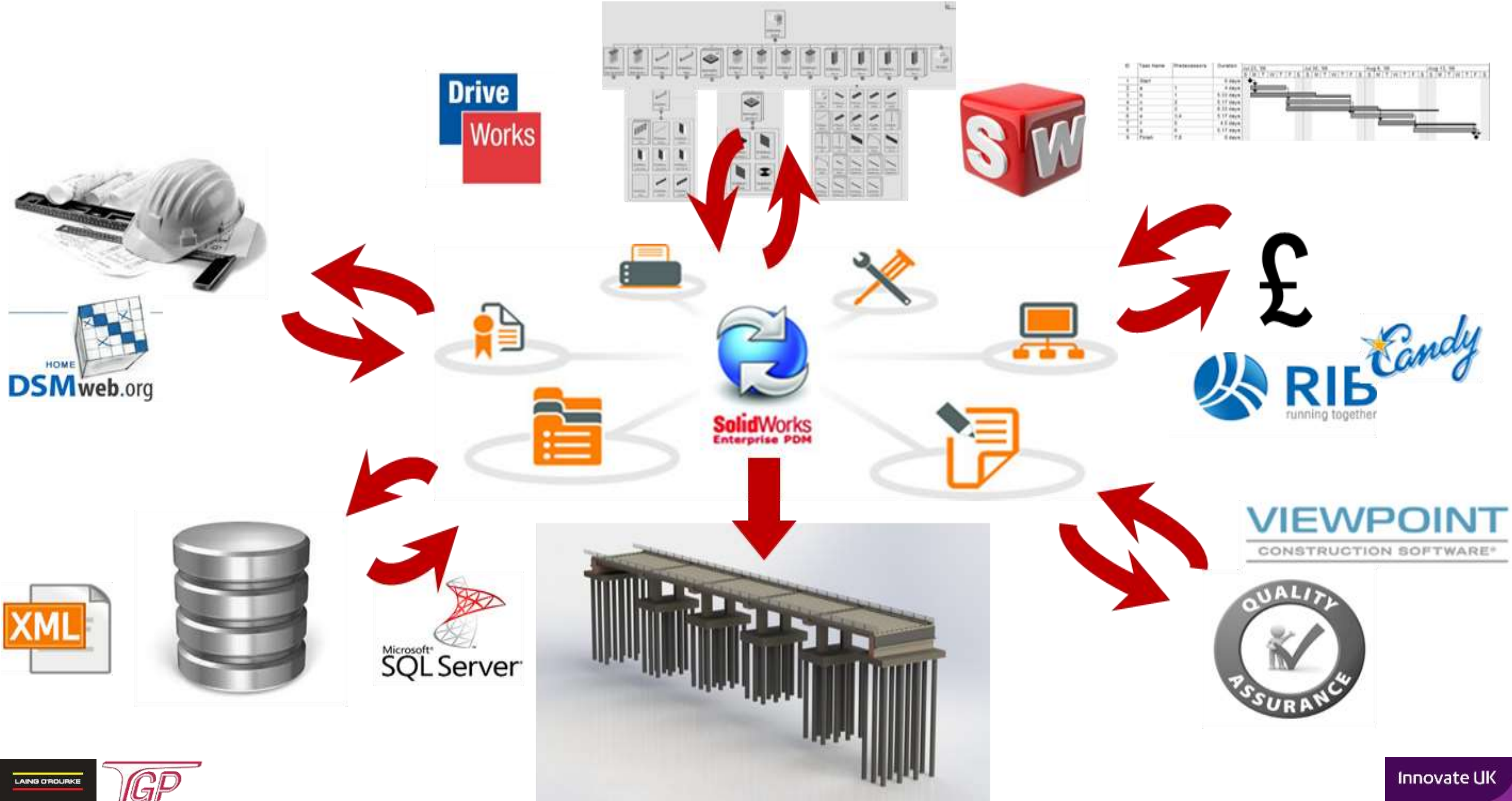
Bridge Delivery

Conceptual Design Iteration

Detailed Design Iteration

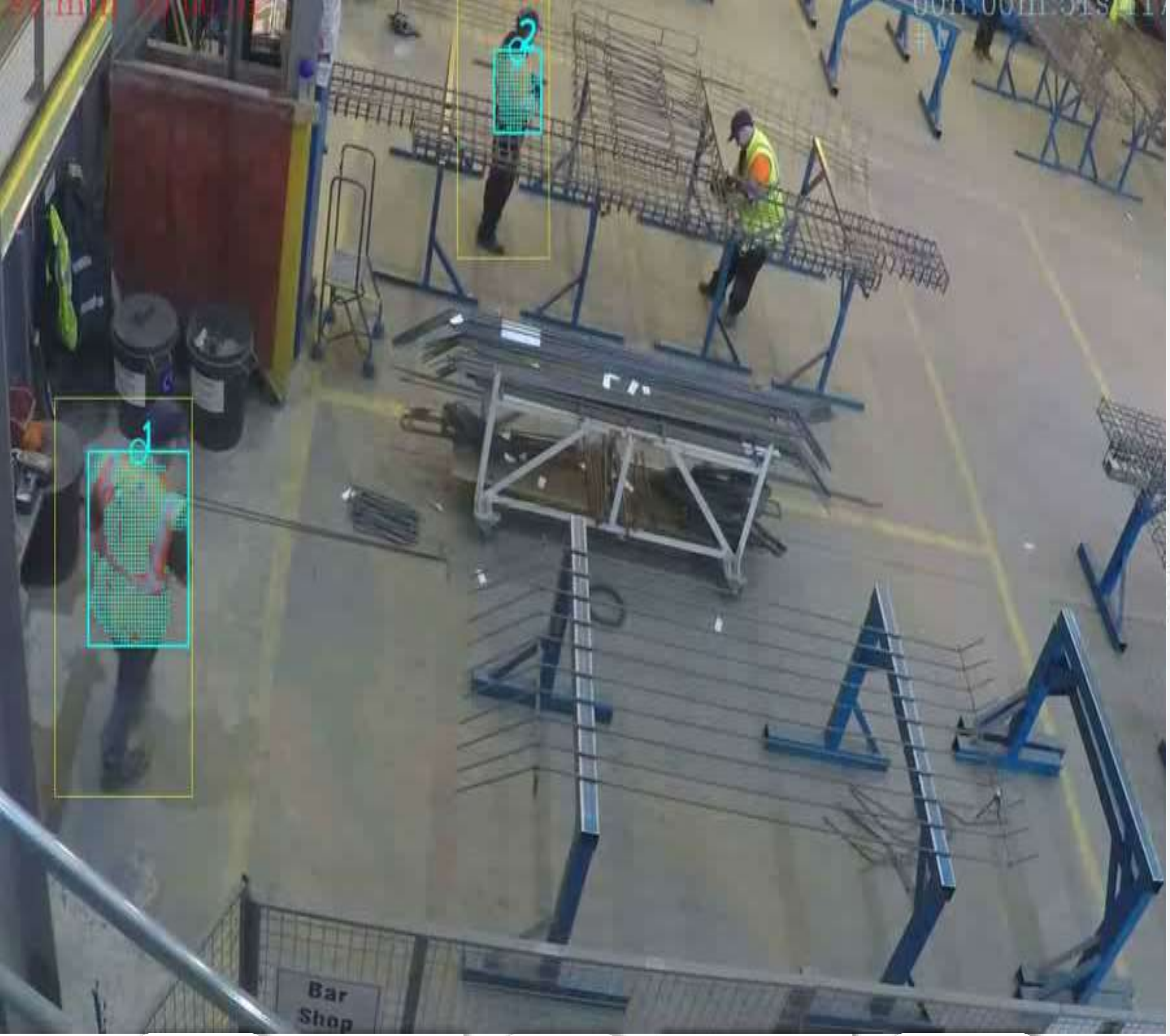
Quality Assurance Iteration

… Within Existing Solutions Space

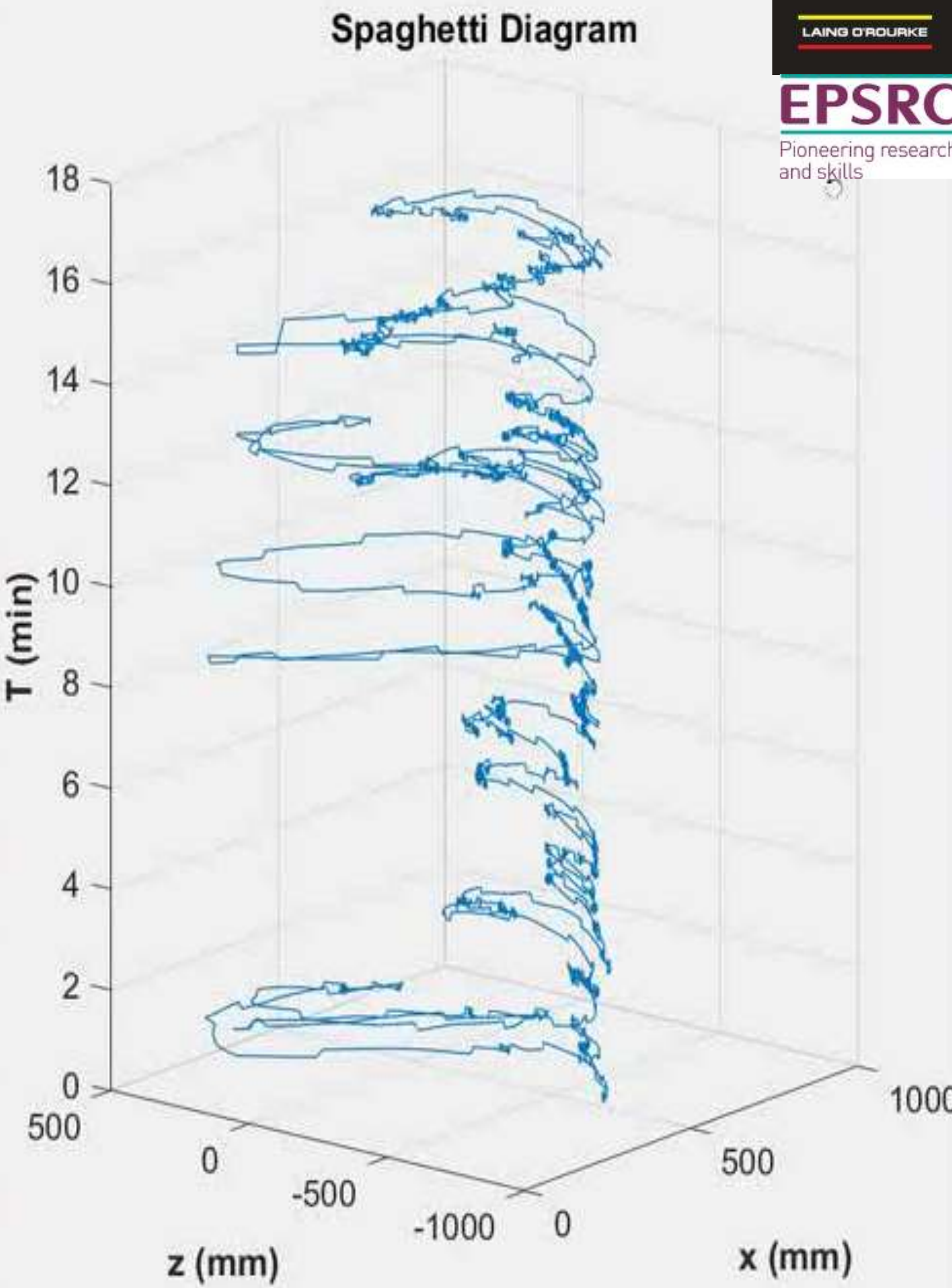


DT exploitation: Construction Phase (MR)

DT exploitation: Construction Phase (MR)



Videos → 4D Tracking → 4D Paths → Productivity Analysis → SubTasks Time



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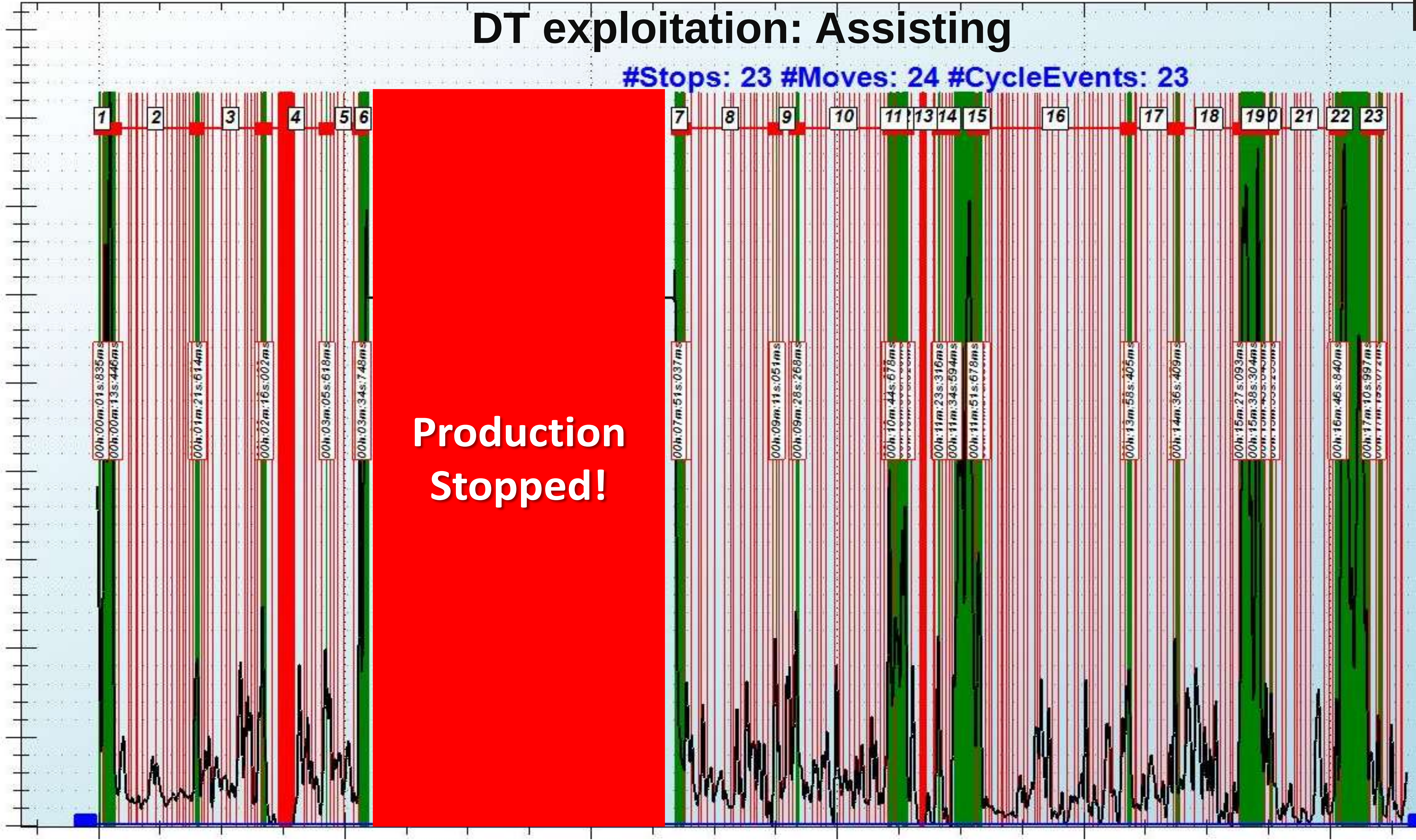
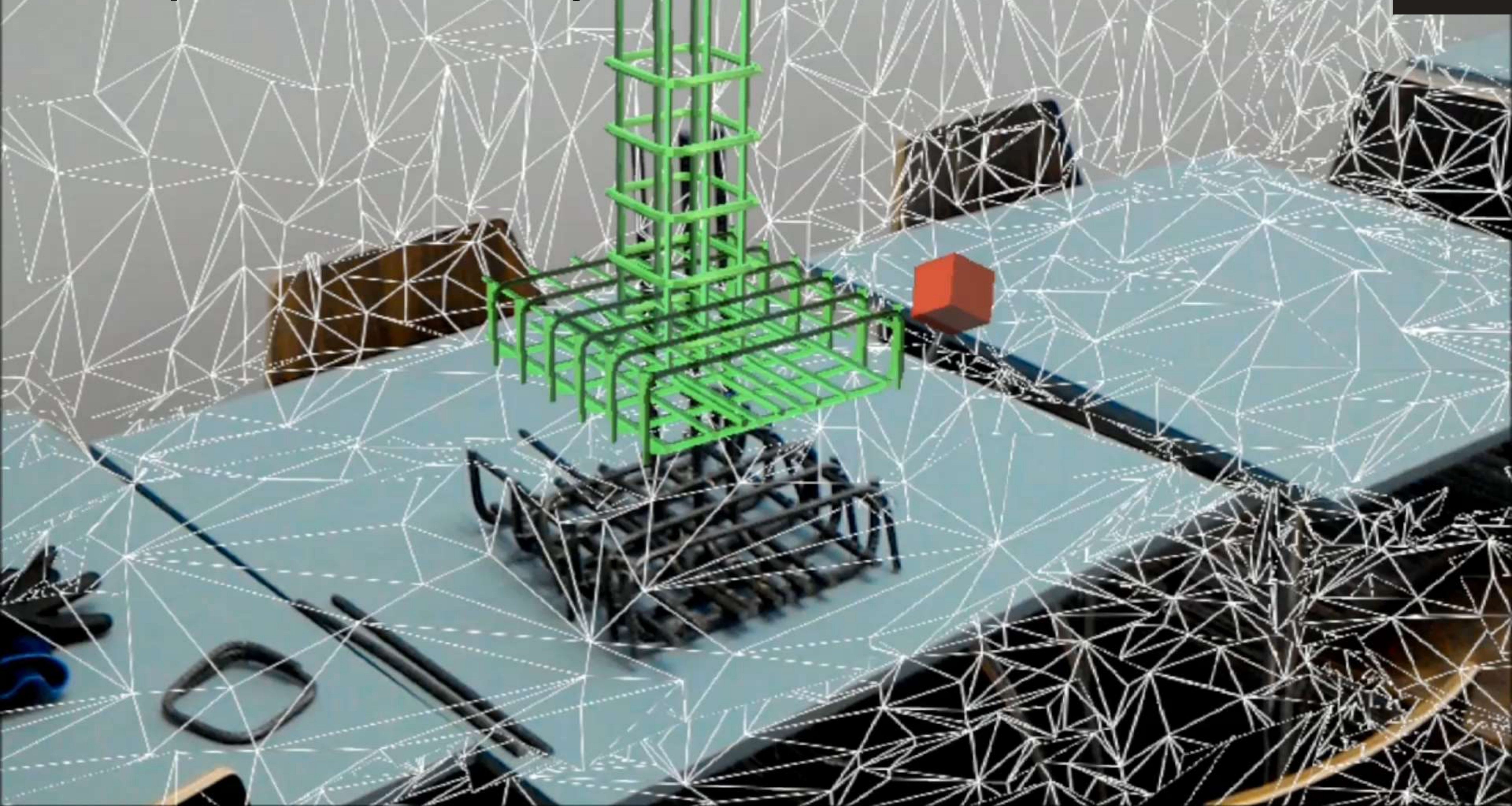
EPSRC
Pioneering research and skills

DT exploitation: Assisting



EPSRC
Pioneering research and skills

DT exploitation: Assisting



DT exploitation: Assisting ++: robotic teleoperation

Real Worker

Visual/Haptic Feedback

Motion Capture

Virtual Worker

Environment Sensing

Remote Control

DT exploitation: O&M Phase (MR)

DT exploitation: O&M Phase (MR)

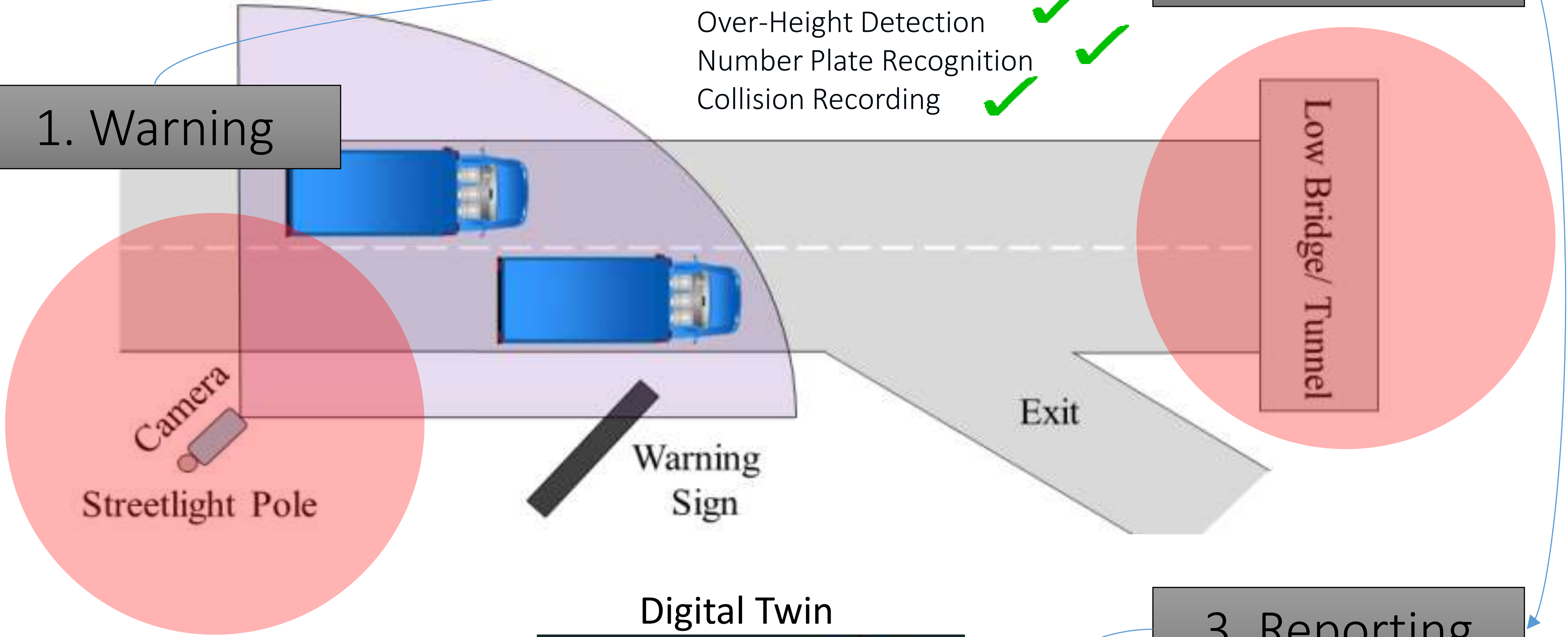
DT exploitation: O&M Phase (VR)

DT exploitation: Asset protection

1. Warning

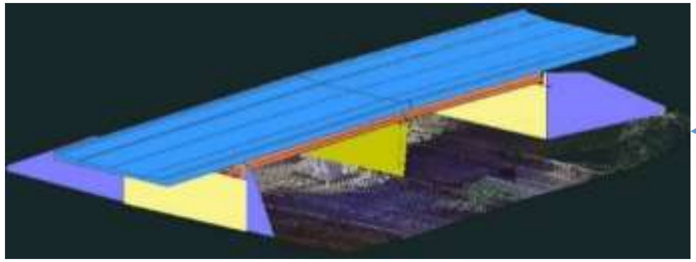
2. Detection

Over-Height Detection ✓
Number Plate Recognition ✓
Collision Recording ✓



3. Reporting

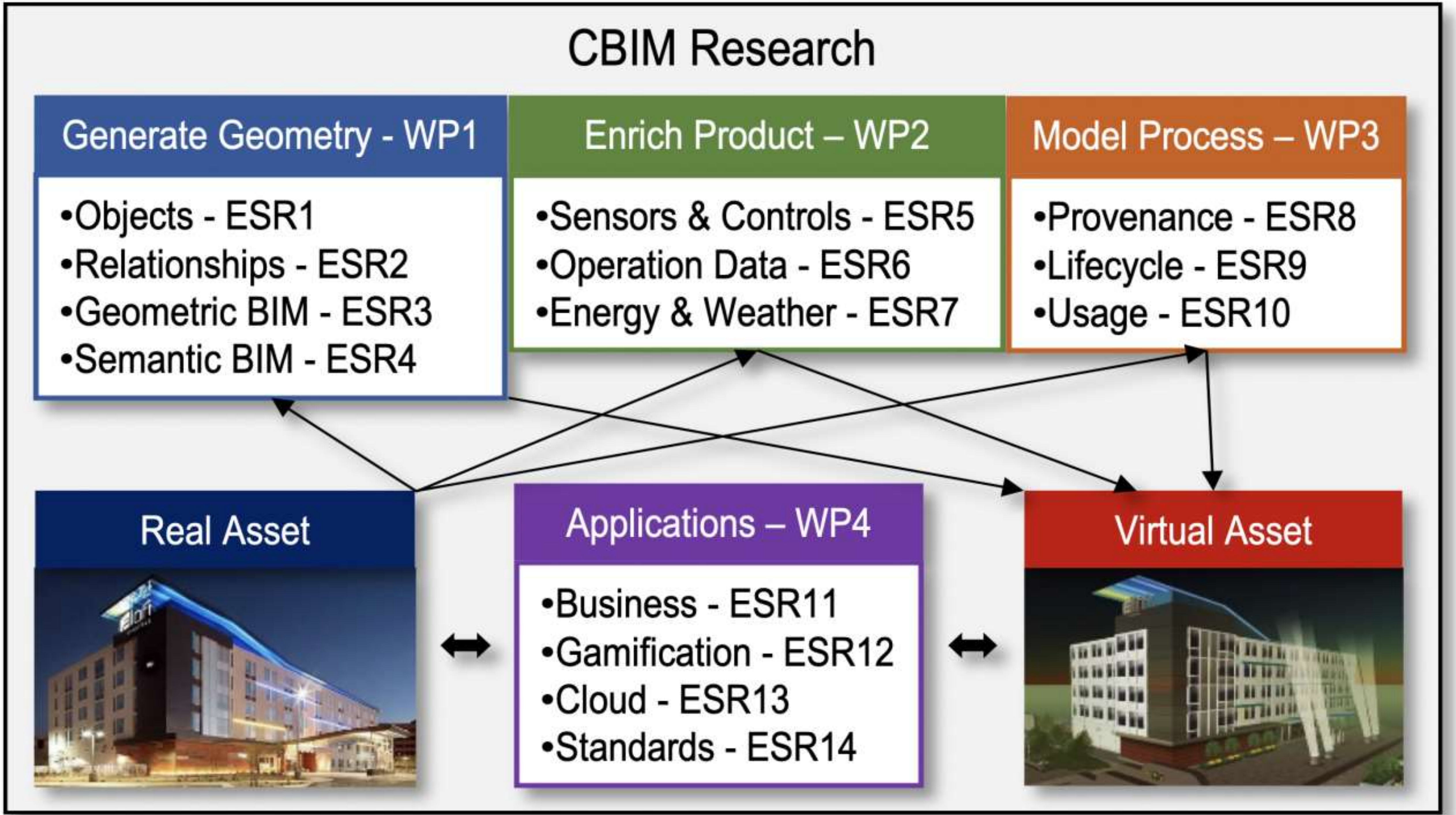
Digital Twin

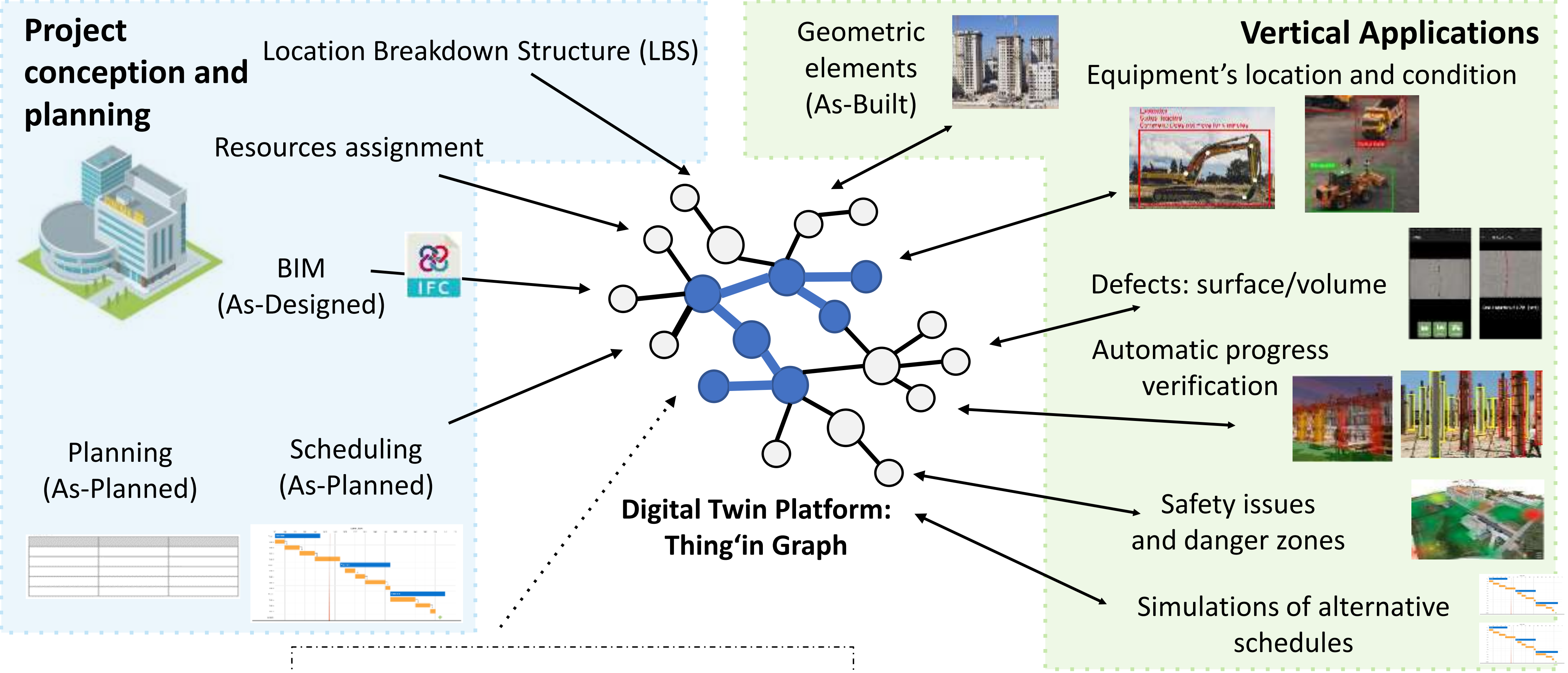


DT exploitation: Asset protection

Height Error ±2.9mm

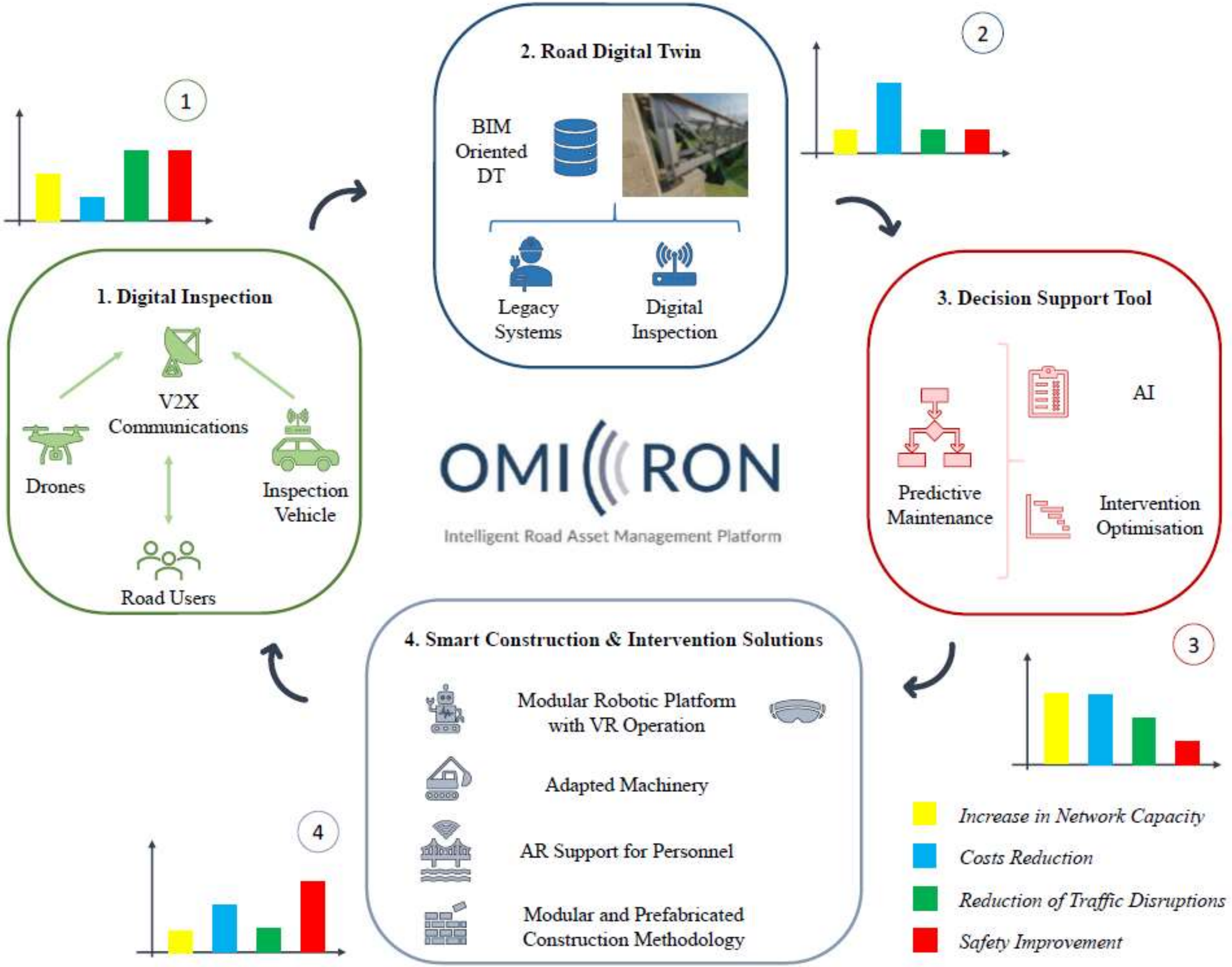
Detection Accuracy 91%


CBIM Research
Generate Geometry - WP1
•Objects - ESR1
•Relationships - ESR2
•Geometric BIM - ESR3
•Semantic BIM - ESR4
Enrich Product – WP2
•Sensors & Controls - ESR5
•Operation Data - ESR6
•Energy & Weather - ESR7
Model Process – WP3
•Provenance - ESR8
•Lifecycle - ESR9
•Usage - ESR10
Real Asset
Applications – WP4
•Business - ESR11
•Gamification - ESR12
•Cloud - ESR13
•Standards - ESR14
Virtual Asset

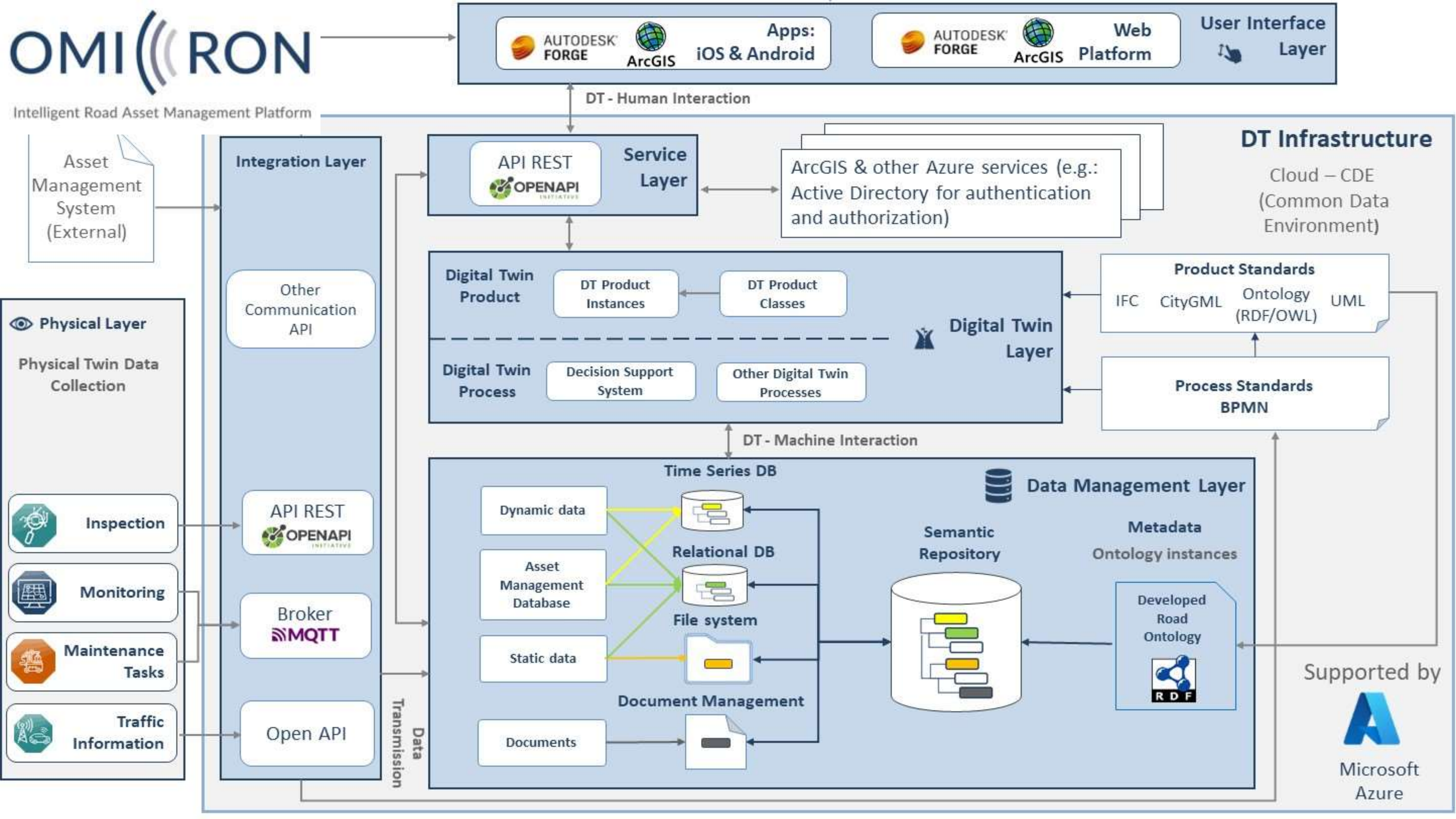


In the future: historical BIM data for improving

OMICRON



1
1. Digital Inspection
V2X Communications
Drones
Inspection Vehicle
Road Users
2. Road Digital Twin
BIM Oriented DT
Legacy Systems
Digital Inspection
2
3. Decision Support Tool
Predictive Maintenance
AI
Intervention Optimisation
3
4. Smart Construction & Intervention Solutions
Modular Robotic Platform with VR Operation
Adapted Machinery
AR Support for Personnel
Modular and Prefabricated Construction Methodology
4
OMICRON
Intelligent Road Asset Management Platform
Increase in Network Capacity
Costs Reduction
Reduction of Traffic Disruptions
Safety Improvement



OMICRON
Intelligent Road Asset Management Platform
AUTODESK FORGE
ArcGIS
Apps: iOS & Android
Web Platform
User Interface Layer
DT - Human Interaction
DT Infrastructure
Cloud – CDE (Common Data Environment)
Asset Management System (External)
Integration Layer
API REST
OPENAPI
Service Layer
ArcGIS & other Azure services (e.g.: Active Directory for authentication and authorization)
Other Communication API
Digital Twin Product
DT Product Instances
DT Product Classes
Digital Twin Layer
Digital Twin Process
Decision Support System
Other Digital Twin Processes
Product Standards
IFC
CityGML
Ontology (RDF/OWL)
UML
Process Standards BPMN
Physical Layer
Physical Twin Data Collection
DT - Machine Interaction
Time Series DB
Data Management Layer
Dynamic data
Relational DB
Asset Management Database
Semantic Repository
Metadata
Ontology instances
File system
Static data
Developed Road Ontology
RDF
Inspection
Monitoring
Maintenance Tasks
Traffic Information
Broker
MQTT
Open API
Data Transmission
Document Management
Documents
Supported by
Microsoft Azure

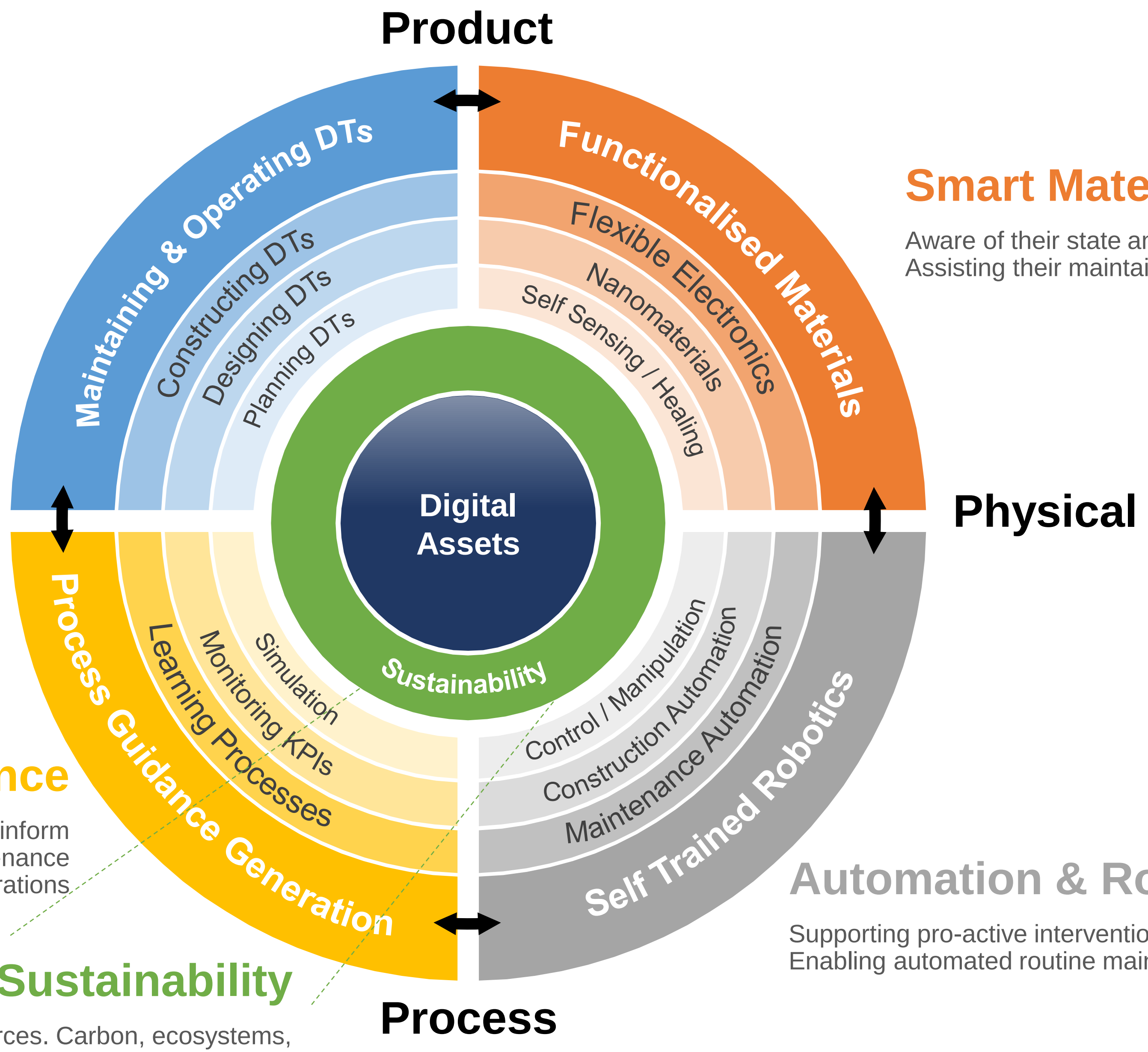
Vision

Digital Twins

Setting the foundations for
asset lifecycle management

Smart Materials

Aware of their state and properties
Assisting their maintainers & users



Data Science

Data driven insight to inform
design, construction, maintenance
and operations

Automation & Robotics

Supporting pro-active interventions
Enabling automated routine maintenance

Sustainability

Of Human & Natural Resources. Carbon, ecosystems,
hazards, lifecycle impacts

Infrastructure Computer Vision

Ioannis Brilakis and Carl Haas

Infrastructure Computer Vision presents computer vision and scene understanding methods that exploit machine learning and data science for collecting civil, industrial, and building infrastructure real-world data, analyzing it into useful information, and fusing the information to generate knowledge. It provides design, construction, and operation/maintenance professionals and students with the technical details for how to apply such techniques to generate and enrich Digital Twins of buildings and infrastructure, to automate processes, and to streamline the management of assets.

Written by two authors with a combined 50 years' experience in the field, ***Infrastructure Computer Vision*** encapsulates all possible applications of computer vision for civil infrastructure. This book is invaluable for professionals and students in built environment disciplines: asset owners, designers, engineers, contractors, subcontractors, and asset operators/maintainers.

Key Features

- Explains how to best capture raw geometrical and visual data from infrastructure scenes and assess their quality
- Offers valuable insights on how to convert the raw data into actionable information and knowledge stored in Digital Twins
- Bridges the gap between the theoretical aspects and real-life applications of computer vision

About the Authors

Ioannis Brilakis completed his PhD in Civil Engineering at the University of Illinois, Urbana Champaign in 2005. He then worked as an Assistant Professor at the Departments of Civil and Environmental Engineering, University of Michigan (2005-2008) and Georgia Institute of Technology (2008-2012) before moving to Cambridge in 2012 as a Laing O'Rourke Lecturer. He was promoted to University Reader in October 2017. Dr Brilakis is an author of over 190 papers in peer-reviewed journals and conference proceedings, an Associate Editor of the ASCE Computing in Civil Engineering, ASCE Construction Engineering and Management, Elsevier Automation in Construction, and Elsevier Advanced Engineering Informatics Journals, and the past chair of the Board of Directors of the European Council on Computing in Construction.

He has been a recipient of the 2019 ASCE J. James R. Croes Medal, the 2018 ASCE John O. Bickel Award, the 2013 ASCE Collingwood Prize, the 2012 Georgia Tech Outreach Award, the NSF CAREER award, and the 2009 ASCE Associate Editor Award.

Carl Thomas Michael Haas completed his PhD in Civil Engineering at Carnegie Mellon University in 1990. He then went on to become assistant Professor at the University of Texas at Austin before becoming a full Professor at the University in 2002. From 2005, Dr Haas has been working as a Professor and Research Chair at the University of Waterloo. Dr Haas serves on a number of editorial boards and on professional committees for organizations such as the American Society of Civil Engineers (ASCE), the Natural Sciences and Engineering Research Council (NSERC) of Canada, and the International Association for Automation and Robotics in Construction (IAARC).

His accomplishments include being elected to the US National Academy of Construction as well as the Canadian Academy of Engineering, receiving the 2014 CSCE (Canadian Society of Civil Engineers) Walter Shanly Award for outstanding contributions to the development and practice of construction engineering in Canada and being awarded the 2015 ASCE Peurifoy Construction Research Award—the premier international career award in construction research. He also received the 2017 University of Waterloo Award of Excellence in Graduate Supervision, the 2019 ASCE Computing in Civil Engineering Award, and the 2019 CSCE Alan Russell Award.

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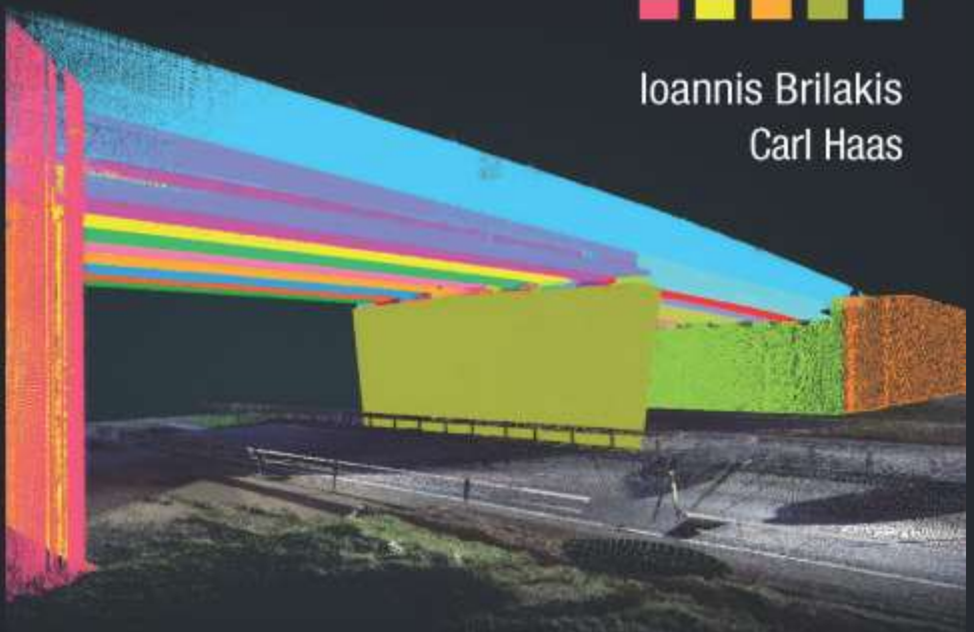
Infrastructure Computer Vision

Brilakis Haas

Infrastructure Computer Vision

Ioannis Brilakis
Carl Haas



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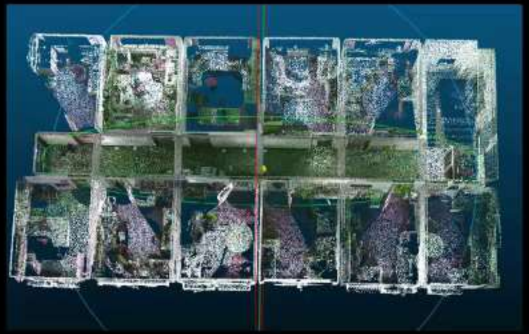
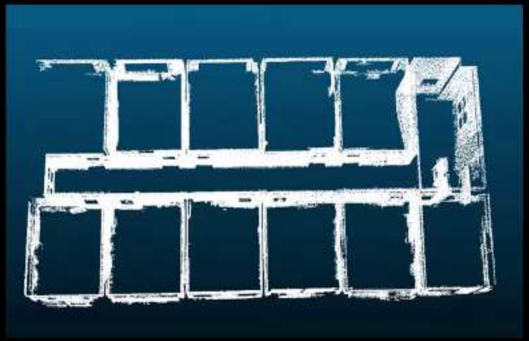
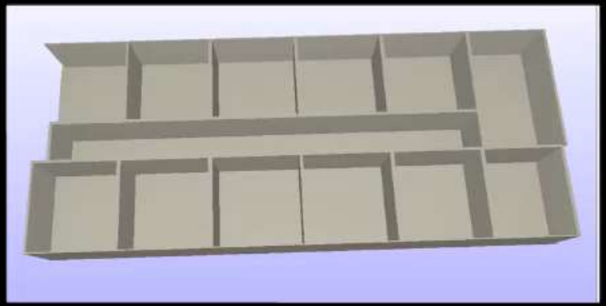
Automated Modelling of Point Clouds and Enrichment with Space Detection



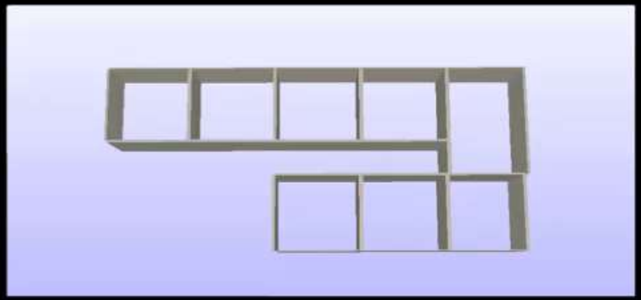
Scan



Classify



Model



Enrich

Thank you!
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