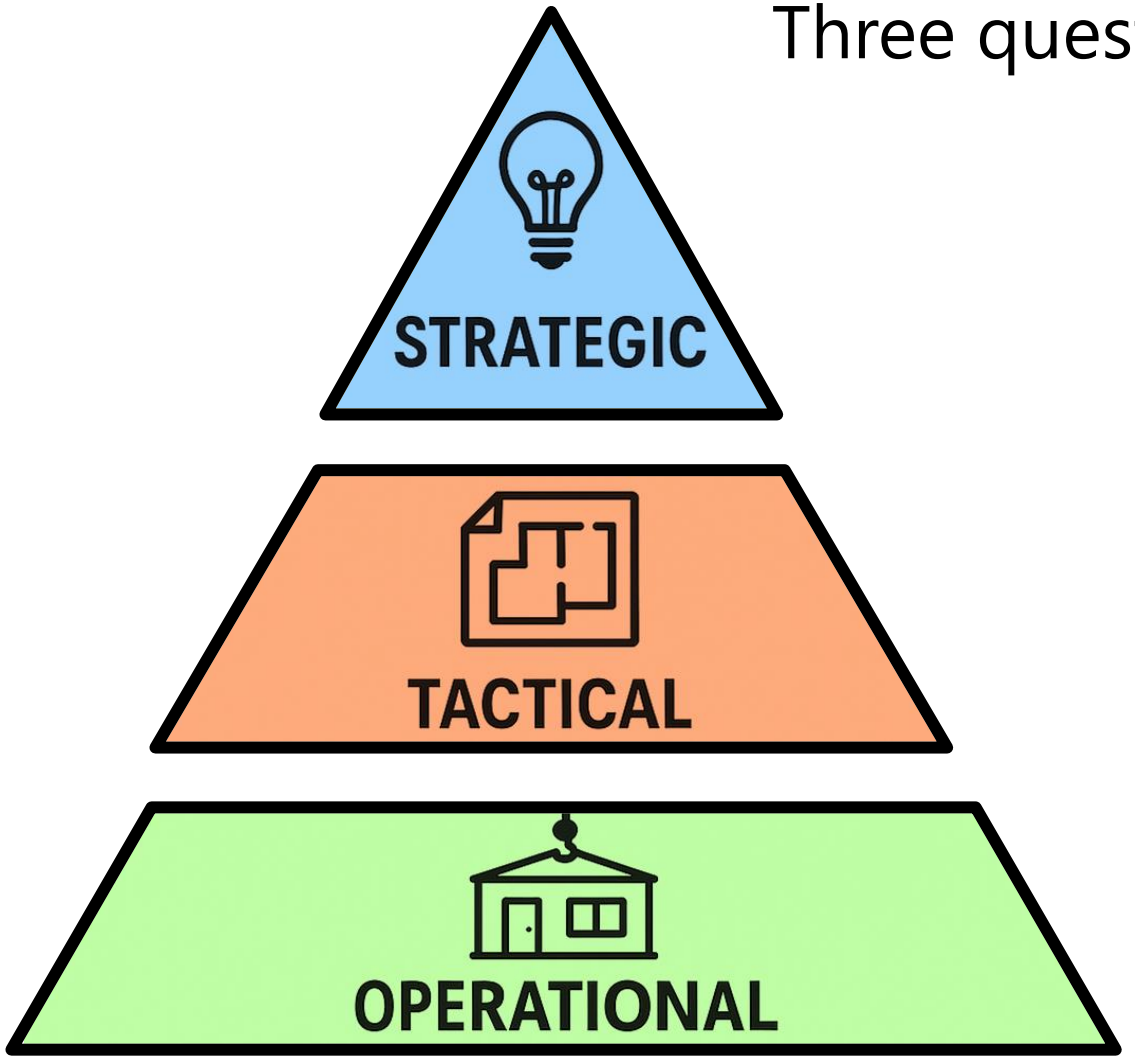
Digital Systems for Product-Process Integration in Industrialized Construction

Daniel Hall, Irfan Čustović

02.07.2025
MTC Coventry, UK

Three questions that keep you awake at night…

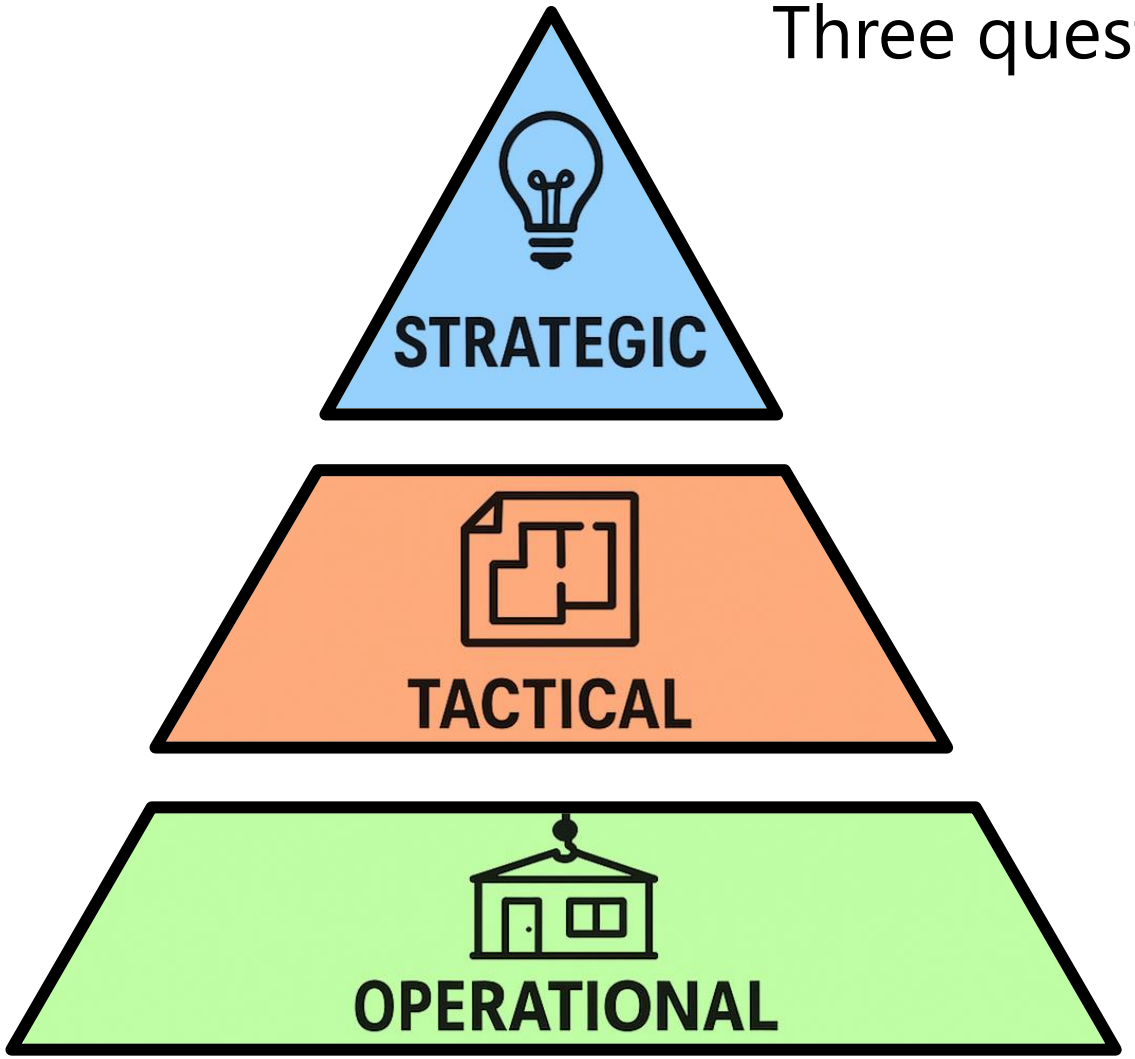


What business model to choose?

How to build what we design?

How to manage uncertainty in complex production?

Three questions that keep you awake at night…



What business model to choose?

How to build what we design?

How to manage uncertainty in complex production?

Over the next 5 years, we think the further integration of digital systems will change the answer to these questions

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Phd Researcher

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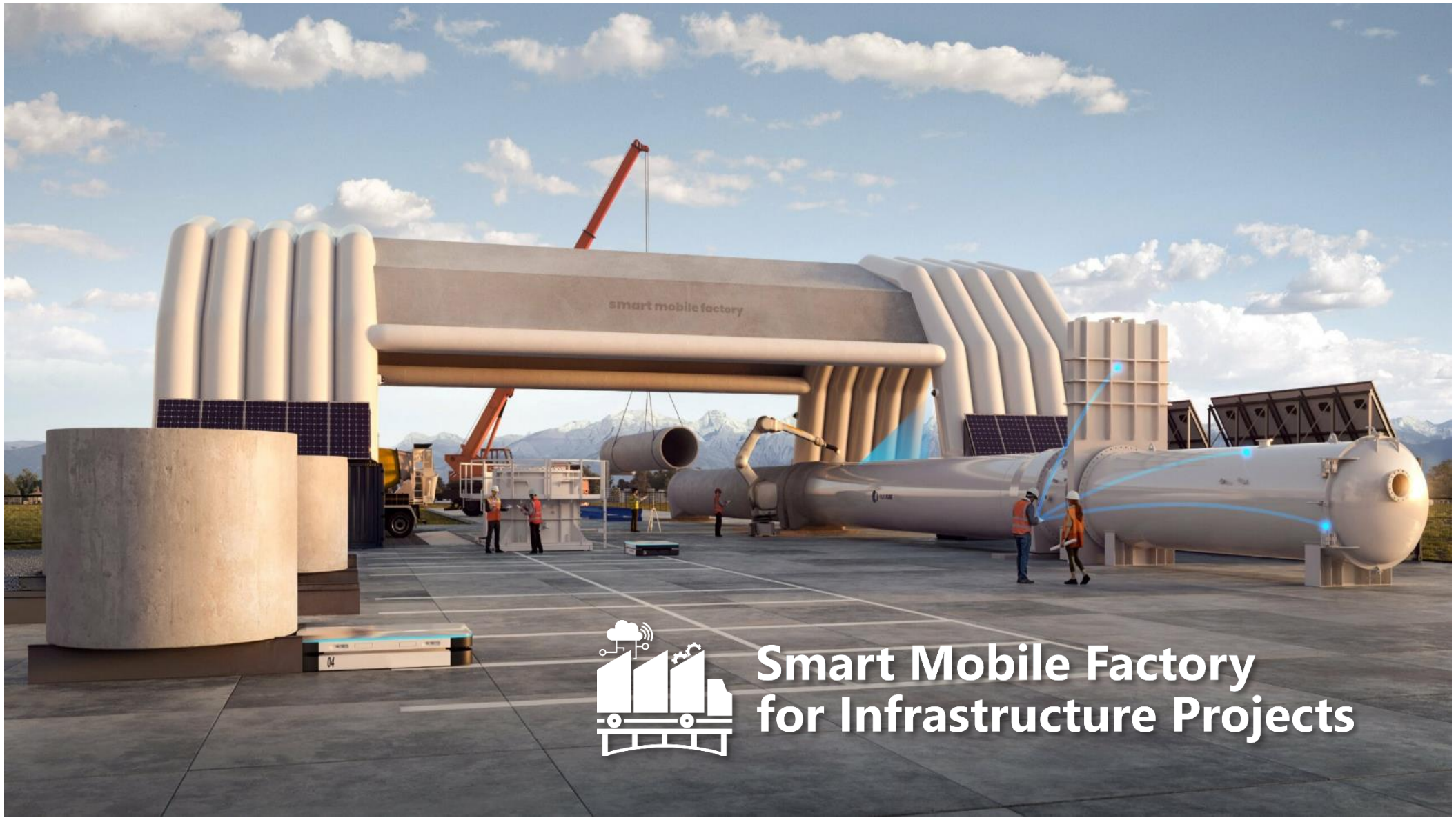

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Smart

Mobile

Factory

Smart factory digitally represents the physical manufacturing systems, enabling a bi-directional flow of data for advanced planning, simulation and on-demand production

Mobile factory can be described as a distributed production facility…

- Composed of reconfigurable and mobile production systems
- That facilitates the adjustment of production capacity and functionality according to on-site conditions

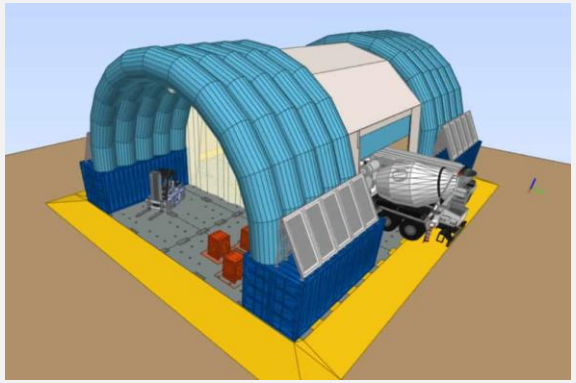
? **How should smart mobile factories be designed to supply infrastructure projects in an economic and environmentally-friendly way?**

DemoTube test track facility
near Zürich, Switzerland

euroTUBE

What are we trying to achieve?

Smart Mobile Factory for Infrastructure Projects



Factory Design

Factory Digital Twin

Sustainable factory

Business model

Tackling *operational* challenges

with digital systems

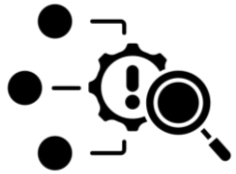
Digital systems for actionable insights in IC

What is happening?

Descriptive

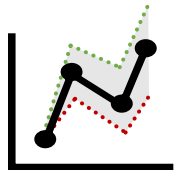
Why is it happening?

Diagnostic



What will likely happen?

Predictive



How can we

develop / download / install / implement

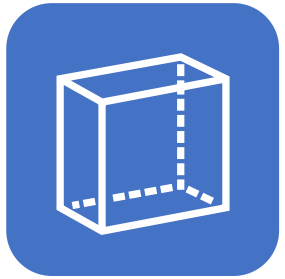
a

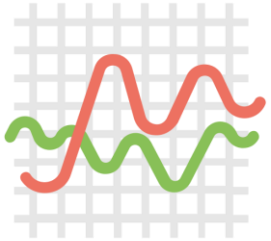
solution / app / software / digital twin

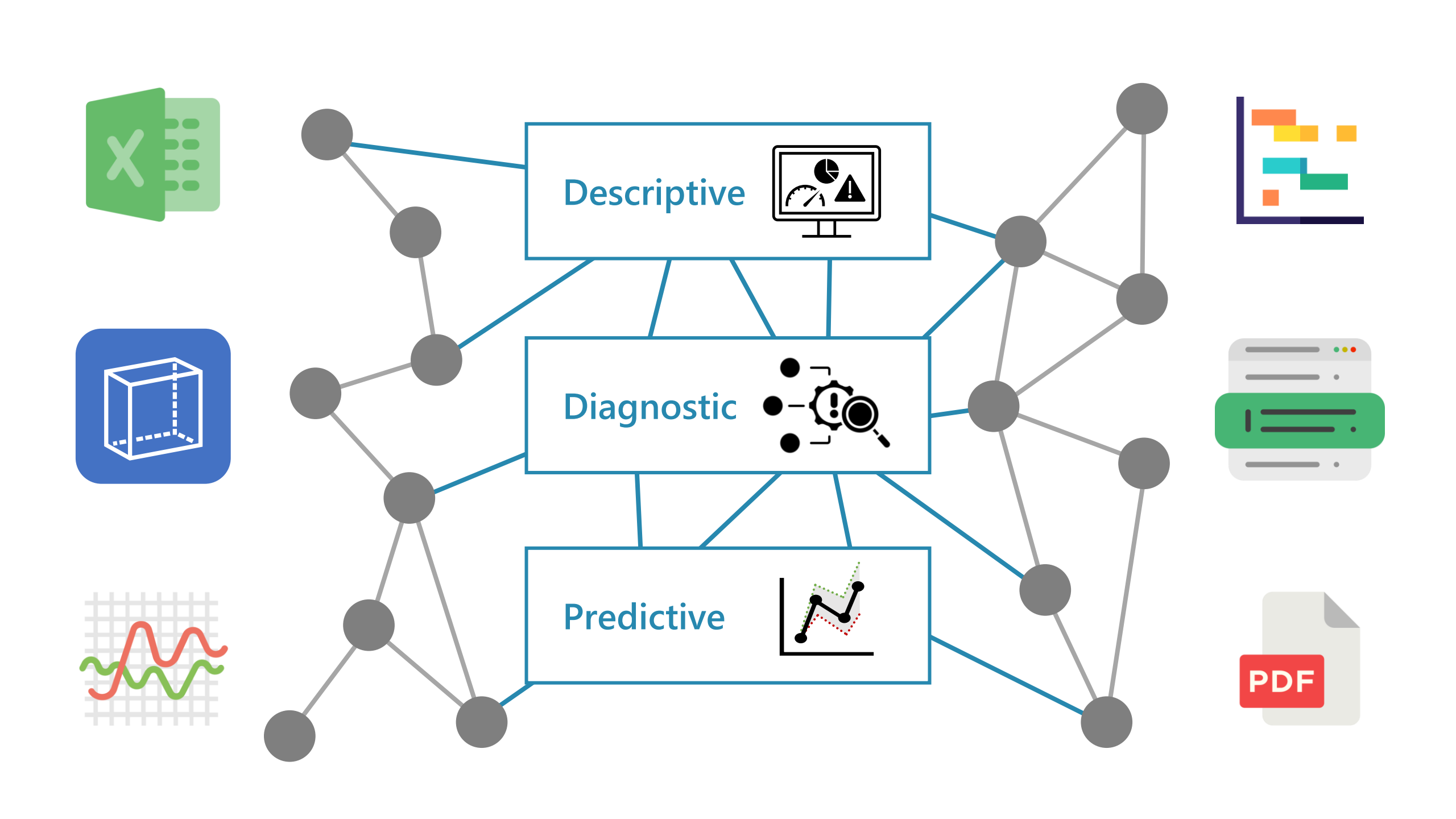
that will provide these insights?

- BIM model
- Assembly schedule
- Product catalogue
- Equipment logs
- ERP software
- Raw material certificates
- Quality management software
- MES system
- Central project server
- IoT sensor readings
- Webservice with weather data
- Custom-made scripts
- Logistics documents









Descriptive
Diagnostic
Predictive
PDF

Descriptive analytics

What is happening?

Application scenario

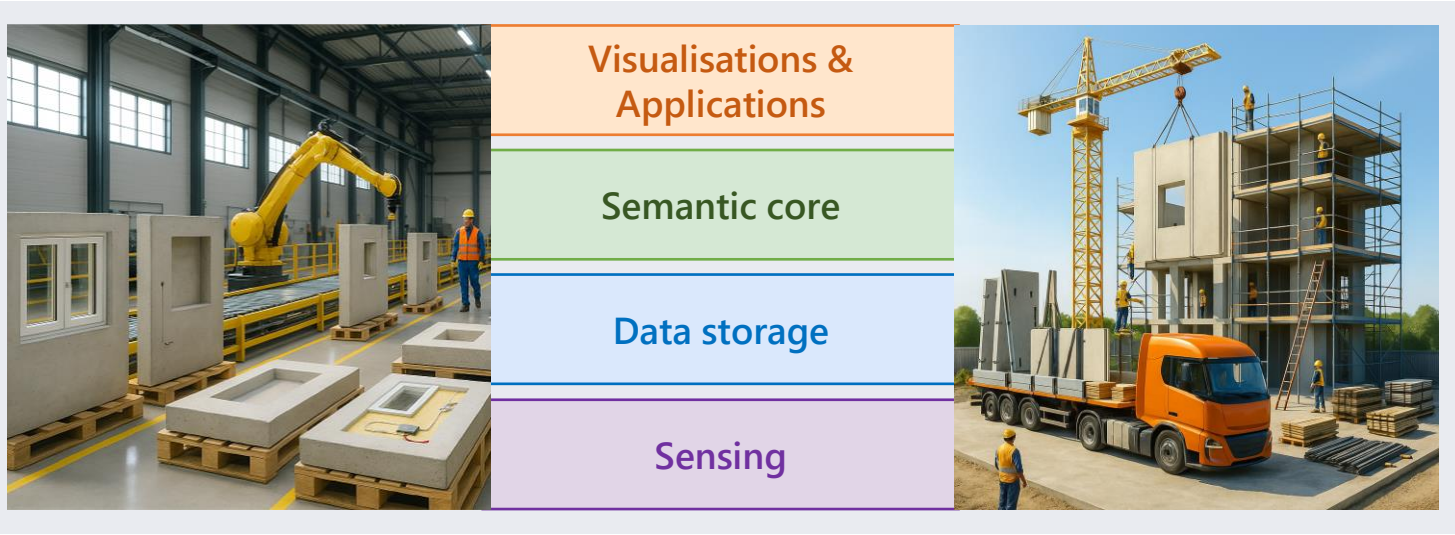
- Production and assembly processes can diverge from plans due to disruptions or execution variability
- Continuous monitoring enables timely action and reduces costly delays

Challenge

- Each discipline runs its own siloed software, formats, and data stores
- Creating an end-to-end, trustworthy view is slow and labor-intensive

Solution

- Development of a modular IT architecture covering factory and site systems
- ‚Plug and play' connection of multiple digital systems



Descriptive analytics

What is happening?

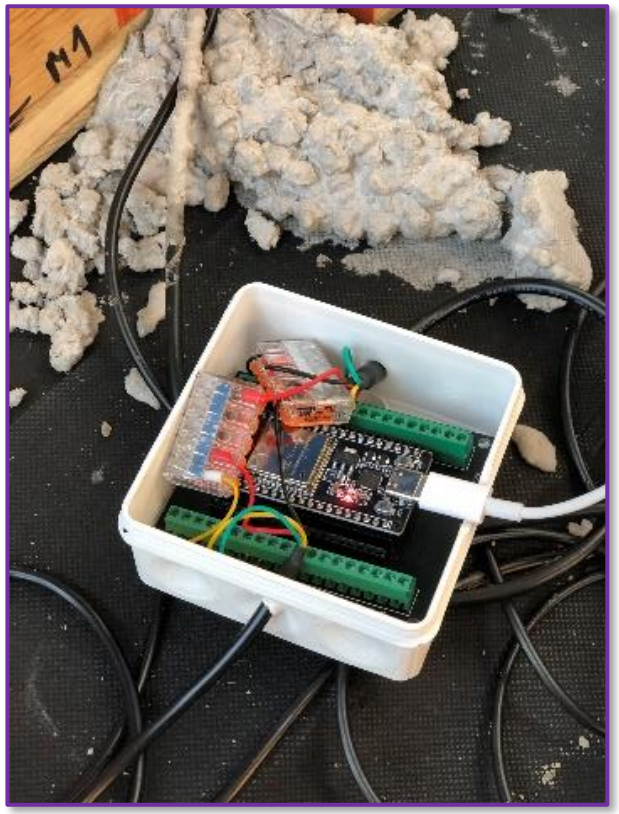
Implementation example

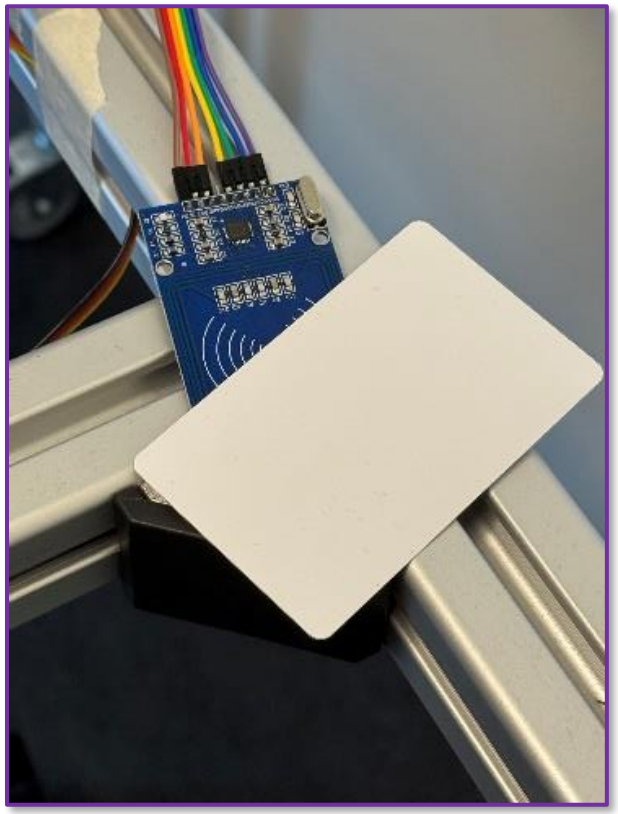
Visualisations & Applications

Semantic core

Data storage

Sensing





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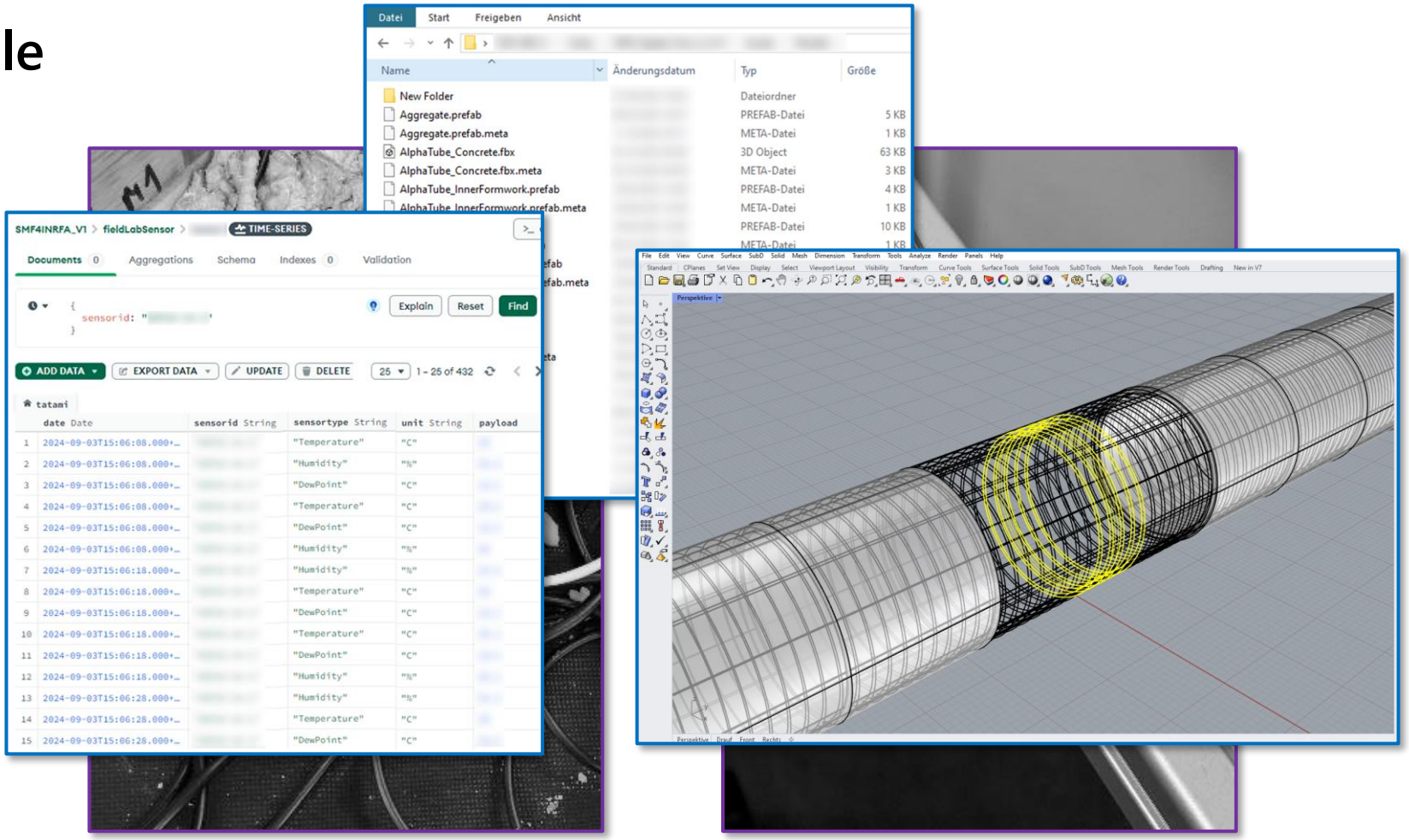

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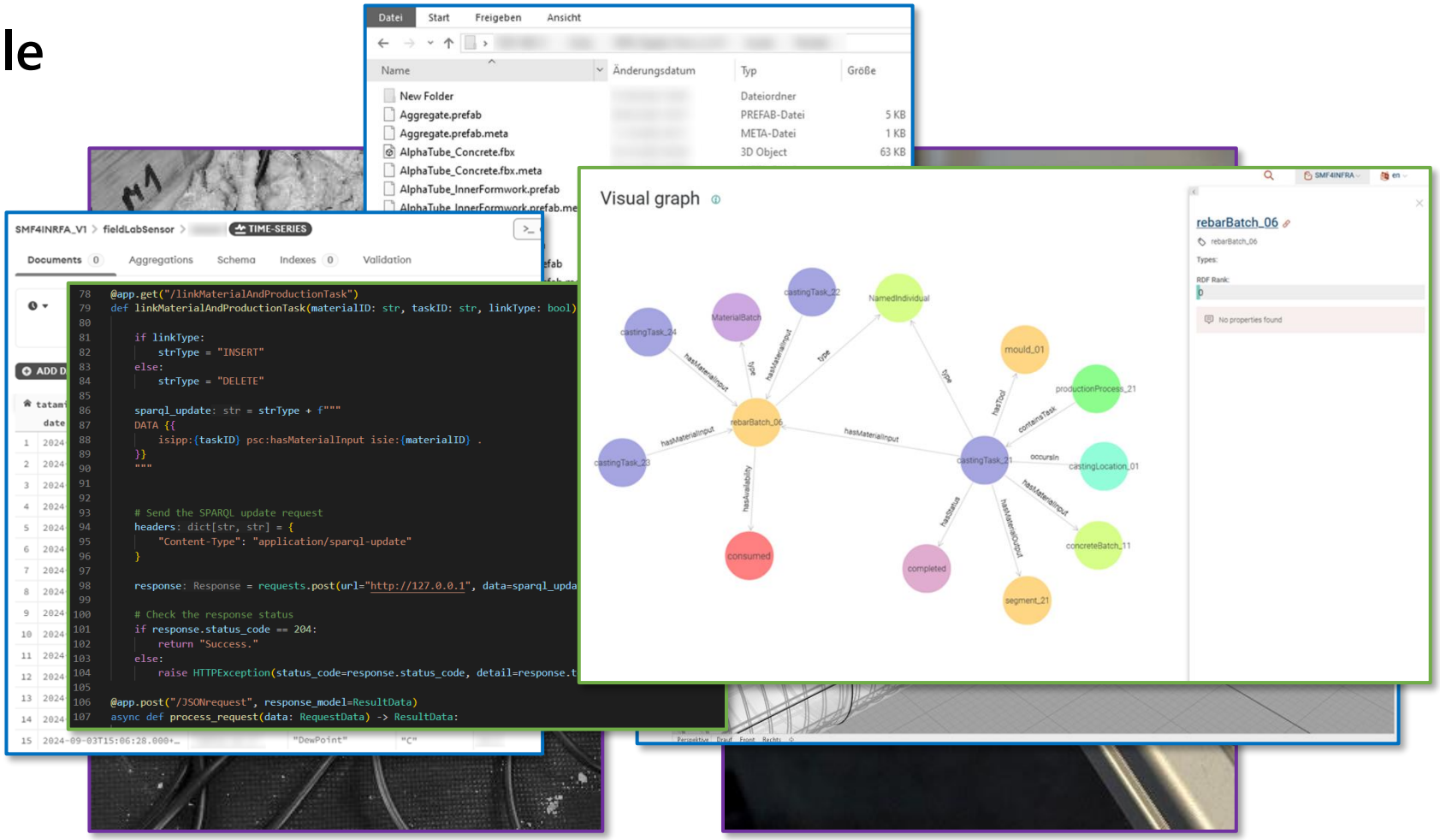

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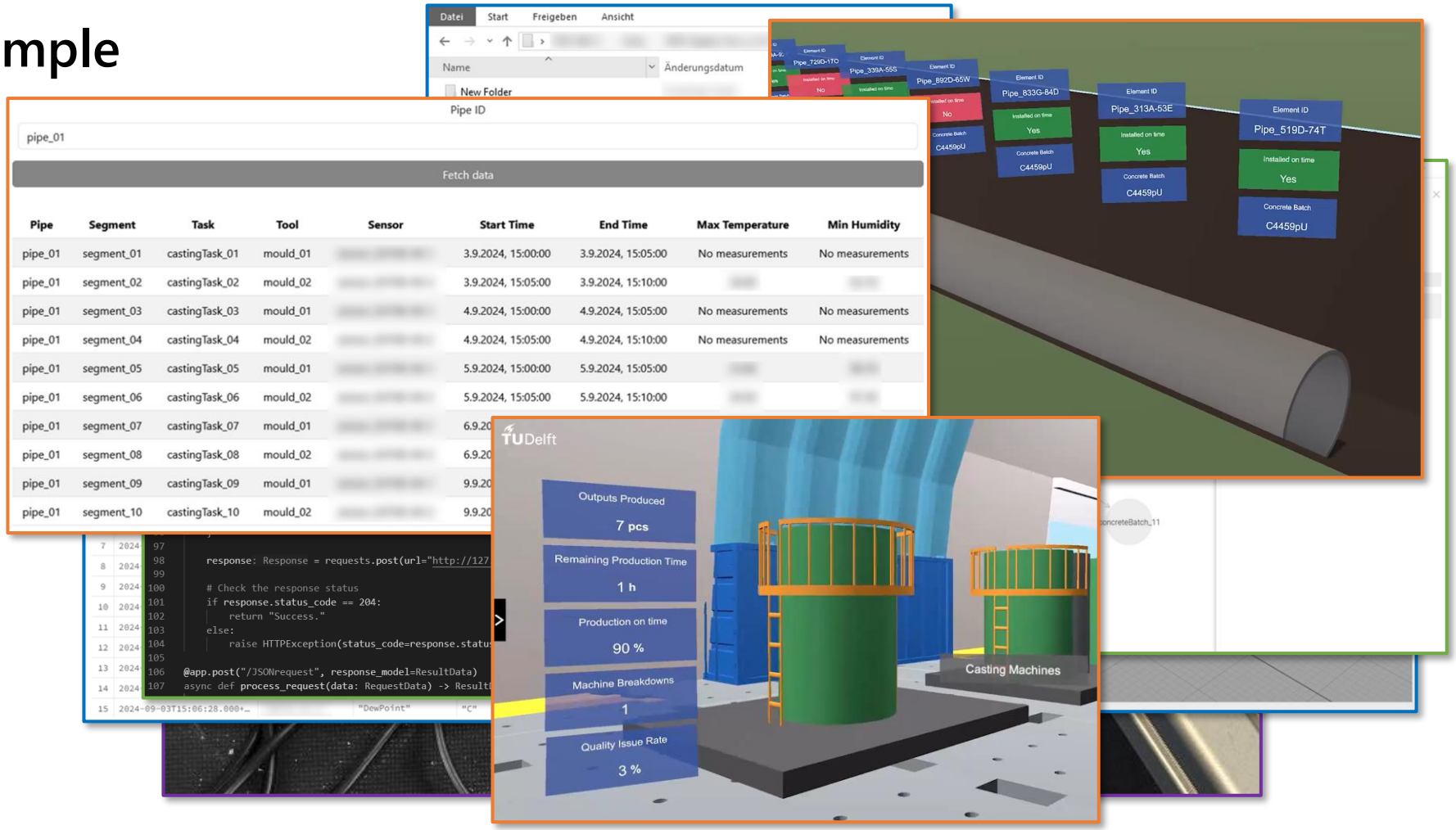


Diagnostic analytics

Why is it happening?

Application scenario

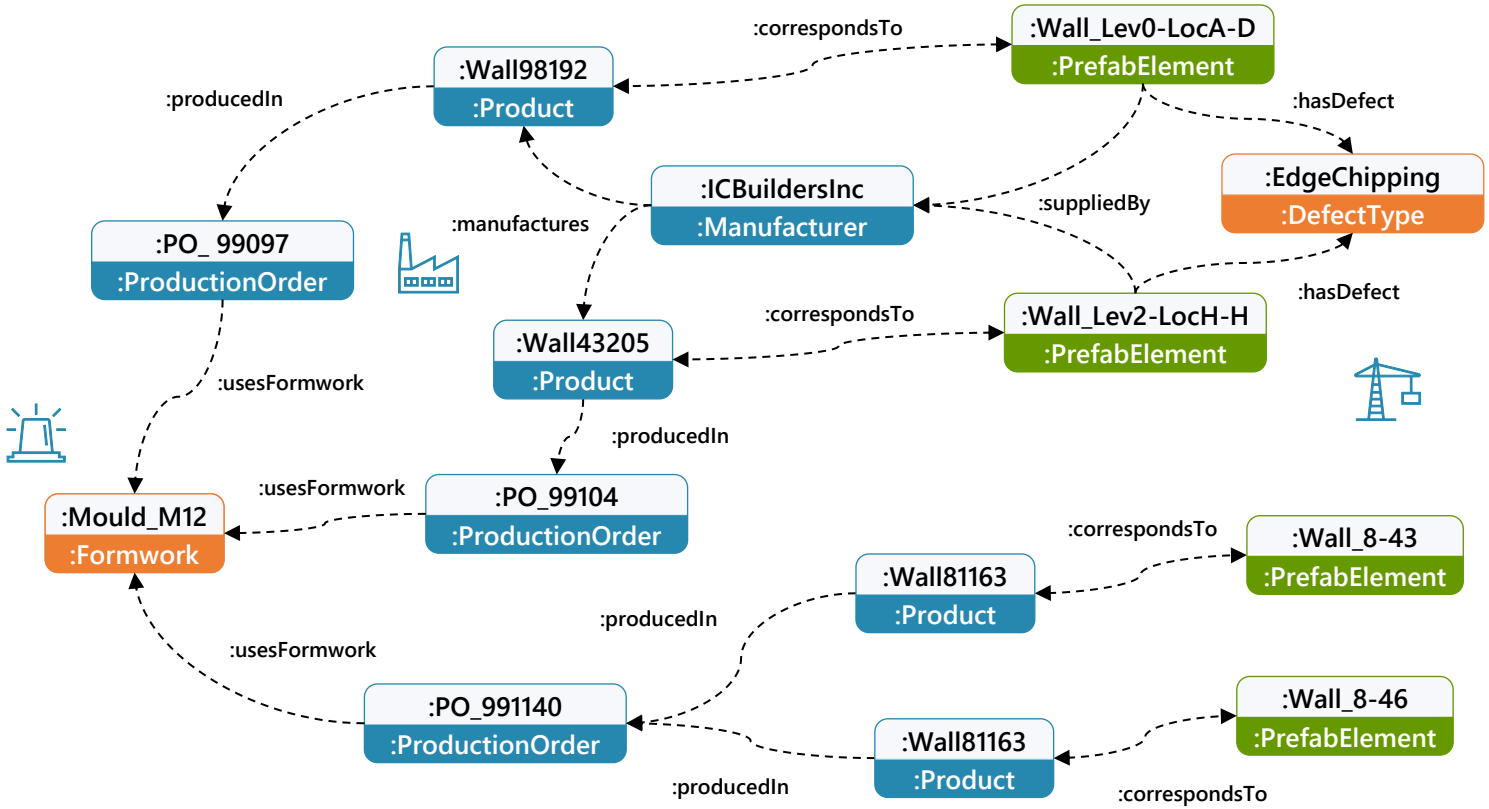
- Defects can silently propagate through modules and assemblies
- If root causes aren't quickly found, they can cause plenty of rework, delays and budget overruns

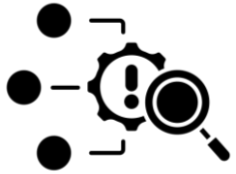
Challenge

- Product histories and process logs live in unlinked silos, blocking quick, data-driven answers when something goes wrong

Solution

- Knowledge graph-based reasoning across products and processes





Diagnostic analytics

Why is it happening?

Solution (Technical deep dive)

During onsite installation, the prefab elements *Wall_Lev0-LocA-D* and *Wall_Lev2-LocH-H* show the same type of defect: chipping at the edges.

Is there a common process parameter for both walls?

Running a single SPARQL query can provide valuable insights.

Root cause analysis

```
1  PREFIX smf: <https://www.smf4infra.net/publications/ontology/>
2
3  SELECT DISTINCT ?prefabElement ?manufacturer ?productionOrder ?formwork
4  WHERE {
5    # the prefab element and its supplier
6    ?prefabElement    smf:hasDefect      "EdgeChipping" ;
7                      smf:suppliedBy     ?manufacturer ;
8                      smf:correspondsTo  ?productionOutput .
9
10   # the manufacturer that produces that prefab element
11   ?manufacturer     smf:manufactures   ?productionOutput .
12
13   # the production order in which the element was produced
14   ?productionOutput smf:producedIn     ?productionOrder .
15   ?productionOrder  smf:usesFormwork   ?formwork .
16 }
17 ORDER BY ?prefabElement
```

Run

keyboard shortcuts

prefabElement	manufacturer	productionOrder	formwork
smf:Wall_Lev0-LocA-D	smf:ICBuildersInc	smf:PO_99097	smf:Mould_M12
smf:Wall_Lev2-LocH-H	smf:ICBuildersInc	smf:PO_99104	smf:Mould_M12

Predictive analytics

What will likely happen?

Application scenario

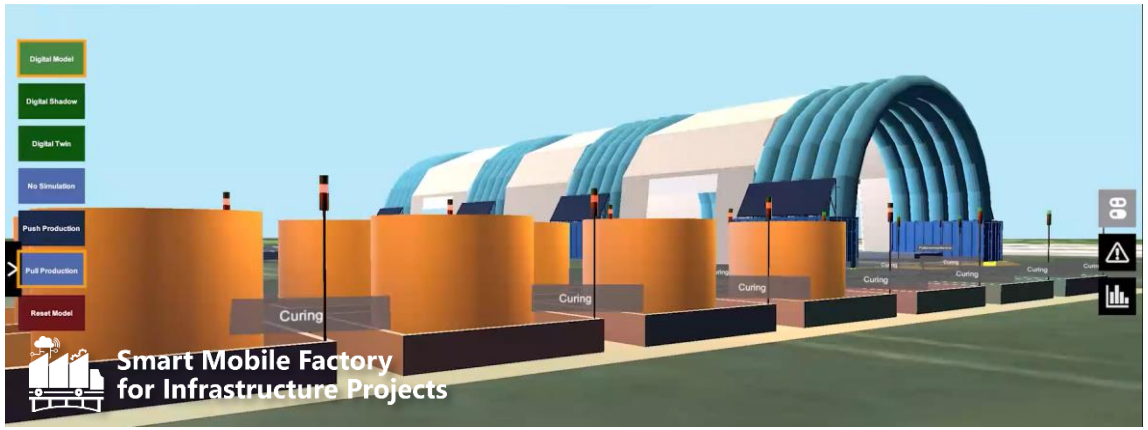
- Dynamic internal and external factors affect operations regularly
- Manager's must continuously detect potential process bottlenecks and coordination clashes

Challenge

- Simulations are promising, but currently run mostly in isolation
- They lack data on live resource availability, learning curves and supply chain fluctuations

Solution

- Digital-twin based simulations that are continuously fed with real-time and contextualized data
- Results can be visualized flexibly:
  - Key performance indicators (e.g. throughput, machine utilization, buffer sizes)
  - Virtual 3D view for intuitive understanding of process flows.



Descriptive: Real-time integration requires modular, interoperable systems

Diagnostic: Automated reasoning requires semantic understanding

Predictive: Requires mastering interoperability and semantic understanding

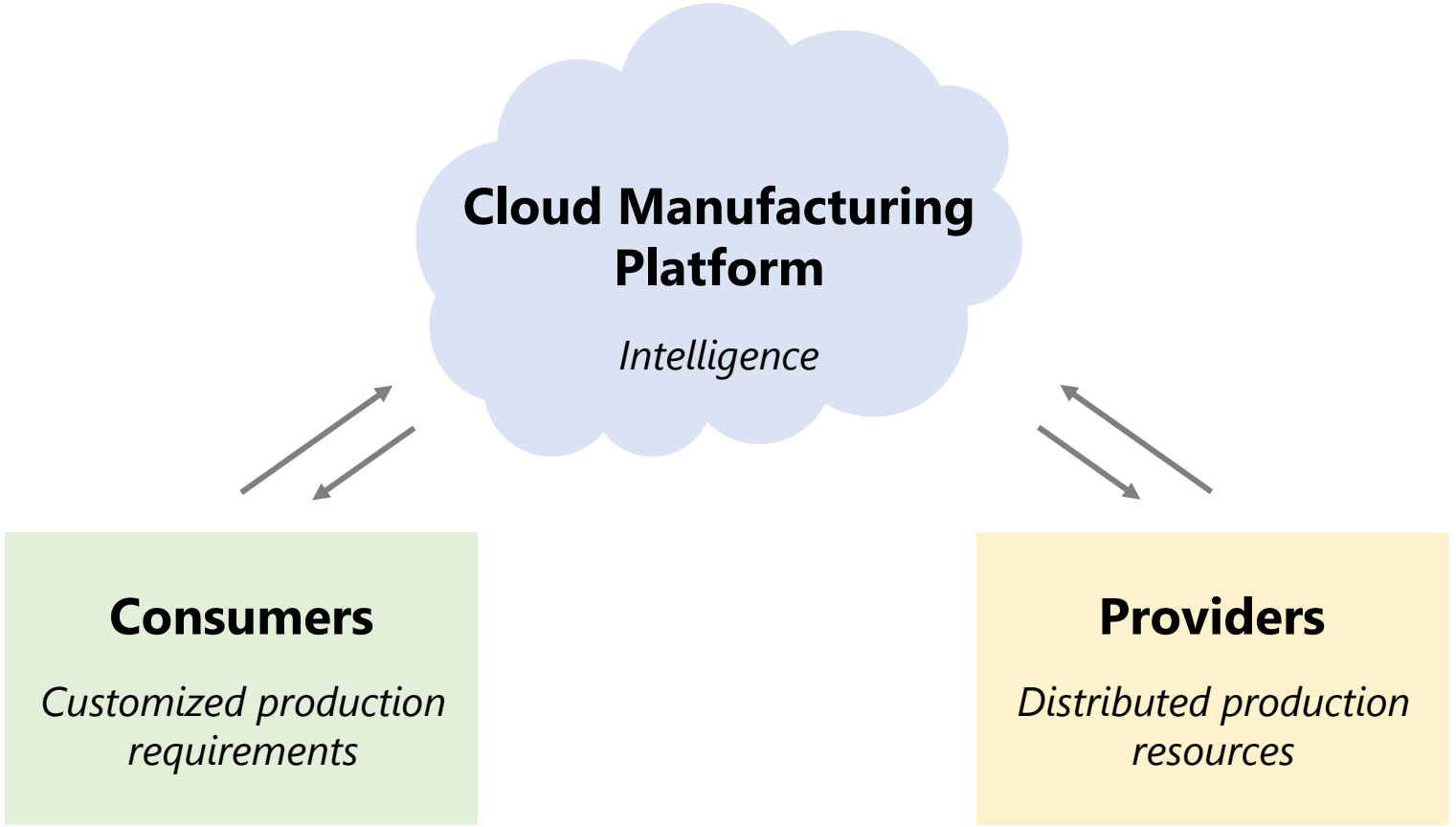
The role of integrated digital systems

Tackling *tactical* challenges

with digital systems

Cloud Manufacturing

- Networks of Manufacturing
  - large scale
  - service-oriented
  - highly collaborative
  - knowledge-intensive



Result: Dynamically configurable manufacturing supply chains

Čustović, I., Cao, J., & Hall, D. M. (2023). Cloud manufacturing for industrialized construction: Opportunities and challenges for a new manufacturing model. Journal of Infrastructure Intelligence and Resilience, 2(1), 100027.

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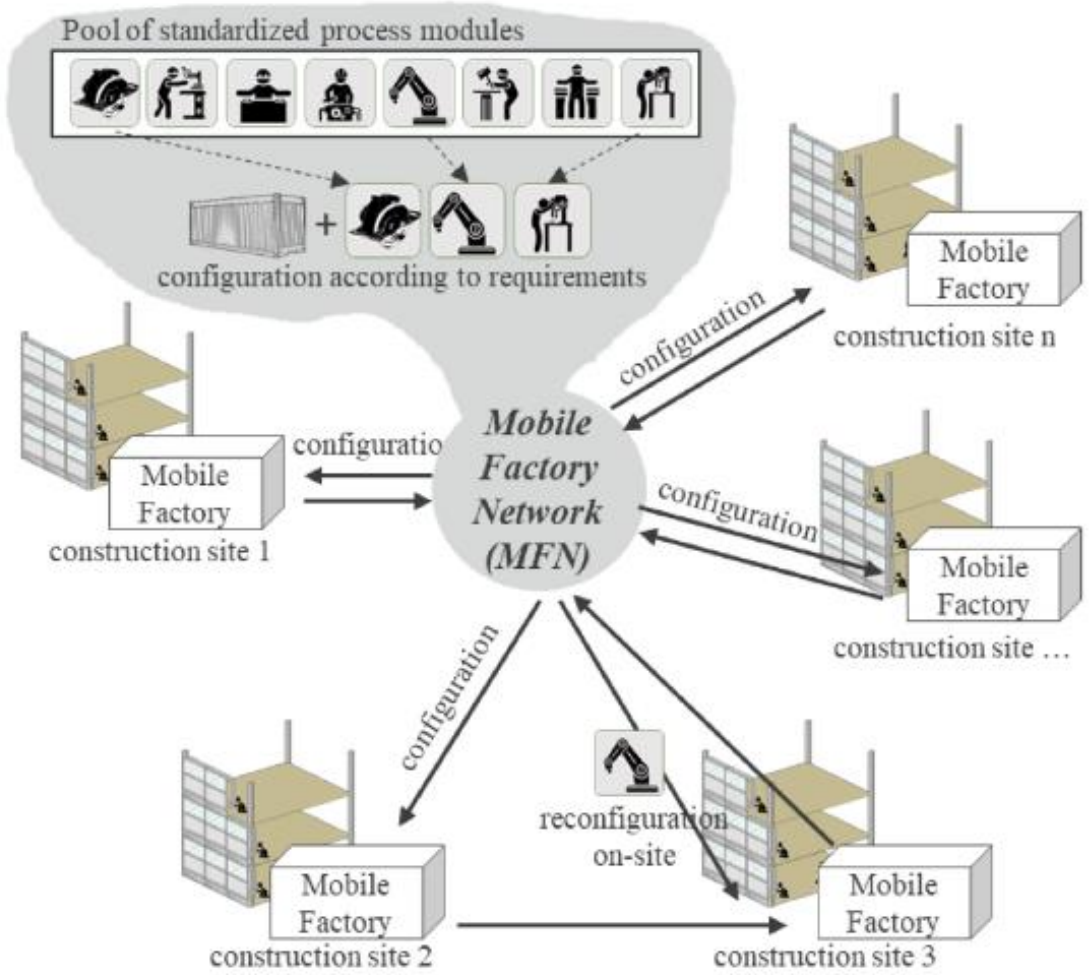
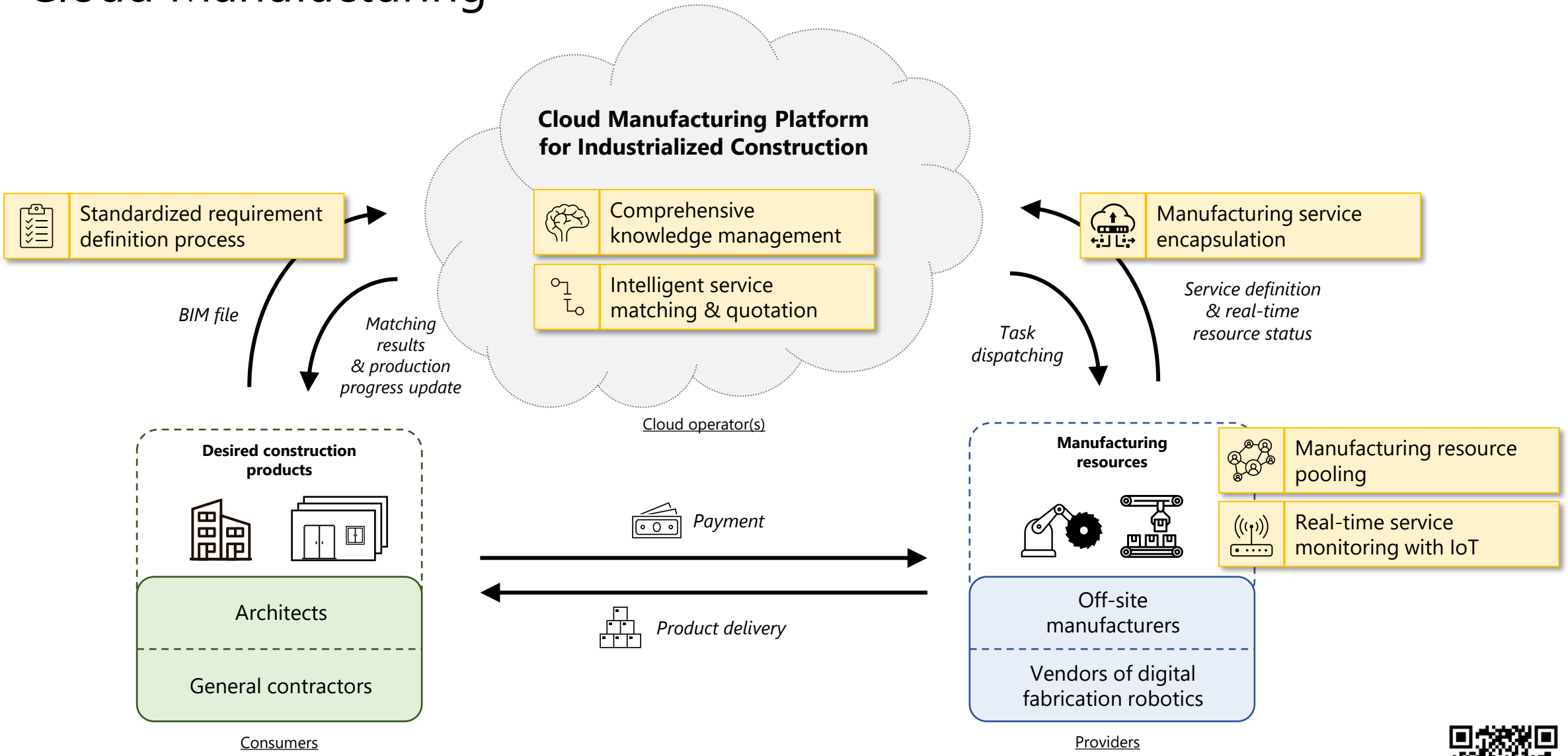


Result: Dynamically configurable manufacturing supply chains

Image Source: Rauch, E., Matt, D. T., & Dallasega, P. (2015, March). Mobile On-site Factories—Scalable and distributed manufacturing systems for the construction industry. In *2015 International Conference on Industrial Engineering and Operations Management (IEOM)* (pp. 1-10). IEEE.

Cloud Manufacturing



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Cloud Manufacturing

Supplier Selection

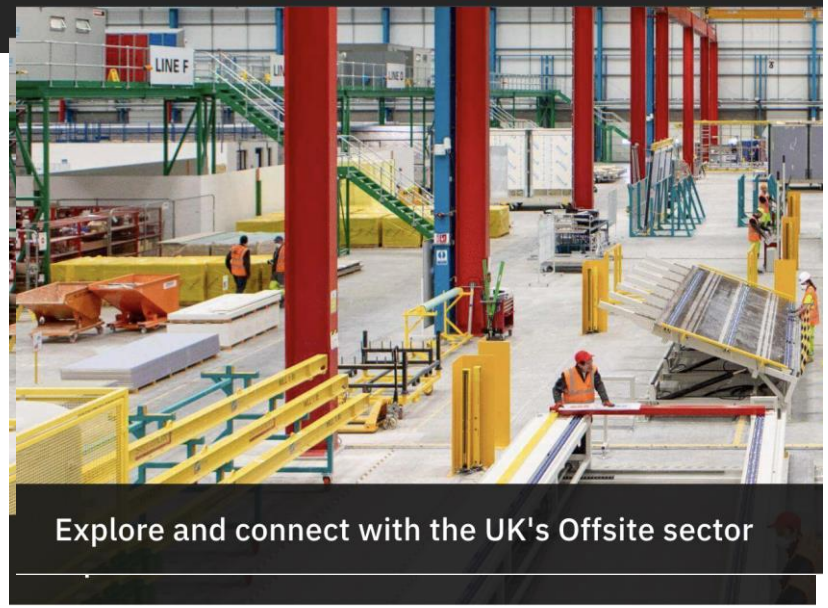
Access the largest database of prefab manufacturers worldwide. Choose the best supplier based on price, delivery time, and environmental impact, ranked to fit your project.

MOD

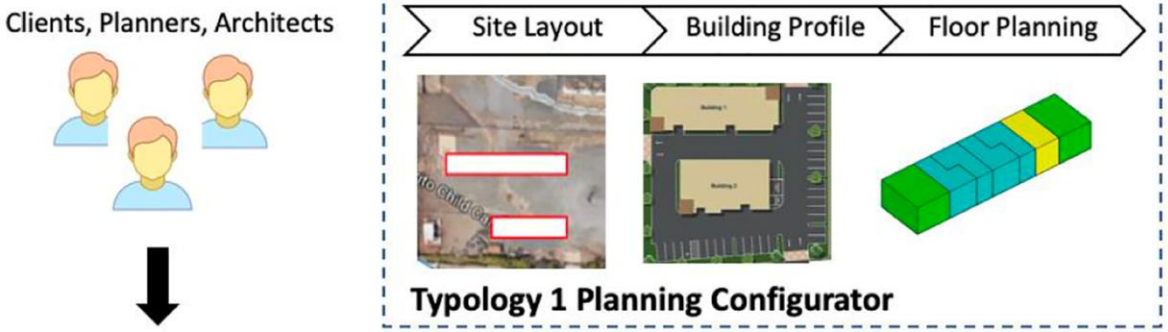
ptblink
DESIGN
MANUFACTURE
INTEGRATE

KOPE

KOPE Market



The Next Generation of Configurators



test fit.io

PRiSM

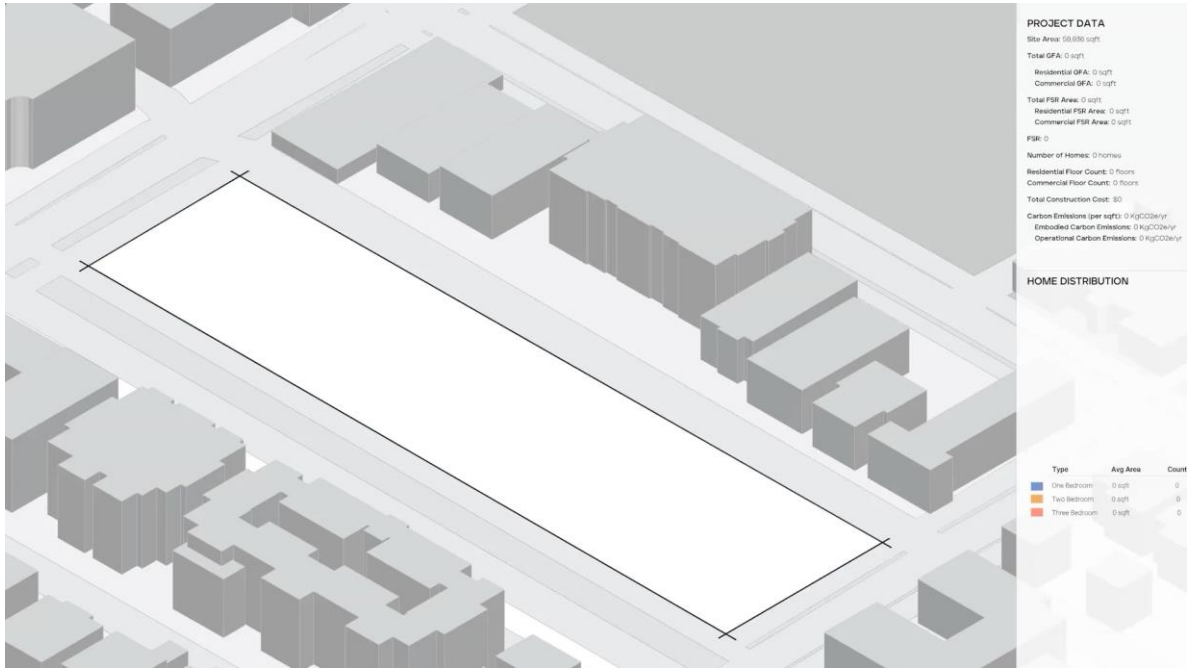
Archistar

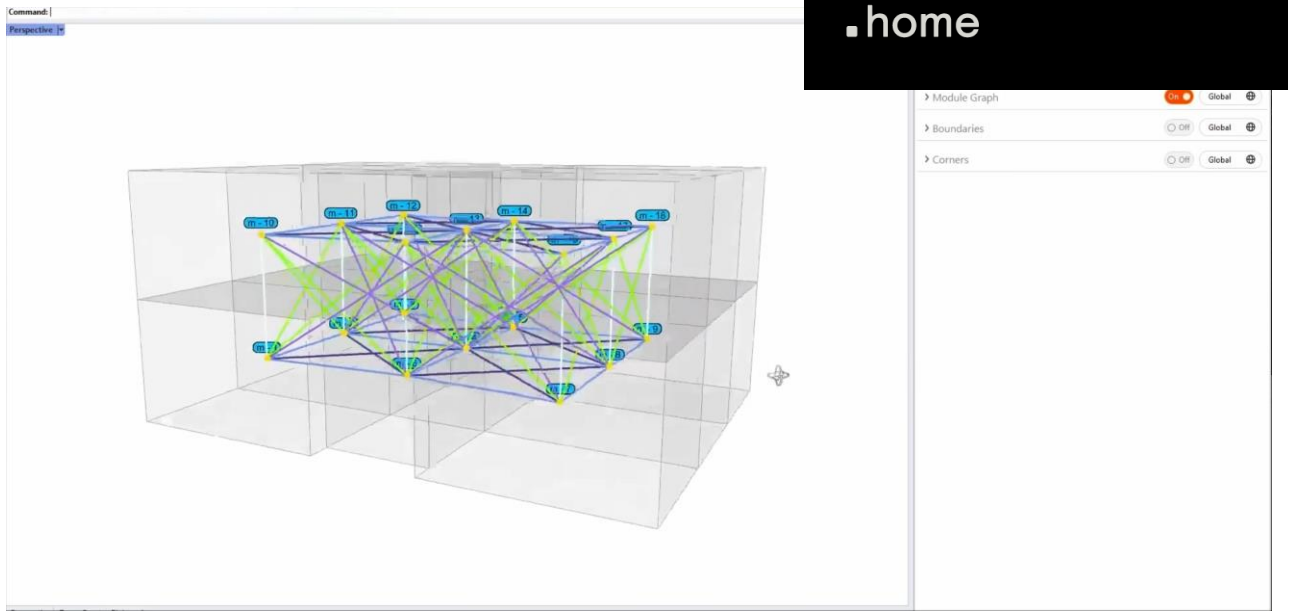
Cao, J., Bucher, D. F., Hall, D. M., & Lessing, J. (2021). Cross-phase product configurator for modular buildings using kit-of-parts. Automation in construction, 123, 103437.

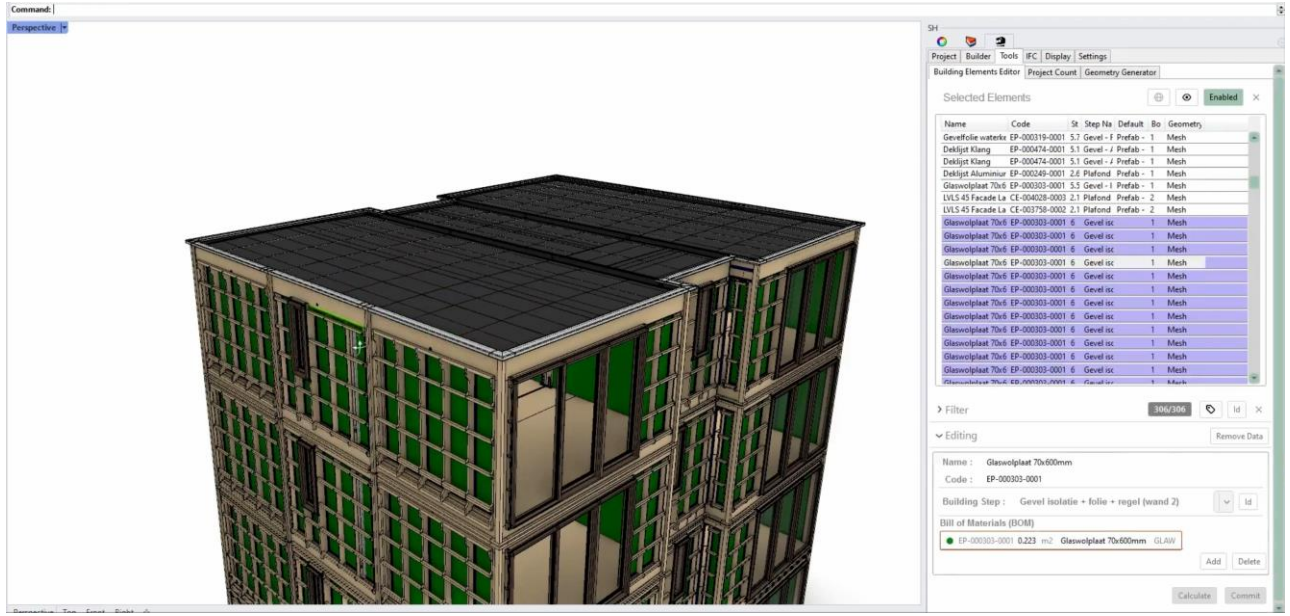
The Next Generation of Configurators

sustainer .home

Intelligent City







The Next Generation of Configurators

Clients, Planners, Architects

Architects, Engineers

Engineers, Manufacturers

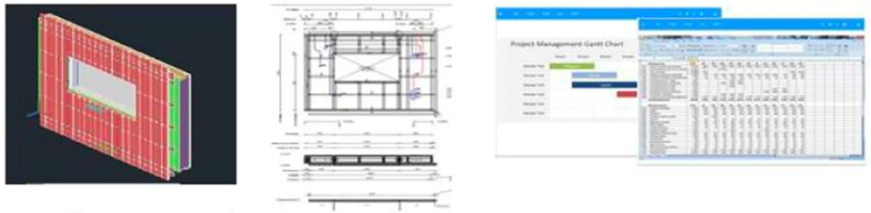
Site Layout | Building Profile | Floor Planning

Typology 1 Planning Configurator

3D Modeling | Model-based Analysis

Typology 2 Design Configurator

Detailed Models | Permit Drawings | Scheduling & BOMs



Typology 3 Production Configurator

Intelligent City

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Tackling *strategic* challenges

with digital systems

3 New Business Models

Spinoff Factory from Tier 1 Contractor

+ Little change to business
+ Structured learning process

- Slower implementation

Vertical Integration

+ Full-stack integration
+ Speed to capture market

- Capital-intensive

Digital Systems Integration

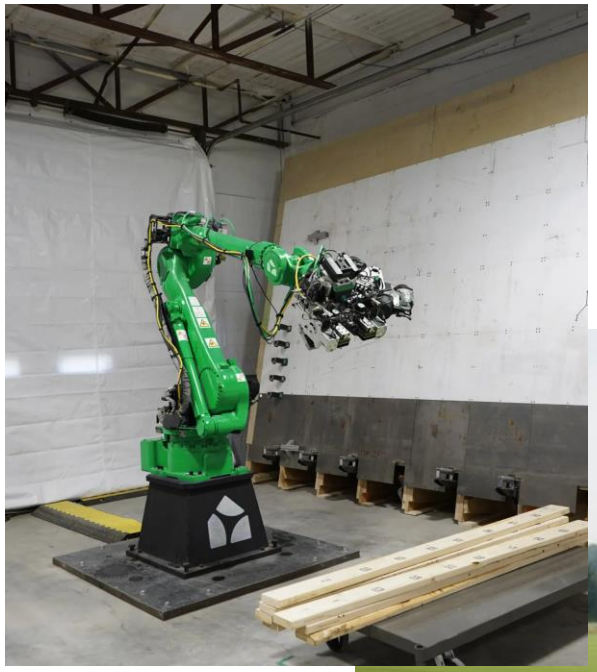
+ Capital-light, industry 4.0
+ Agile development

- Longer co-creation process

Hall, D. M., Lessing, J., & Whyte, J. (2022). New business models for industrialized construction. Industry 4.0 for the Built Environment: Methodologies, Technologies and Skills, 297-314.

Future Strategy – Localized, Mobile Production Cells

Reframe SYSTEMS



cuby

facit

Mobile and Micro Factories: Localized and Automated Cell Production

Cloud Manufacturing: Dynamic configurability of supply and demand

Next Generation of Configurators: Integrating from planning to fabrication

Descriptive: Real-time integration requires modular, interoperable systems

Diagnostic: Automated reasoning requires semantic understanding

Predictive: Requires mastering interoperability and semantic understanding

The role of integrated digital systems

Thank you for your attention!

TU Delft

Parts of this work is carried out within the project

Smart Mobile Factory for Infrastructure Projects

and was kindly supported by the Swiss National Science Foundation (SNSF) [grant number 204852]

Scan to connect via LinkedIn:

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Irfan Čustović