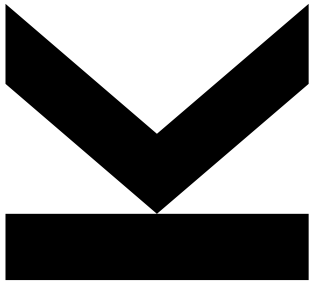
From Design-Time to Runtime and Back Again with Liquid Models



Manuel Wimmer

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https://cdl-mint.se.jku.ac.at

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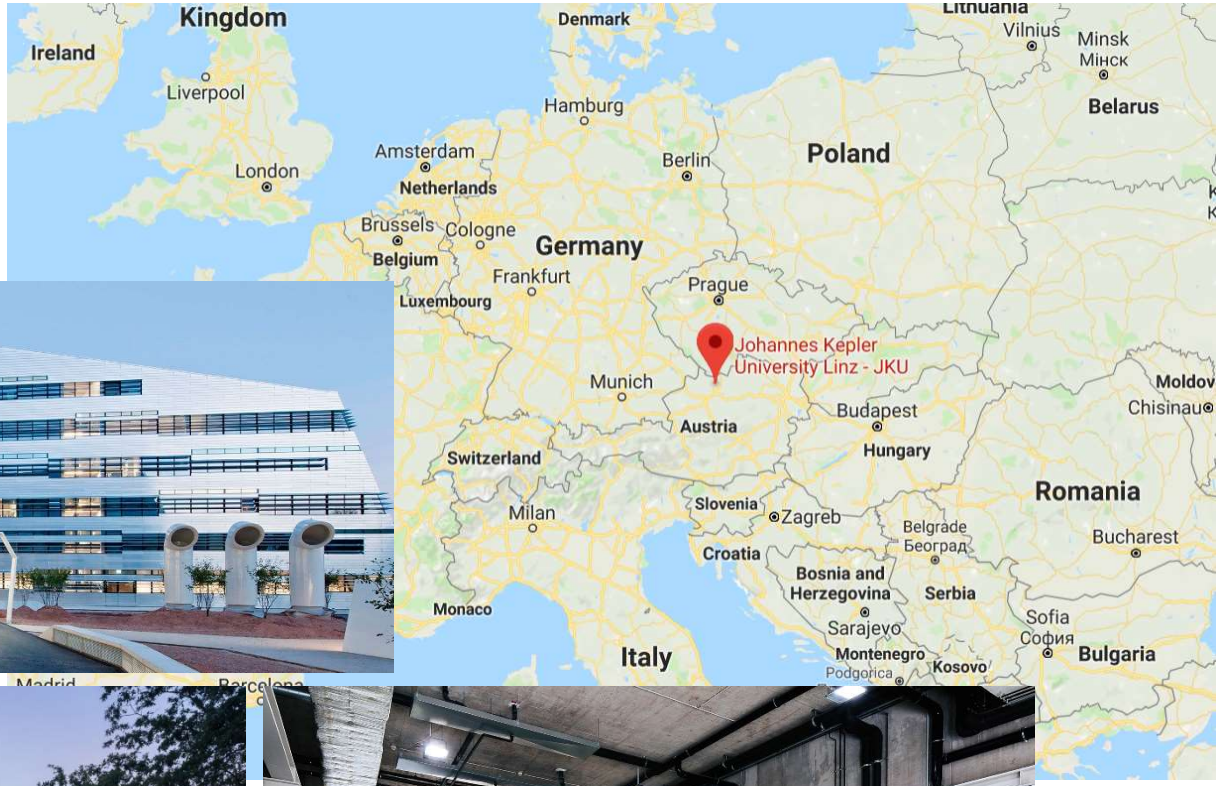
JKU Linz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Milan
Belgrade
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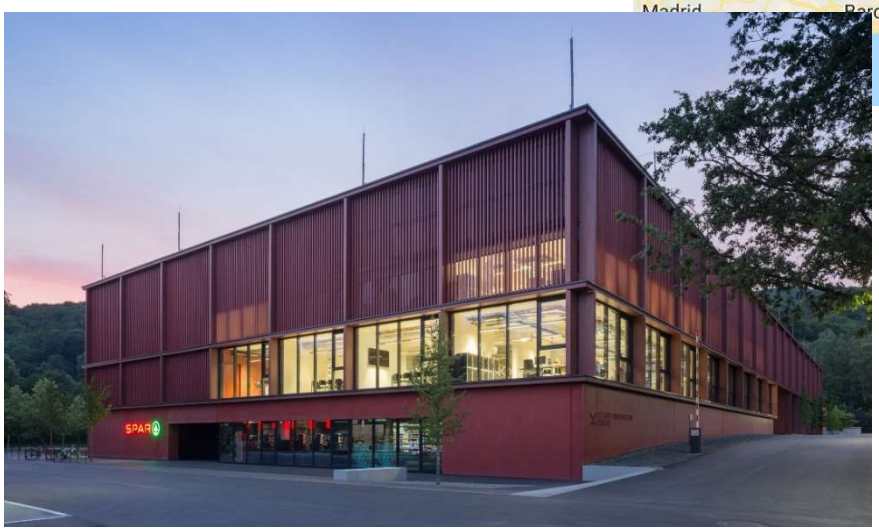
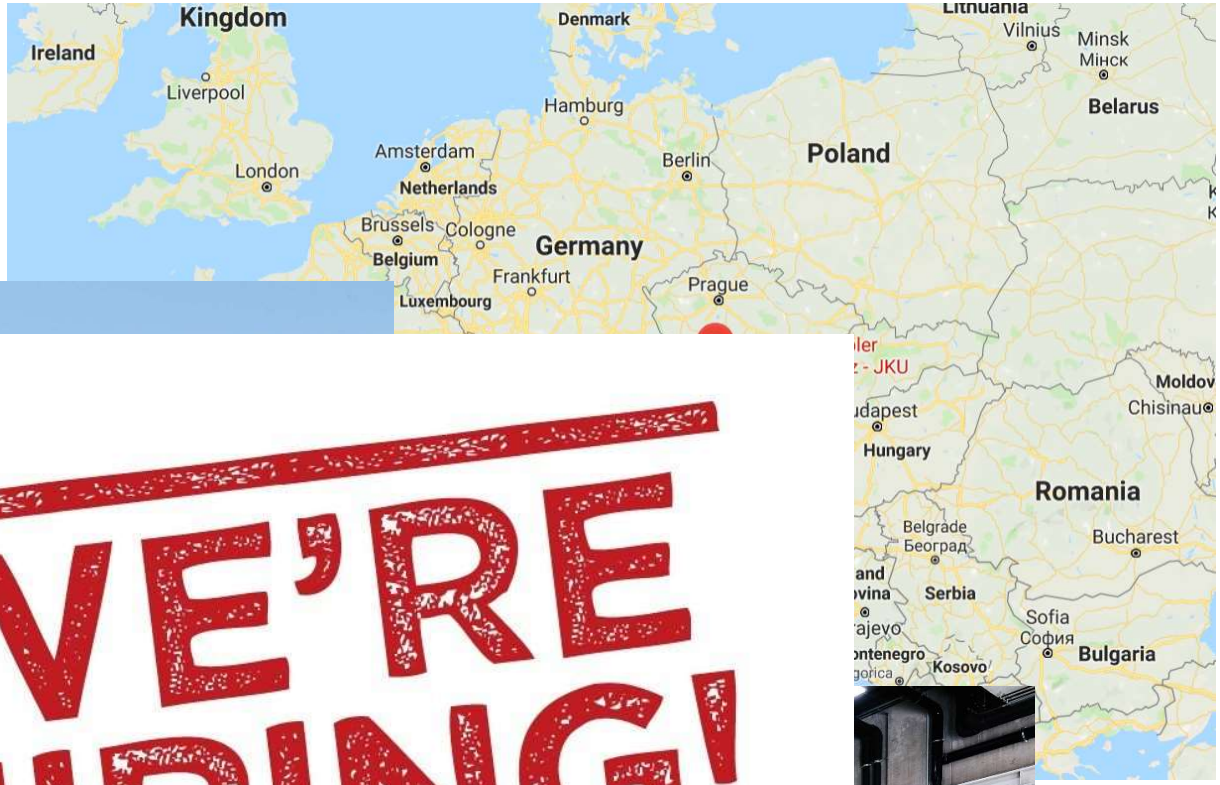

SPAR


e-motion 100
ENGEL

JKU Linz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Moldov
Chisinau
Hungary
Romania
Belgrade
Београд
Bucharest
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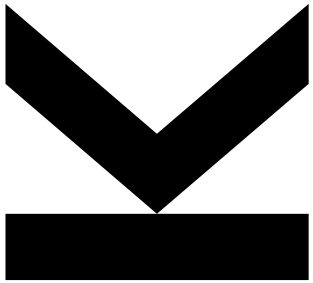
Bulgaria
Kosovo

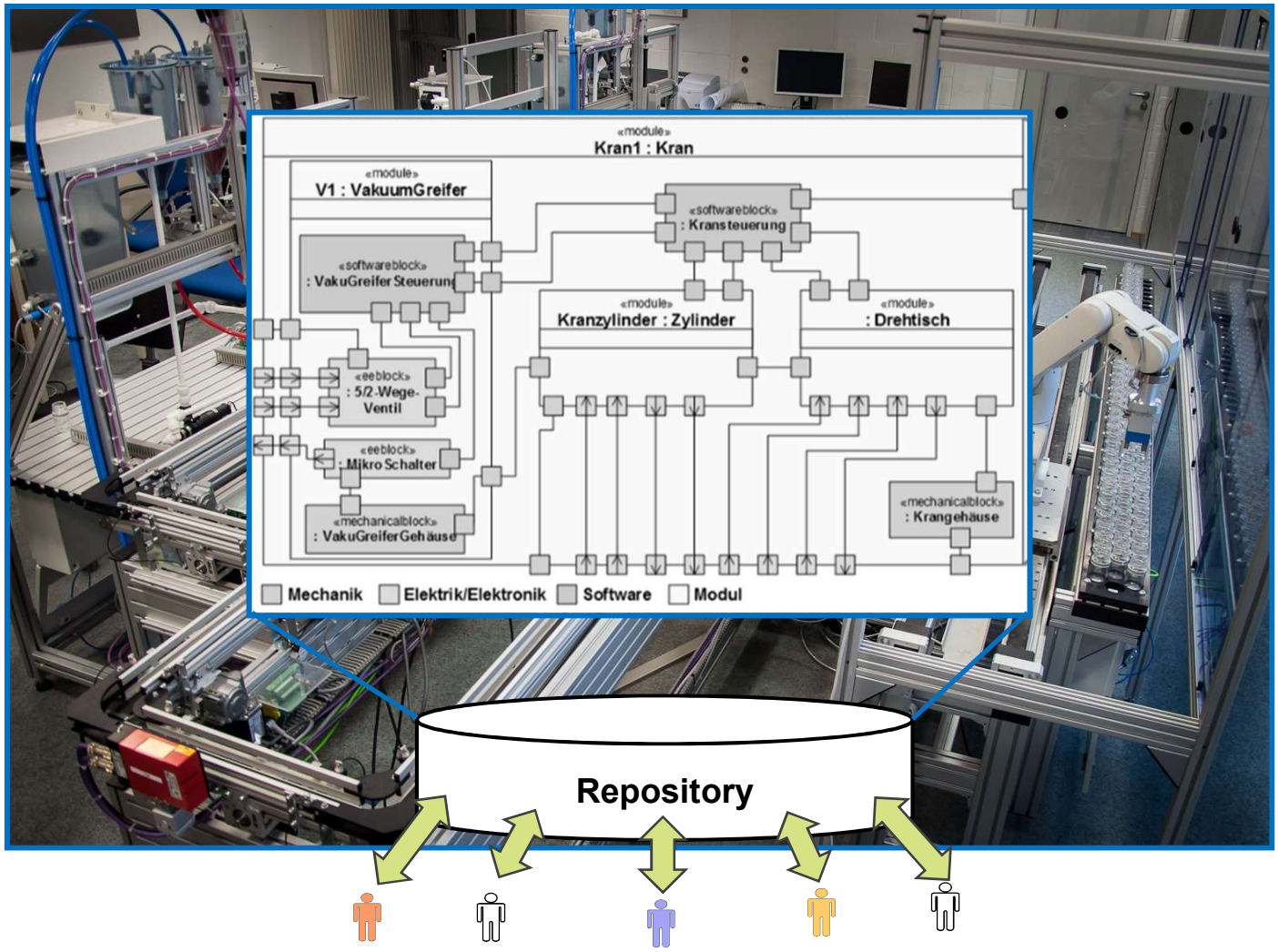

WE'RE
HIRING!


SPAR

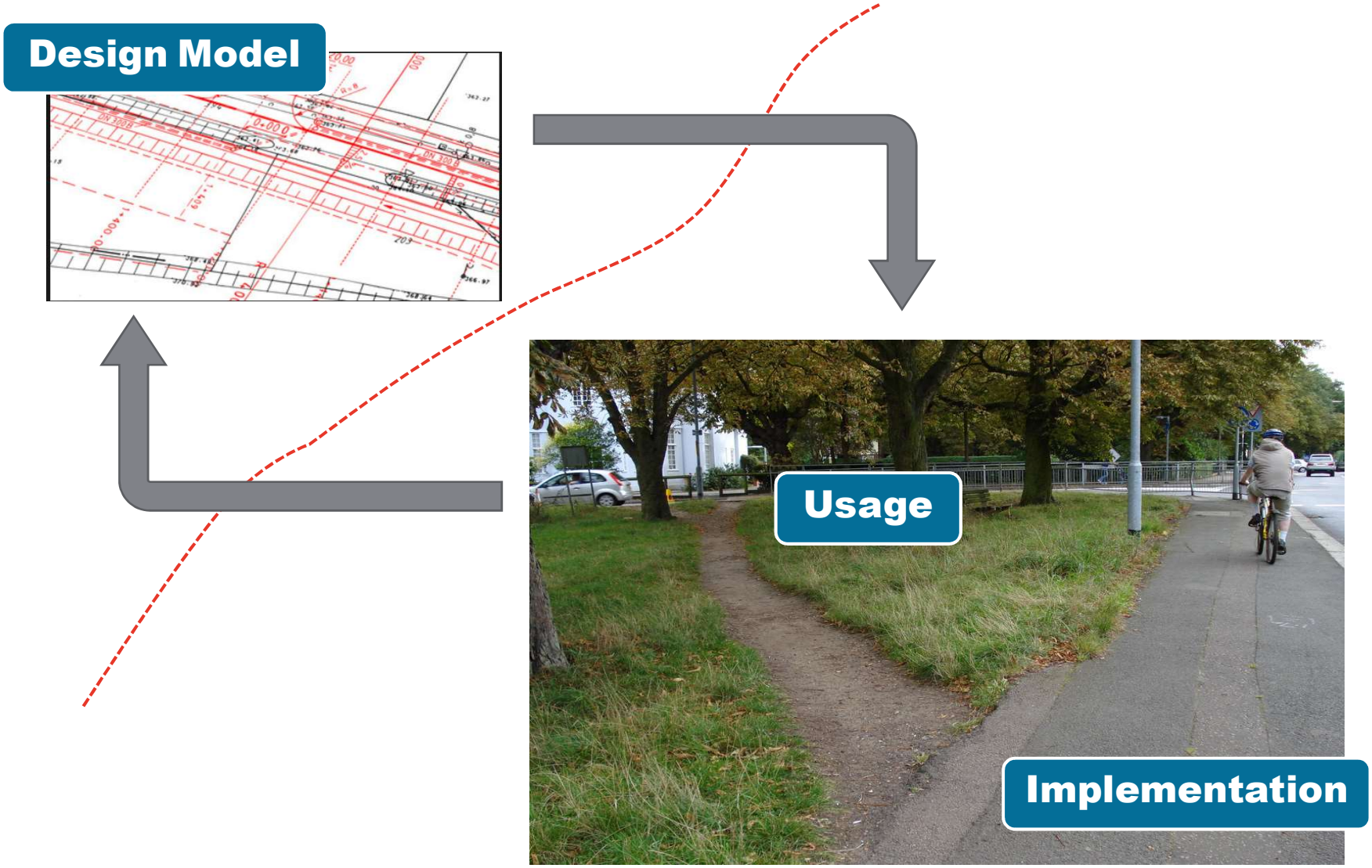
Why Design-Time
AND RUNTIME?



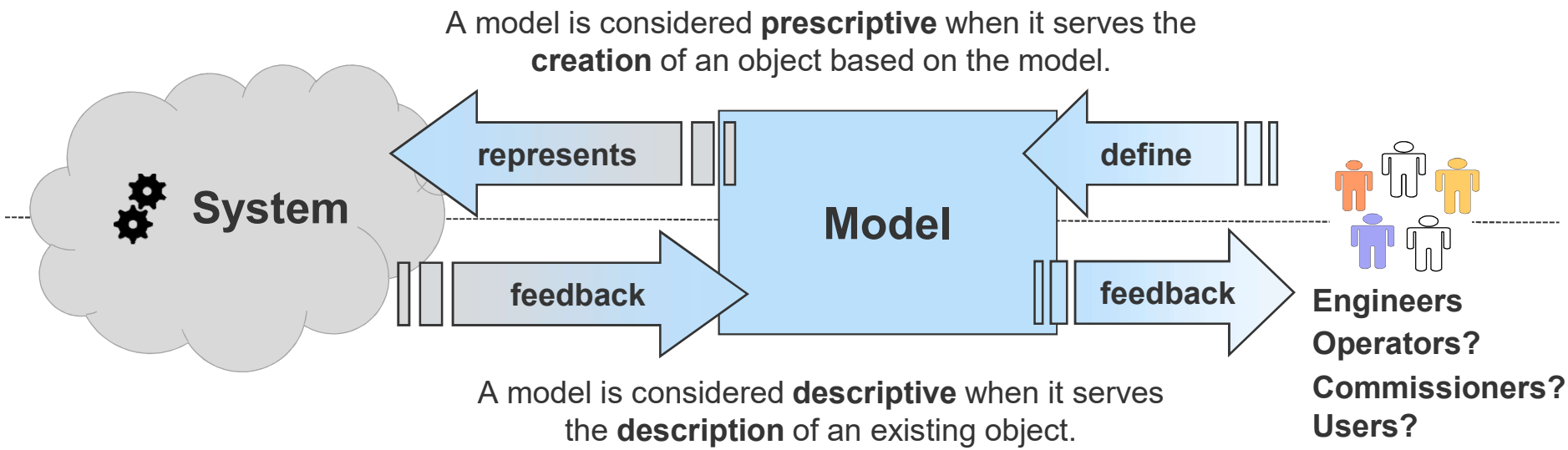
Software & Systems Engineering



Design-Time versus Runtime



Revisiting Model-Driven Engineering

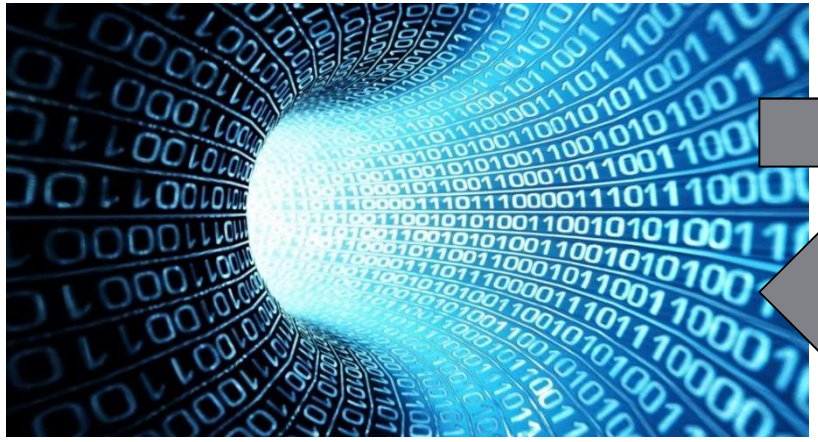


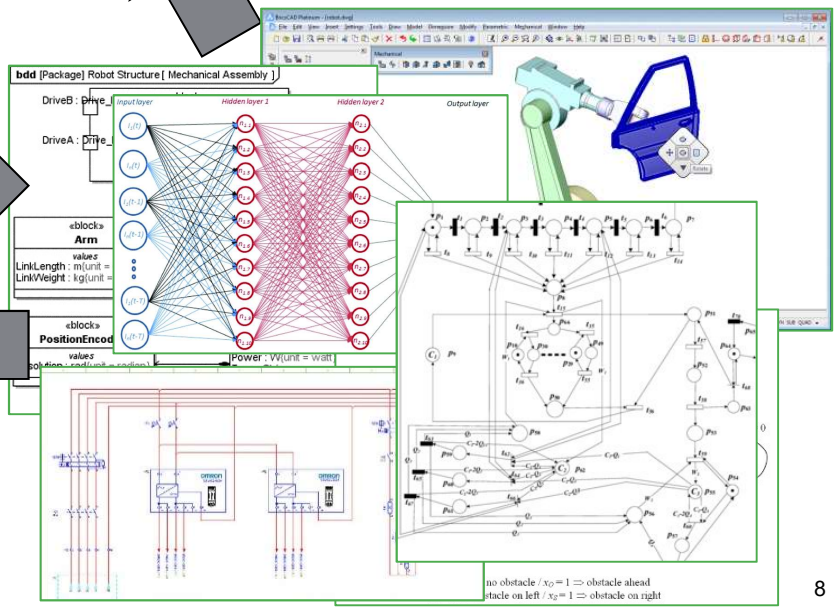
Ludewig: *Modelle im Software Engineering - eine Einführung und Kritik*.
In: Tagungsband der Modellierungskonferenz, pp. 7-22, 2002

Example: Cyber-Physical Systems

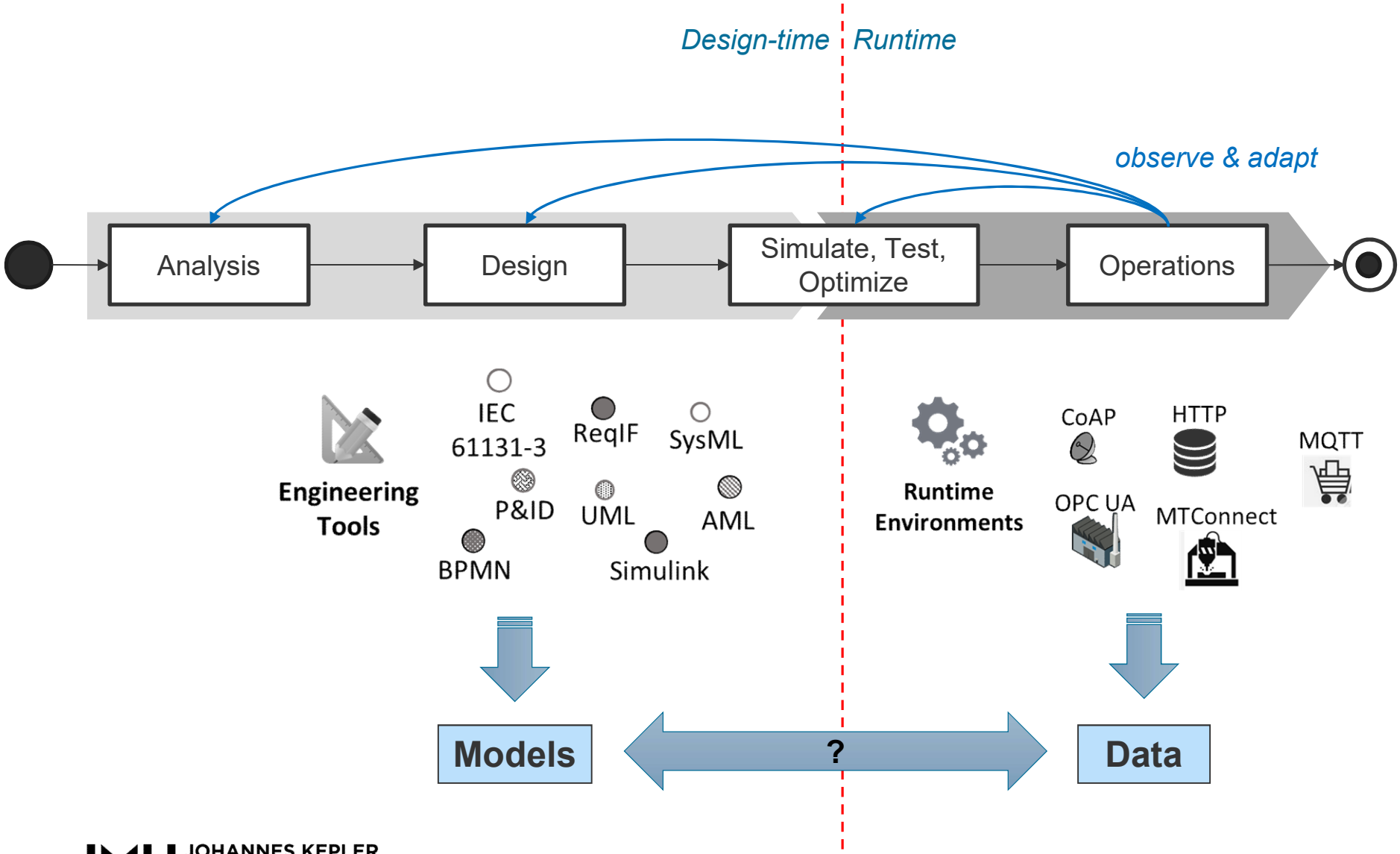
Real System

Digital Representation

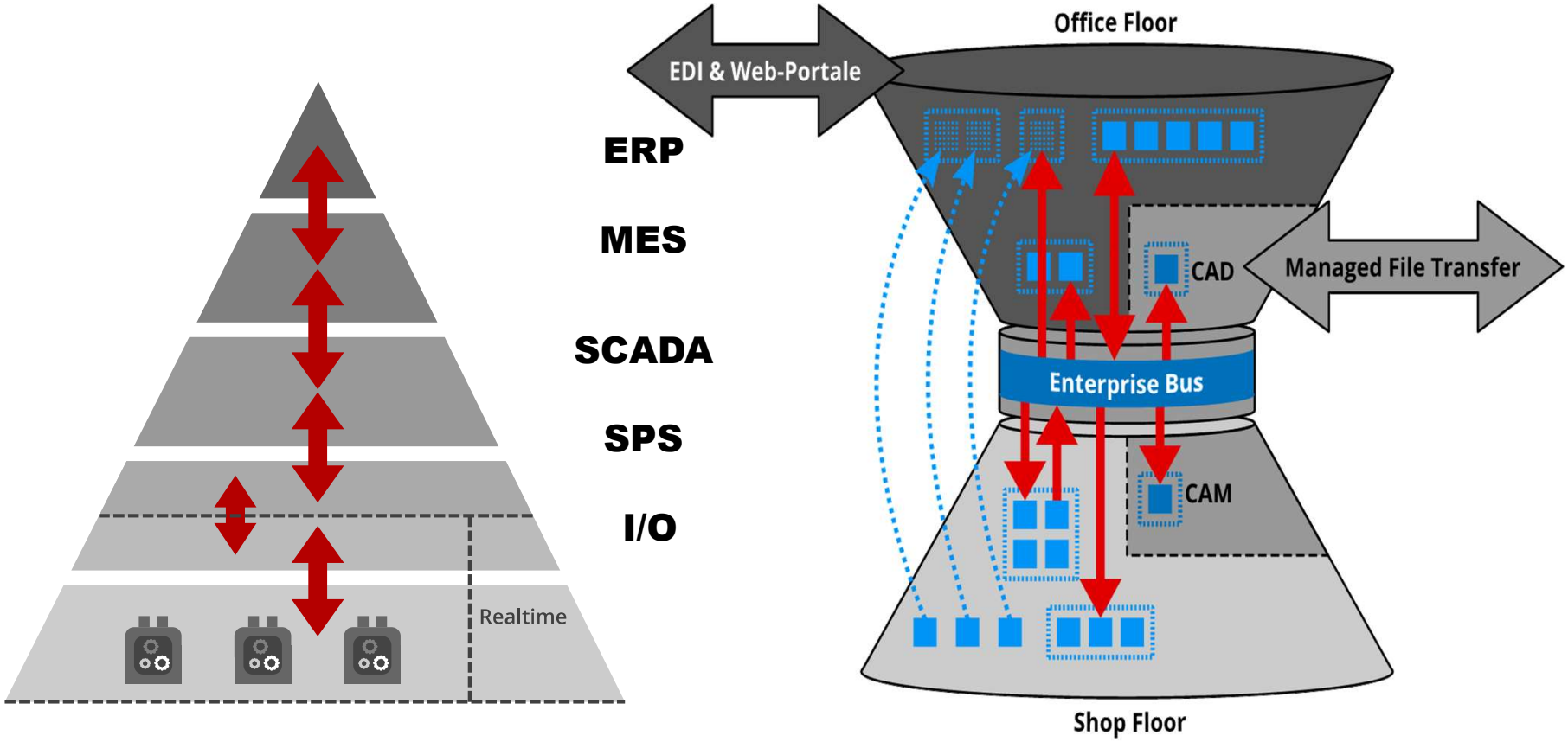




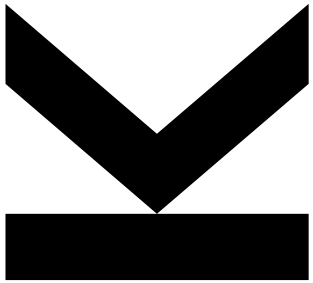
Engineering Viewpoint



Operational Viewpoint



Liquid Models



Towards a Platform for Liquid Models

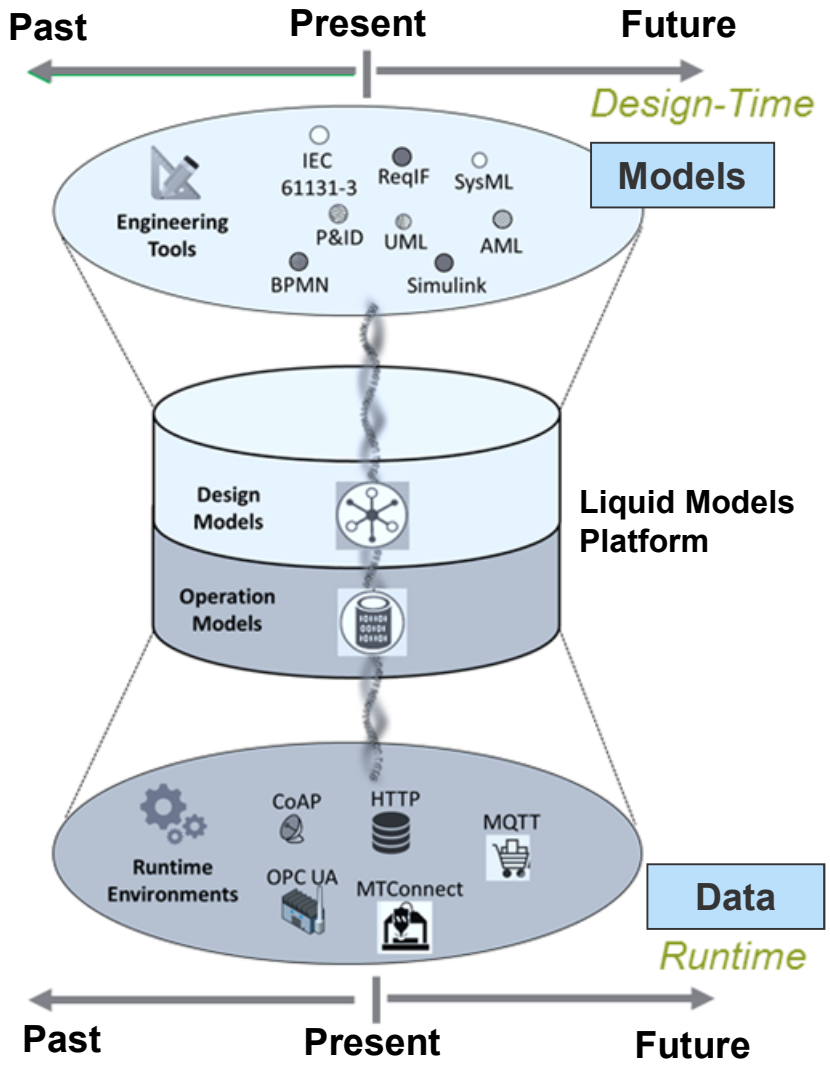
Christian Doppler Laboratory
Model-Integrated Smart Production (CDL-MINT)

www.cdl-mint.se.jku.at

LieberLieber

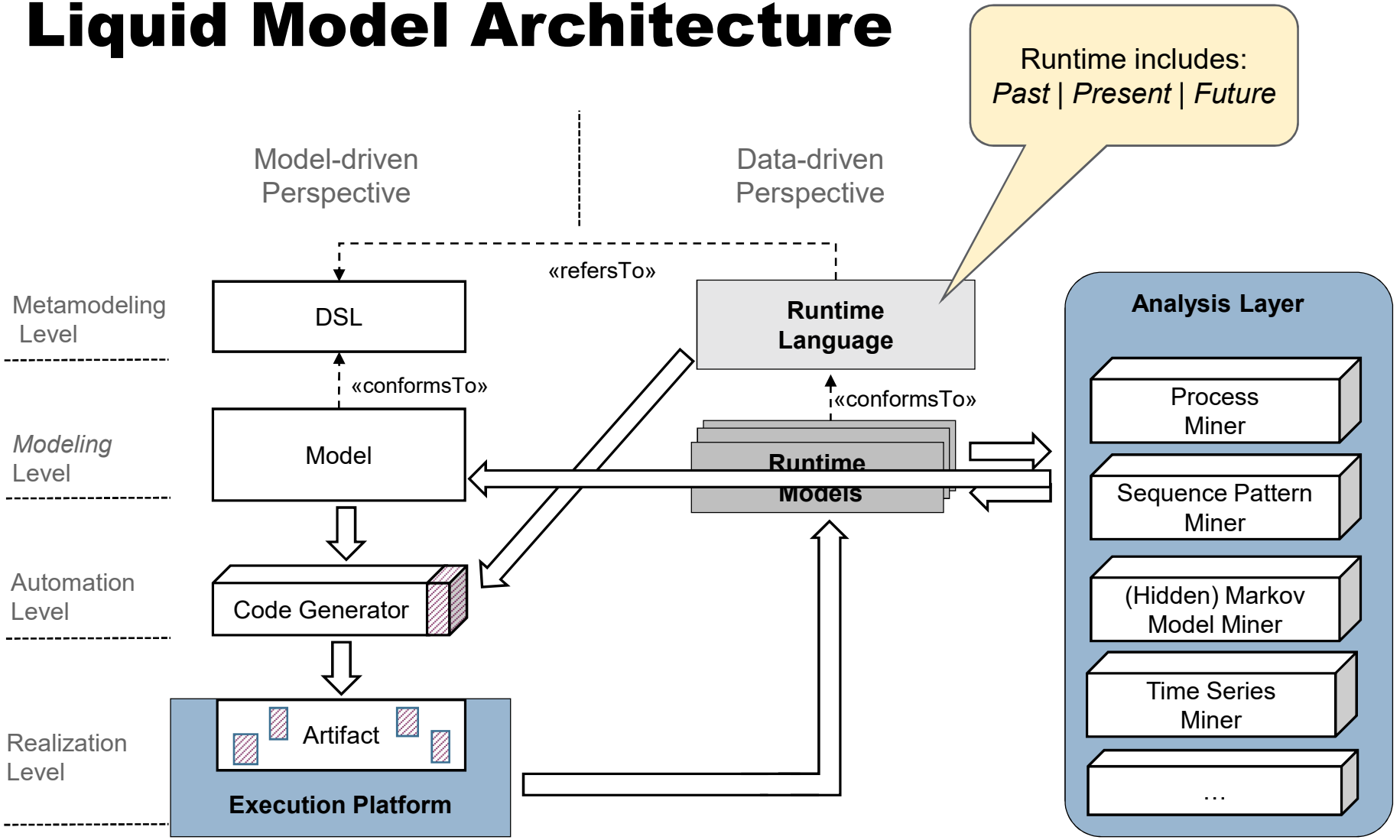
CERTICON
ADDED VALUE SOLUTIONS

Christian Doppler Forschungsgesellschaft



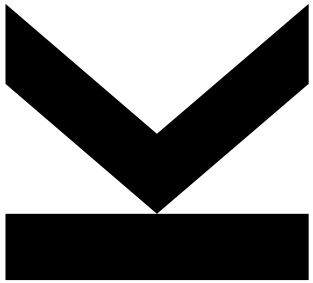
Mazak, Wimmer: *Towards Liquid Models: An Evolutionary Modeling Approach*. In: Proc. of the Int. Conf. on Business Informatics, pp.: 104-112, 2016

Liquid Model Architecture

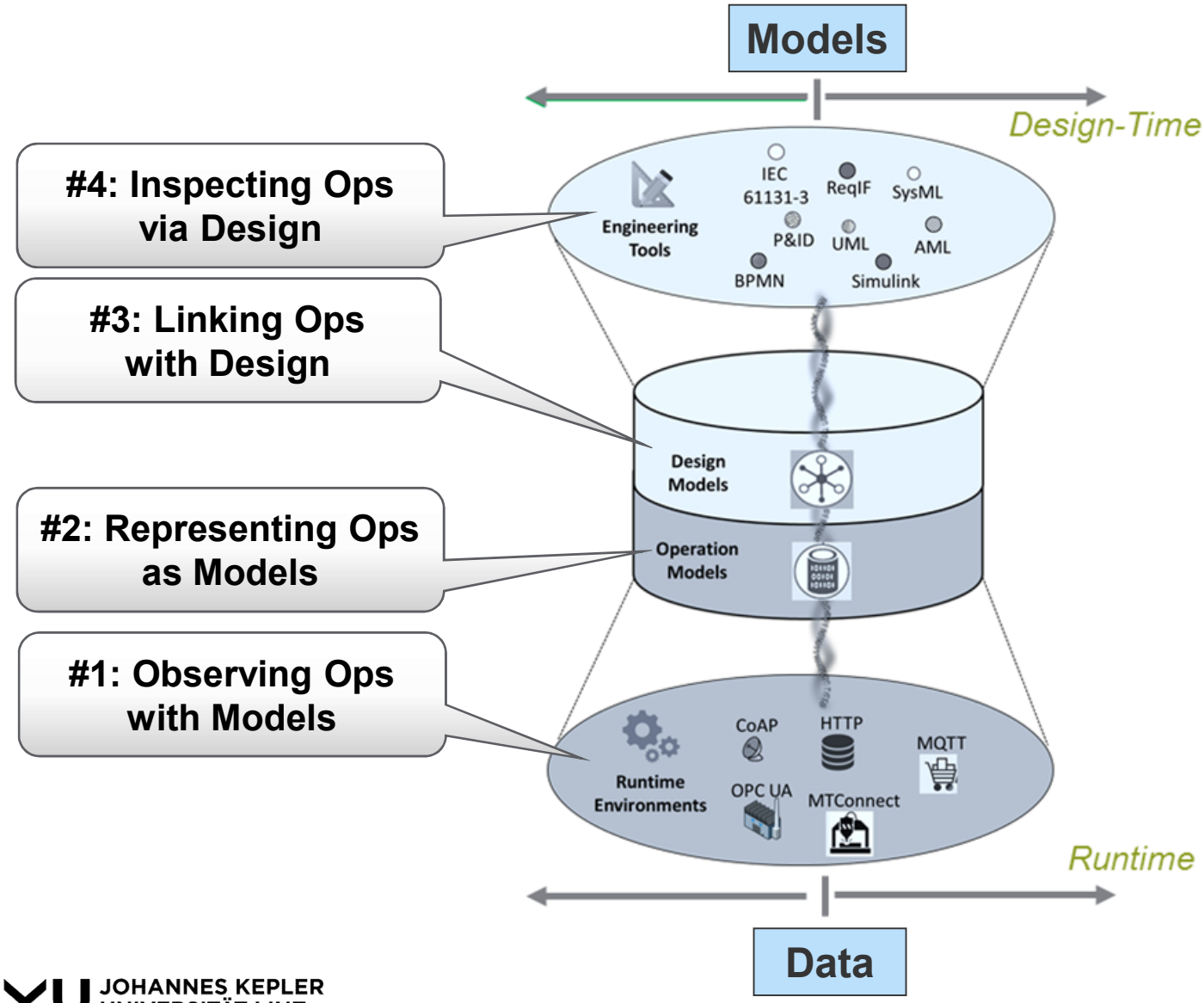


Mazak, Wimmer, Patsuk-Bösch: *Execution-Based Model Profiling*.
In: Proc. of Int. Symp. on Data-Driven Process Discovery and Analysis., pp. 37–52, 2018

A Tour on Selected Research Topics



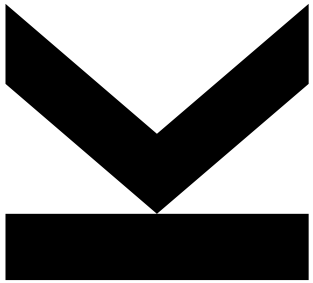
Selected Research Topics



#1: Observing Ops with Models

+

#2: Representing Ops as Models



Problem Statement, Challenge, and Contribution

Problem: *Discrete* design vs. *continuous* operation

- Systems do not switch in a time discrete manner between states
- Variables are continuously evolving to intended values of next states

Challenge: *State identification*

- Transform specific value configurations to states
- Precision of system realization
- Measurement uncertainty

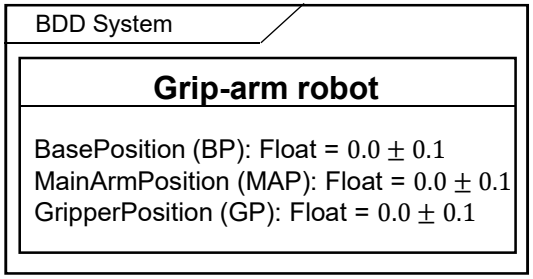
Contribution: Model-Driven RuntIme State identification (MD-RISE)

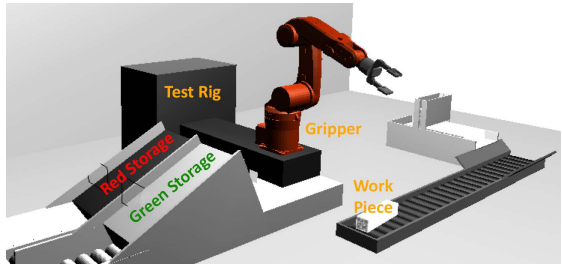
- Transforms values streams into event streams
- Allows to explore a system by hypothesis testing

Example System

Design Model

Structure



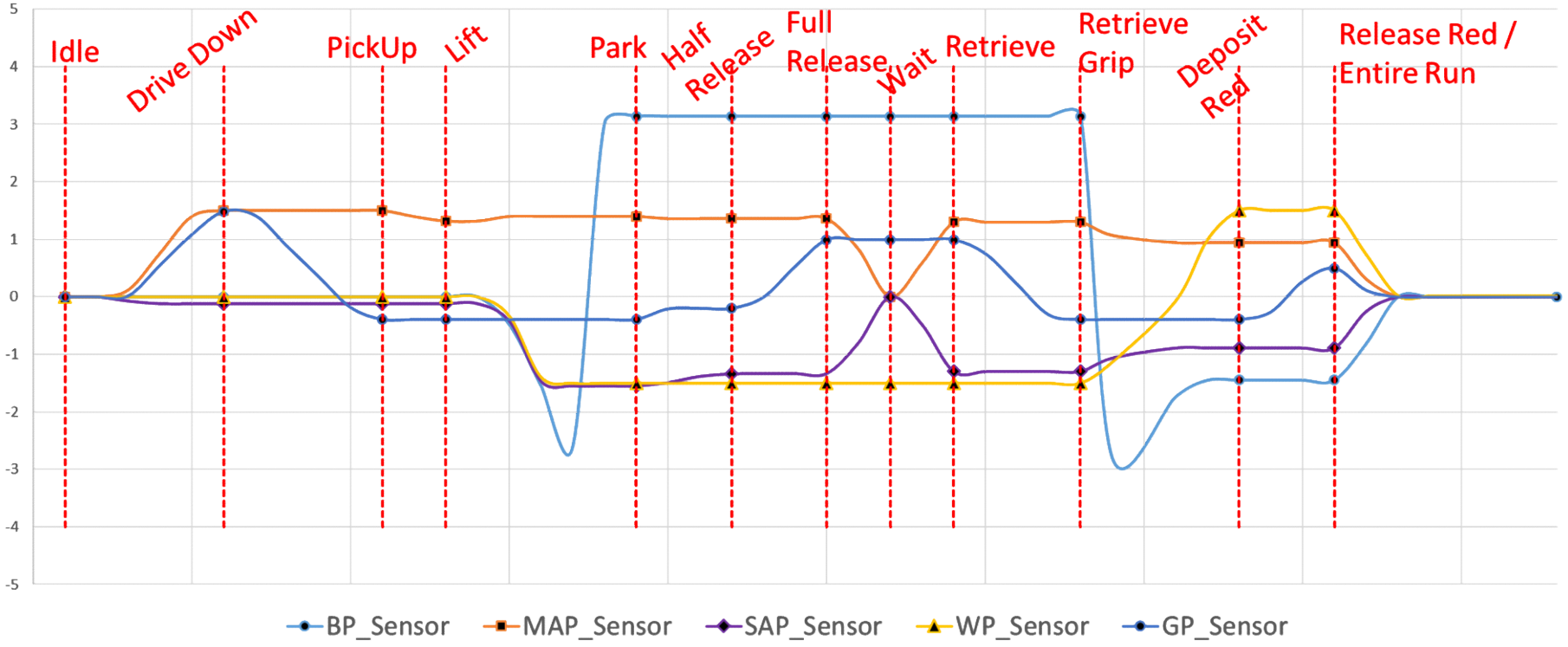


Behavior

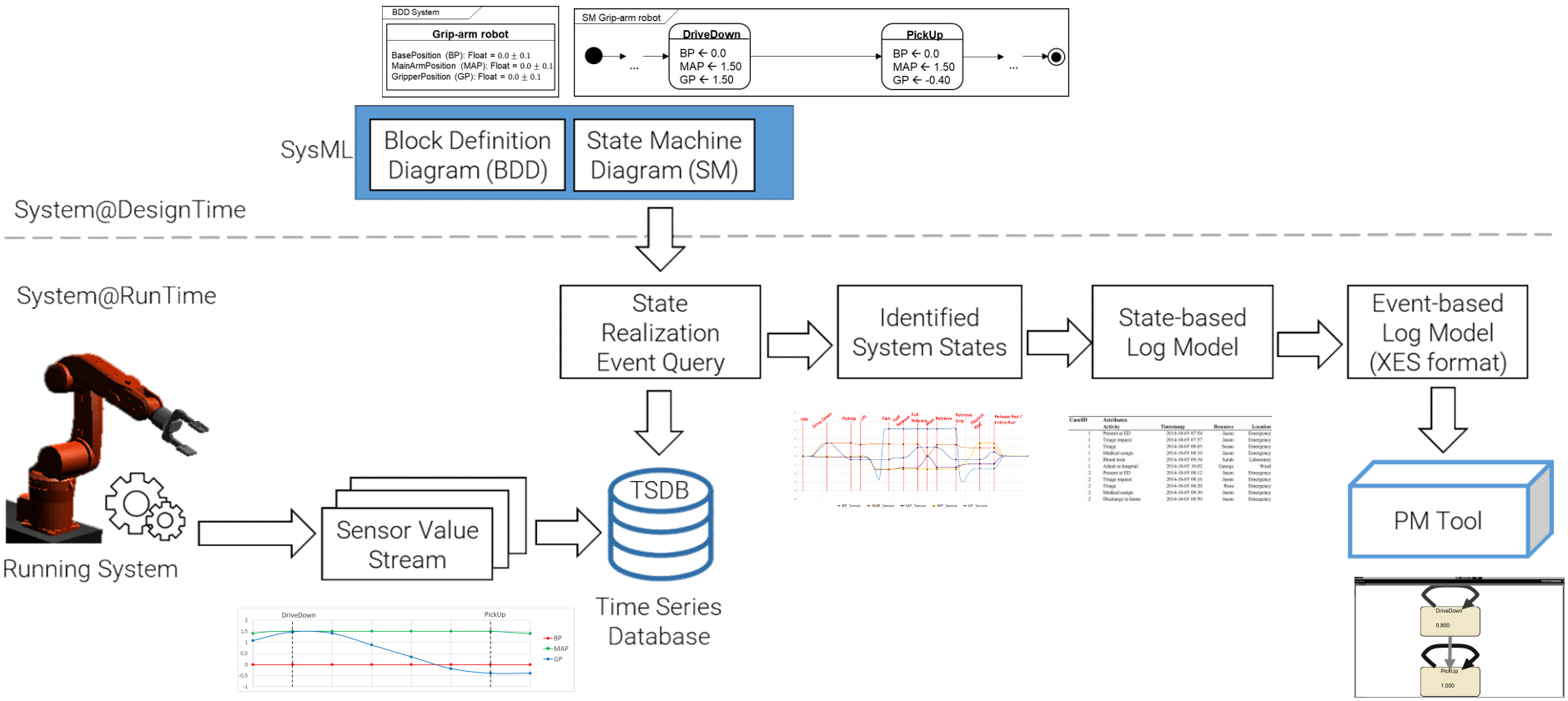
Runtime Data

Sensor Values

State Identification: IR Problem?



MD-RISE Architecture



Wolny, Mazak, Wimmer, Huemer: *Model-driven Runtime State Identification*. In: Proc. of the Conference on Enterprise Modeling and Information Systems Architectures (EMISA), 2019

Evaluation Results

RQ1 – Precision

- Correct recognition of states depends on
  - Tolerance range
  - Distinctness of states
  - Number of sensor

RQ2 - Recall

- Completeness of the states identification depends on
  - Tolerance range

RQ3 – Performance

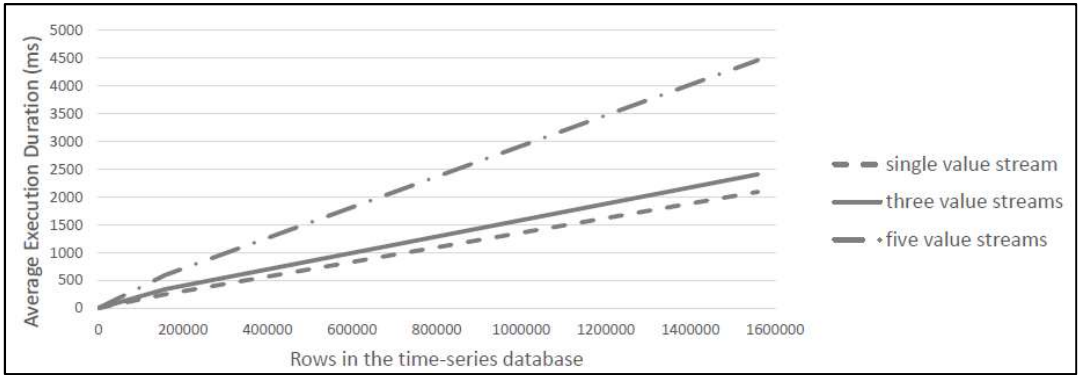
- Influenced by
  - Number of data records
  - Number of sensors

Single sensor value stream

	DriveDown			PickUp		
tolerance range	**precision**	**recall**	**f-measure**	**precision**	**recall**	**f-measure**
0	NaN	0	NaN	NaN	0	NaN
0.01	NaN	0	NaN	0.08	1	0.14
0.02	**1**	**1**	**1**	**0.08**	**1**	**0.14**
0.03-0.05	1	1	1	0.07	1	0.14
0.06-0.08	1	1	1	0.07	1	0.13
0.09-0.11	0.75	1	0.86	0.07	1	0.13
0.12-0.19	0.75	1	0.86	0.07	1	0.12
0.20-0.30	0.6	1	0.75	0.05	1	0.10
0.31-0.37	0.5	1	0.67	0.05	1	0.10
0.38-0.39	0.5	1	0.67	0.05	1	0.09

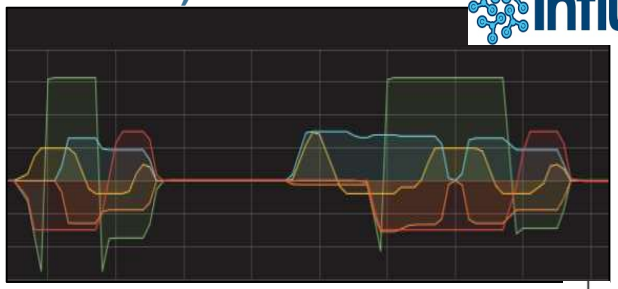
Five sensor value streams

	DriveDown			PickUp		
tolerance range	**precision**	**recall**	**f-measure**	**precision**	**recall**	**f-measure**
0	NaN	0	NaN	NaN	0	NaN
0.01	NaN	0	NaN	1	0.33	0.5
0.02-0.08	**1**	**1**	**1**	**1**	**1**	**1**
0.09-0.10	0.75	1	0.86	1	1	1
0.11-0.12	0.75	1	0.86	0.6	1	0.75
0.13-0.16	0.75	1	0.86	0.5	1	0.67
0.17-0.18	0.75	1	0.86	0.43	1	0.6
0.19	0.75	1	0.86	0.25	1	0.4
0.20-0.21	0.6	1	0.75	0.25	1	0.4
0.22-0.3	0.6	1	0.75	0.23	1	0.375
0.31-0.39	0.5	1	0.67	0.23	1	0.375



Multi-View Digital Shadow Platform

View 1: Time-Series (Digital Shadow)

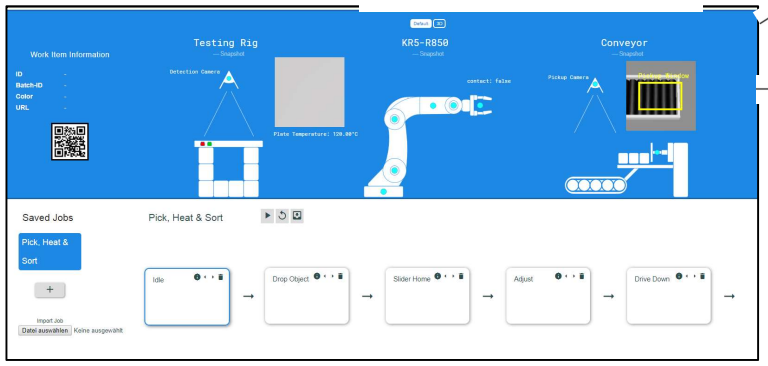


InfluxDB

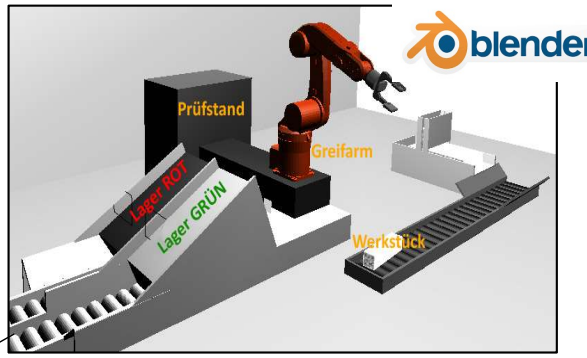
View 2: Automation (Logical View)

Backend

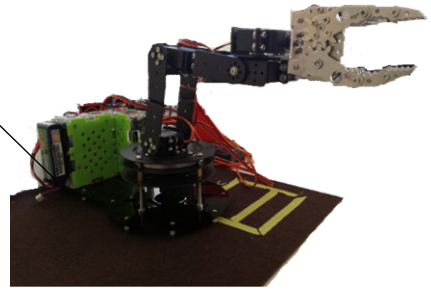
Kotlin



View 3: Animation (Physical View)



MQTT



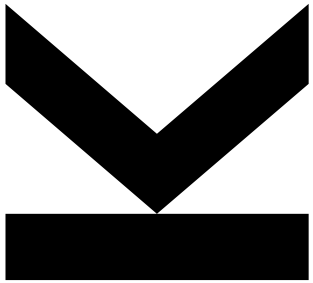
System

Wolny, Mazak, Wimmer, Konlechner, Kappel: *Model-Driven Time-Series Analytics*. Enterprise Modelling and Information Systems Architectures 13: 252-261 (2018)

#3: Linking Ops with Design

+

#4: Inspecting Ops via Design



Problem Statement, Challenge, and Contribution

Problem: Text-based traces for collecting logging messages

- Long, difficult, often unstructured
- Reasoning and analyzing on isolated text files is limited

Challenge: Provide *semantically* enhanced logs

- Align runtime data to design models
- Define analysis through design models

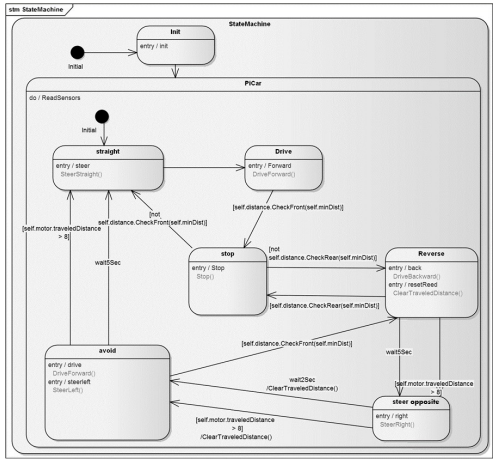
Contribution: *Temporal* models

- Introduce runtime history viewpoints in modeling languages
- Define runtime analysis on model level as queries or derived properties

Example Systems

System 1: PiCar

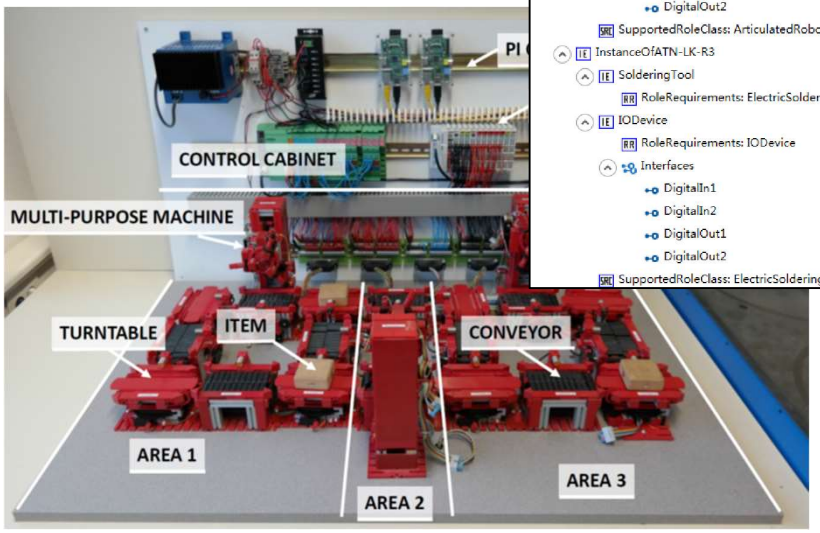
Design Model



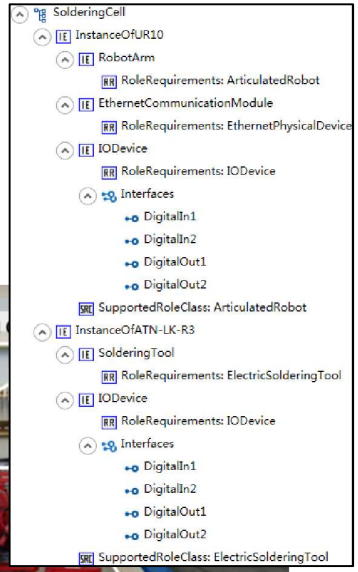
Runtime Data

caseID;timestamp;Sender;Receiver;Message;ParameterValue;kind
1;2017-02-27 17:38:13.914;Car;Car;InitAll;none;REQ
1;2017-02-27 17:38:13.917;Car;DistanceSensors;InitSensors;none;REQ
1;2017-02-27 17:38:13.928;DistanceSensors;Car;InitReader;none;RES
1;2017-02-27 17:38:13.934;Car;MotorControl;InitializeMotor;none;REQ
1;2017-02-27 17:38:13.950;MotorControl;Car;InitializeMotor;none;RES
1;2017-02-27 17:38:13.954;Car;ServoControl;InitializeServo;none;REQ
1;2017-02-27 17:38:13.964;ServoControl;Car;InitializeServo;none;RES
1;2017-02-27 17:38:13.991;Car;Car;SteerStraight;none;REQ
1;2017-02-27 17:38:13.992;Car;ServoControl;SteerTo;direction=7;REQ
1;2017-02-27 17:38:15.145;ServoControl;Car;SteerTo;direction=7;RES
1;2017-02-27 17:38:15.147;Car;Car;SteerStraight;none;RES
…

System 2: IAF Plant



Design Model

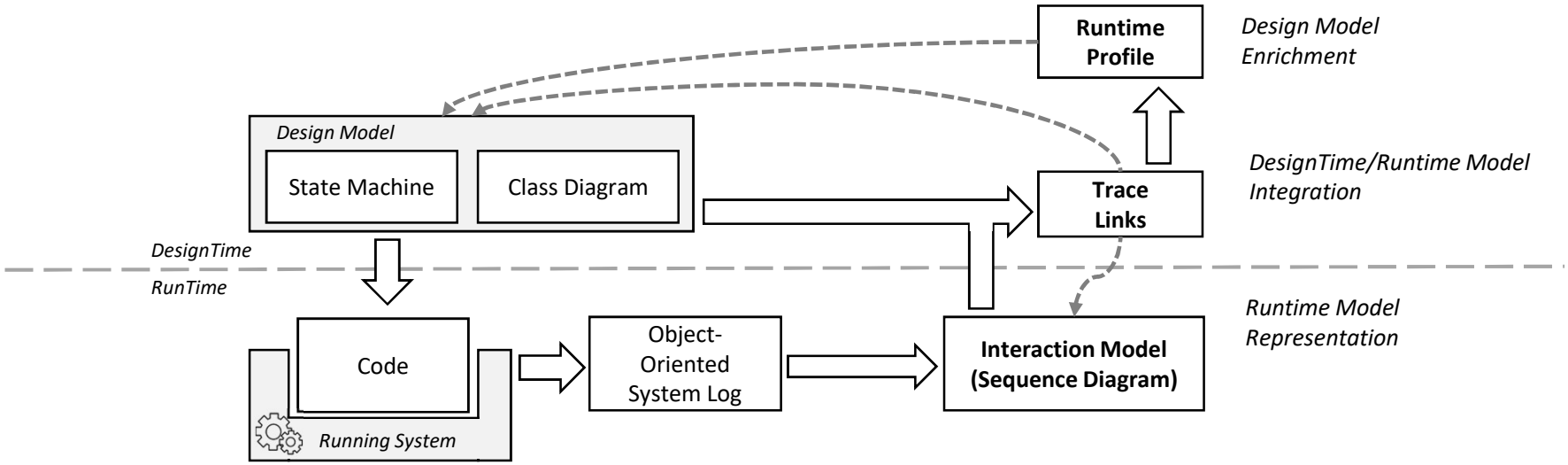


Runtime Data

#Fields: component, timestamp, item
entered –/IAF/a2/t1,2017–02–08–23–28–51,923b4ff191d5
entered –/IAF/a2/c1,2017–02–08–23–28–54,923b4ff191d5
entered –/IAF/a2/t1,2017–02–08–23–28–57,83e5f507cff2
entered –/IAF/a2/t2,2017–02–08–23–28–61,923b4ff191d5
entered –/IAF/a2/c1,2017–02–08–23–28–63,83e5f507cff2
entered –/IAF/a2/m1,2017–02–08–23–28–69,923b4ff191d5
entered –/IAF/a2/t1,2017–02–08–23–28–74,5b73647866d4
…

Capturing Runtime in UML and SysML

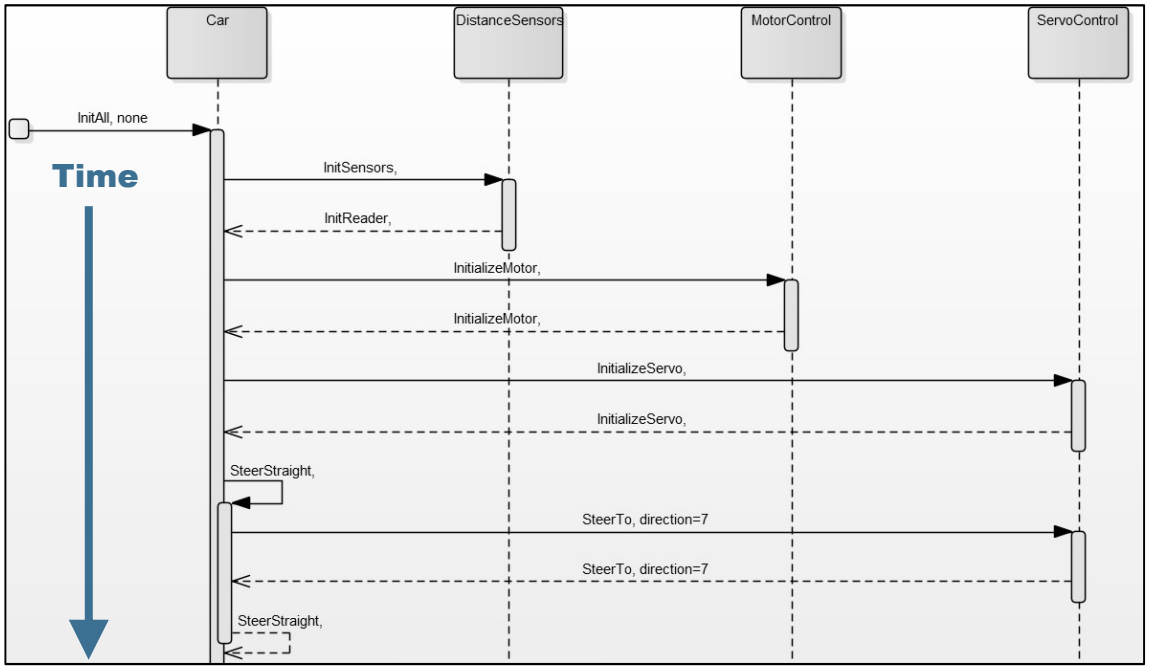
- UML/SysML **already provide** runtime viewpoints
  - Object diagram, interaction diagrams, …
- Injecting logs into UML/SysML models as **linked elements**
- Profiles for **computing aggregated** runtime information



Wolny, Mazak, Wimmer: *Automatic Reverse Engineering of Interaction Models from System Logs*. In: Proc. of the 24th IEEE Conference on Emerging Technologies and Factory Automation (ETFA), 2019

EA Sequence Miner

- **Execution logs** as **UML Sequence Diagrams**
  - **Communication** between components via messages
  - **Standard** UML
  - Play-in/play-out sequences
  - Filters, queries, and **transformations**



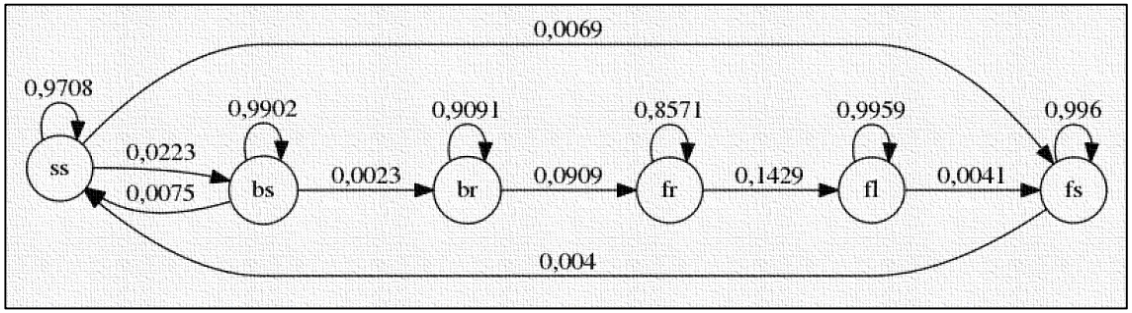
- Realized **episodes**

MotorControl

- drive_forward (f)
- drive_backward (b)
- stop (s)

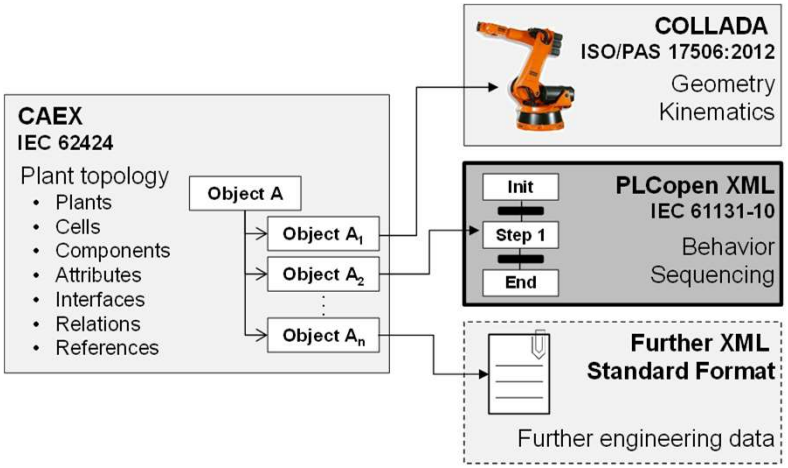
ServoControl

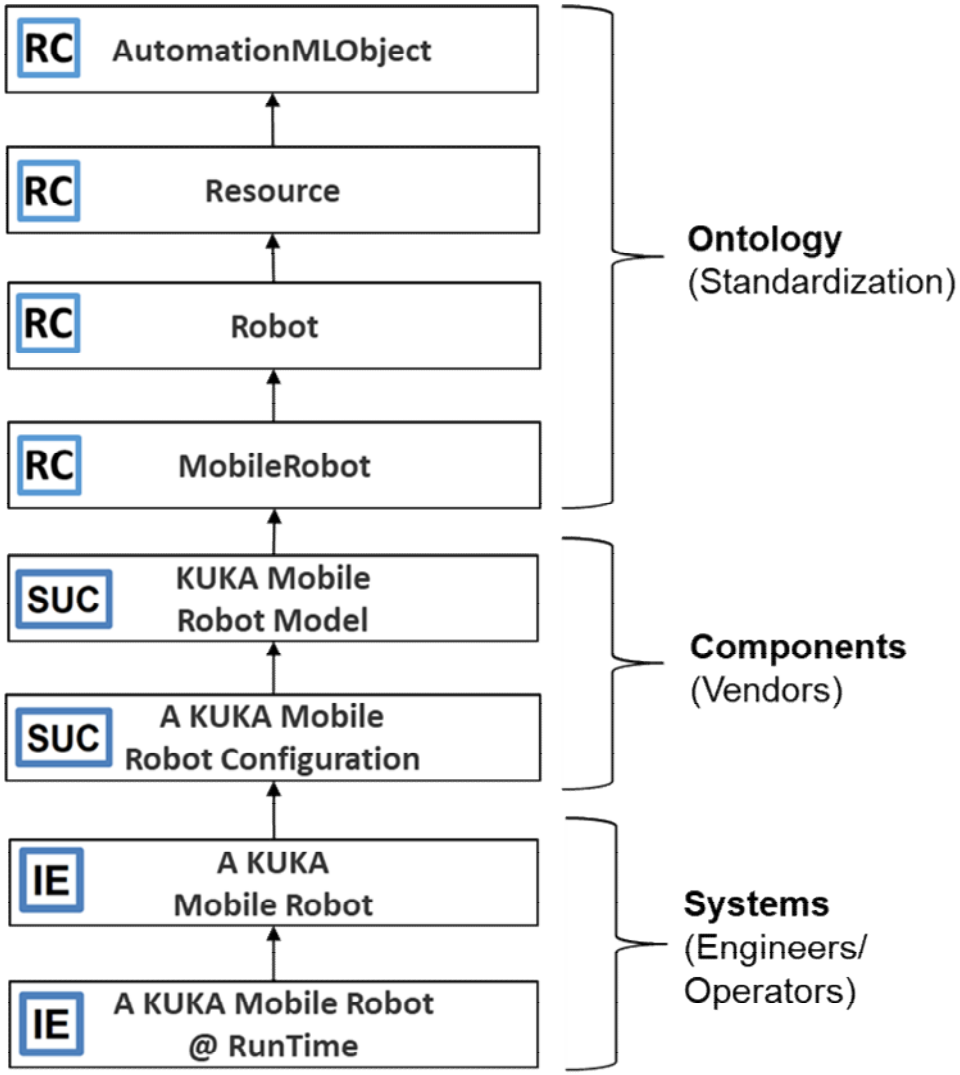
- steer_left (l)
- steer_straight (s)
- steer_right (r)



Capturing Runtime in <AutomationML/>

- AutomationML **lacks** runtime viewpoints
- But allows **language inherent extensions**
- Maps to standardized operational frameworks

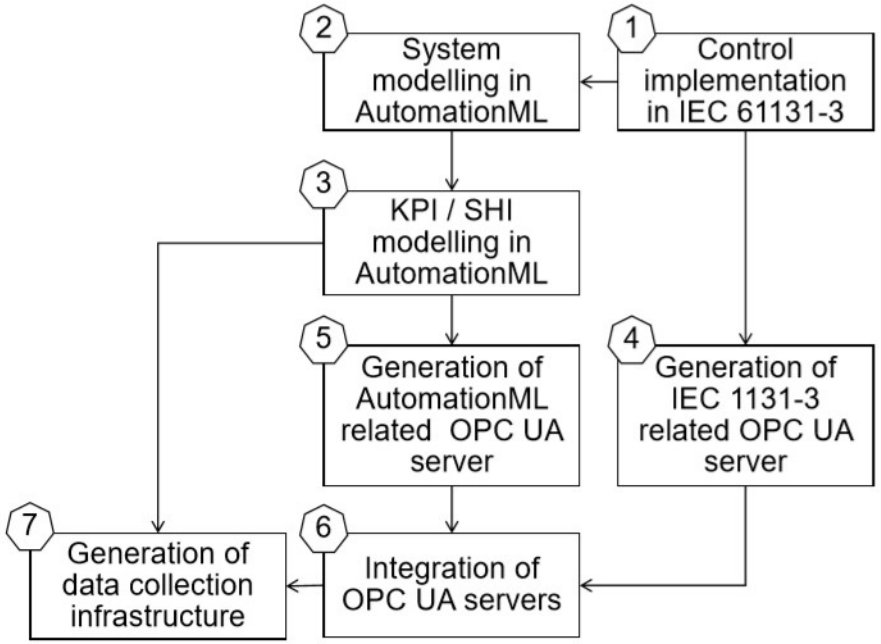




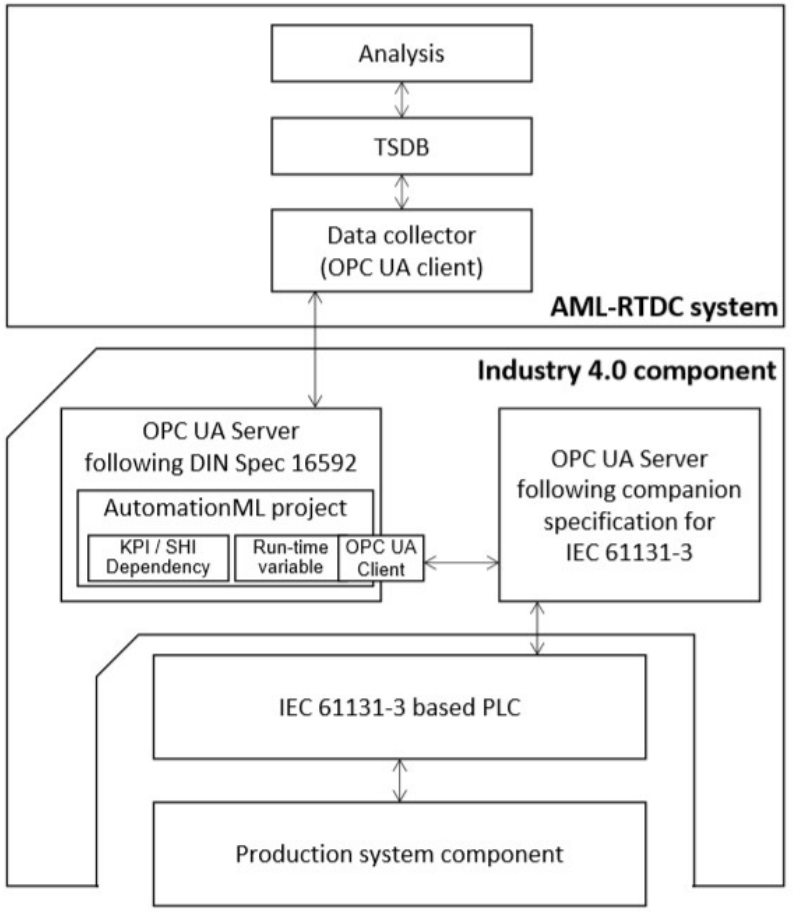
Mayerhofer, Wimmer, Berardinelli, Drath: *A Model-Driven Engineering Workbench for CAEX - Supporting Language Customization and Evolution*. IEEE Trans. Industrial Informatics 14(6): 2770-2779 (2018)

<AutomationML/> Runtime Extension

Modeling & Generation Process



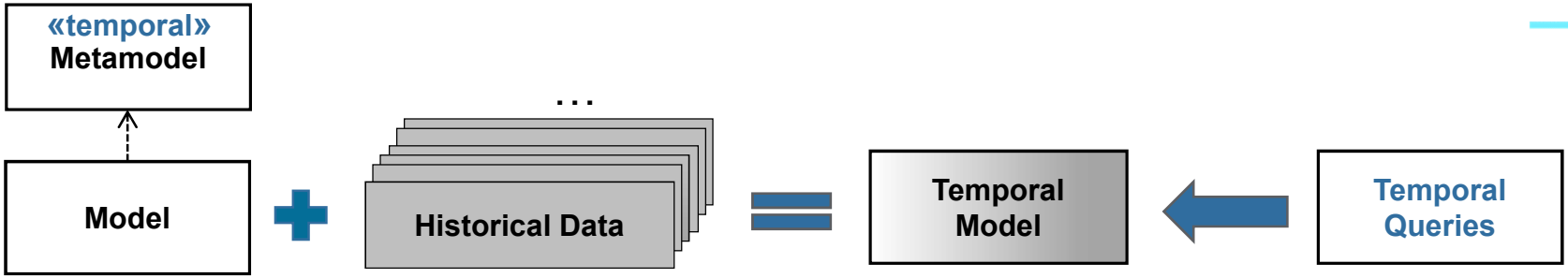
Runtime Architecture

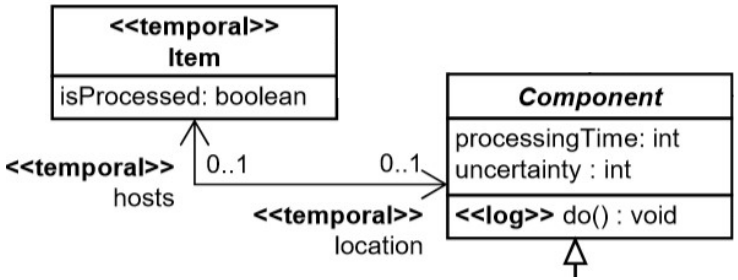


Mazak, Lüder, Wolny, Wimmer, Winkler, Kirchheim, Rosendahl, Bayanifar, Biffl:
Model-based generation of run-time data collection systems exploiting AutomationML.
Automatisierungstechnik 66(10): 819-833 (2018)

Capturing Runtime in any DSL

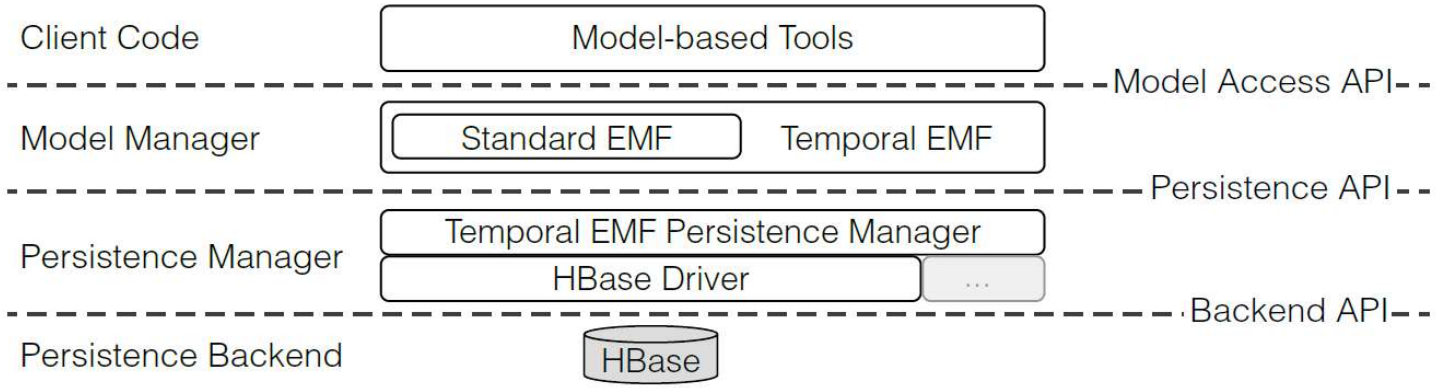
Joint work with: Universitat Oberta de Catalunya





Find the components which had an item assigned at a particular point in time

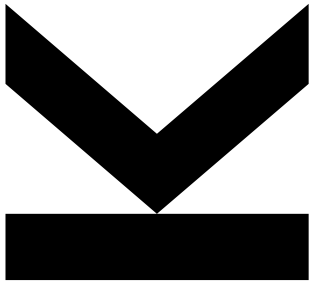
```
TObject::eGetAt(i:instant, f:feature)
```



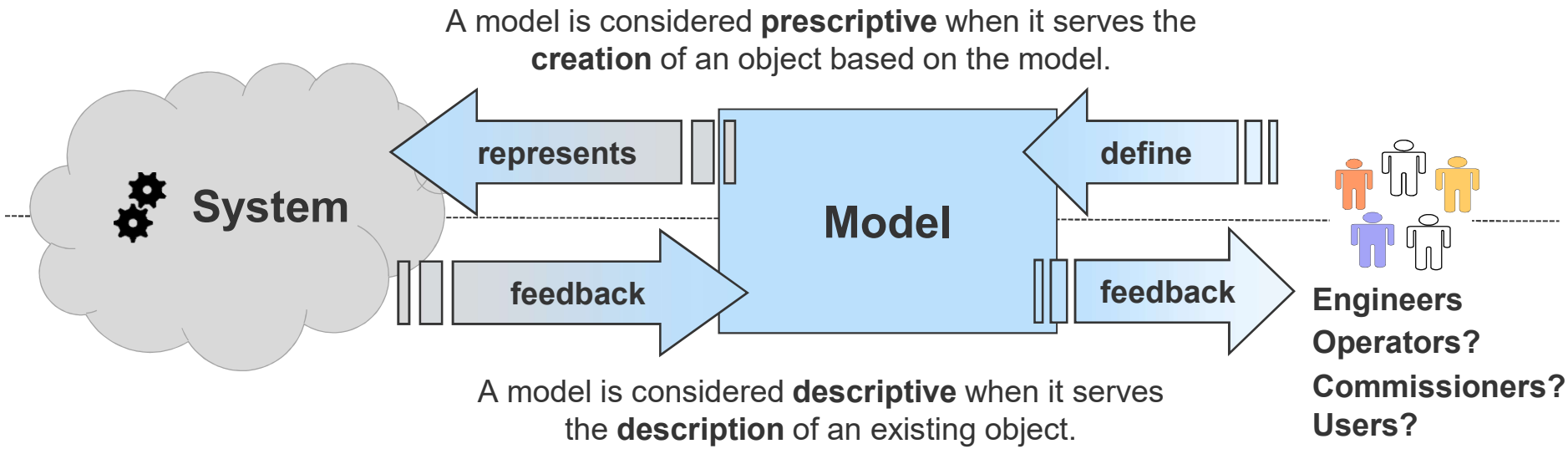
JOHANNES KEPLER UNIVERSITÄT LINZ

Gómez, Cabot, Wimmer: *TemporalEMF: A Temporal Metamodeling Framework*. In: Proc. of the Conceptual Modeling Conference (ER) 2018: 365-381

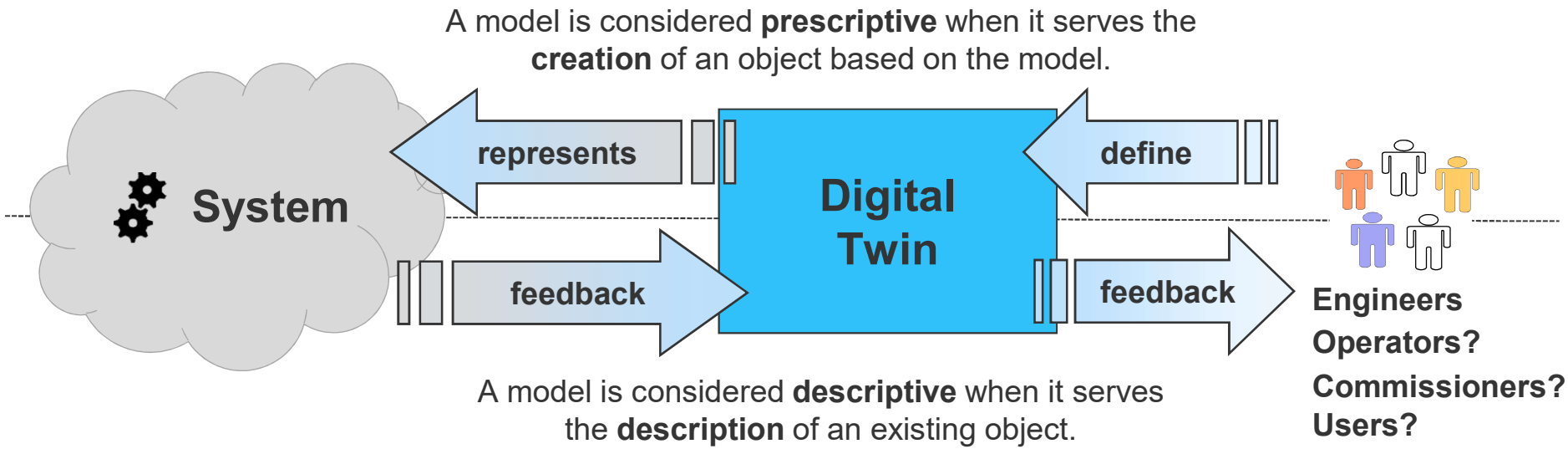
Conclusion & Outlook



From MDE...

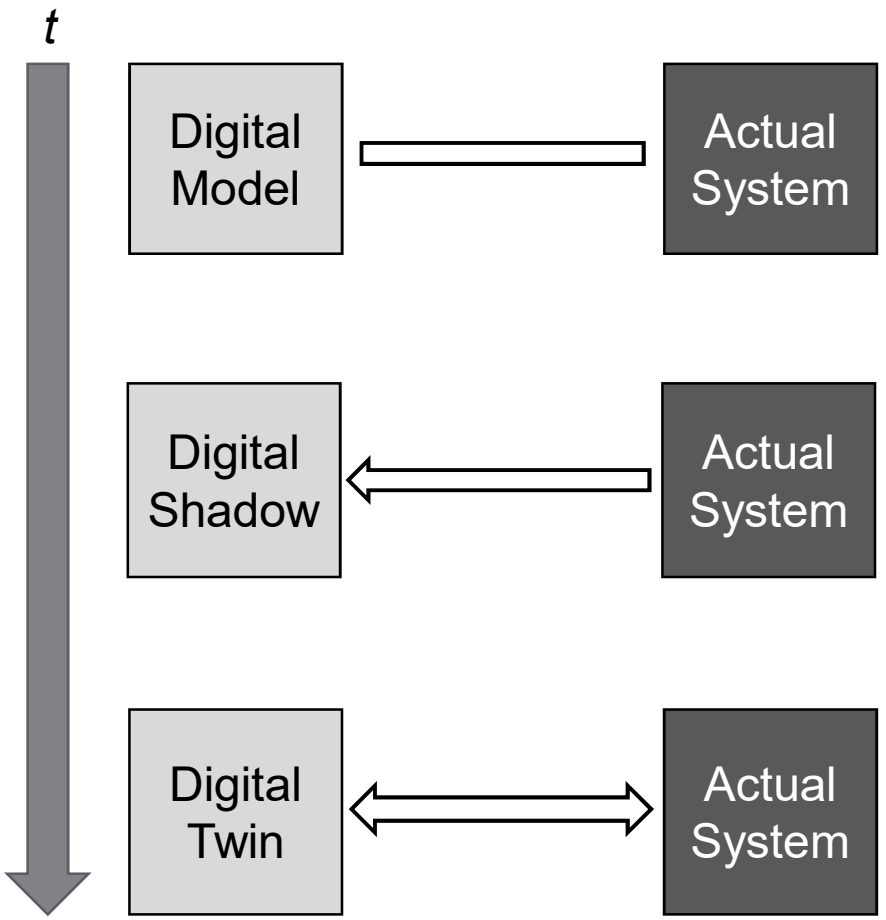

A model is considered **prescriptive** when it serves the **creation** of an object based on the model.
System
represents
define
Model
feedback
feedback
Engineers
Operators?
Commissioners?
Users?
A model is considered **descriptive** when it serves the **description** of an existing object.

… to Digital Twins



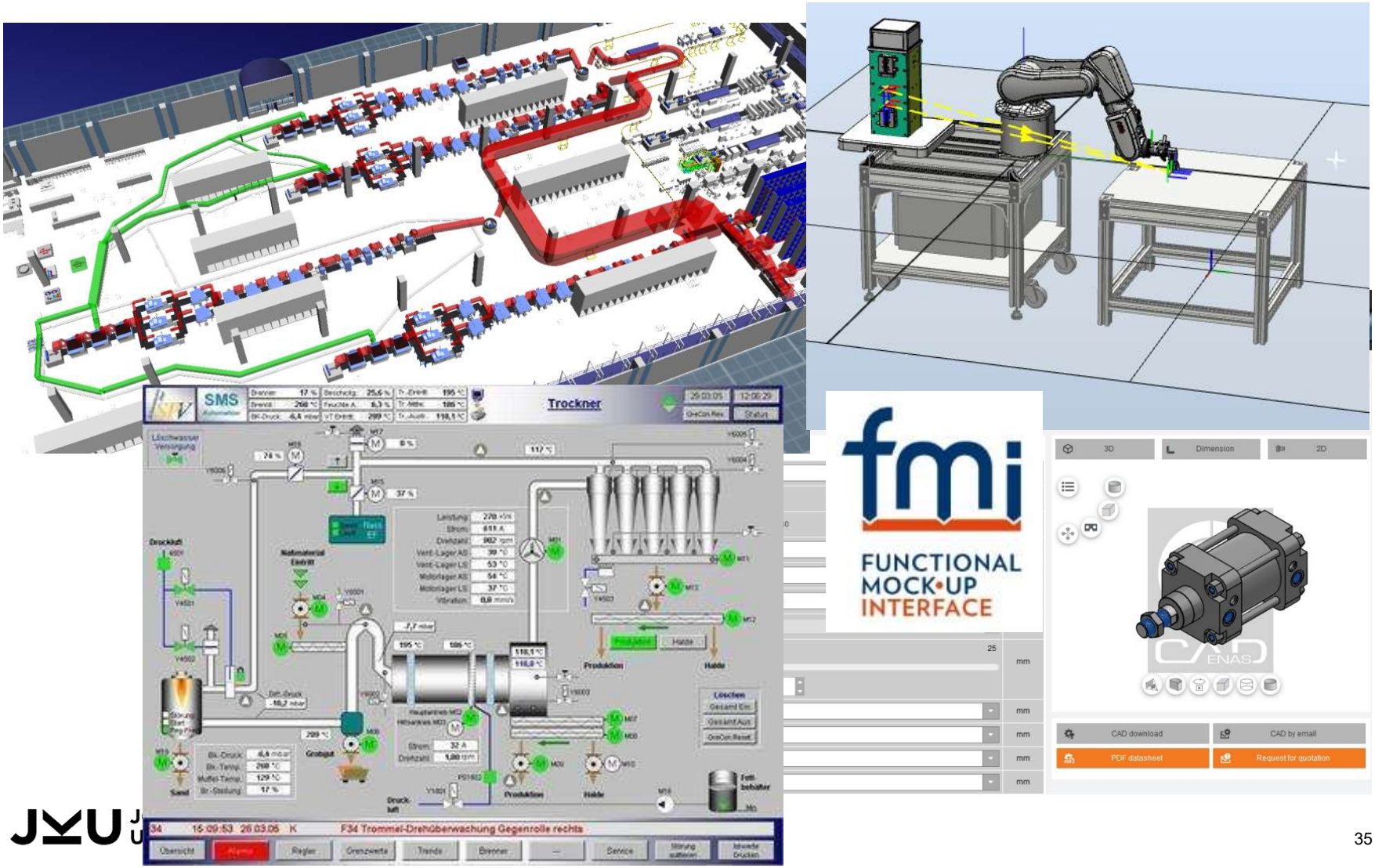
Digital Twin Engineering

- **Digital Model**
  - Documentation & communication
  - Simulation & code generation
  - Design-space exploration
  - Commissioning
- **Digital Shadow**
  - State inspection
  - Runtime monitoring
  - Predictive reasoning
  - Conformance checking
- **Digital Twin**
  - Runtime adaptation
  - Live updates & rollbacks
  - Decision making
  - Autonomy



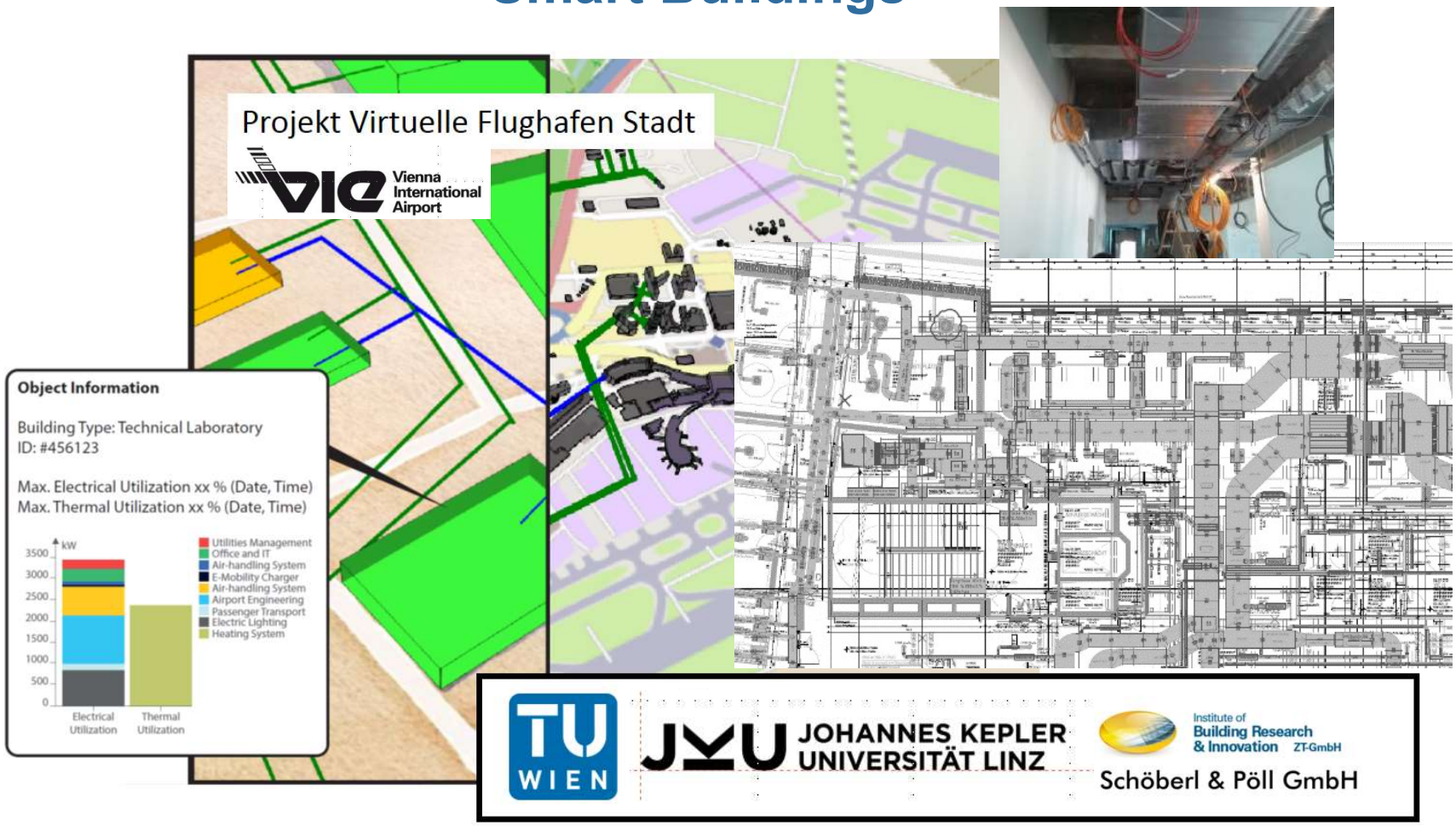
Emerging Digital Twin Domains (1/4)

Smart Production



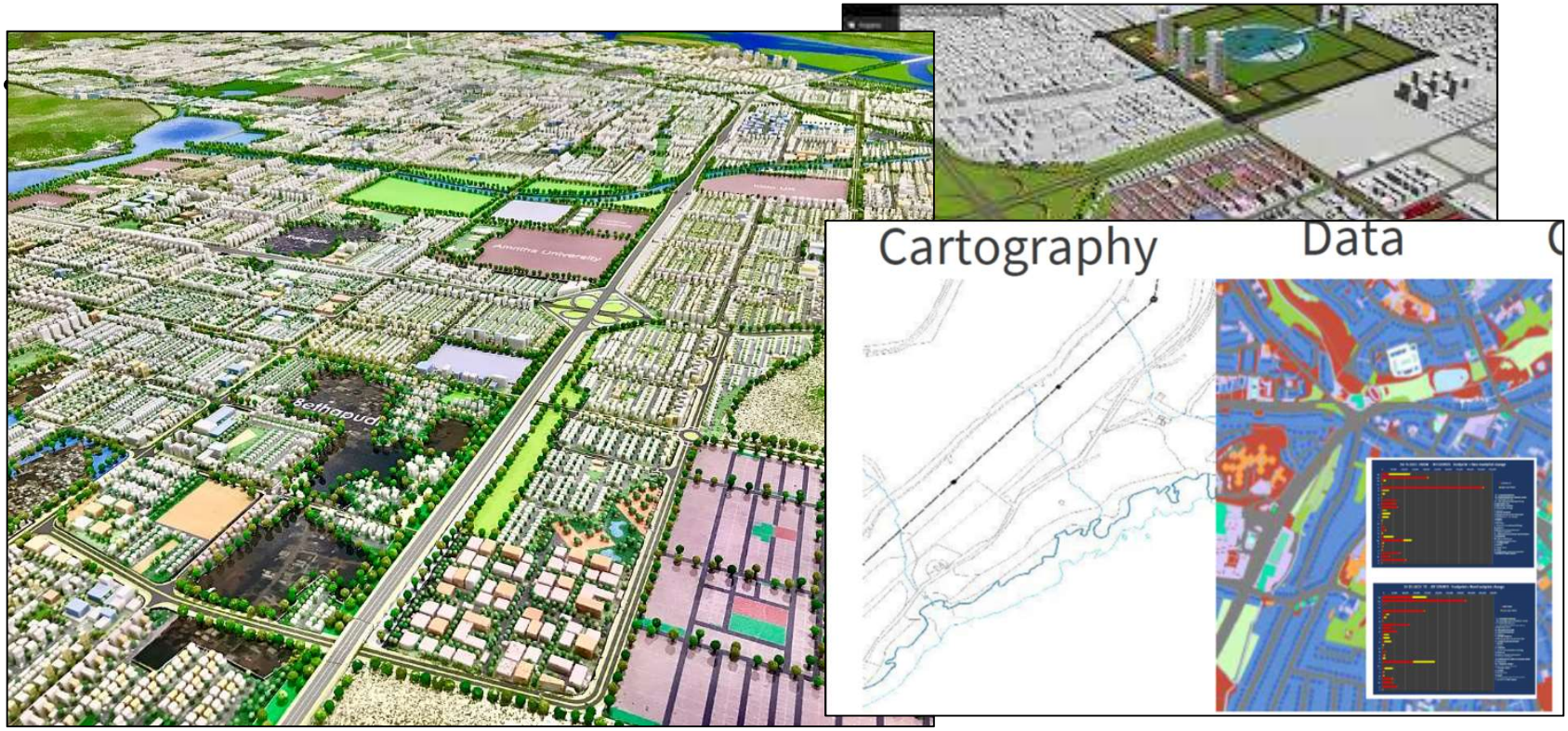
Emerging Digital Twin Domains (2/4)

Smart Buildings



Emerging Digital Twin Domains (3/4)

Smart Cities

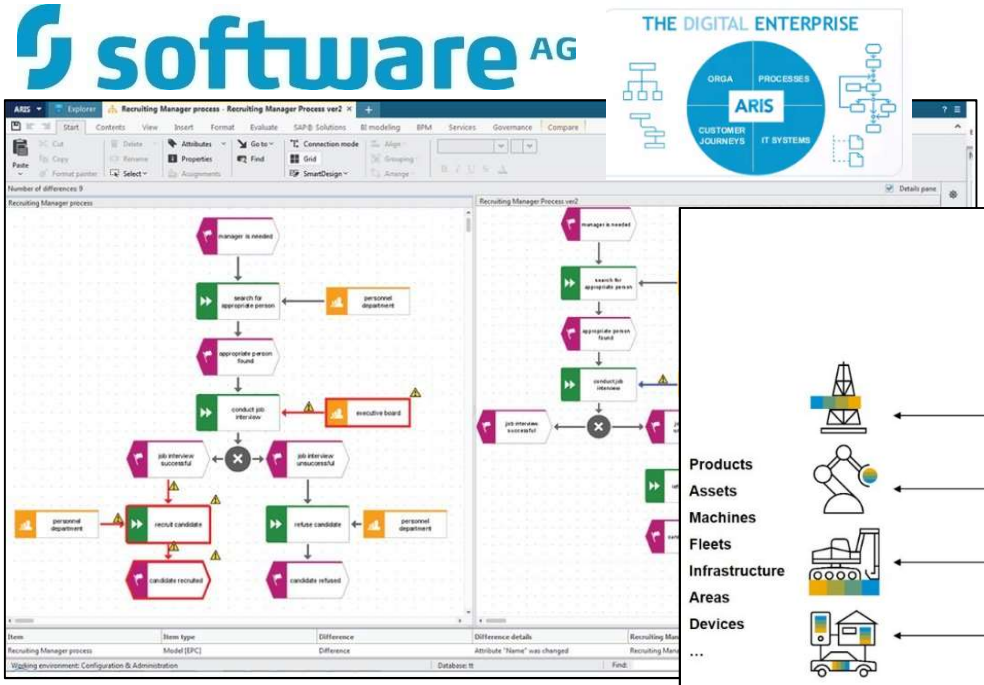


***Amaravati**, the new capital of the Indian state of Andhra Pradesh, is thought to be the **first entire city born with a digital twin**.*

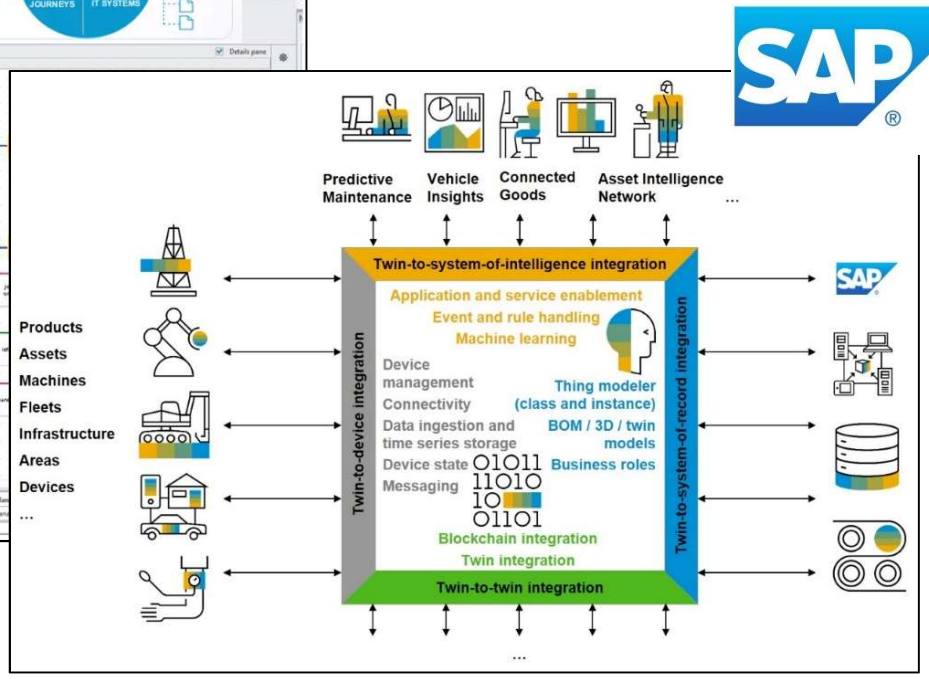
https://www.smartcitiesworld.net/news/digital-twin-created-for-new-indian-smart-city-3674
https://www.bbc.com/news/business-46880468

Emerging Digital Twin Domains (4/4)

Smart Enterprise



https://industrie.de/top-list/software-ag-stellt-enterprise-digital-twin-framework-vor/



https://blogs.sap.com/wp-content/uploads/2017/09/Digital_Twin_Implementation.jpg

Thank you!

Comments? Questions? Feedback?

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Publications (1/2)

- Wolny, Mazak, Wimmer: Automatic Reverse Engineering of Interaction Models from System Logs. ETFA 2019
- Wolny, Mazak, Wimmer, Huemer: Model-driven Runtime State Identification. EMISA 2019
- Mazak, Lüder, Wolny, Wimmer, Winkler, Kirchheim, Rosendahl, Bayanifar, Biffl: *Model-based generation of run-time data collection systems exploiting AutomationML*. Automatisierungstechnik 66(10): 819-833 (2018)
- Wolny, Mazak, Wimmer, Konlechner, Kappel*: Model-Driven Time-Series Analytics*. Enterprise Modelling and Information Systems Architectures 13: 252-261 (2018)
- Gómez, Cabot, Wimmer: *TemporalEMF: A Temporal Metamodeling Framework*. ER 2018: 365-381

Publications (2/2)

- Bill, Mazak, Wimmer, Vogel-Heuser: *On the Need for Temporal Model Repositories*. STAF Workshops 2017: 136-145
- Mazak, Wimmer, Patsuk-Boesch: *Reverse engineering of production processes based on Markov chains*. CASE 2017: 680-686
- Wolny, Mazak, Konlechner, Wimmer: *Towards Continuous Behavior Mining*. SIMPDA 2017: 149-150
- Mazak, Wimmer, Patsuk-Bösch: *Execution-Based Model Profiling*. SIMPDA 2016: 37-52
- Mazak, Wimmer: *On Marrying Model-driven Engineering and Process Mining: A Case Study in Execution-based Model Profiling*. SIMPDA 2016: 78-88
- Mazak, Wimmer: *Towards Liquid Models: An Evolutionary Modeling Approach*. CBI 2016: 104-112