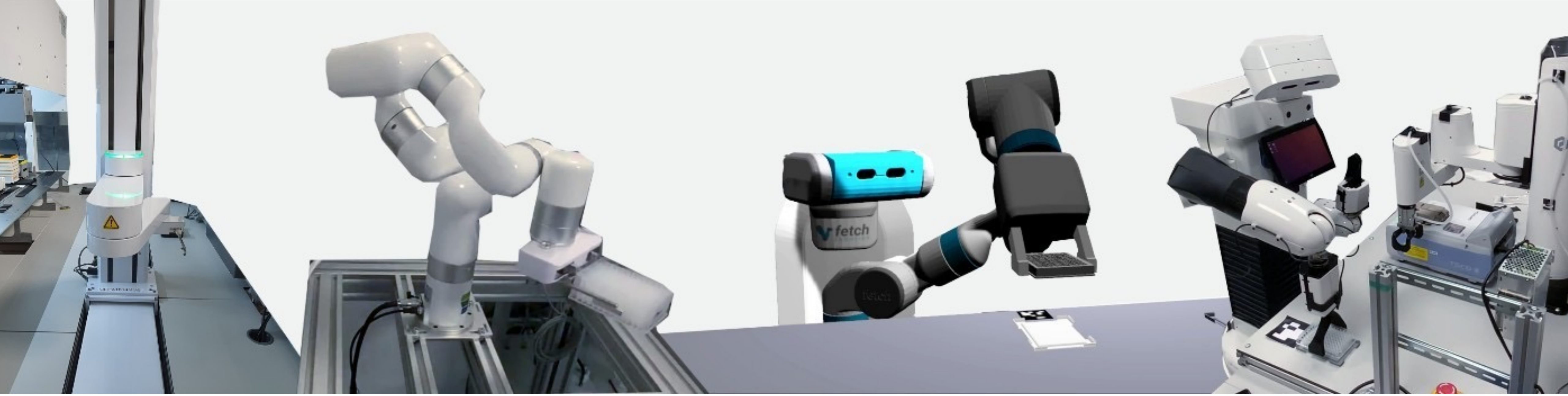

Teaching-free robot integration with the LAPP digital twin

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Pharmaceutical Sciences, Sustainability & Technology

31.MAY.2023

Better Health, Brighter Future

Agenda

- **Robotized lab automation systems**
  and their challenges
- **Our journey with mobile manipulators**
  on the technology readiness level scale
- **Taking lab robots a step further**
  with the Laboratory Automation Plug & Play (LAPP) framework
- **Hierarchical decomposition**
  Pick & place labware transfer activity
- **Ontologies**
  Pick & place labware transfer activity
- **Position representations for mobile robots**
  with the LAPP Digital Twin
- **Control pyramid**
  Reference architecture model

Robotized lab automation systems

and their challenges

Laboratory automation in R&D

High throughput
- Routine tests, repetitive workflows
- Highly customized purpose-made cells
- Set-up-and-leave / lights-out

High flexibility
- Dynamic workflows
- Stand-alone, often not robot-friendly devices
- Humans need to interface and connect them

Collaborative & mobile robotics
- Operate in human-designed (less-structured) environments
- Interface with modular equipment
- Cooperative & collaborative operation

	Stationary robot	**MoMa***	**Human**
Throughput	High	Low	Middle
Availability	High	Middle	Low
Flexibility	Low	High	High

[1]

* Mobile manipulator robot

Mobile manipulators in laboratory automation

Usage

- Pick & place type sample transportation
- Standard objects
- Pre-defined hand-over positions

Anatomy

- Mobile base with simultaneous localization and mapping (SLAM)
    - cm accuracy
- Robot arm of 4-6 degrees-of-freedom (DoF)
- Fine-positioning system
    - Vision [13]
    - Mechanical probe
- Parallel gripper
    - Mostly for microplates [16]

Challenges

- Complex, multi-layer integration
- Many inter-connected components
- Many sources of errors

	Omnidrive	Differential drive
Small circular footprint 4 DoF (SCARA)	 KEVIN – Fraunhofer IPA	 OMRON – Biosero
Bigger rectangular footprint 6-7 DoF articulated arm	 KUKA – Gearu	 UniteLabs – Astech Projects

Our journey with mobile manipulators

on the technology readiness level scale

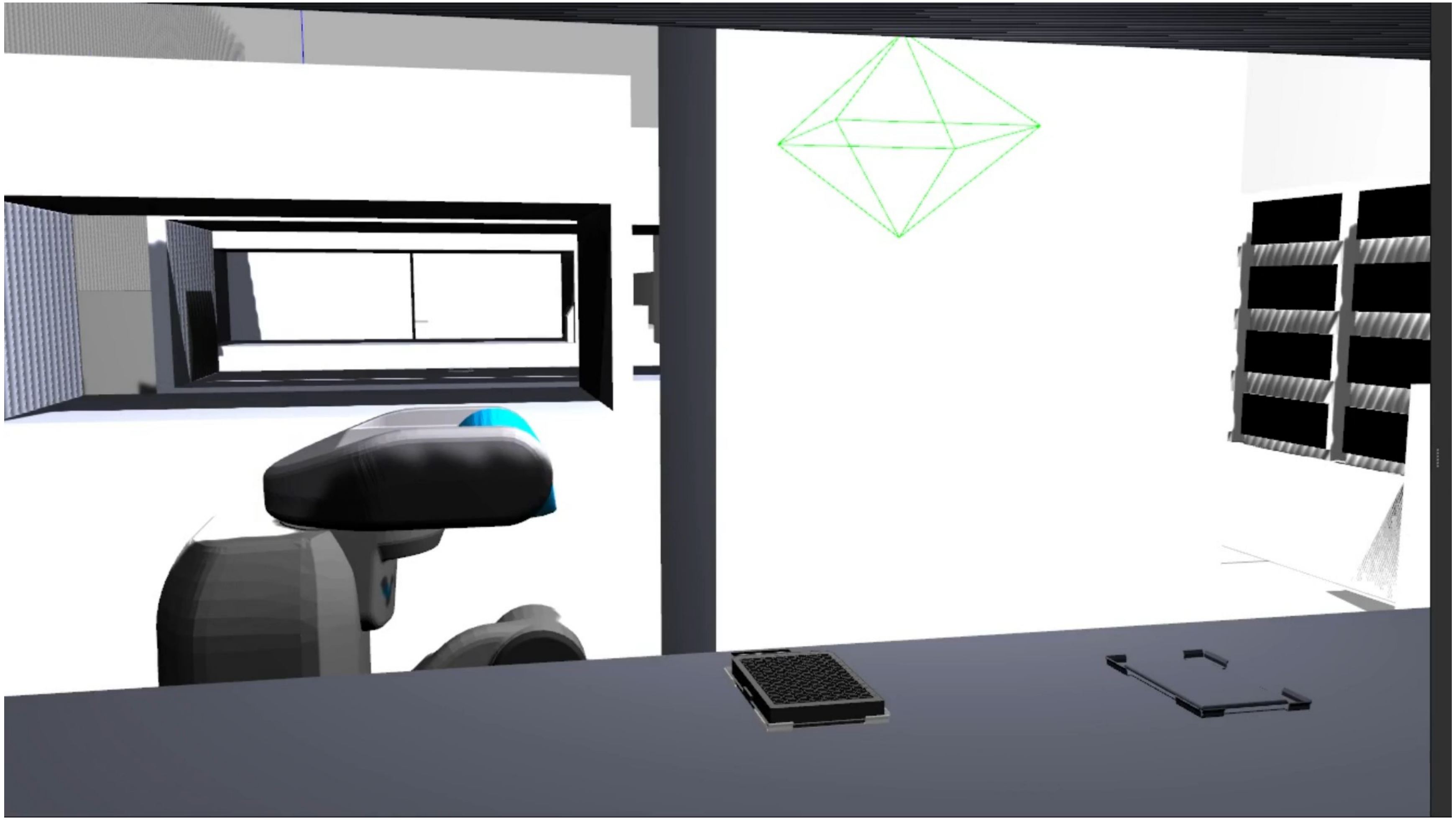
Technology readiness levels (TRL)

TRL	Definition
1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

MoMa, TRL 1

TRL	EU definition	MoMa example	Timeline
1	Basic principles observed	AR-Marker detection identified as a means for position detection	2019, Q1

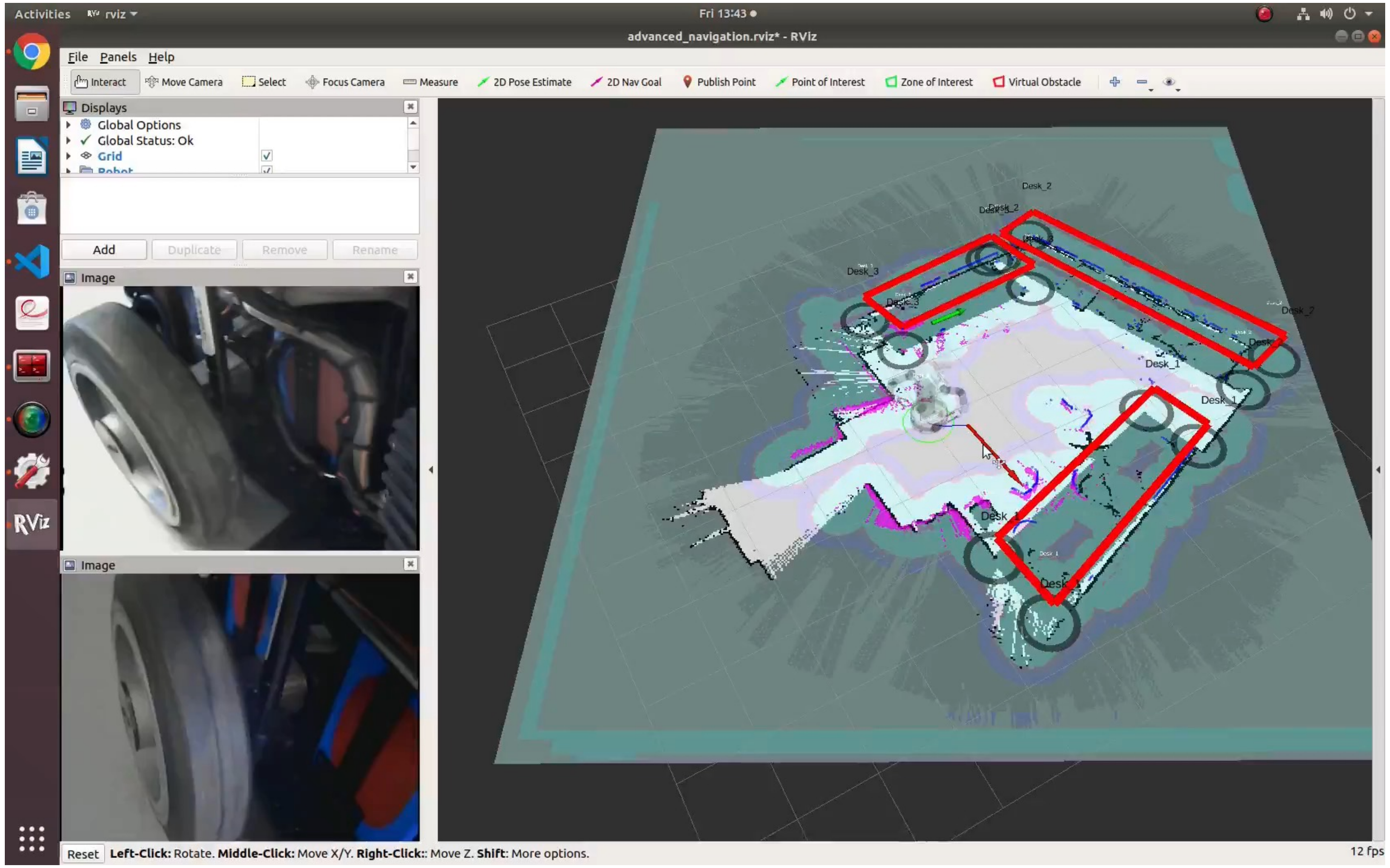
MoMa, TRL 2



TRL	EU definition	MoMa example	Timeline
2	Technology concept formulated	Simulation-based study for marker-based pick-and-place sample transportation (master thesis)	2019 Q1 - 2019 Q3

MoMa, TRL 3

- Safety aspects
  - No certificate
  - Detailed risk-assessment was needed
  - New and challenging field for safety experts
- IT
  - Development environment with special requirements
  - Security aspects
  - Open-source and in-house developed software
- Hardware and software bugs
  - Very supportive vendor



TRL	EU definition	MoMa example	Timeline
3	Experimental proof of concept	Initial tests with TIAGo in our lab	2020 Q1 - 2021 Q2

MoMa, TRL 4

Standardization in Laboratory Automation (SiLA) Consortium

SiLA Robotics Working Group (SRWG)

- Open community, monthly exchange meetings
- Feature definition unification workstream
- Ontologies workstream (more details later)
- Hackathons: BioSASH, a BioLAGO-SiLA Project

Industrial-Academical projects

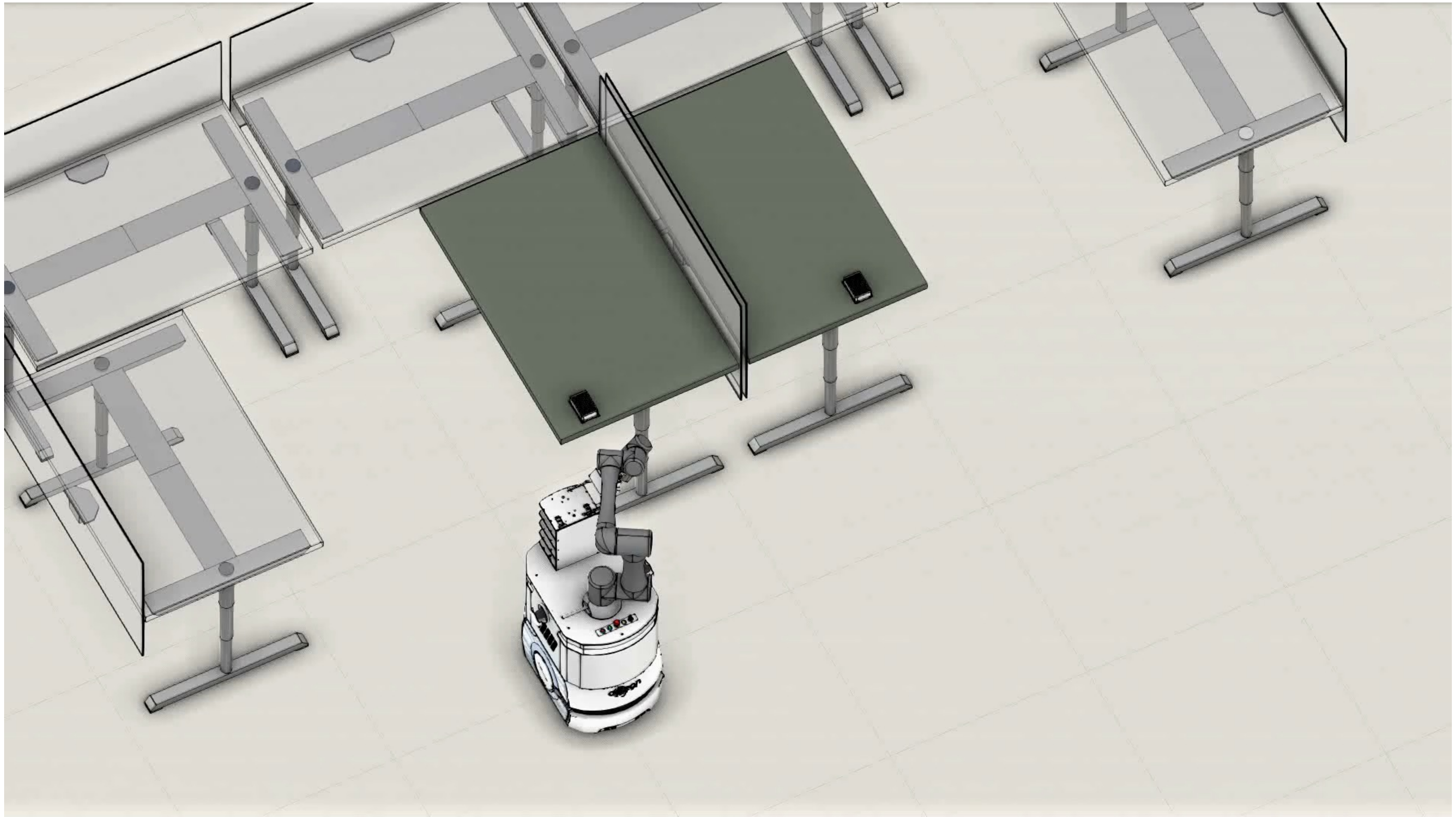
- Óbuda University
- Takeda's global MoMa PoC (more details later)

biolago.org

uni-obuda.hu

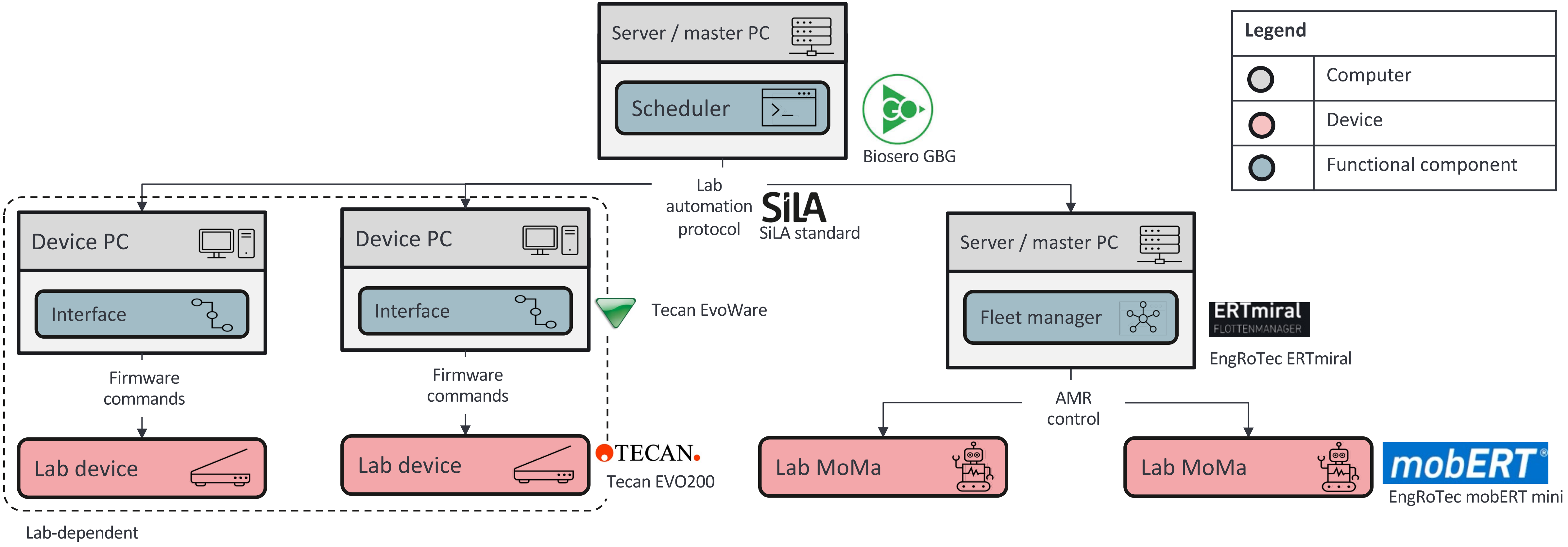
TRL	EU definition	MoMa example	Timeline
4	Technology validated in lab	SiLA Working Group & Uni Óbuda Collab	2023 Q1 - present

MoMa, TRL 5



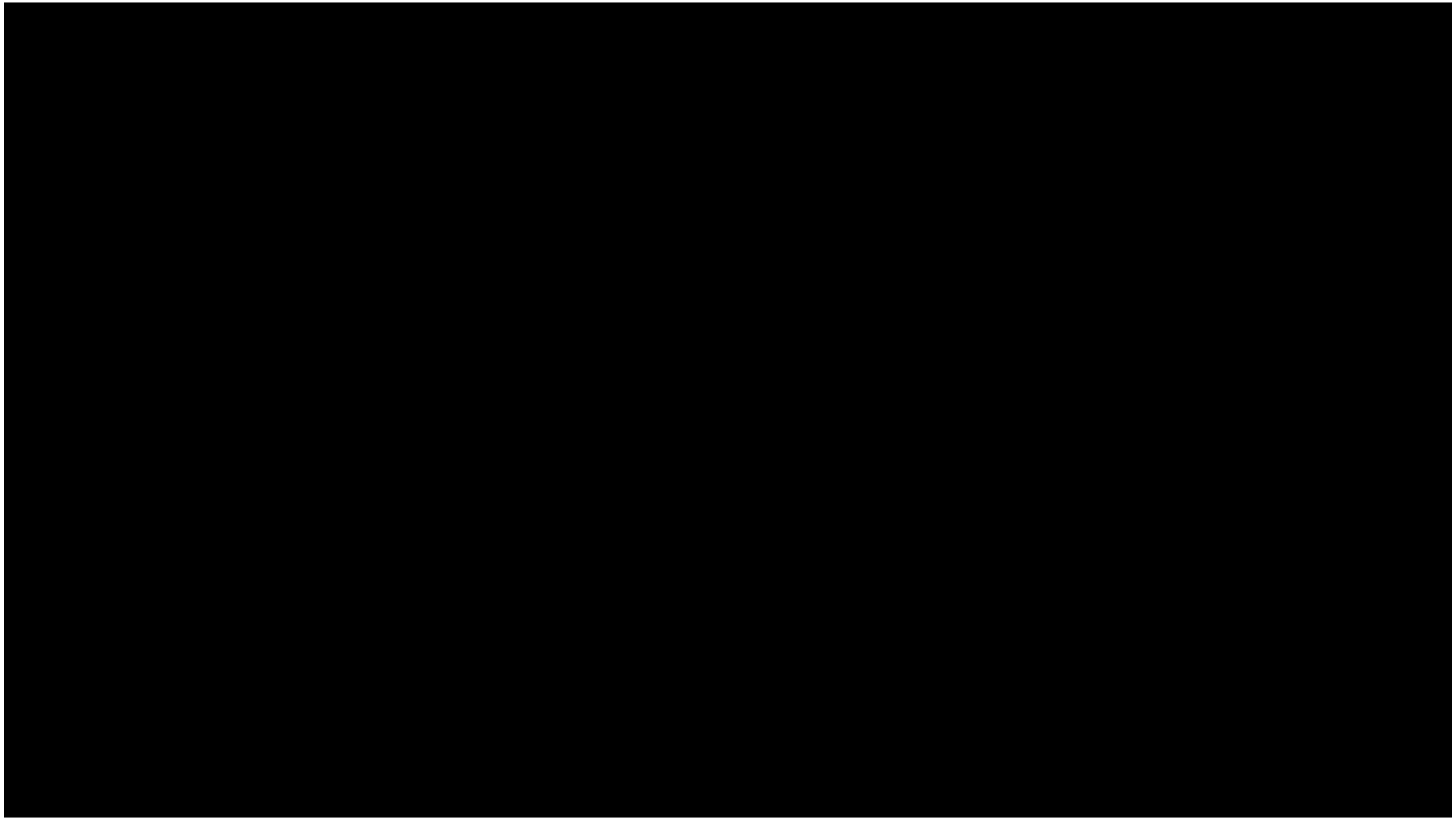
TRL	EU definition	MoMa example	Timeline
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Omron pick-and-place demo, bench	2022 Q4 - present

MoMa, TRL 6



TRL	EU definition	MoMa example	Timeline
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Device integration	2023,Q2

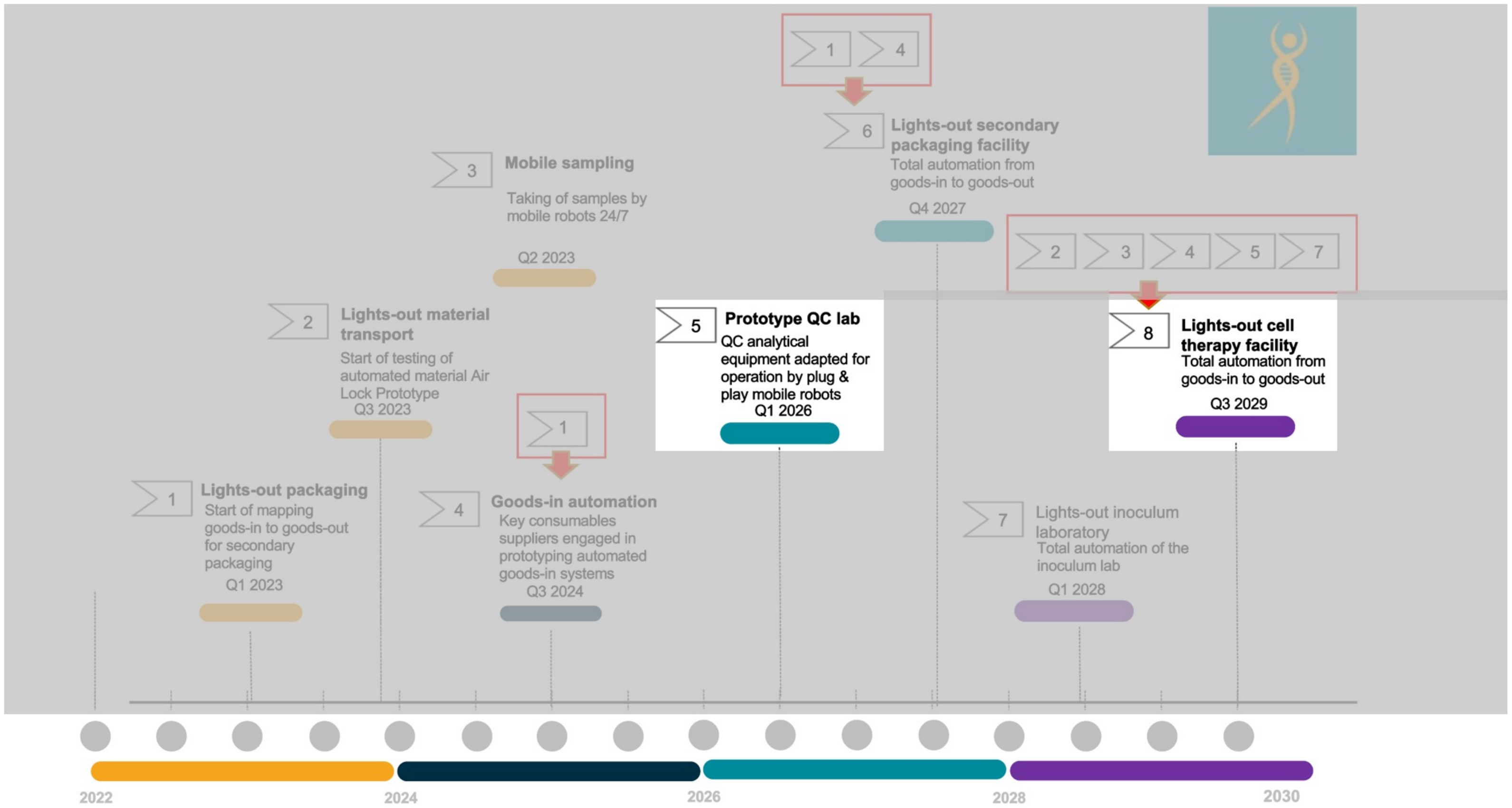
MoMa, TRL 7



TRL	EU definition	MoMa example	Timeline
7	System prototype demonstration in operational environment	Global Engineering, storage integration endeavor	2024 Q1

MoMa, TRL 8-9

Robotics roadmap- biomanufacturing to 2030 (v1. Mar 2022)



TRL	EU definition	MoMa example	Timeline
8	System complete and qualified	Qualified QC system	2025 Q4
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	Deployed QC system	2026 Q1

Taking lab robots a step further

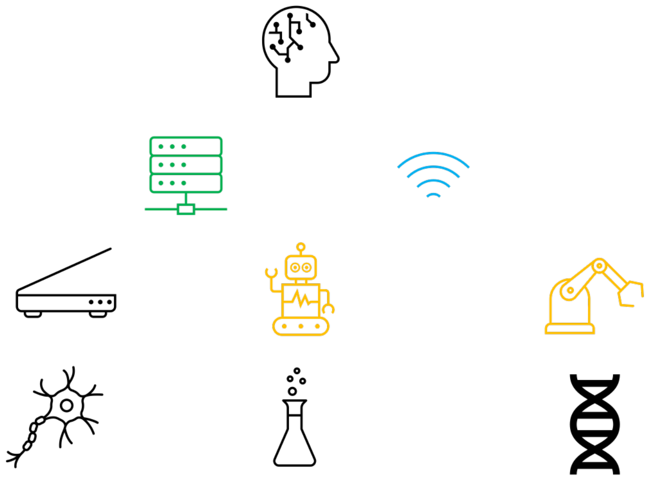
With the Laboratory Automation Plug & Play (LAPP) framework

Standardization and plug & play integration for lab robots

The Laboratory Automation Plug & Play (LAPP) framework

A reference architecture model to provide a comprehensive integration framework

- Hierarchical decomposition of robotized lab workflows
- Multi-layer control architecture
- Device-centric information representation in the digital twin
    - Teaching positions for robot motions, expressed in a device-attached coordinate frame
- Communication protocols
    - SiLA for communication and control (scheduler → device, scheduler → robot)



Public project site

Hierarchical decomposition

of laboratory workflows

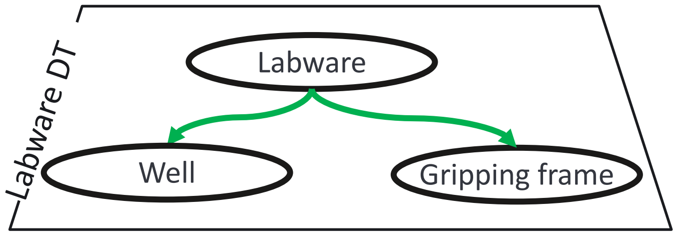
Hierarchical decomposition of lab workflows

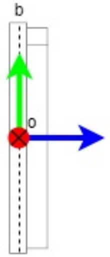
Level nr	Level name	Description	Examples	
			Liquid handling	Robotics
7	Service	The entirety of the laboratory’s capabilities	High throughput and/or microscale services	
6	Procedure (Experiment / assay)	An experiment or assay	Chromatography run	
5	Task	An elemental, device-level action item	Liquid transfer	Labware transfer
4	Subtask	An intermediary layer that represent parts of a task Accomplish minor landmarks	Aspirate	Pick, Place
3	Motion sequence	The robot performs a sequence of motions. E.g., in order to approach a handover site	Approach well position	Move through sequence
2	Motion primitive	An elemental motion of a robot or other mechanism	Motion vector	Linear movement
1	Actuator primitive	An output excerpted by a certain actuator E.g., robot joint or pump	Pump control	Joint control

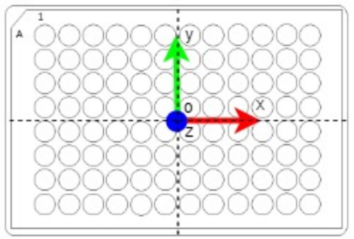
Ontologies

Pick & place labware transfer

Labware ontologies







Motivation

- Represent robot-relevant information about the lab entities

The endeavor

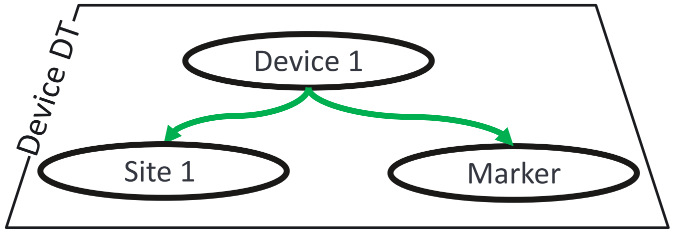
- Lead by Mark Dörr, Uni Greifswald
- Part of the Bits in Bio / Bioprotocols / LAB-OP group
- An SRWG subgroup to focus on the robot-related aspects

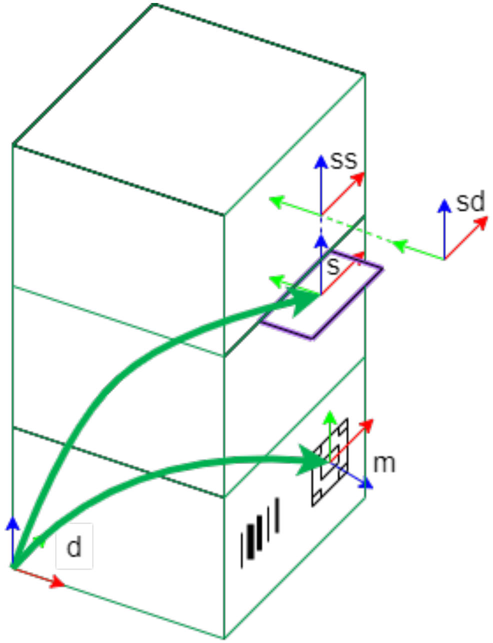
Stack

- OWL / Python classes
- EMMO base ontology + extensions
- SiLA server for queries
- Dockerized

Next step

- Adapt to the concept and stack to device ontologies
- With that, implement the LAPP Digital Twin
- Encode site and marker positions



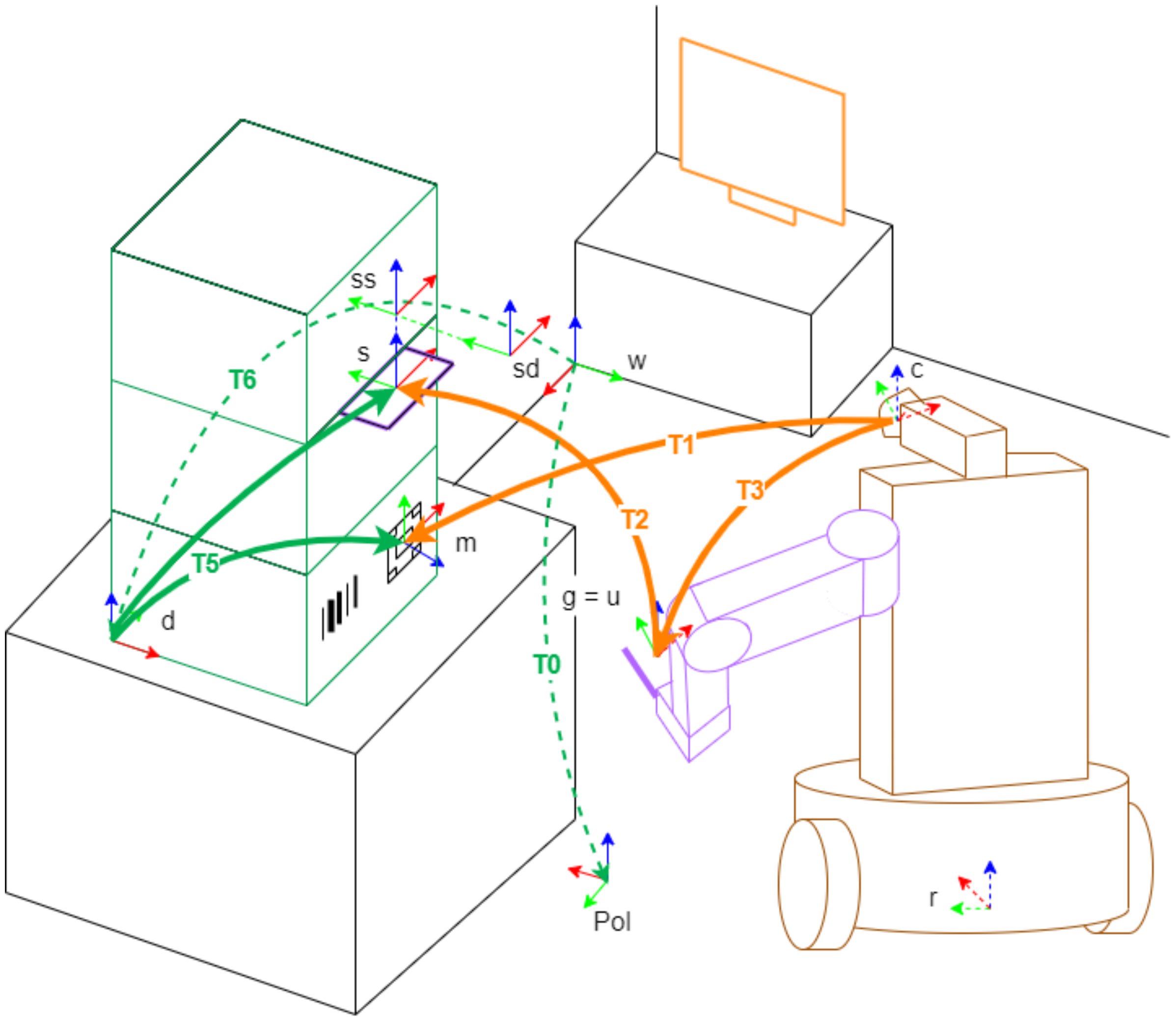


Position representations for mobile robots

with the LAPP Digital Twin

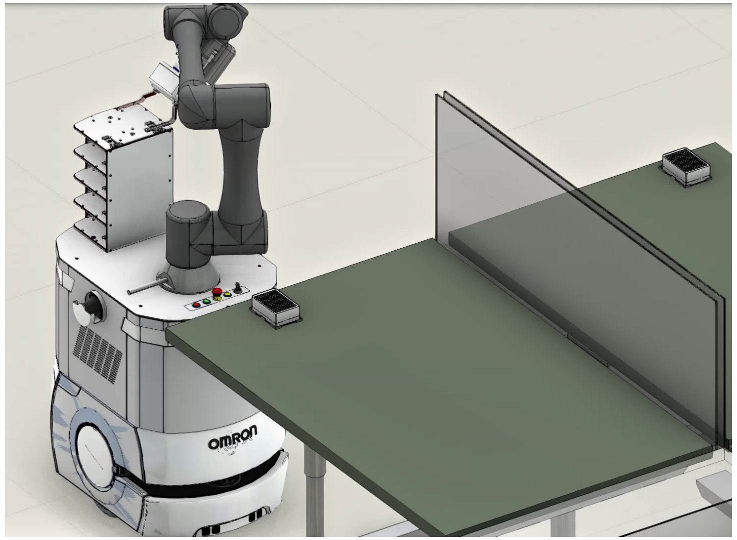
Position representations for mobile robots with the LAPP DT

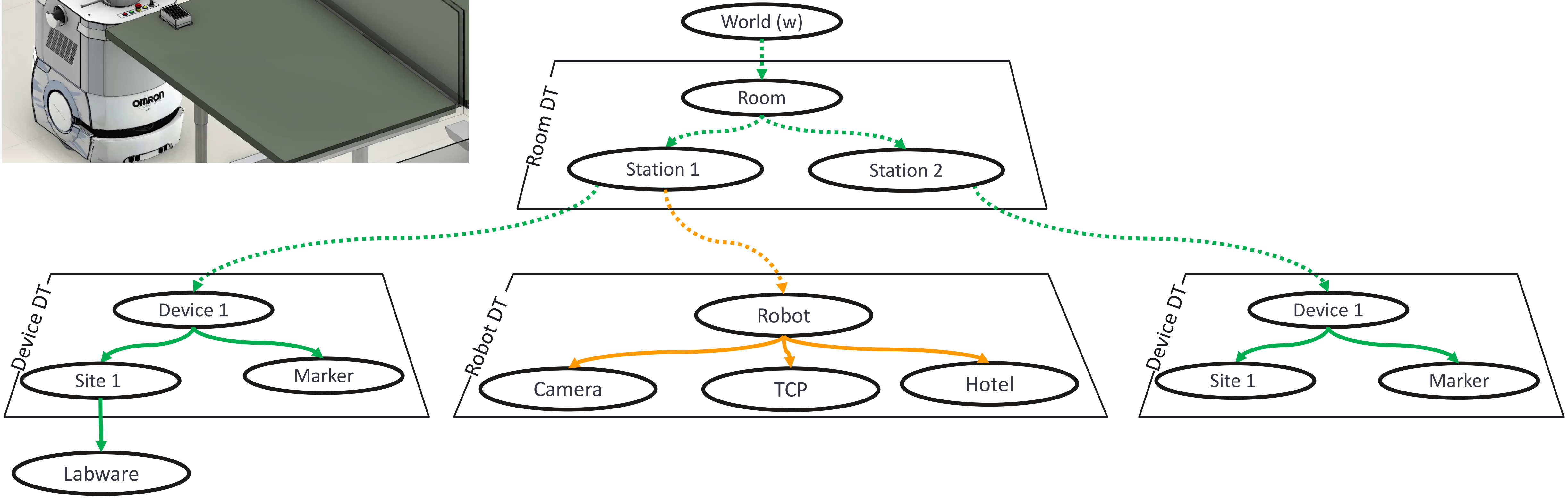
- Top-down position definitions
- Stored in parent



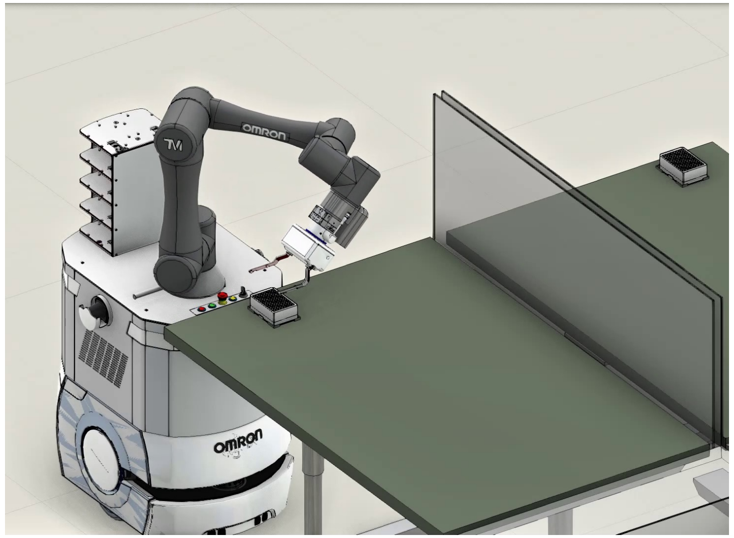
Legend	
(yellow)	Live, robot-level, not exposed towards SiLA
(green)	Stored in the LAPP DT Represented as high-level **SiLA** properties (references)
......	Transformation originates from inaccurate base odometry
——	Transformation originates from accurate sources • robot kinematics • marker detection • positions stored in the digital twin

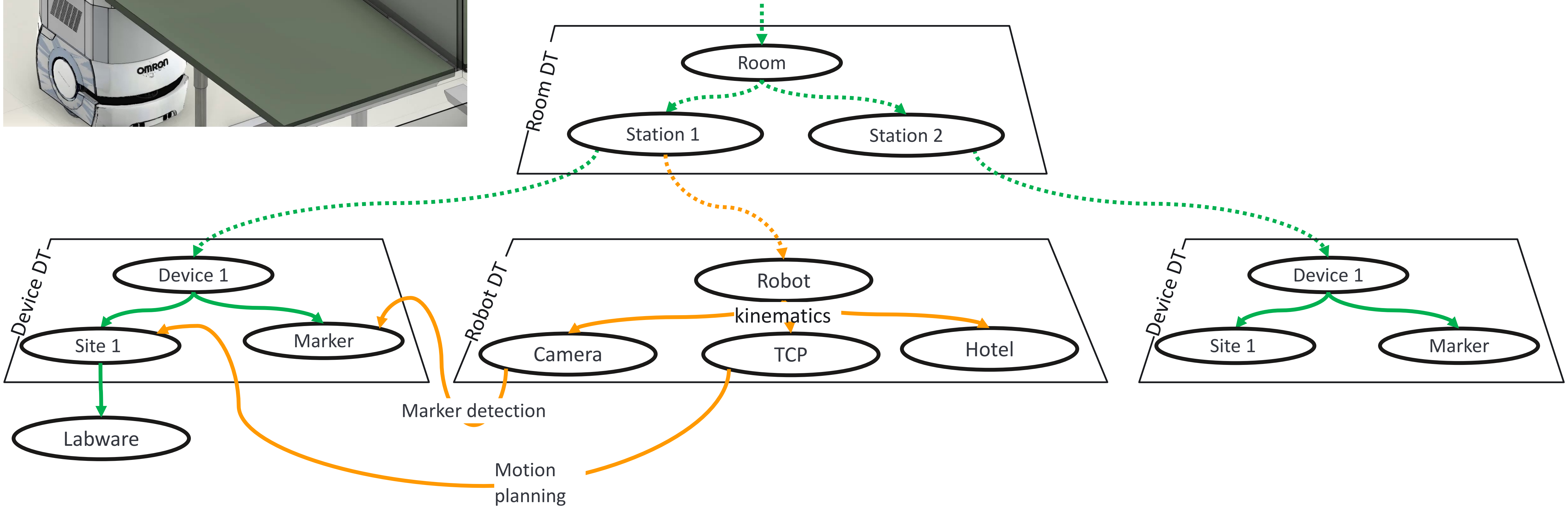
Robot docked to station 1



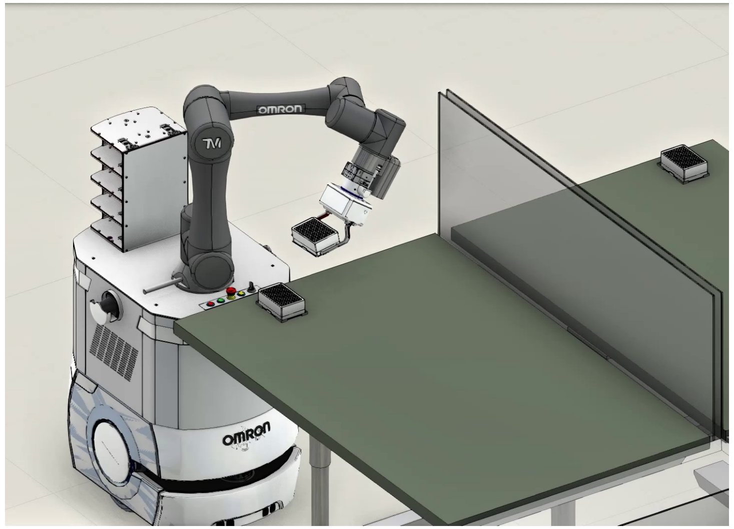


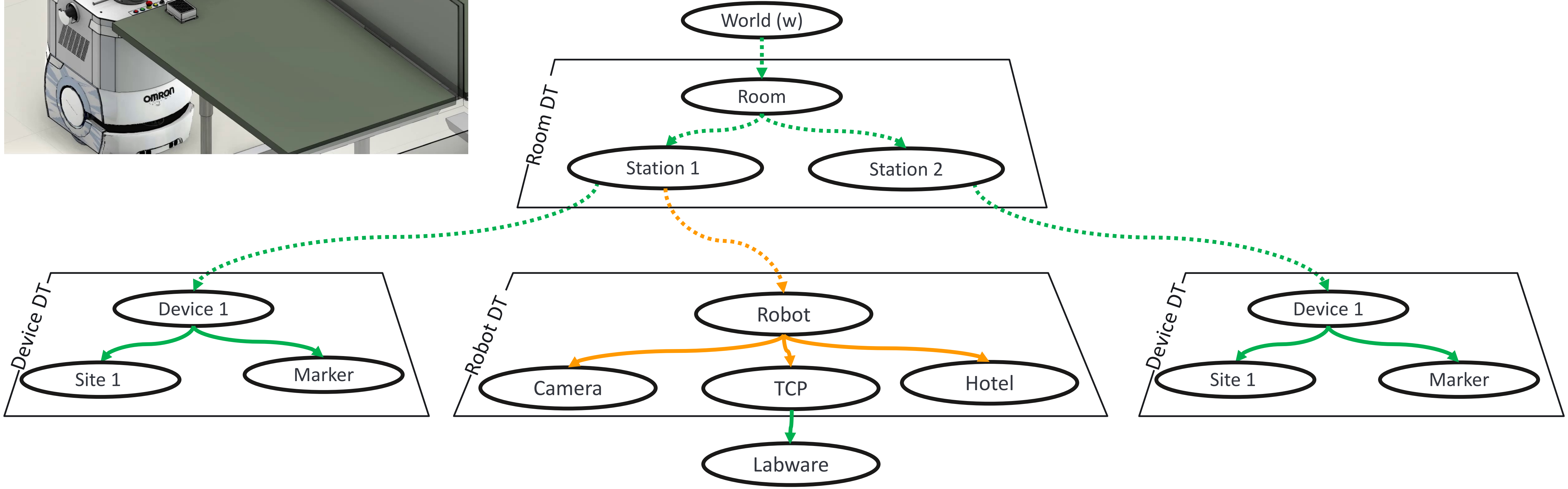
Pick from station_1.device_1.site_1



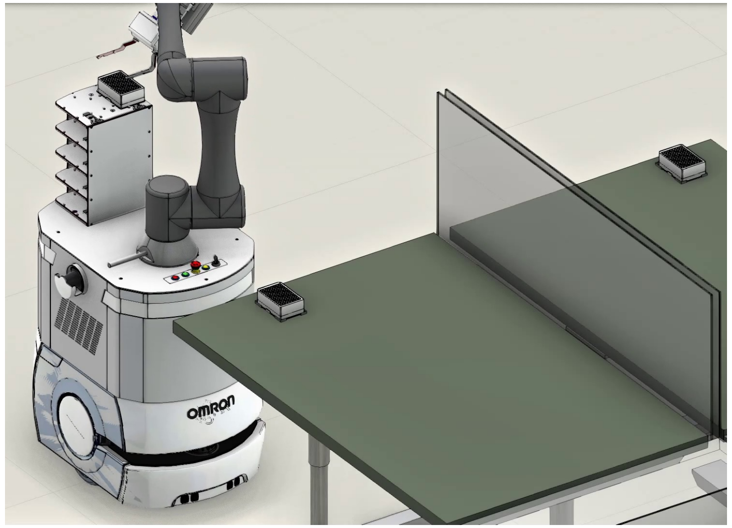


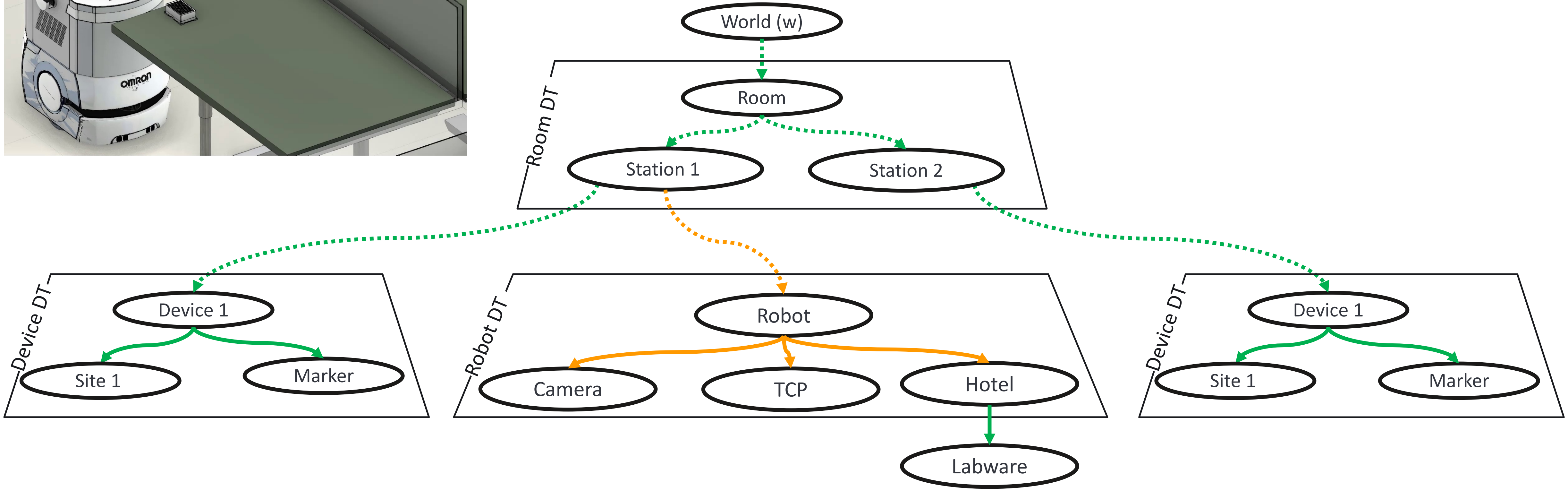
Pick from station_1.device_1.site_1 → Labware in gripper



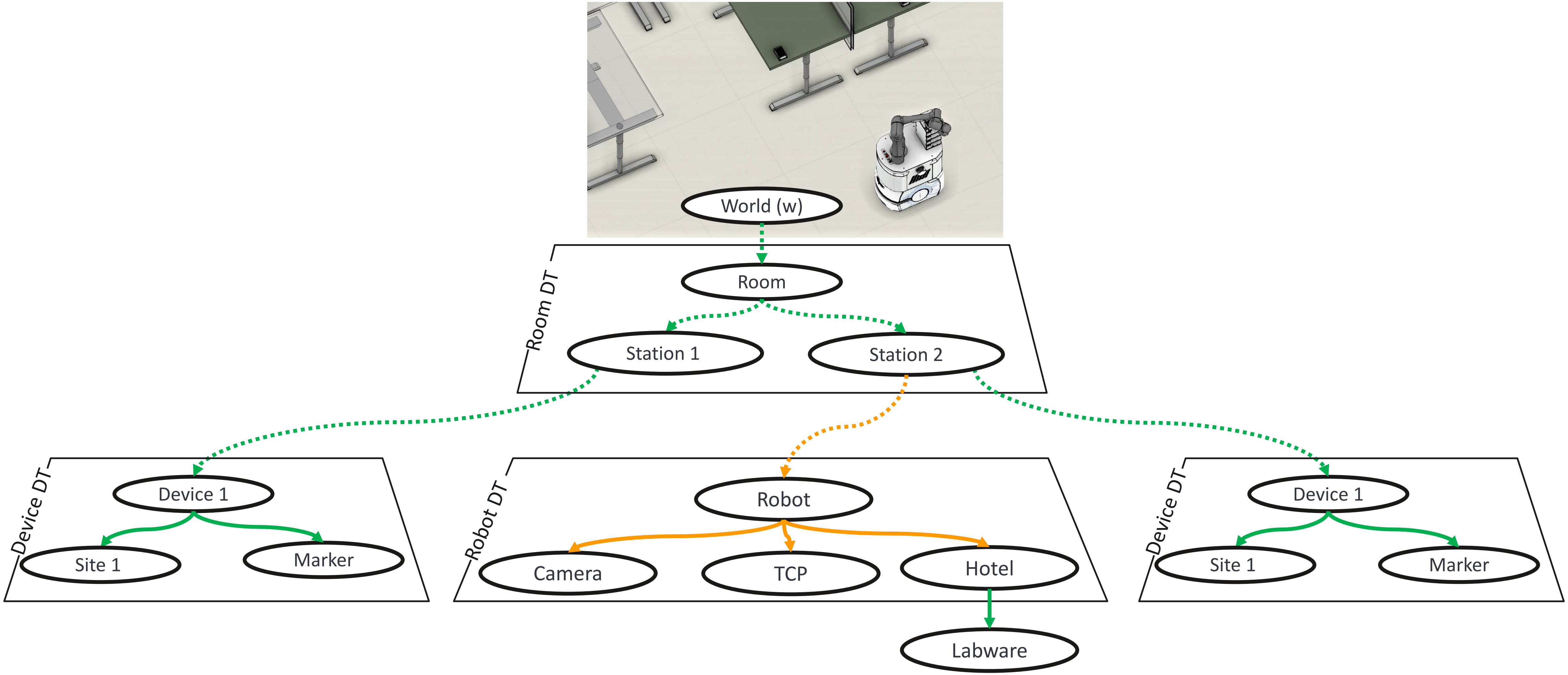


Place on on-board hotel

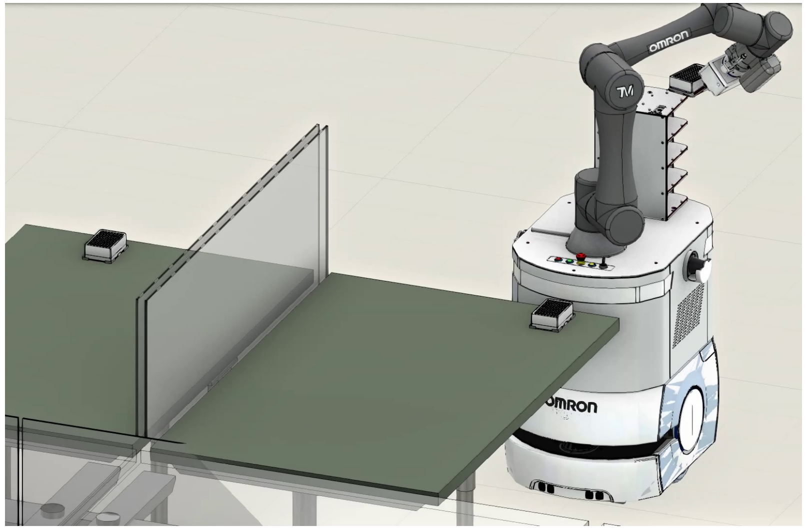


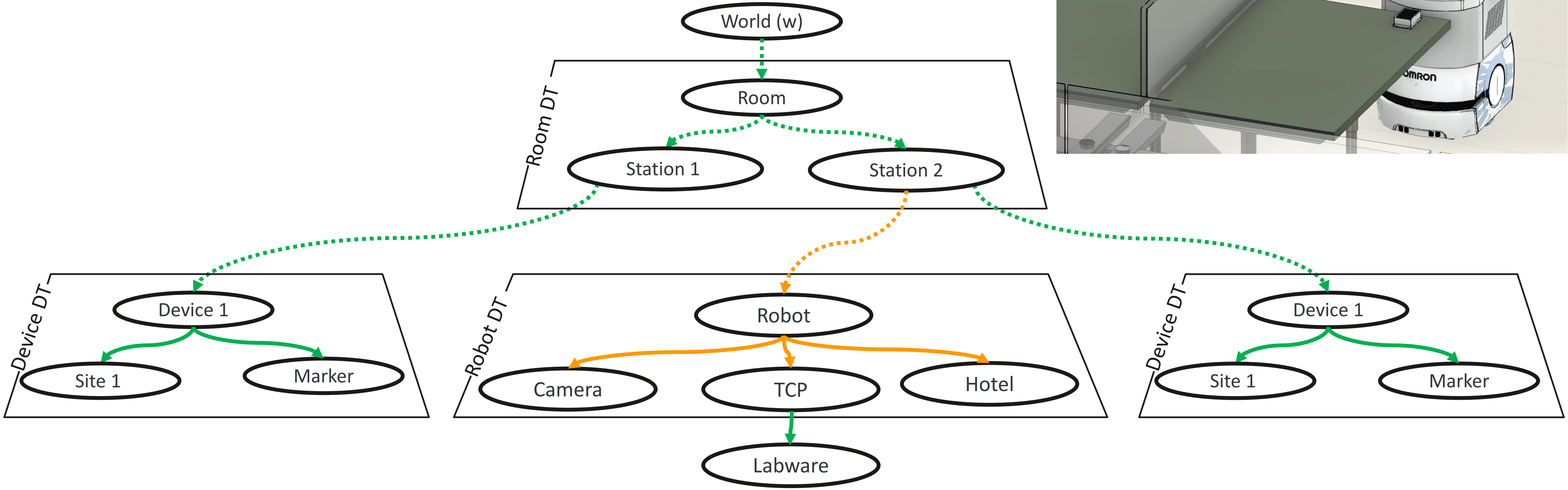


Switch to Station 2 → Undock, navigate and dock

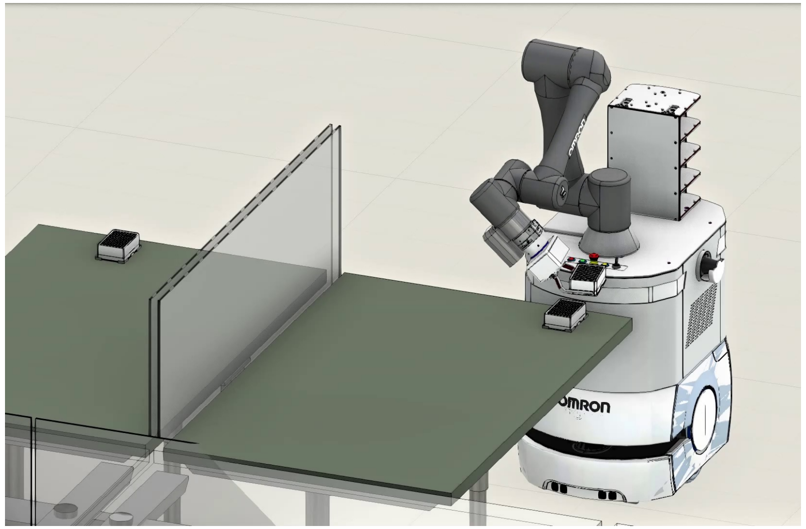


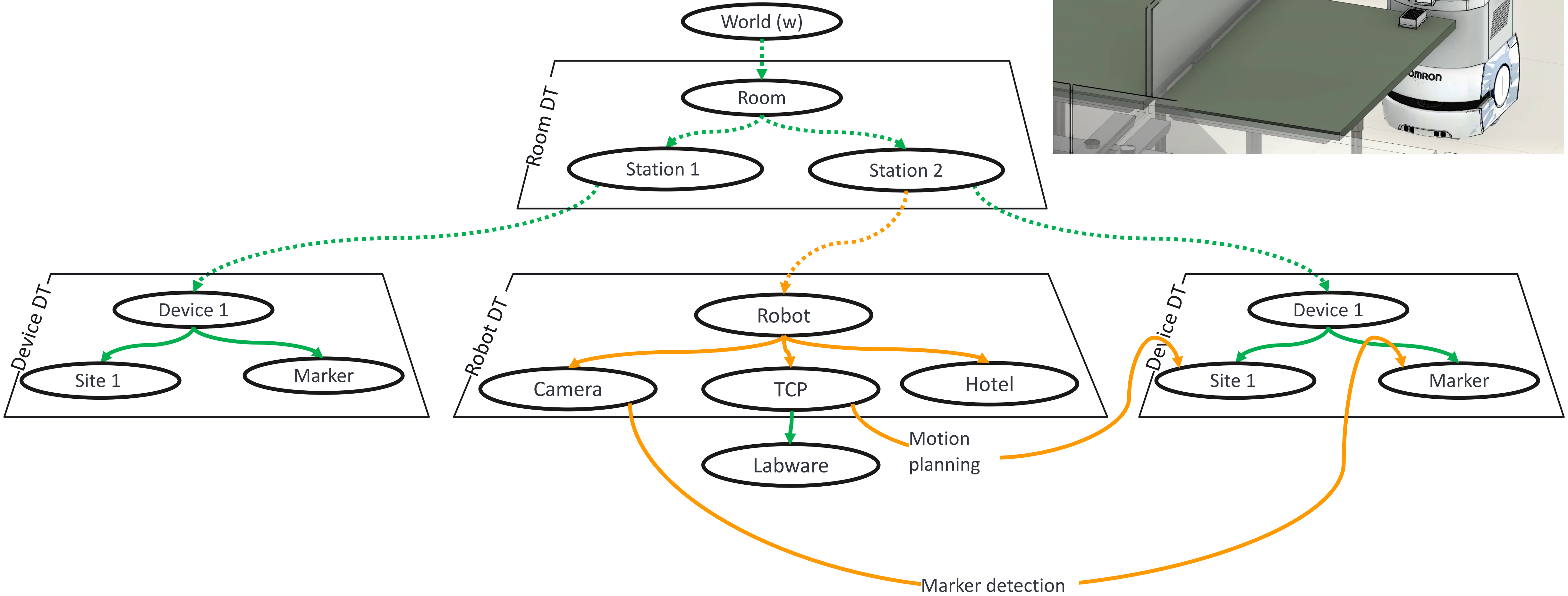
Pick from on-board hotel → Labware in gripper



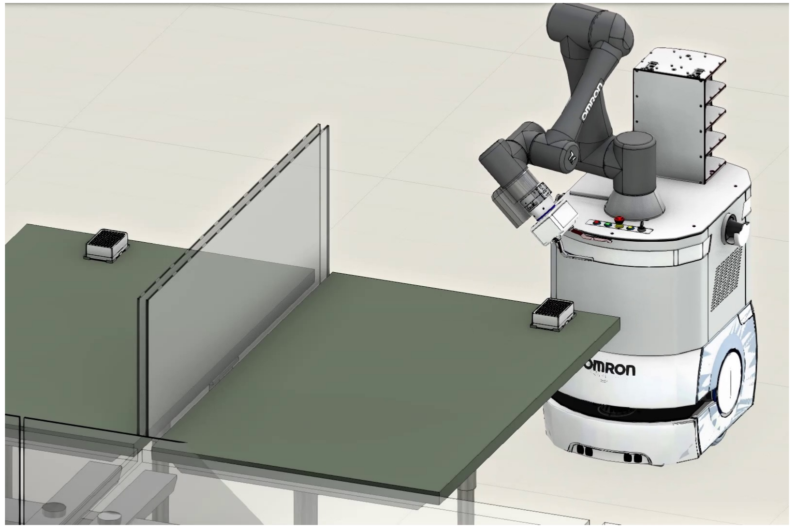


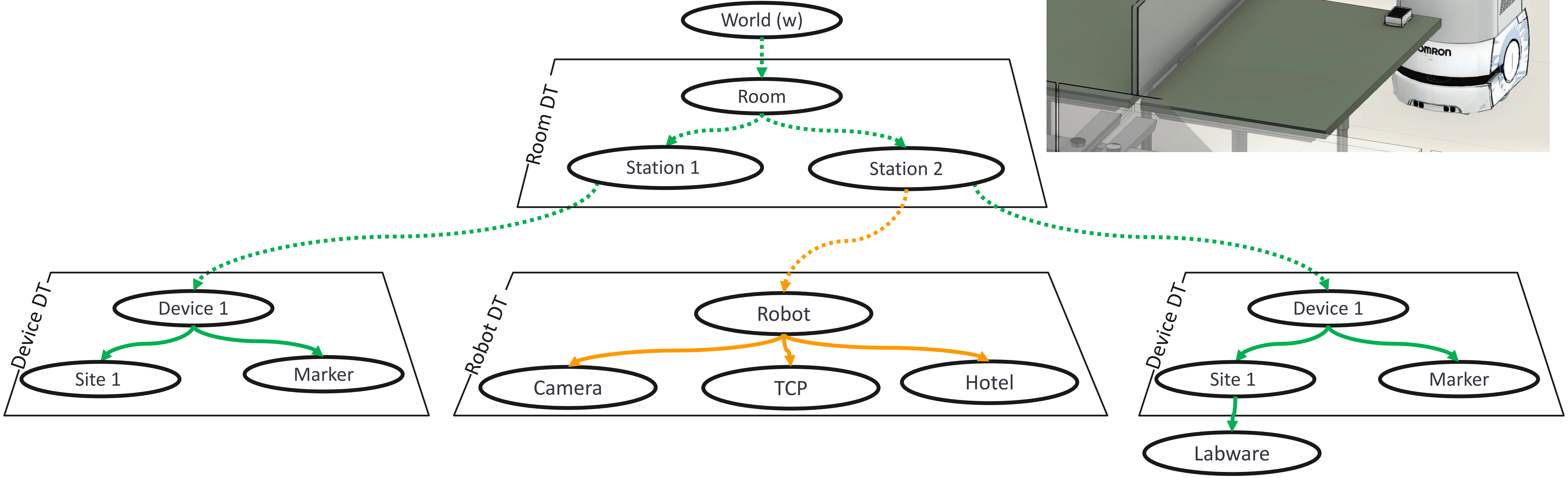
Place to station_2.device_1.site_1





Placed to station_2.device_1.site_1





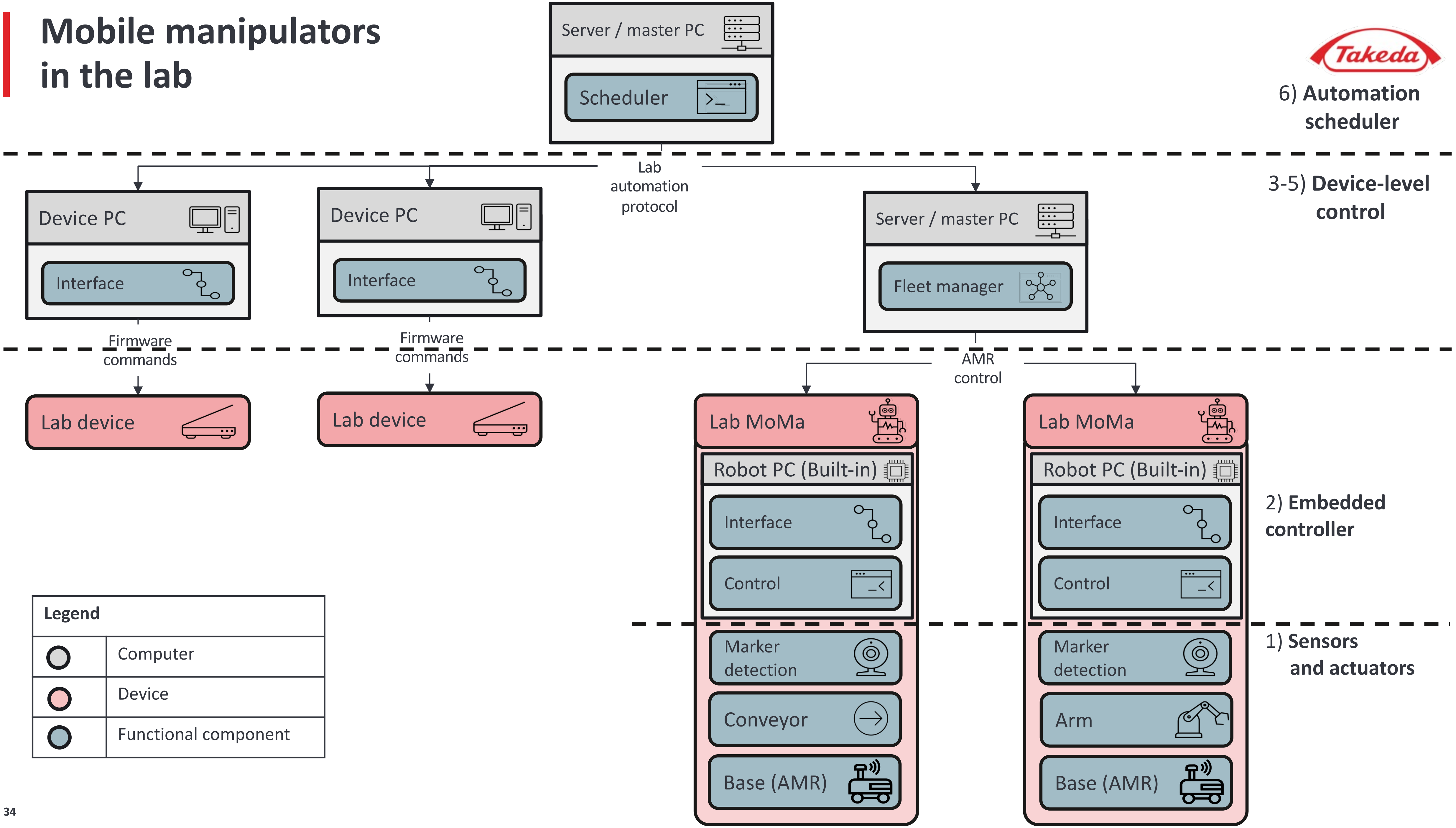
Control pyramid

Reference architecture model

Layers and elements of the control architecture

Level nr	Level name	Layers of the control architecture
7	Service	**Lab management** Laboratory Information Management System (LIMS), Electronic Lab Notebook (ELN)
6	Procedure (Experiment / assay)	**Automation scheduler** Laboratory Execution System (LES)
5	Task	**Device-level control** Dedicated PC
4	Subtask	
3	Motion sequence	
2	Motion primitive	**Embedded controller** Microcontroller or Programmable Logic Controller (PLC)
1	Actuator primitive	

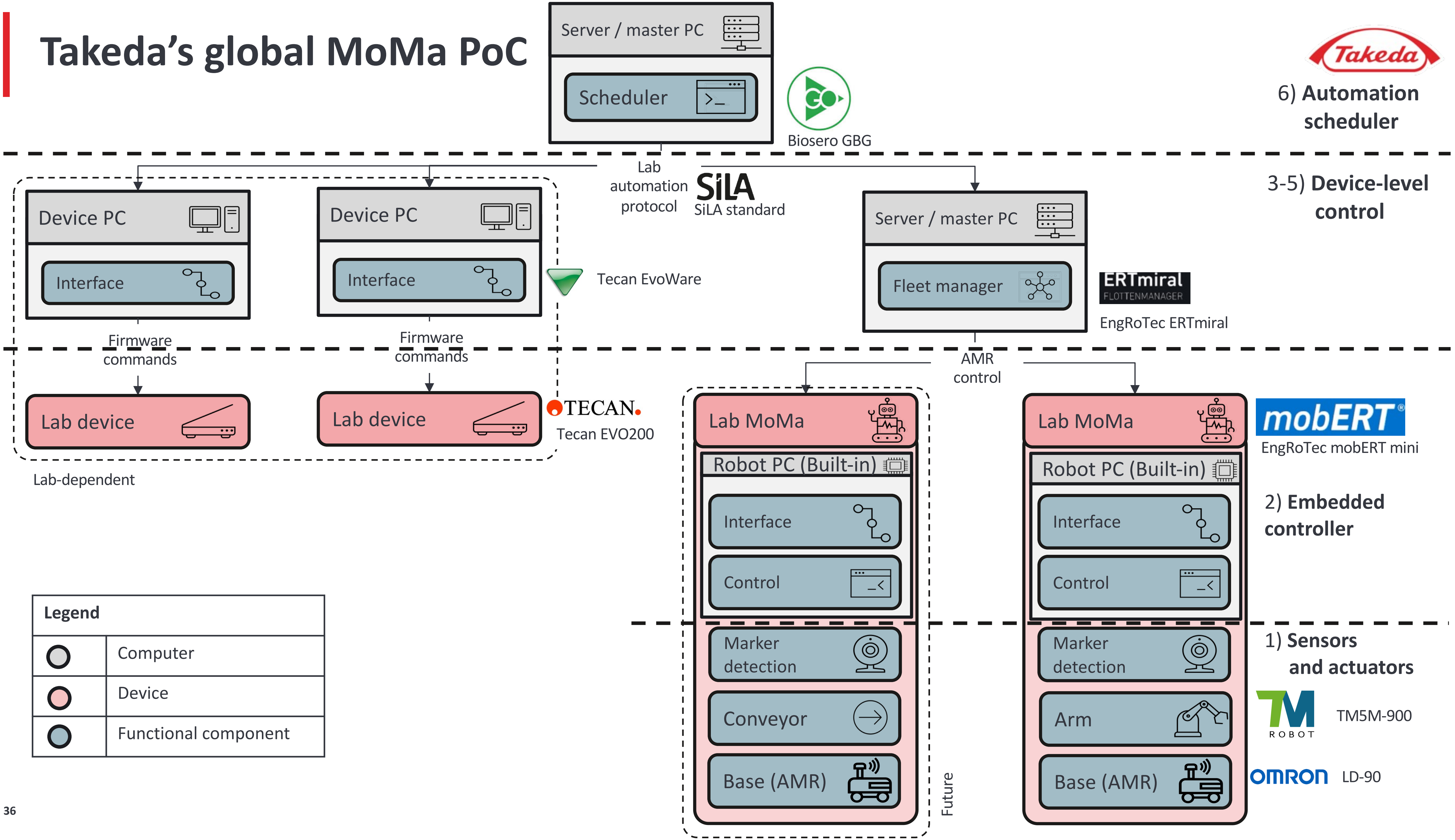
Mobile manipulators in the lab



Proof-of-concept studies

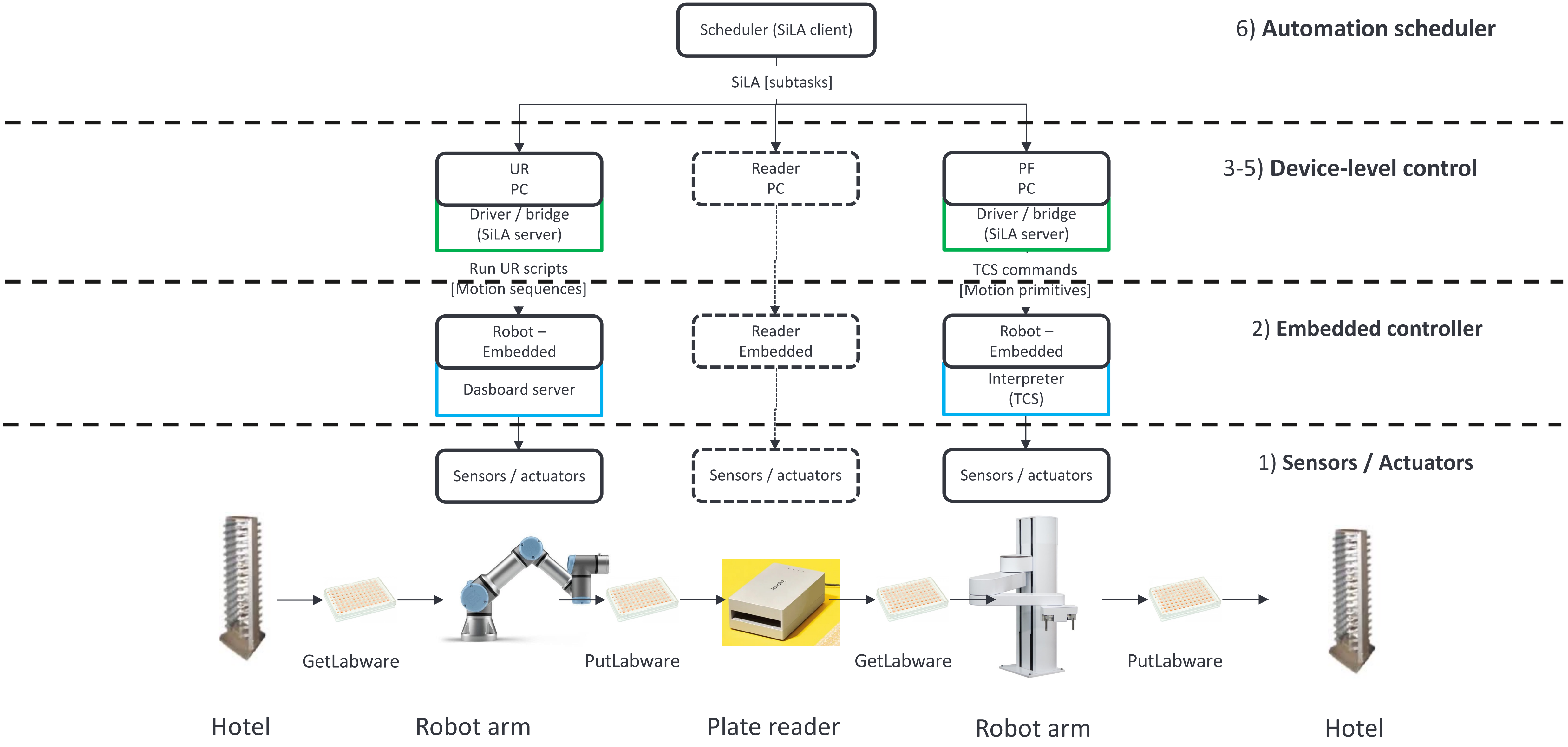
Consortia & academia

Takeda's global MoMa PoC

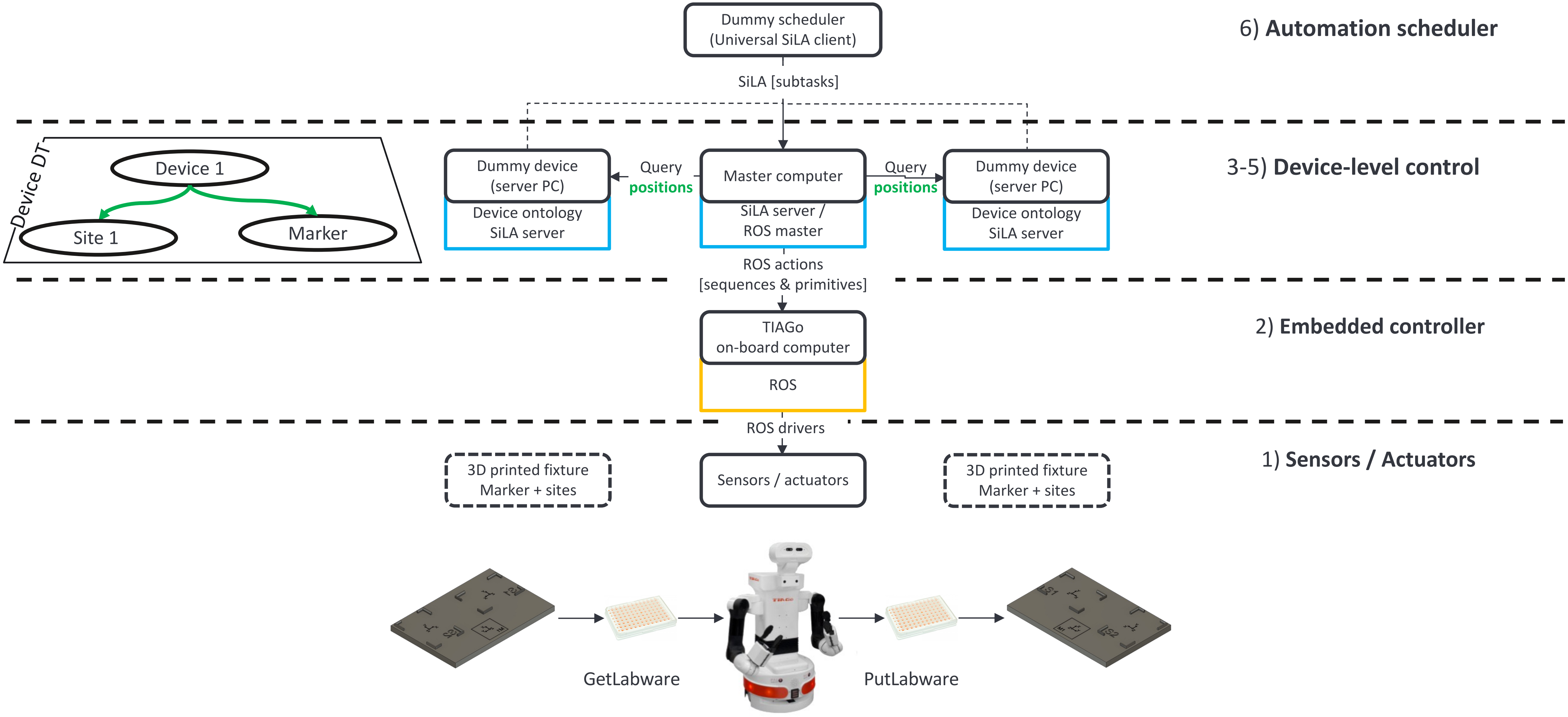


Legend	
◯	Computer
◯	Device
◯	Functional component

Reference implementations – SiLA Hackathon



Reference implementations – TIAGo, Uni Óbuda, Panna Zsoldos



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Georg Hinkel

SiLA Robotics Working Group

SiLA Board

EngRoTec

Omron

Biosero

PAL Robotics

Public LAPP project website

https://wlfdm.github.io/LAPP/

Thank you for your attention.

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