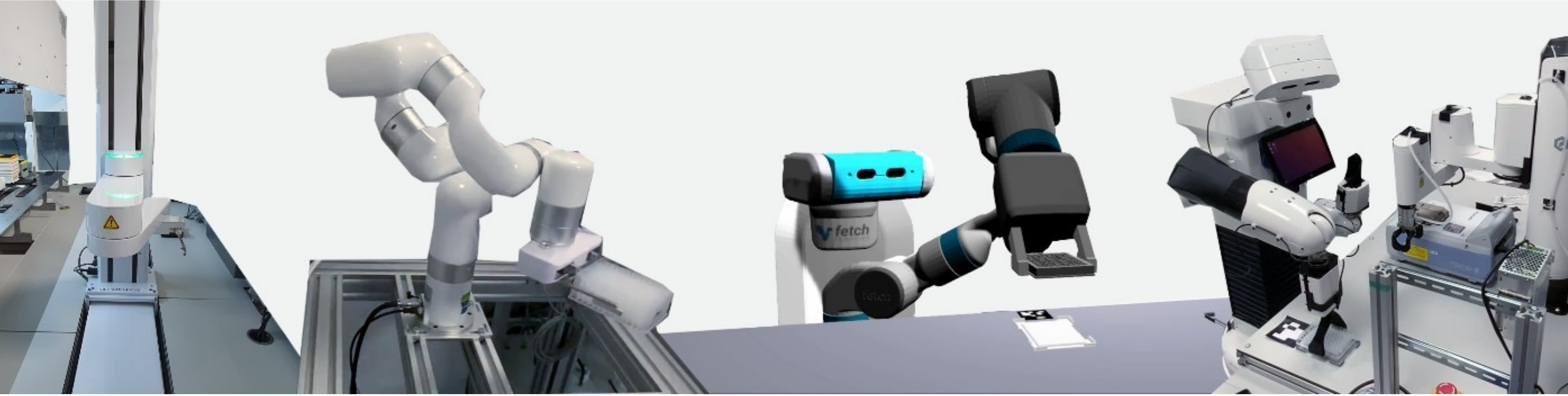


Towards Robotic Laboratory Automation Plug & Play: The LAPP Reference Architecture Model

Ádám Wolf
Staff Engineer, Digital Laboratory
Pharmaceutical Sciences, Sustainability & Technology

24-25.JAN.2024

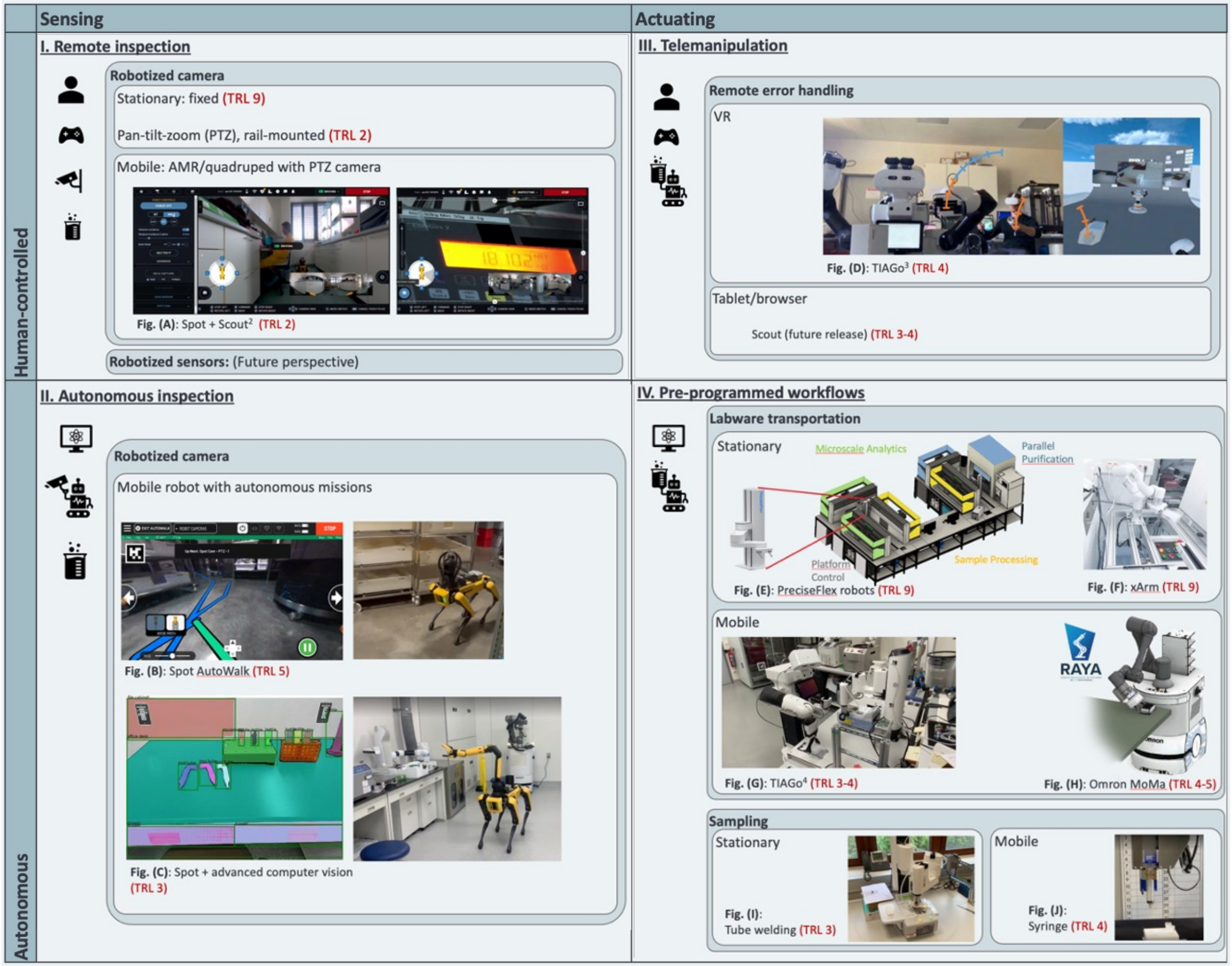
Better Health, Brighter Future

Agenda

- Supportive robotics in lab automation
- The Laboratory Automation Plug & Play framework
- Proof-of-concept studies – Consortia & Academia
- A selection of ongoing industrial projects

Supportive robotics in lab automation

The lab robotics matrix



I. Remote inspection

Robotized camera

Stationary: fixed **(TRL 9)**

Pan-tilt-zoom (PTZ), rail-mounted **(TRL 2)**

Mobile: AMR/quadruped with PTZ camera

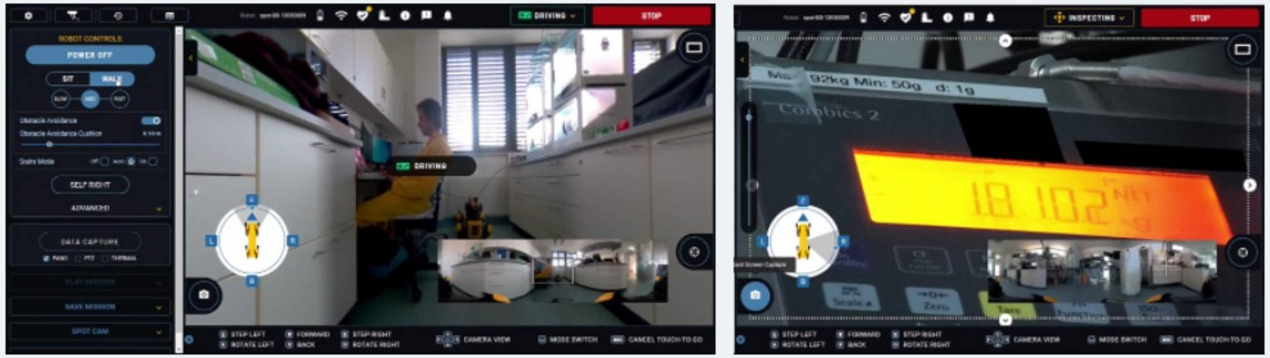


Fig. (A): Spot + Scout[2] **(TRL 2)**

Robotized sensors: (Future perspective)

II. Autonomous inspection

Robotized camera

Mobile robot with autonomous missions

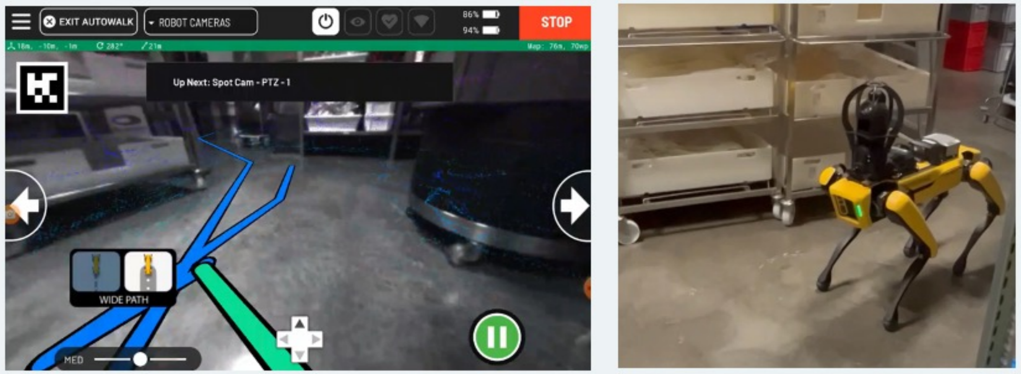


Fig. (B): Spot AutoWalk (TRL 5)

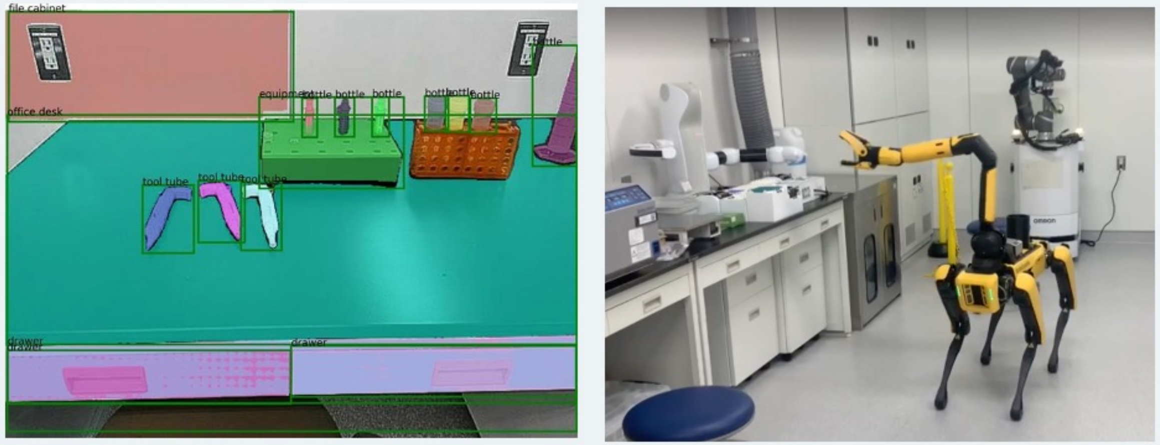


Fig. (C): Spot + advanced computer vision (TRL 3)

III. Telemanipulation

Remote error handling

VR

Fig. (D): TIAGo³ (TRL 4)

Tablet/browser

Scout (future release) (TRL 3-4)

IV. Pre-programmed workflows

Labware transportation

Stationary

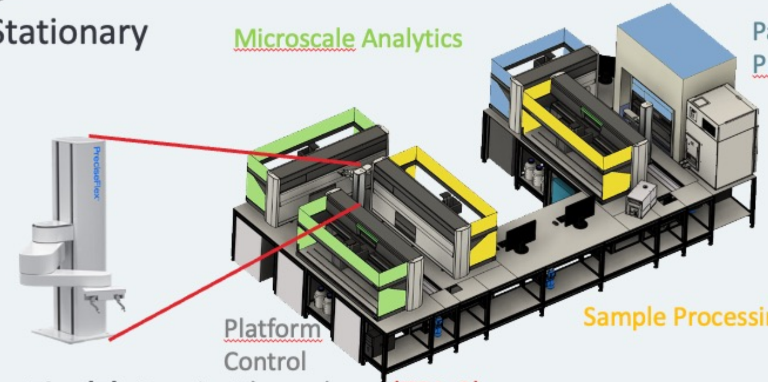


Fig. (E): PreciseFlex robots **(TRL 9)**

Fig. (F): xArm **(TRL 9)**

Mobile

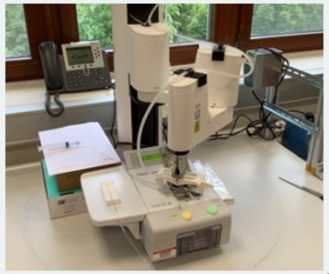
Fig. (G): TIAGo[4] **(TRL 3-4)**

Fig. (H): Omron MoMa **(TRL 4-5)**

Sampling

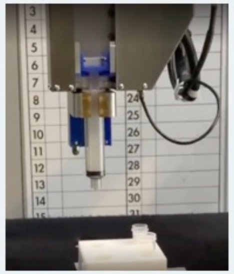
Stationary

Fig. (I):
Tube welding **(TRL 3)**



Mobile

Fig. (J):
Syringe **(TRL 4)**



Mobile manipulators in laboratory automation

Takeda

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 these

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

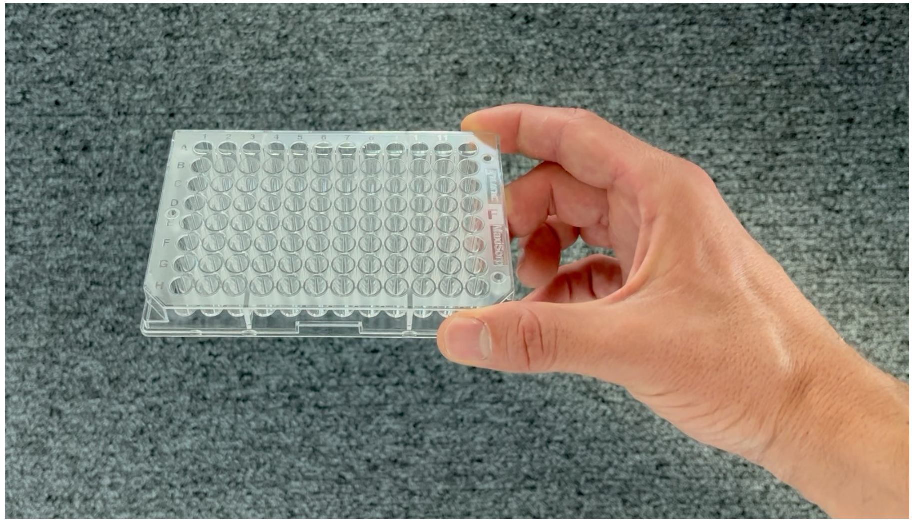
[1]

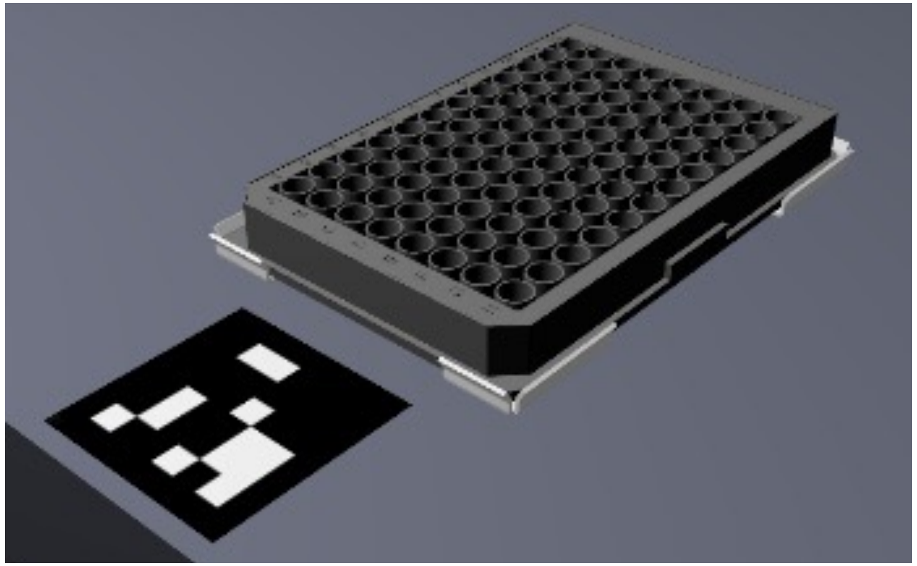
* Mobile manipulator robot

The use case

Pick-and-place transportation of standardized sample containers

- ANSI/SLAS-conform (aka. SBS) microplate[1]
- Fixed hand-over positions (aka. sites) within lab devices
- Fixtures (aka. nests) that allow < 1mm tolerance
- Landmarks (aka. fiducial markers) for position detection
- Pick-up (source) and drop-off (destination) positions selected via command parameter
- Source and destination can be located across the room
- Secondary scope: different rooms/floors → elevator access





[1] Meets the Standards ANSI/SLAS 1-2004 through ANSI/SLAS 4-2004.

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

The Laboratory Automation Plug & Play (LAPP) framework As a Reference Architecture Model

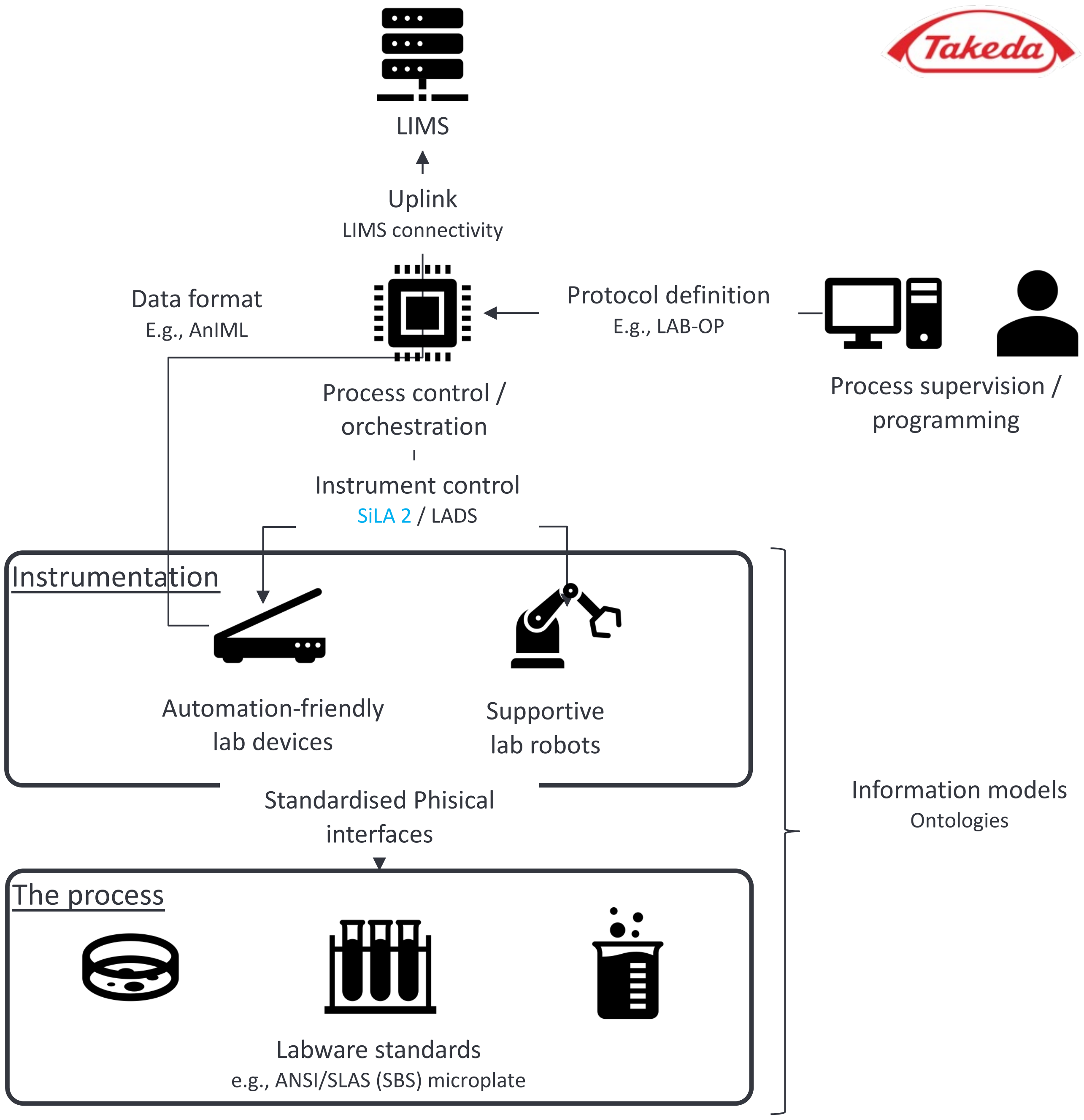
Motivation

Problem statement

- Lab automation systems are becoming increasingly **complex**
- The present-day landscape in terms of system architecture and interoperability is **heterogeneous**
- This poses a **barrier** for implementing **integrated systems**

Vision

- Create a holistic and agnostic reference architecture model for the whole vertical of lab automation systems
- Outline the canonical layers and components in the integrated system
- Standardize the communication between the components
- Create semantic descriptions of capabilities on different granularity levels
- Bind it with a workflow representation framework that enables scalability and transferability between labs
- Create ontologies to represent information in a suitable fashion for advanced control on all levels

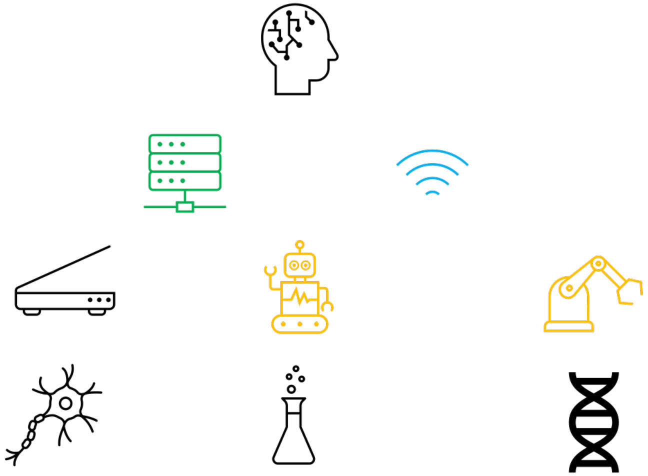


Standardization and plug & play integration for lab robots

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)



TRL*	Description	Form
1-2	Scientific conceptualization	Concept papers
3-4	Academical and collaborative PoC's	University collaboration
5-7	Implementation	Global MoMa PoC
	Standardization, communication	SiLA

* Technology readiness level

Public project site

Hierarchical decomposition of laboratory workflows

Hierarchical decomposition of lab workflows

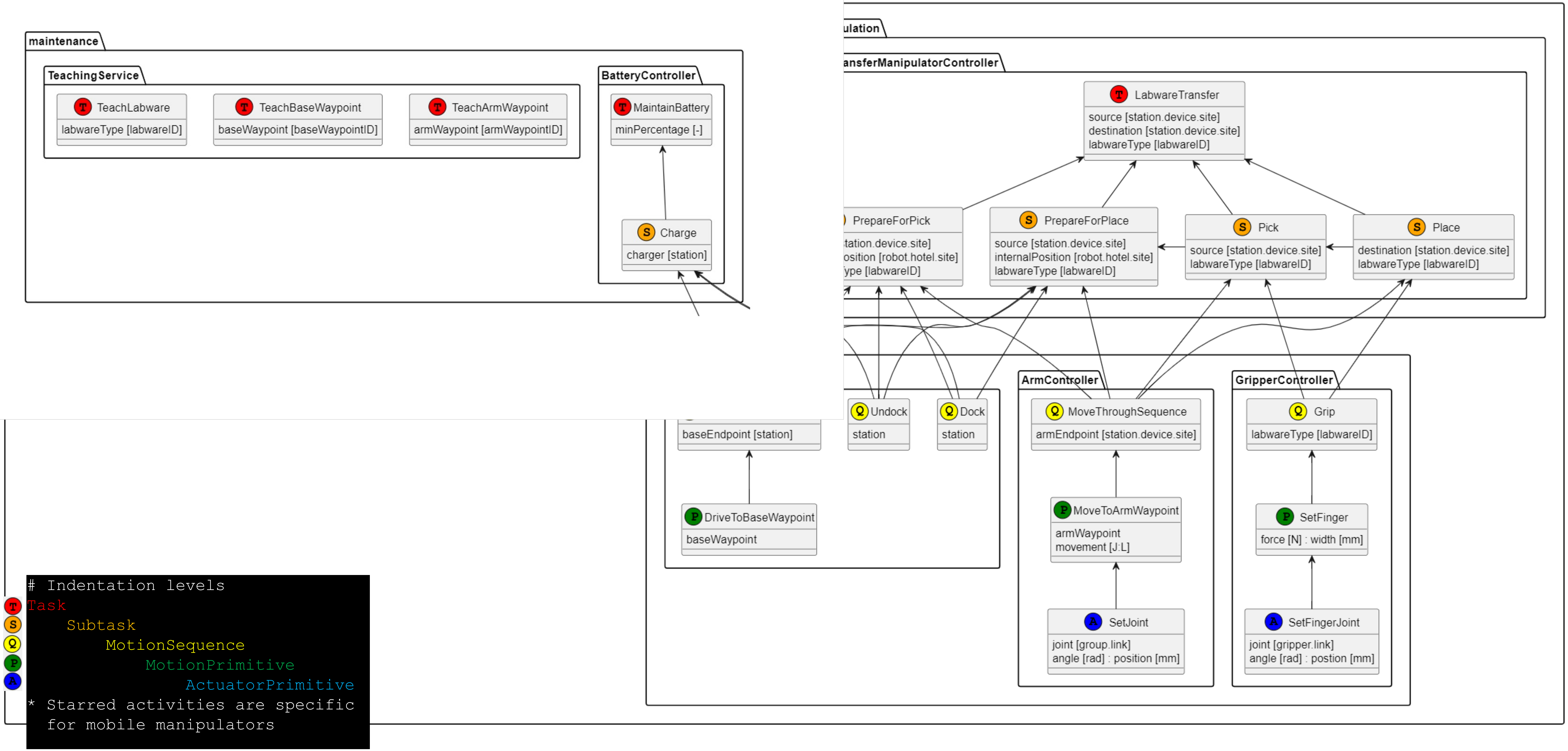
Level nr	Level name	Description	Examples	
			Liquid handling	Robotics
7	Service	The entirety of the laboratory's capabilities	High throughput and/or microscale services	
6	Procedure (Experiment / assay)	An experiment or assay	Chromatography run	
5	Task	An elemental, device-level action item	Liquid transfer	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

Canonical layers and elements of the control architecture

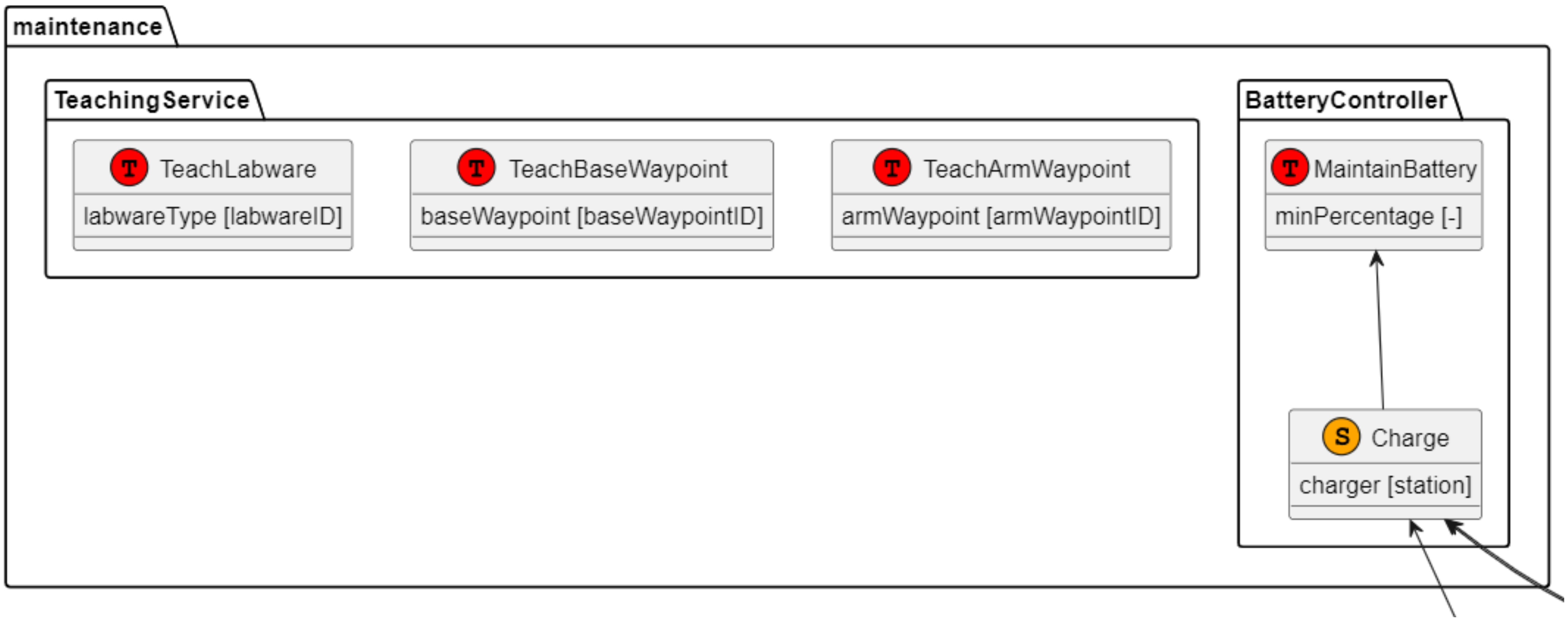
Level nr	Level name	Layers of the control architecture
7	Service	**Lab management** Laboratory Information Management System (LIMS), Electronic Lab Notebook (ELN)
6	Procedure (Experiment / assay)	**Automation scheduler** Laboratory Execution System (LES)
5	Task	**Device-level control** Dedicated PC
4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

Pick & place labware transfer – Maintenance activities

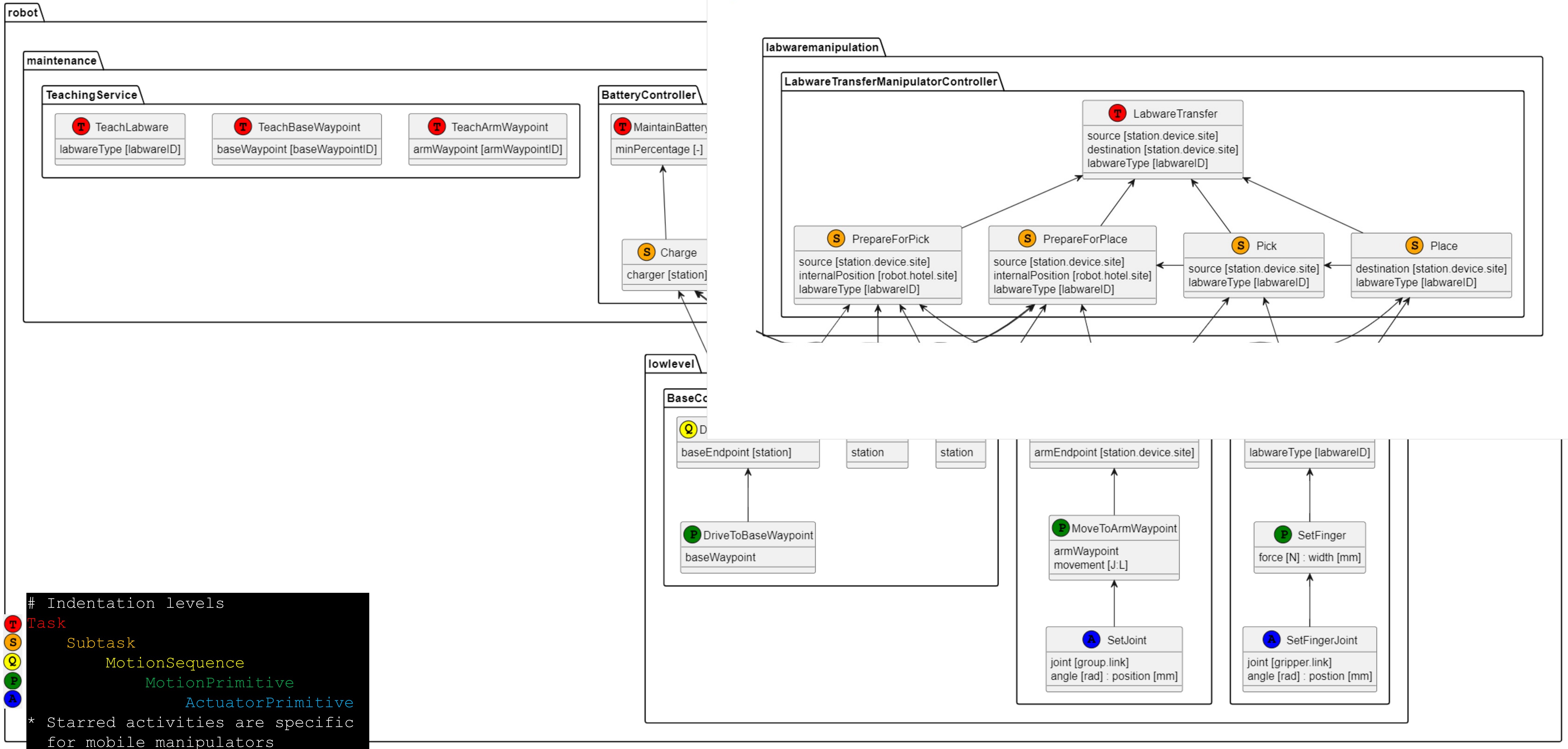
ical activity decomposition



Pick & place labware transfer – Maintenance activities



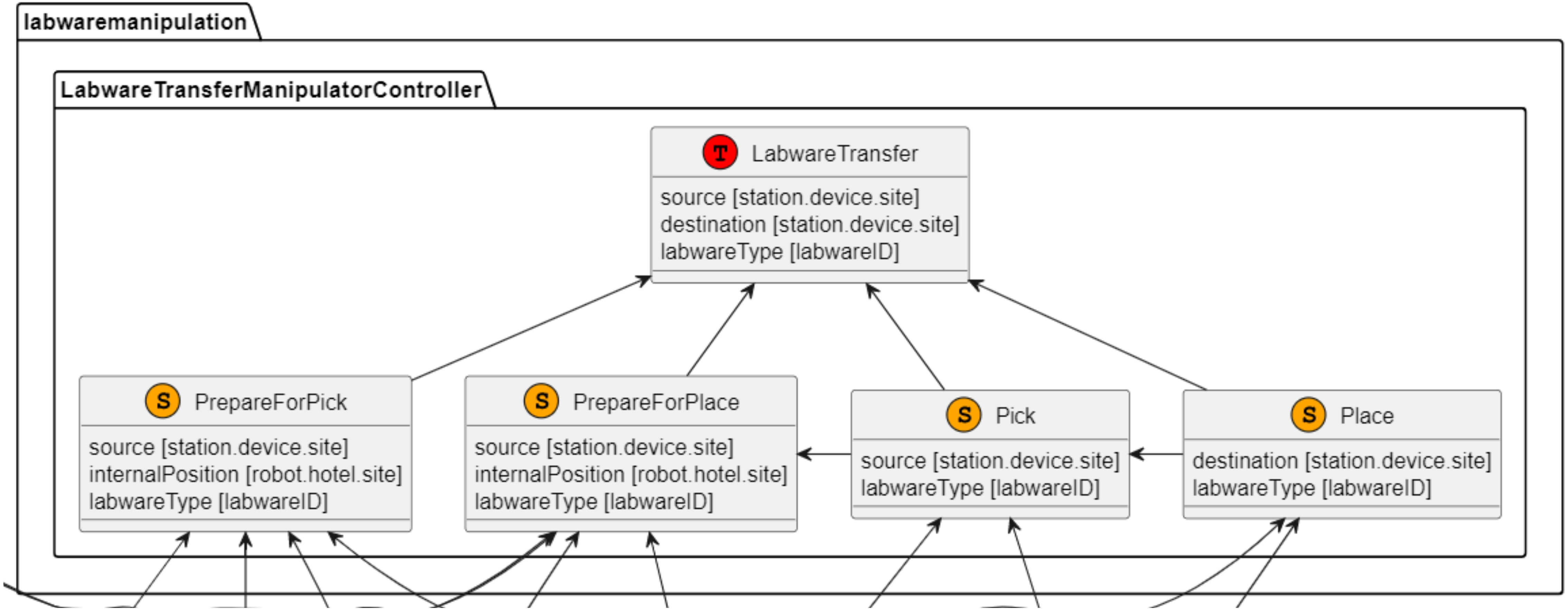
Pick & place labware transfer – Hi



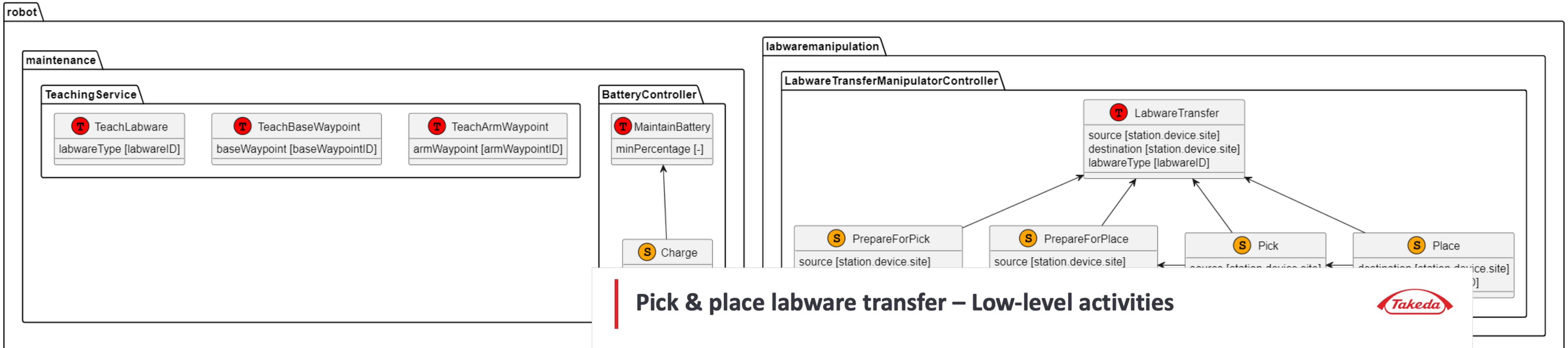
Pick & place labware transfer – High-level activities


```
# Indentation levels
Task
    Subtask
        MotionSequence
            MotionPrimitive
                ActuatorPrimitive
* Starred activities are specific
  for mobile manipulators
```

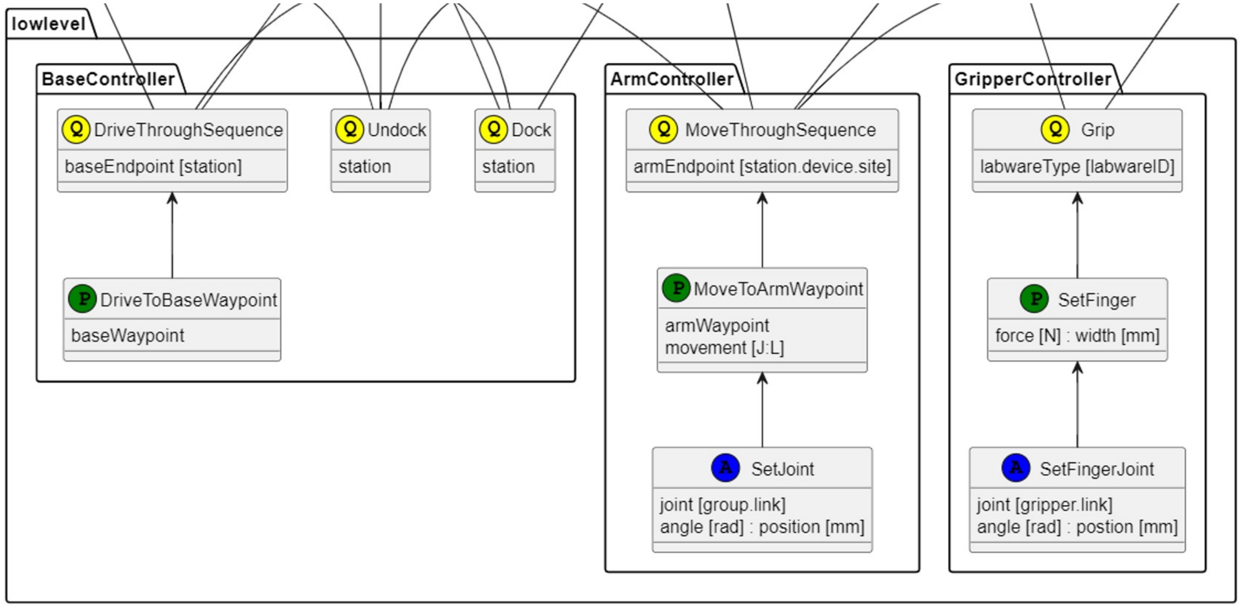
Pick & place labware transfer – High-level activities



Pick & place labware transfer – Hierarchical activity decomposition

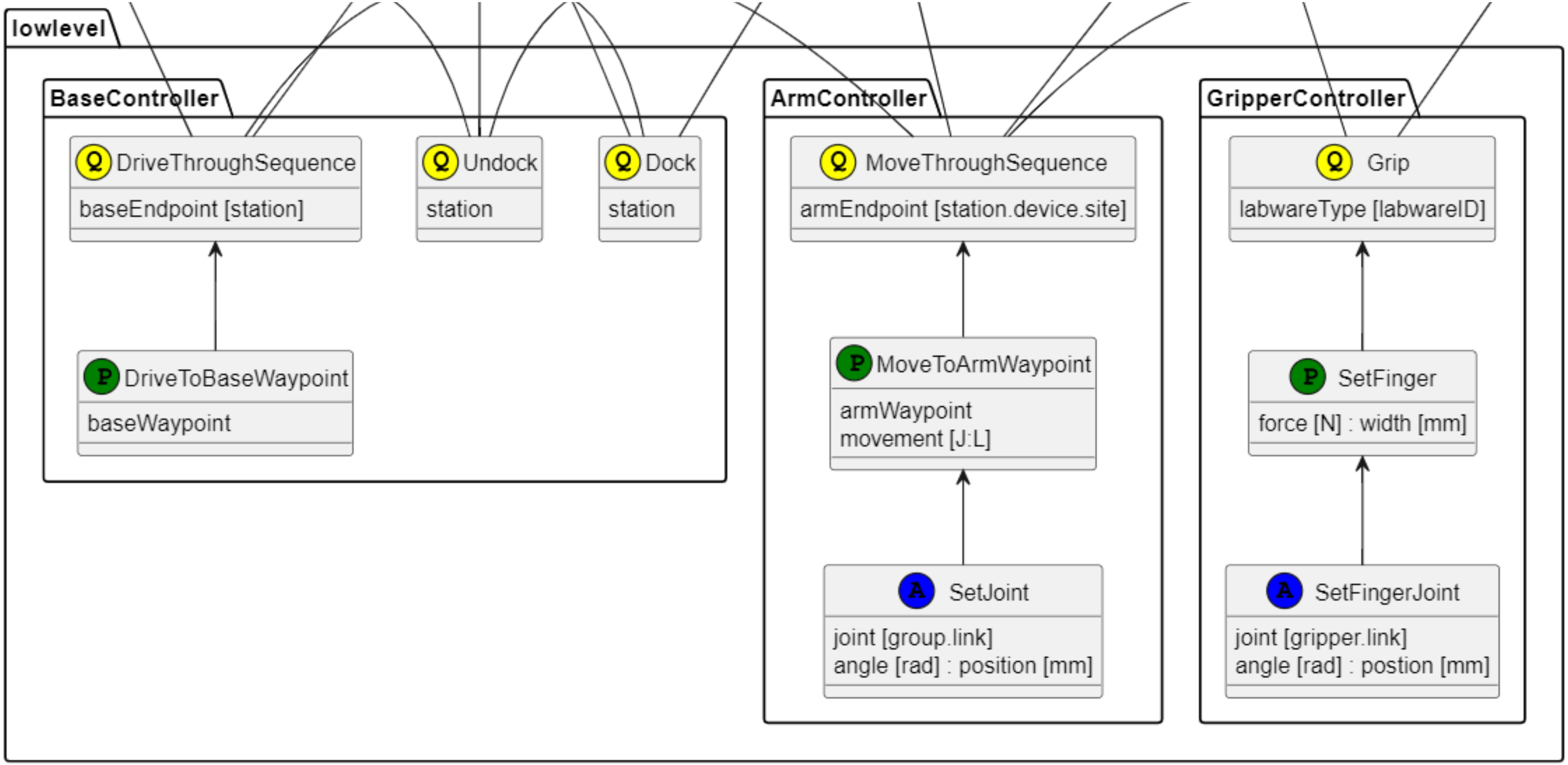


Pick & place labware transfer – Low-level activities




```
# Indentation levels
Task
    Subtask
        MotionSequence
            MotionPrimitive
                ActuatorPrimitive
* Starred activities are specific
  for mobile manipulators
```

Pick & place labware transfer – Low-level activities



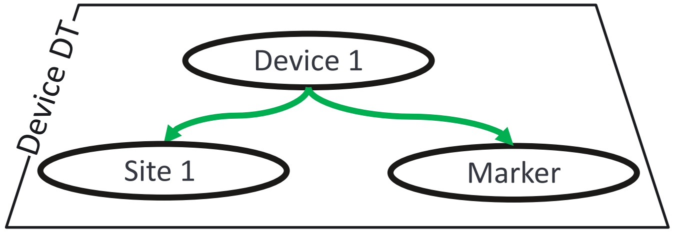
Ontologies

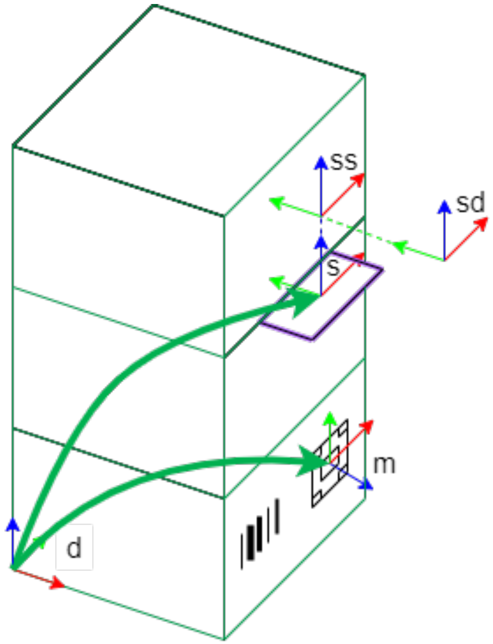
Pick & place labware transfer

Labware ontologies for manipulator robots

<u>Device ontologies</u>

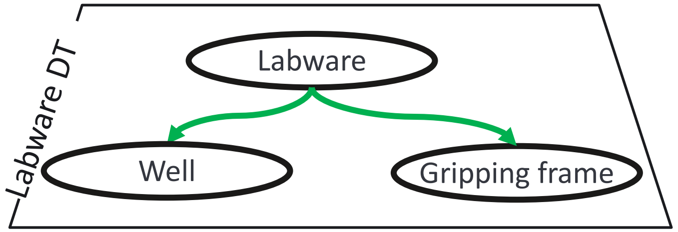
- Implementation of the LAPP Digital Twin
- Site and marker positions

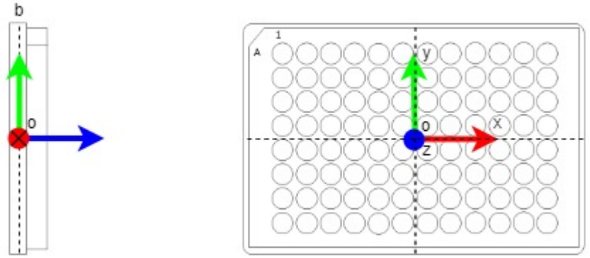




<u>Labware ontologies</u>

- Dimensions and gripping properties
- Well positions and properties
- Material properties





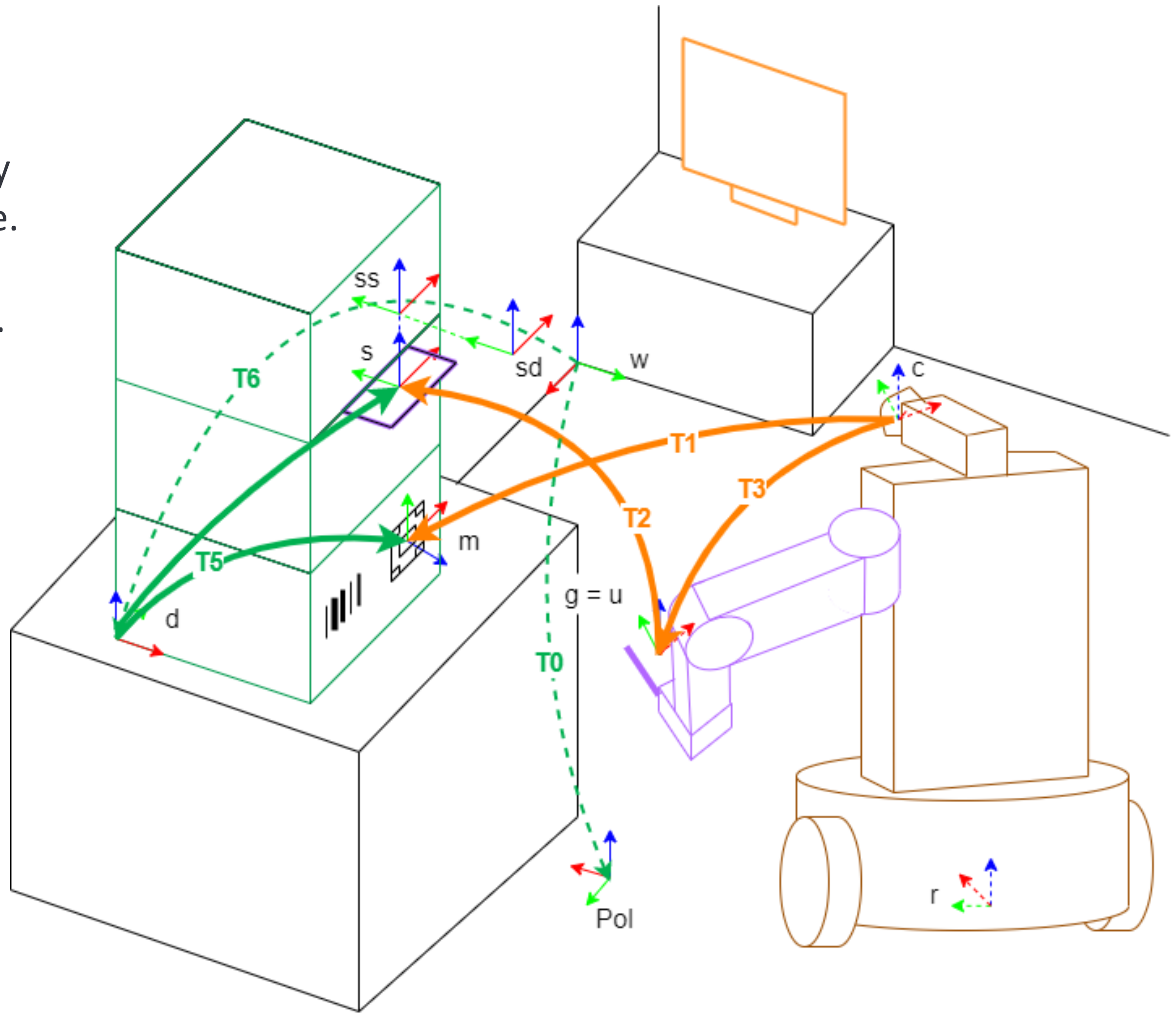
Position representations for mobile robots

with the LAPP Digital Twin

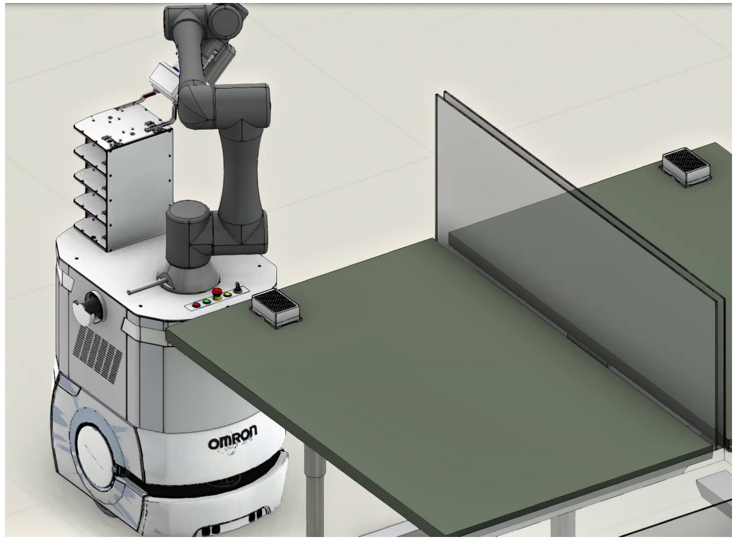
Position representations for mobile robots with the LAPP DT

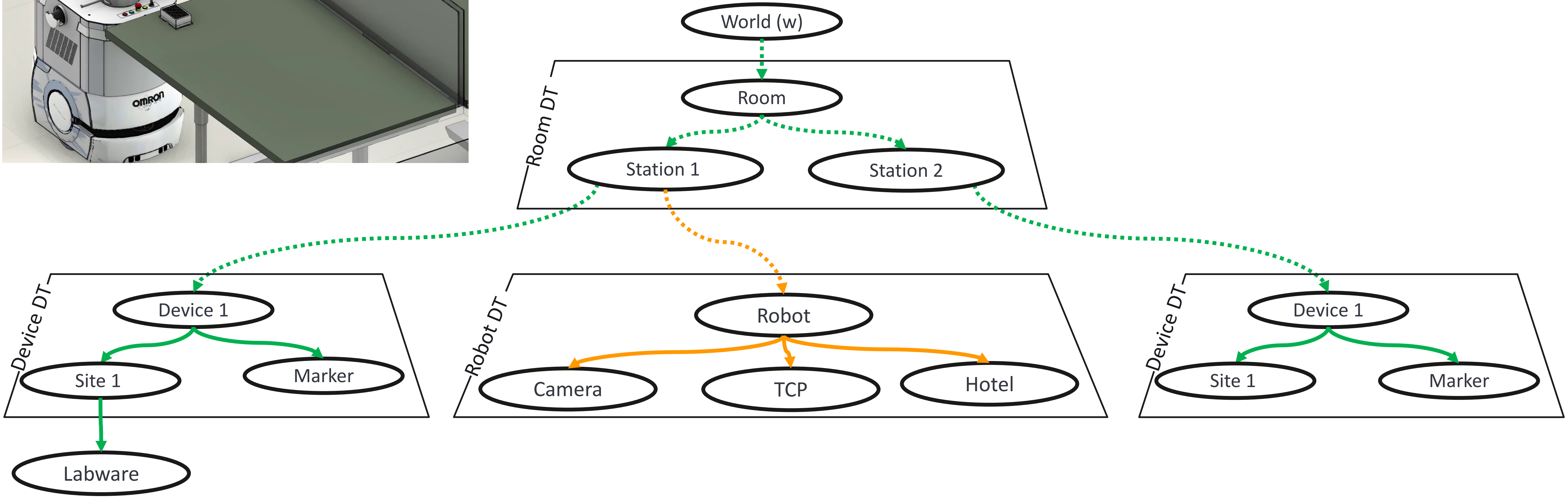
- Teaching-free integration of lab devices with labware transportation robots
- Based on the Digital Twin (DT) concept
- The robot positions must be defined in a device-attached coordinate system (CS) by the vendor.
- This CS must be detectable by the vision system of the robot by means of optical markers placed on the front side of the device.
- With that, the robot can tend the machine by performing the pick-and-place type transportation of standard sample carriers.

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

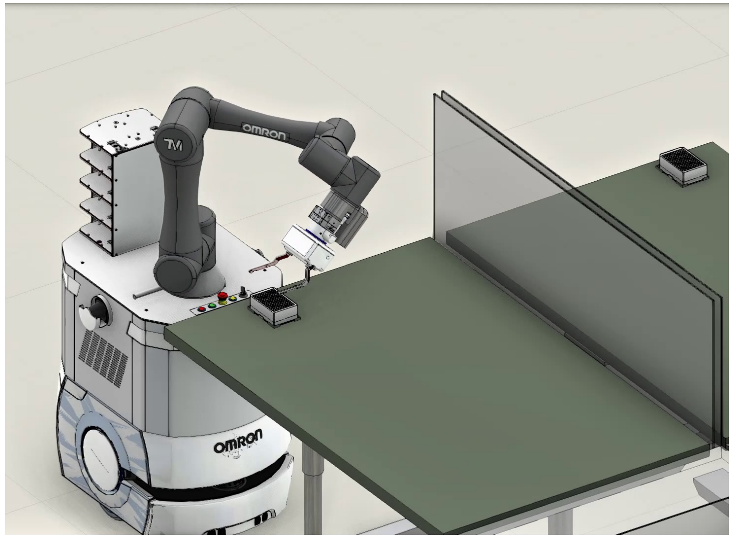


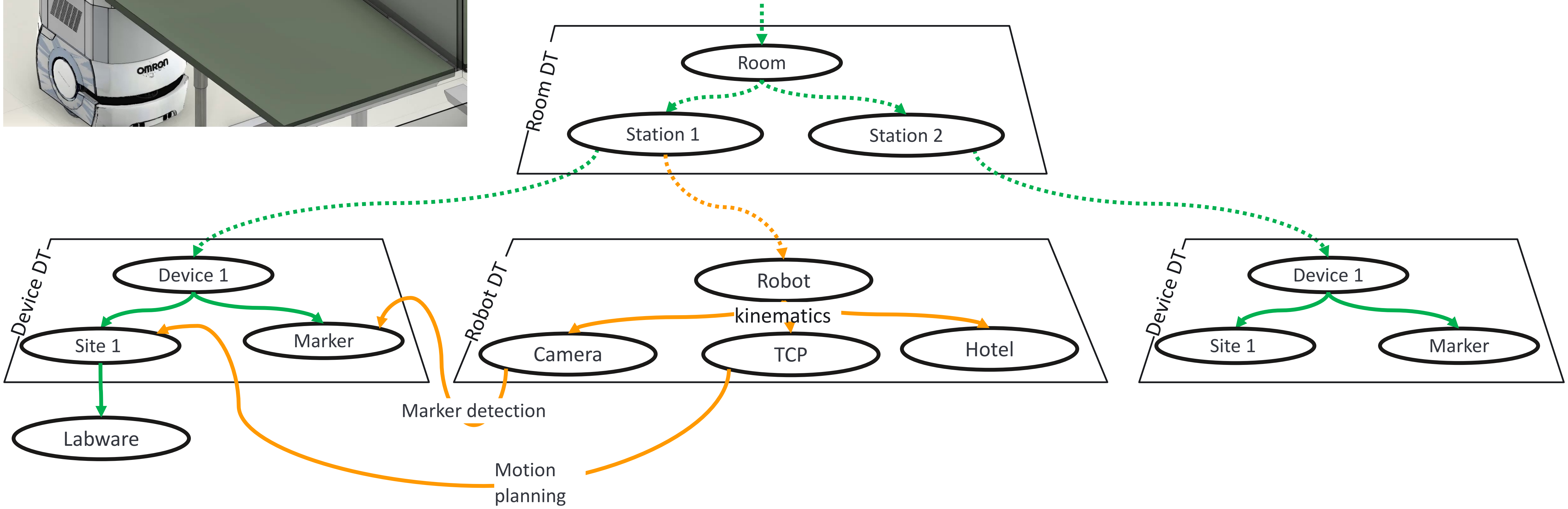
Robot docked to station 1



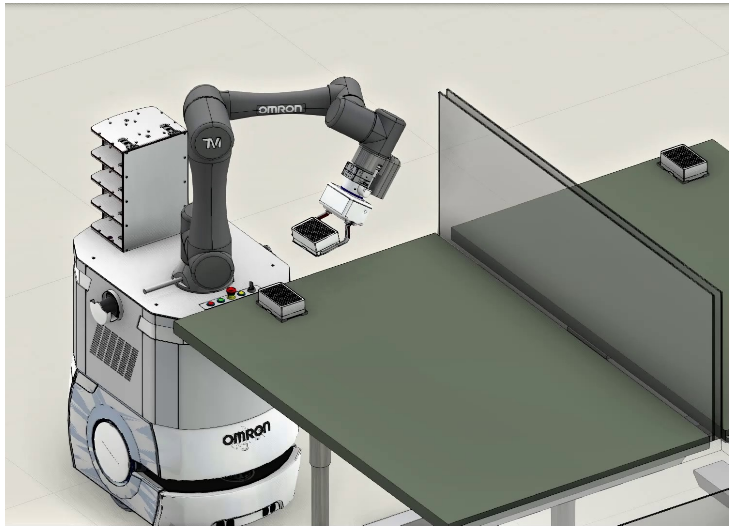


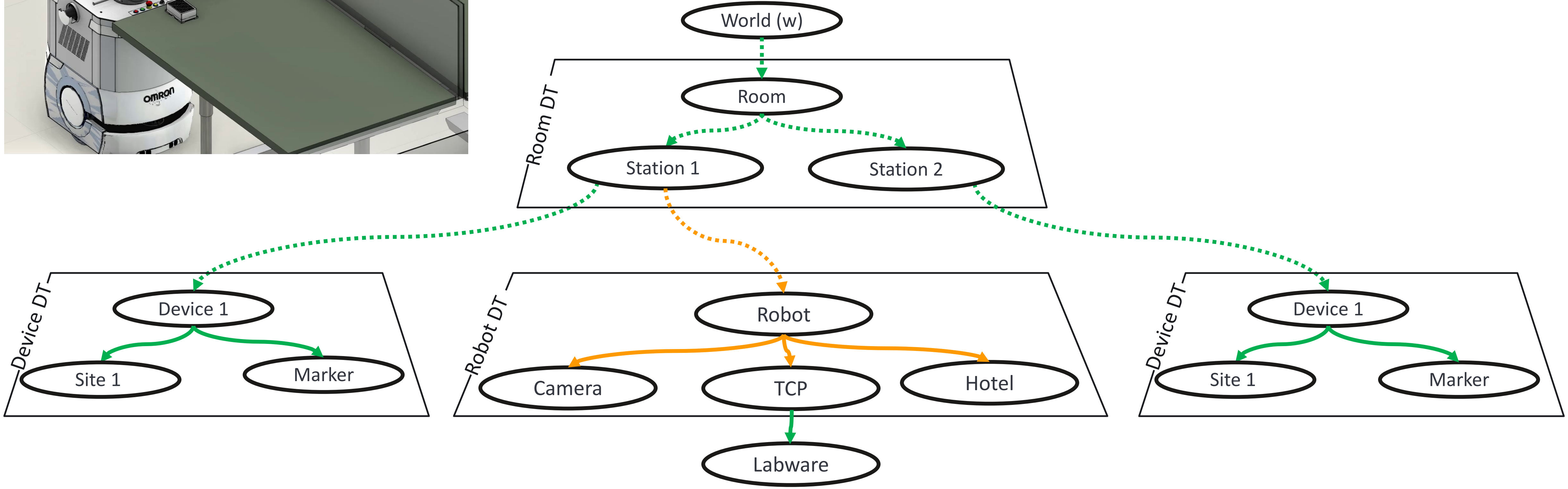
Pick from station_1.device_1.site_1



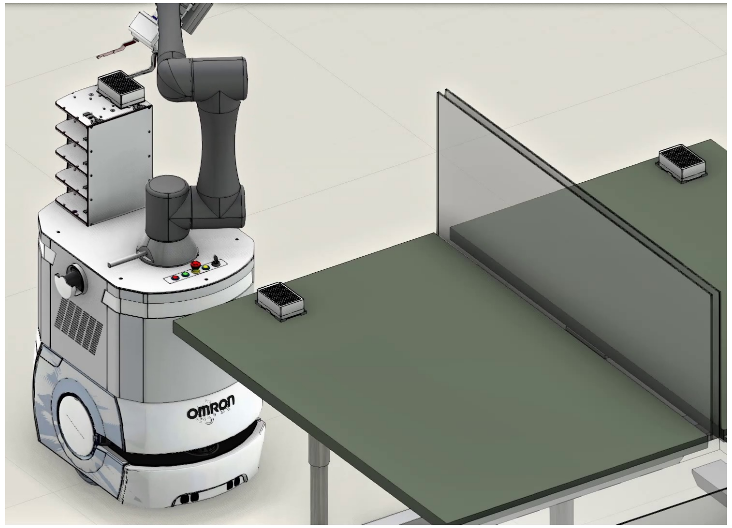


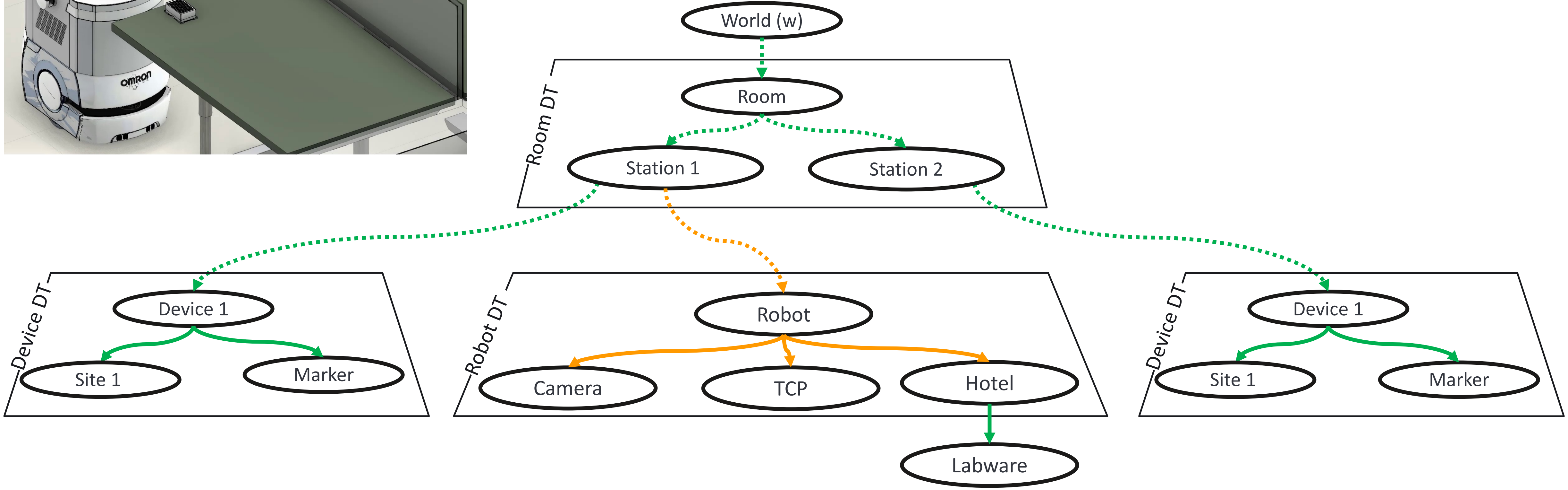
Pick from station_1.device_1.site_1 → Labware in gripper



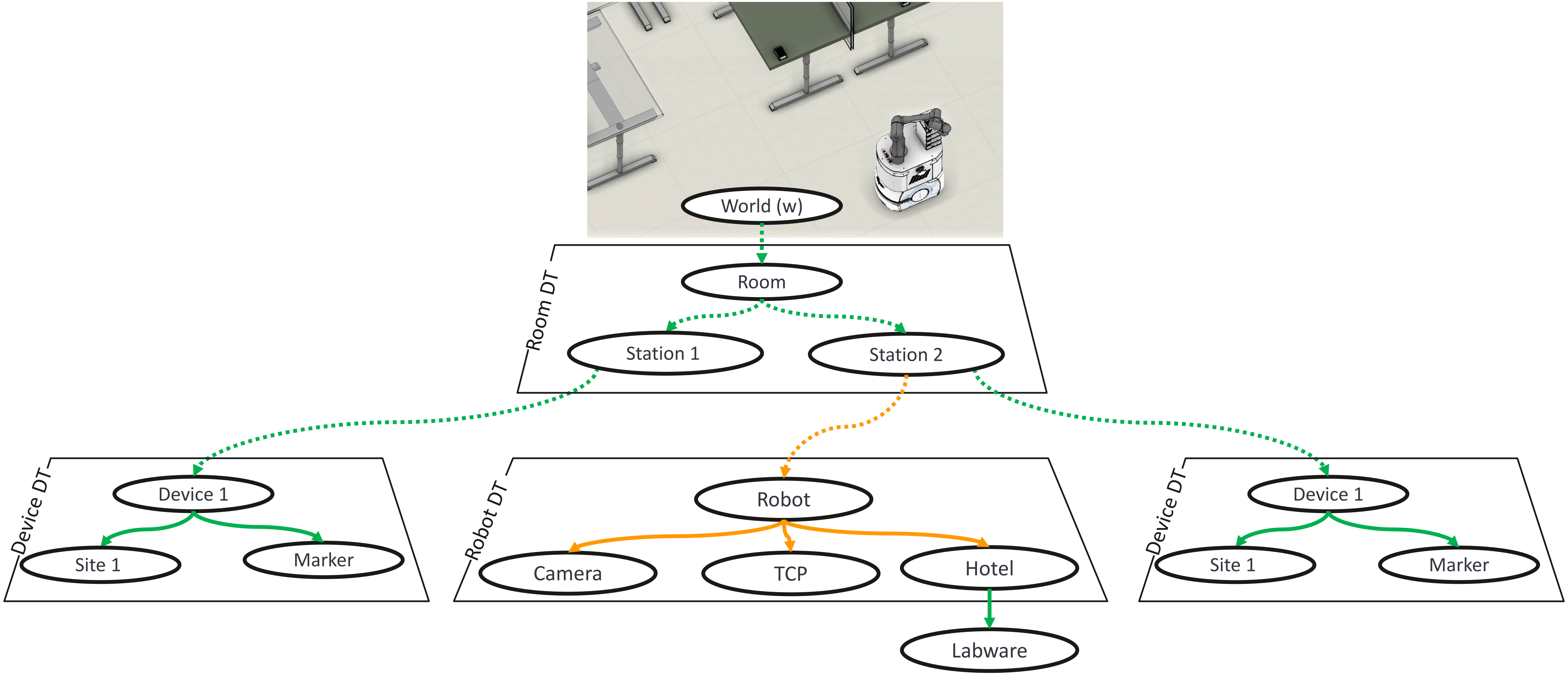


Place on on-board hotel

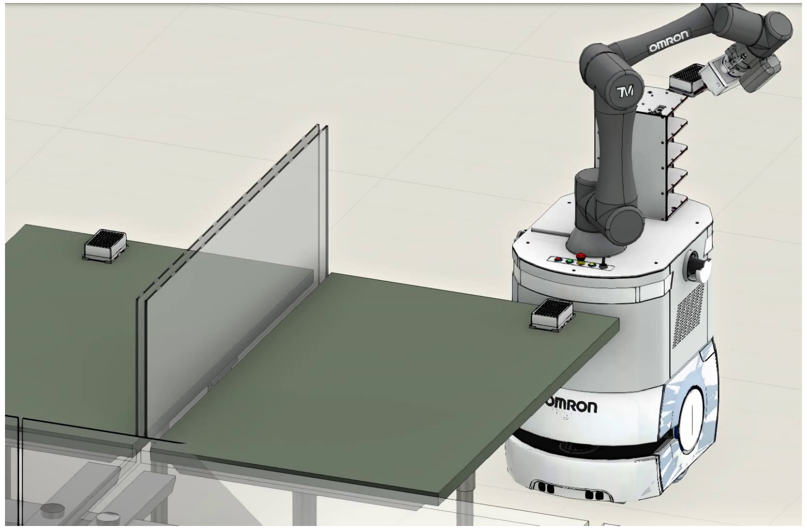


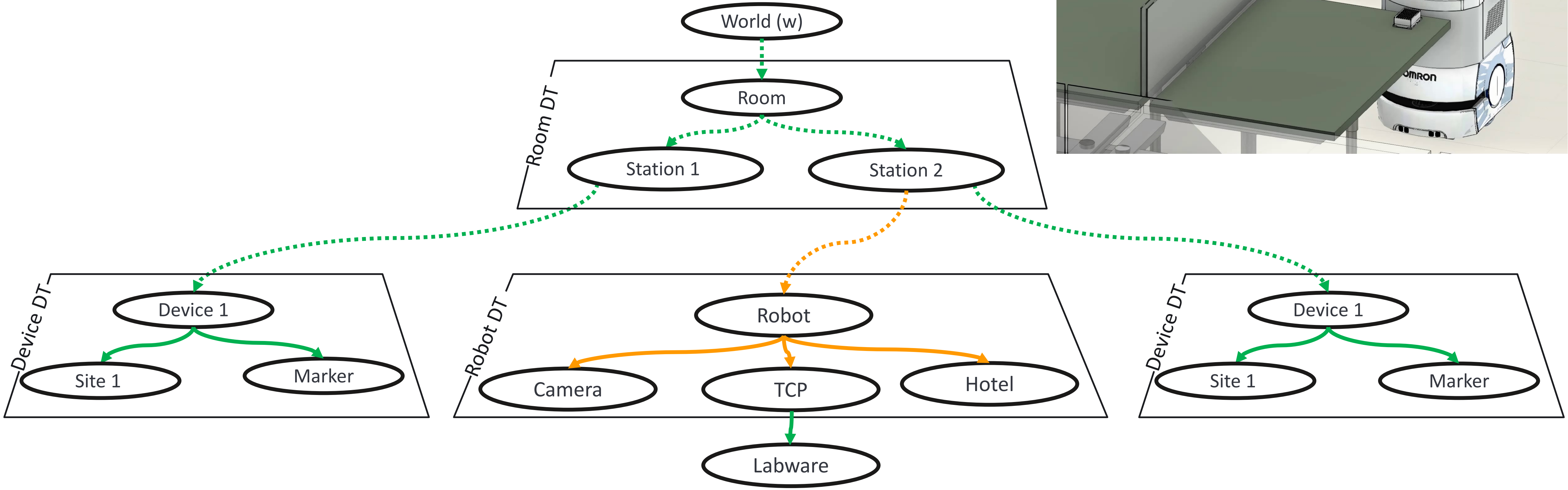


Switch to Station 2 → Undock, navigate and dock

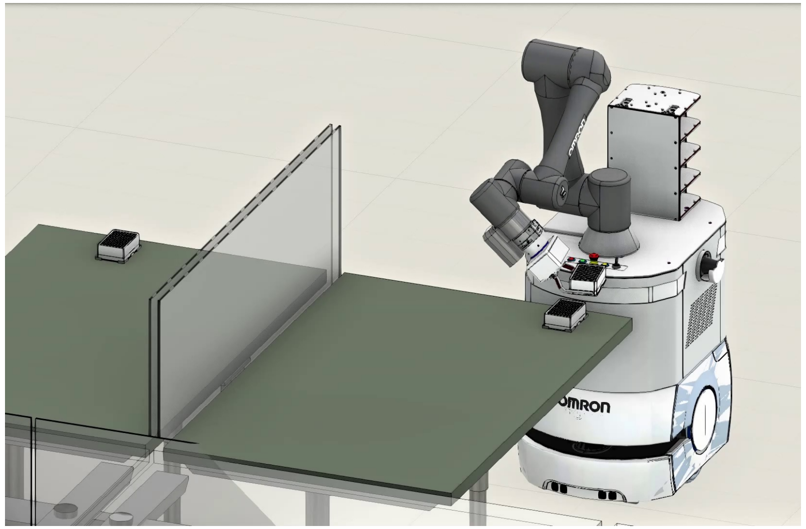


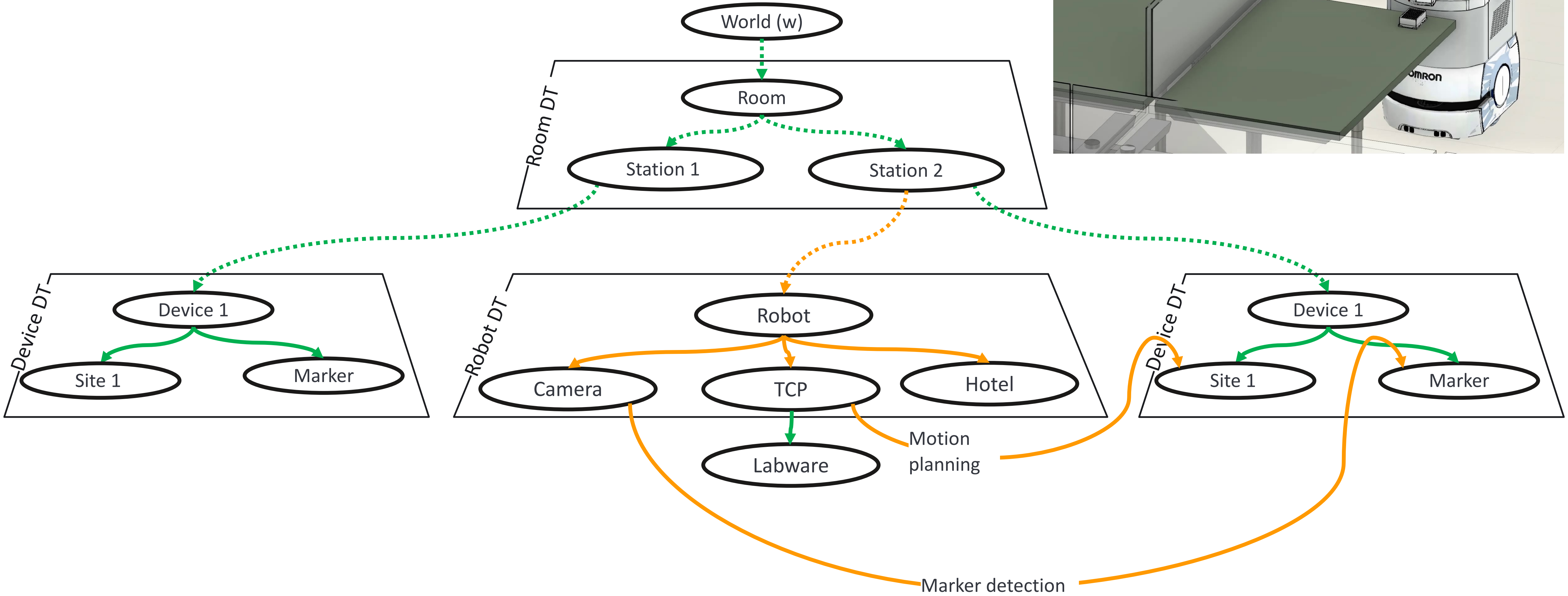
Pick from on-board hotel → Labware in gripper



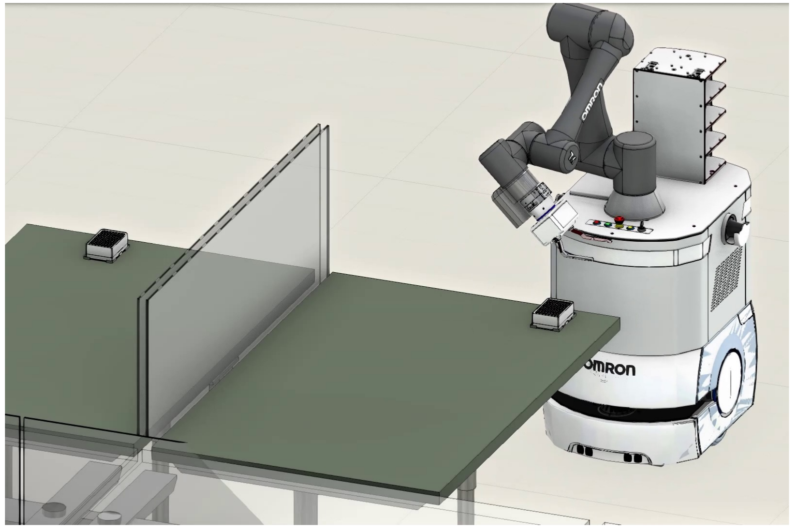


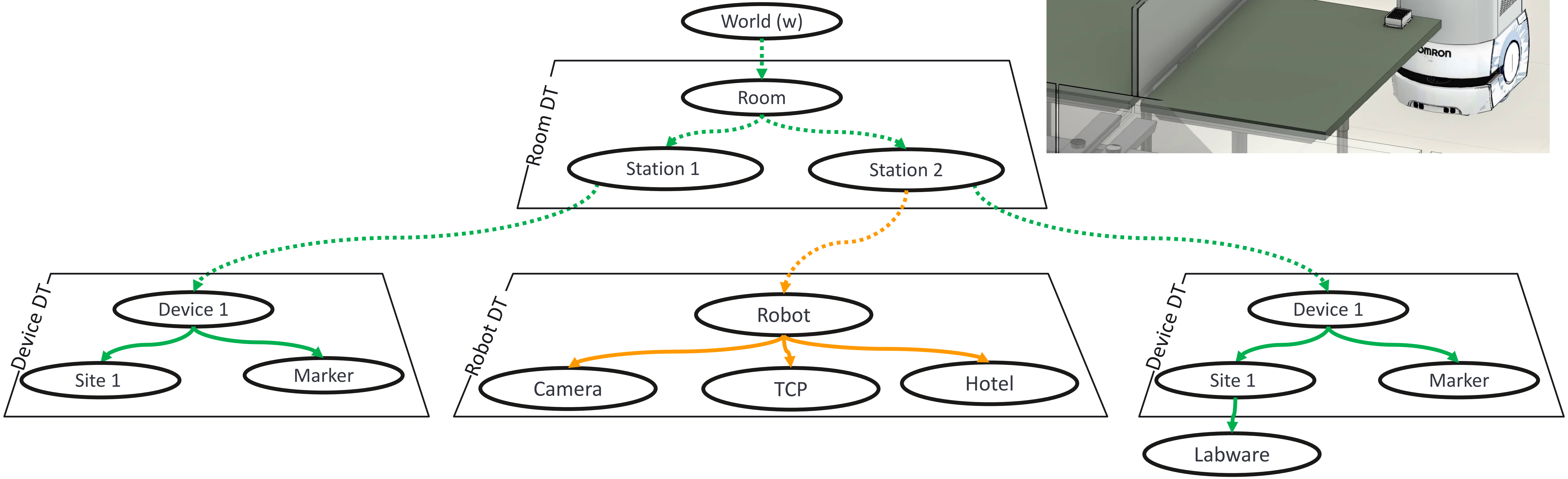
Place to station_2.device_1.site_1





Placed to station_2.device_1.site_1





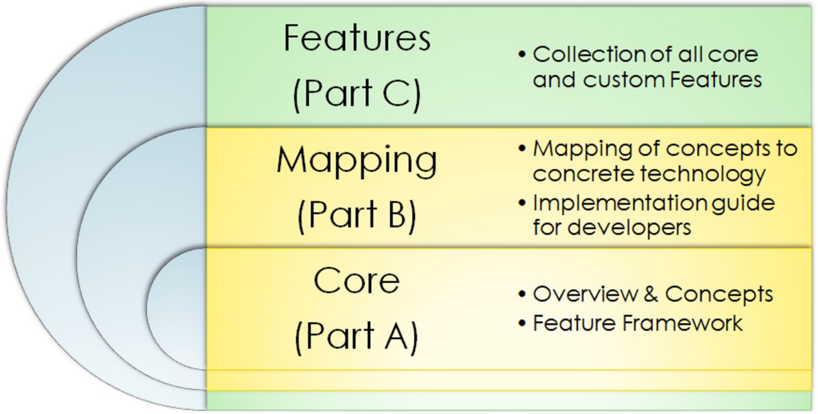
Proof-of-concept studies

Consortia & academia

SiLA

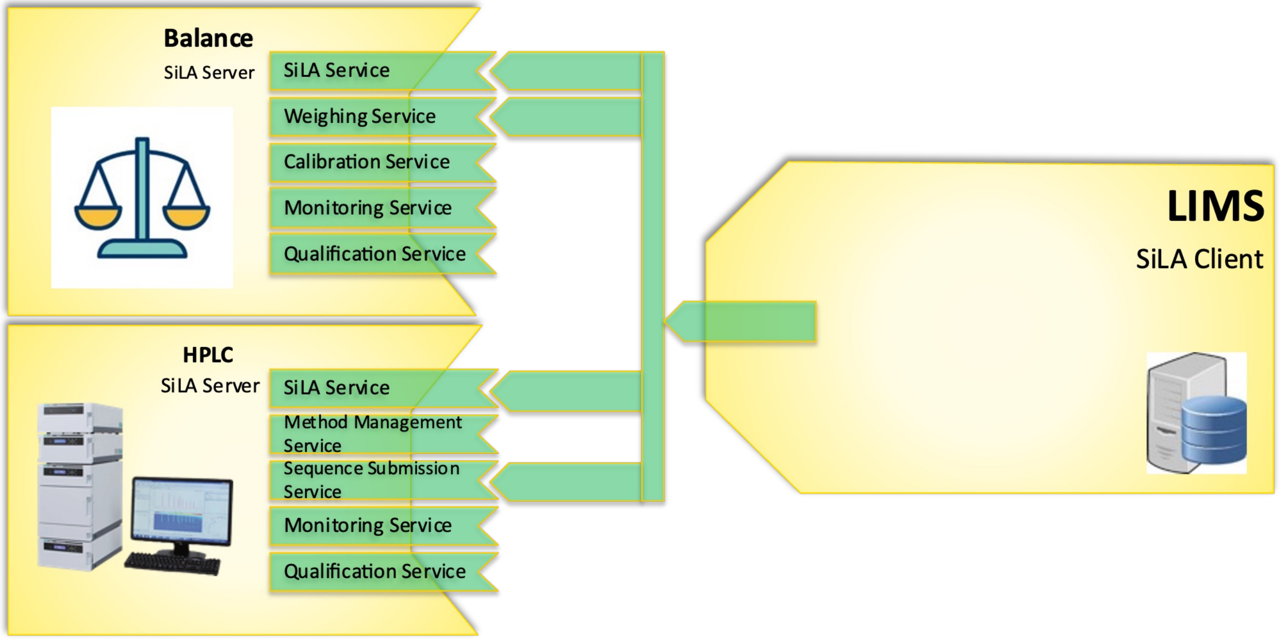
The consortium

- Not-for-profit
- Membership organization: users and solution providers
- Exchange and collaborate
- Working groups
  - Core: to maintain and develop the standard specs and reference implementations
  - Domain-specific WGs (e.g., Robotics): to unify feature definitions and harmonize integration best practices



The standard

- Service-oritented interoperability protocol
- A lab device (or robot) implements a set of features, and acts as a server
- A scheduler controls these devices by triggering commands and supervising their execution, acting as a client
- The featuer definition acts as a semantic description of the features, and serves a contract between the server and the client



The SiLA Robotics Working Group (SRWG)

Vision

- Standardized communication and interoperability for (mobile) robots in automated laboratories
- Plug & play integration
- Vendor-independent solutions

Mission

- Rely on existing technologies
- Unify, scale-up and extend functionality
- Incorporate new concepts
- Extend the SiLA stack
- Facilitate exchange in the lab automation robotics community

Core values

- Community effort
- Open-source implementations
- Open access publications

Operating model

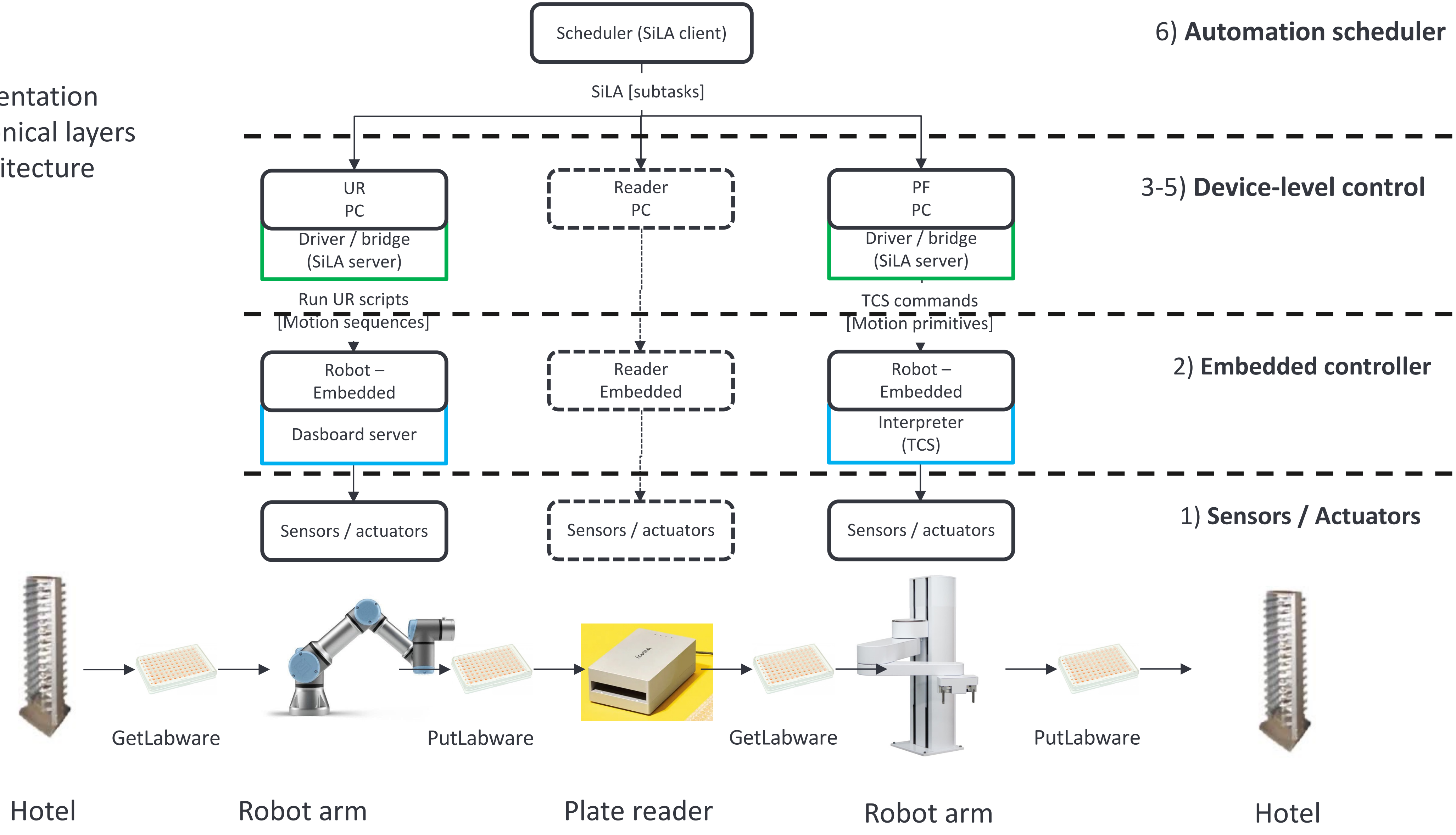
- Hackathons
  - BioSASH
- Regular meetings
  - Monthly
- Focus groups
  - Use case oriented
  - Technology oriented

Work packages

- Feature unification
  - LabwareTransfer
  - Extended framework
- Reference implementations
  - SiLA-ROS bridge
  - LabwareTransfer for stationary robots
  - LabwareTransfer for mobile manipulators (in progress)
- Ontologies
  - Labware (in progress)
  - Devices (planned)

SiLA interface for stationary robots

- Reference implementation
- Featuring the canonical layers of the control architecture



SiLA interface for MoMas

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

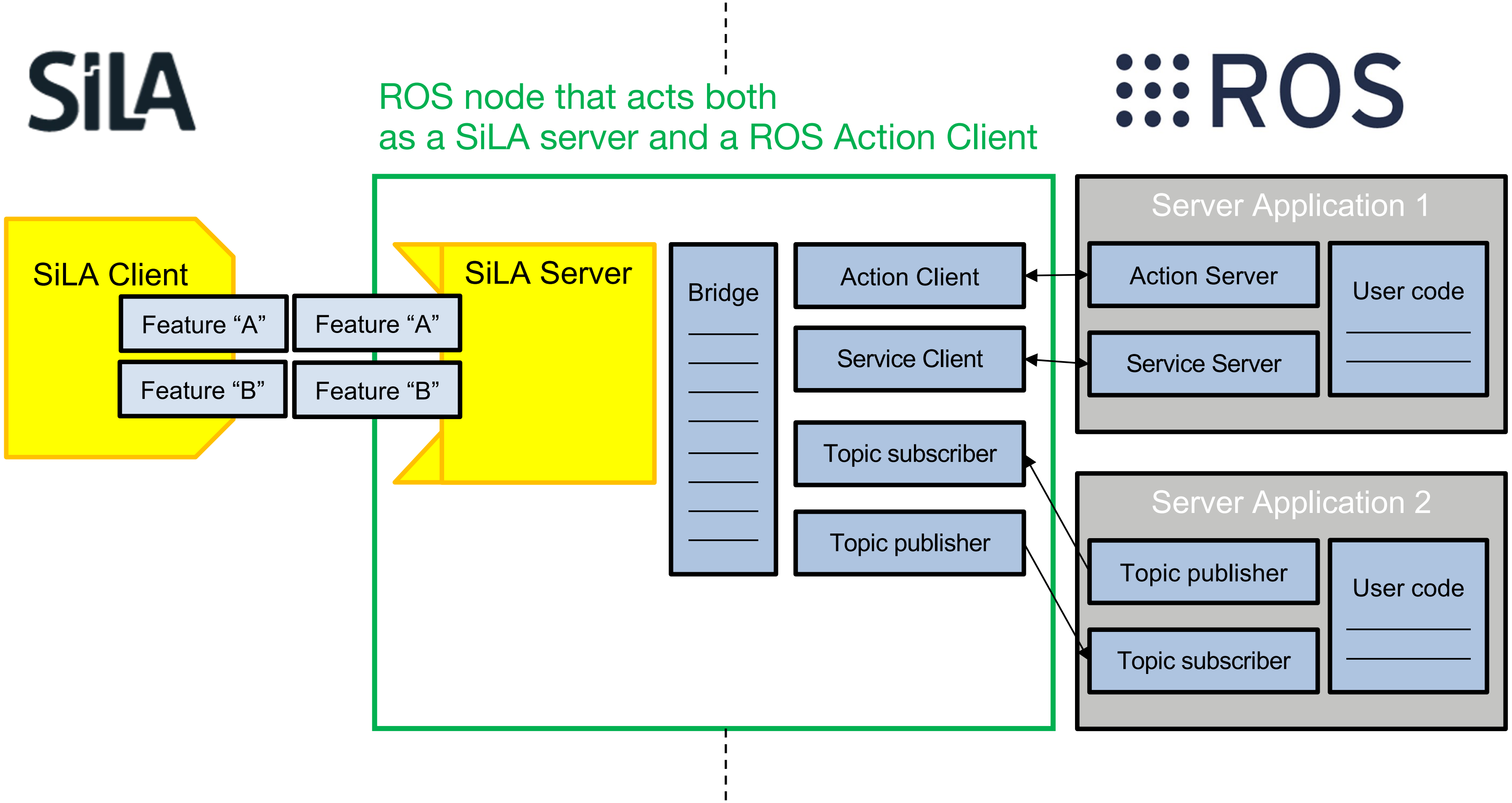
- Óbuda University
- Takeda’s global MoMa PoC (more details later)

biolago.org

uni-obuda.hu

The SiLA-ROS bridge

- Reference implementation
- Bridging the lab automation ecosystem with the robotics ecosystem
- SiLA for high-level control
- ROS for low-level control

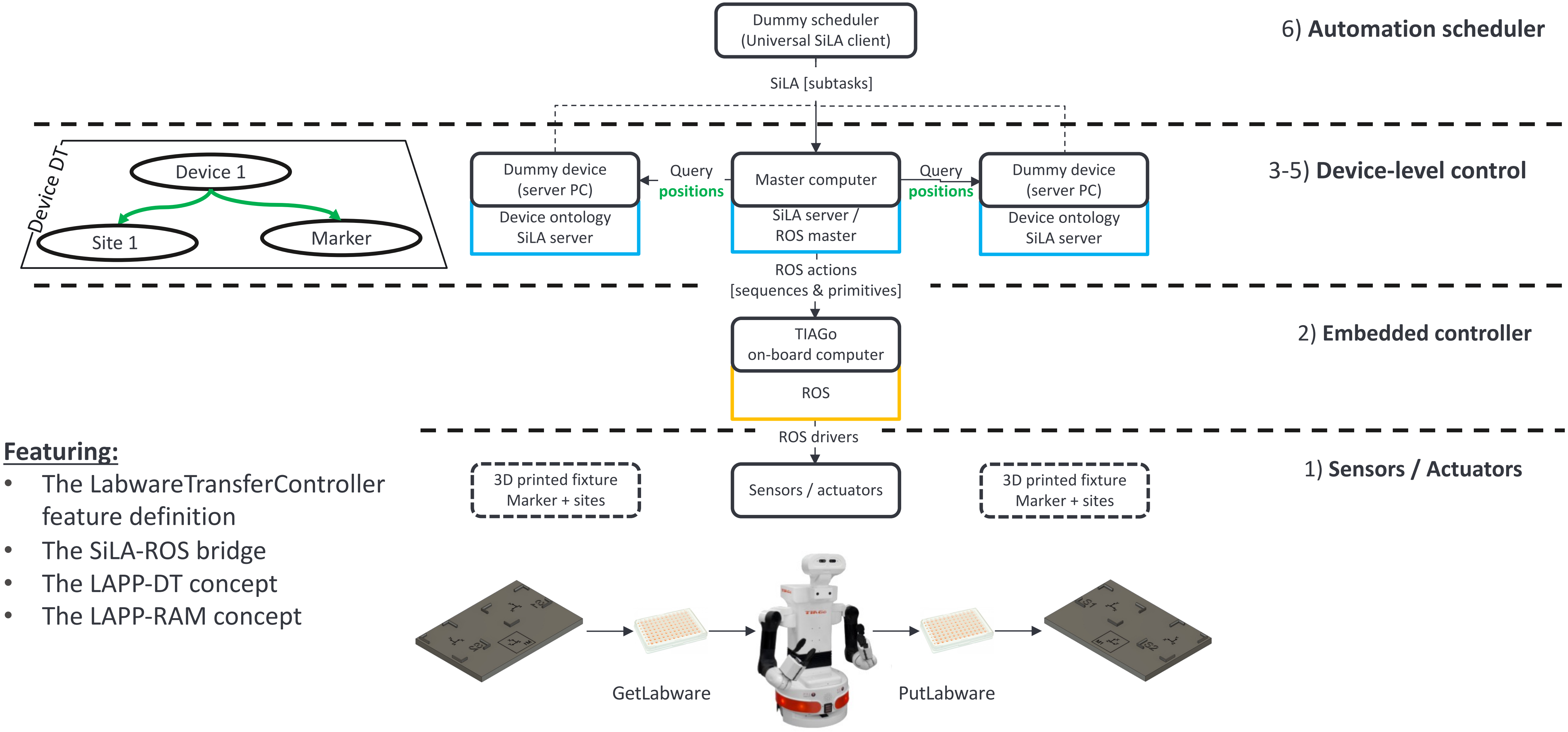


Mapping SiLA concepts to ROS concepts

Conceptual correspondence between elements of the SiLA ecosystem and the ROS ecosystem

SiLA	ROS
SiLA server / client	Node
Data type	Message definition
Observable property	Topic
Unovsevable property	Parameter
Observable command	Action / Topic
Unobservable command	Service / Topic
Command parameter	Action goal
Command return value	Action result
Estimated remaining time; progress	Action feedback

Reference implementations – TIAGo, Uni Óbuda, Panna Zsoldos

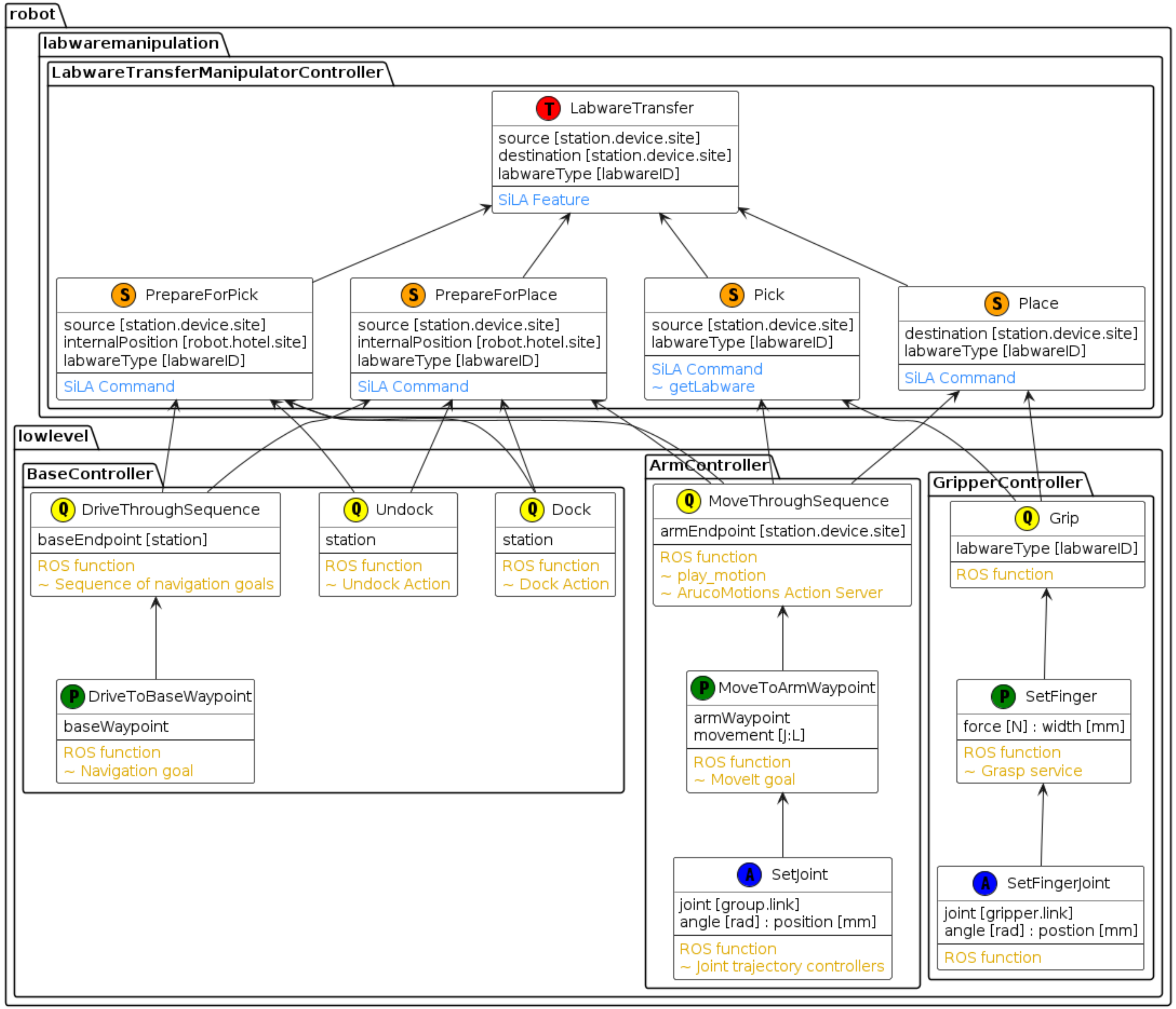


Featuring:

- The LabwareTransferController feature definition
- The SiLA-ROS bridge
- The LAPP-DT concept
- The LAPP-RAM concept

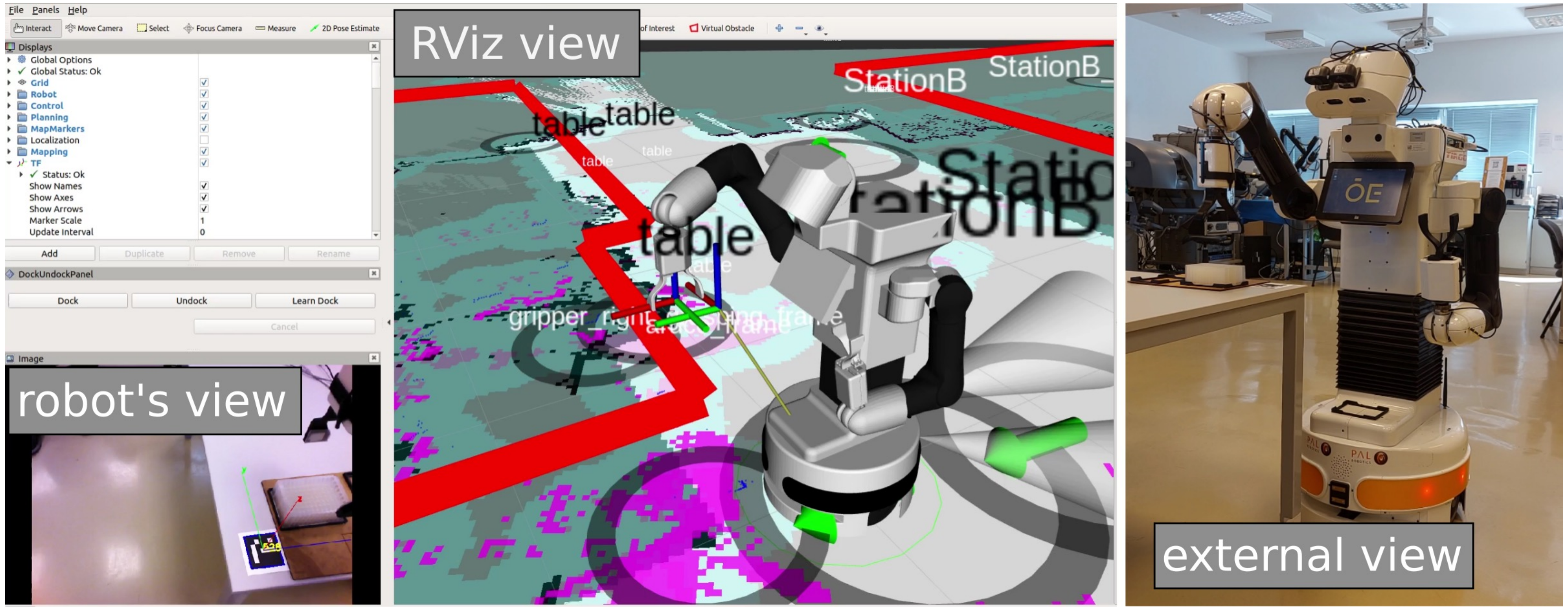
Mapping SiLA and ROS concepts to the LAPP-RARs

- The hierarchical decomposition of lab workflows with the LAPP robotic activity representations (RARs)
- SiLA commands implementing Subtasks
- ROS implementing motion sequences, motion primitives and actuator primitives



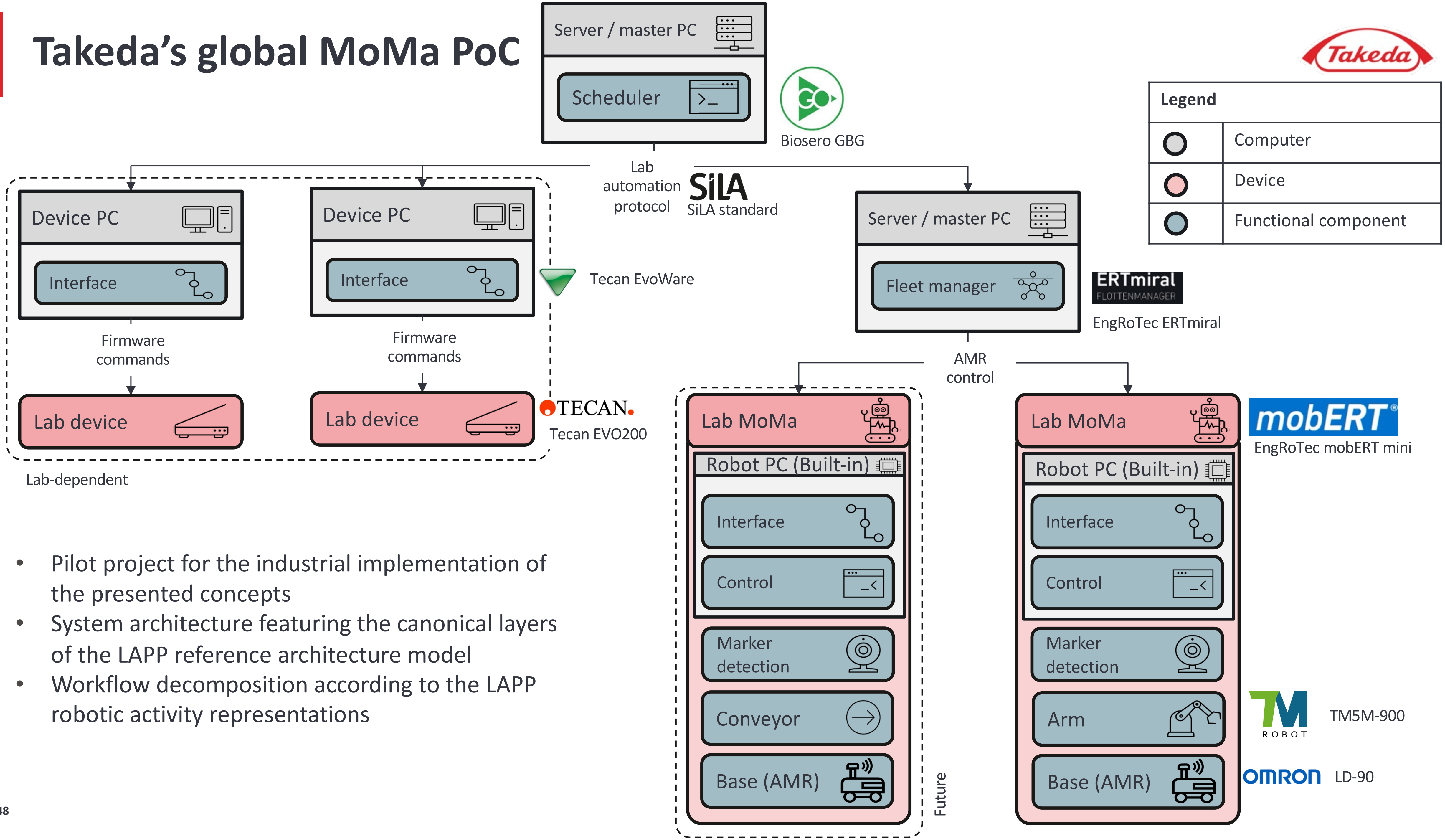
Testing of the ArUco based arm motions and the microplate picking

- RViz view of the simulated robot state
  - Dark grey areas framed by red lines are restricted areas
  - Light grey areas show where the robot is allowed to navigate
  - Green arrows are the POIs placed on the map
  - Magenta dots are the real-time obstacle data detected by the LIDAR
  - grey circles mark the virtual objects on the map which can be modified by dragging and moving them
- Robot's head camera view
- External view



Takeda's Global MoMa PoC

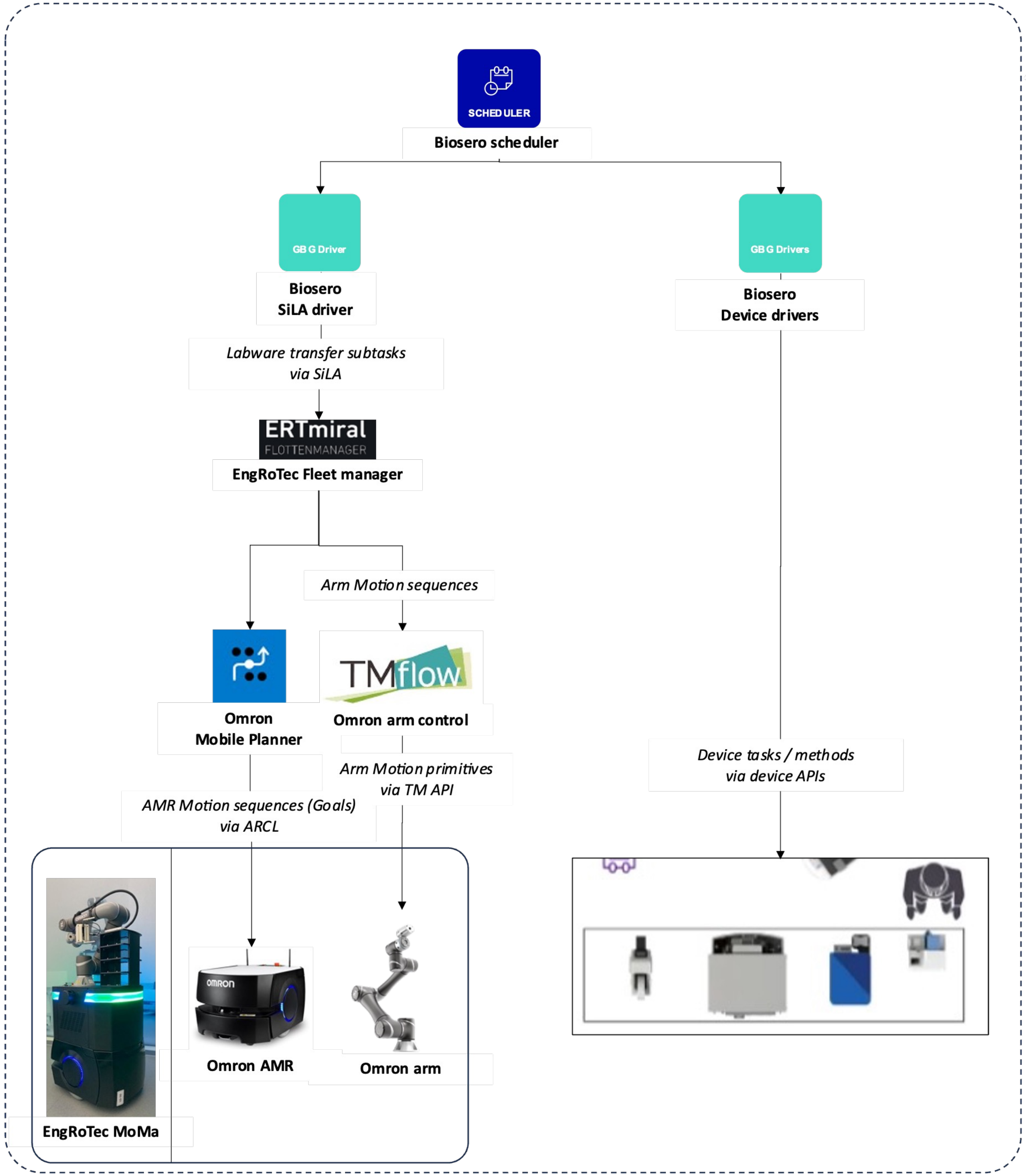
Takeda's global MoMa PoC



- Pilot project for the industrial implementation of the presented concepts
- System architecture featuring the canonical layers of the LAPP reference architecture model
- Workflow decomposition according to the LAPP robotic activity representations

System architecture

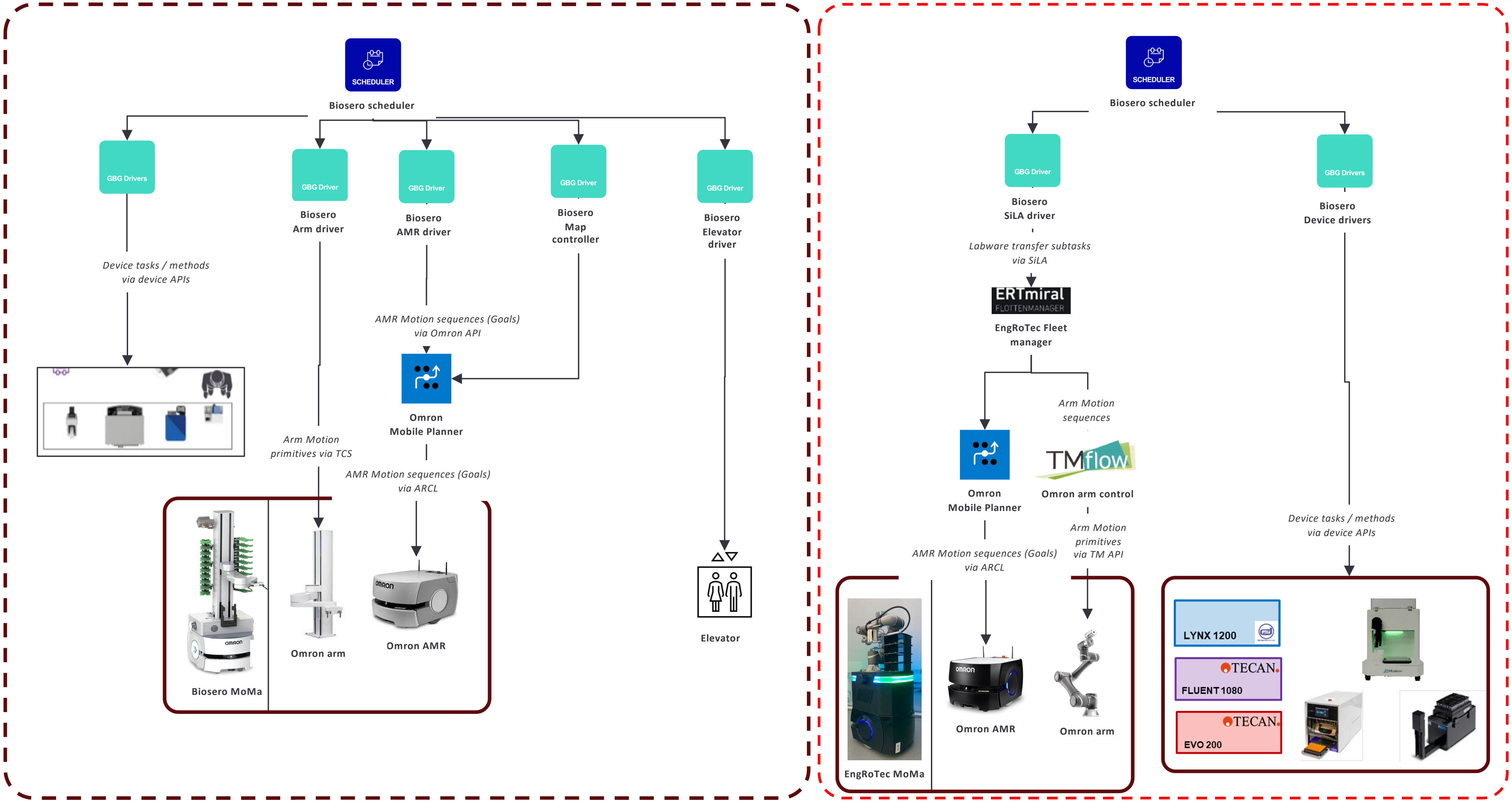
- With concrete technical building blocks
- From scheduler down to robot components
- Considering the future integration of a second robot from a different integrator
- Fuse the two systems together (see next slide)



Phase 1

Separated GBG instances for each of the two labs

No orchestrator

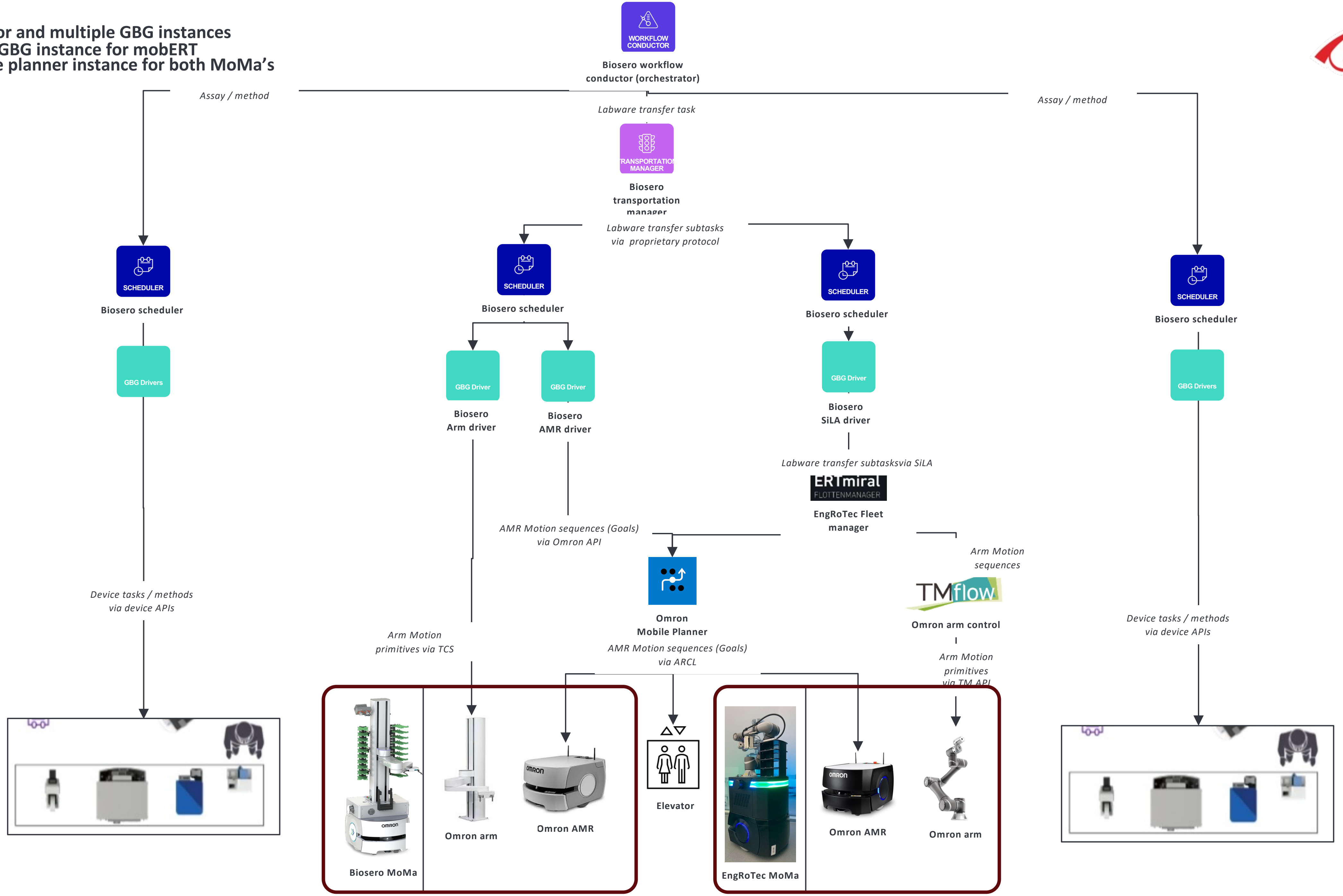


Lexington AD (Rachel, earlier purchase)

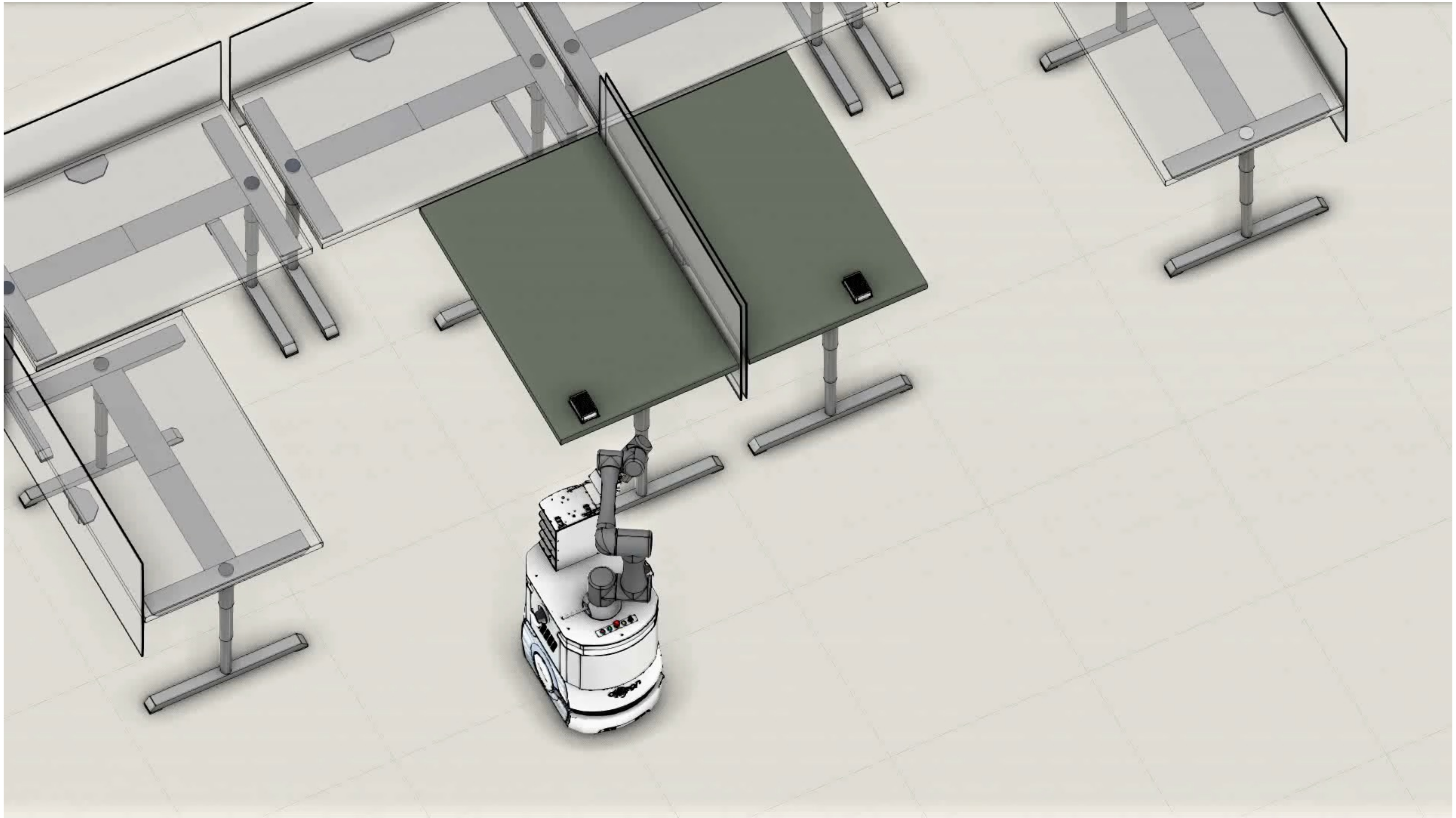
Lexington BPD (Elena, FY22 purchase)
(Identical: Vienna AD (Ádám, FY22 purchase))

Phase 2

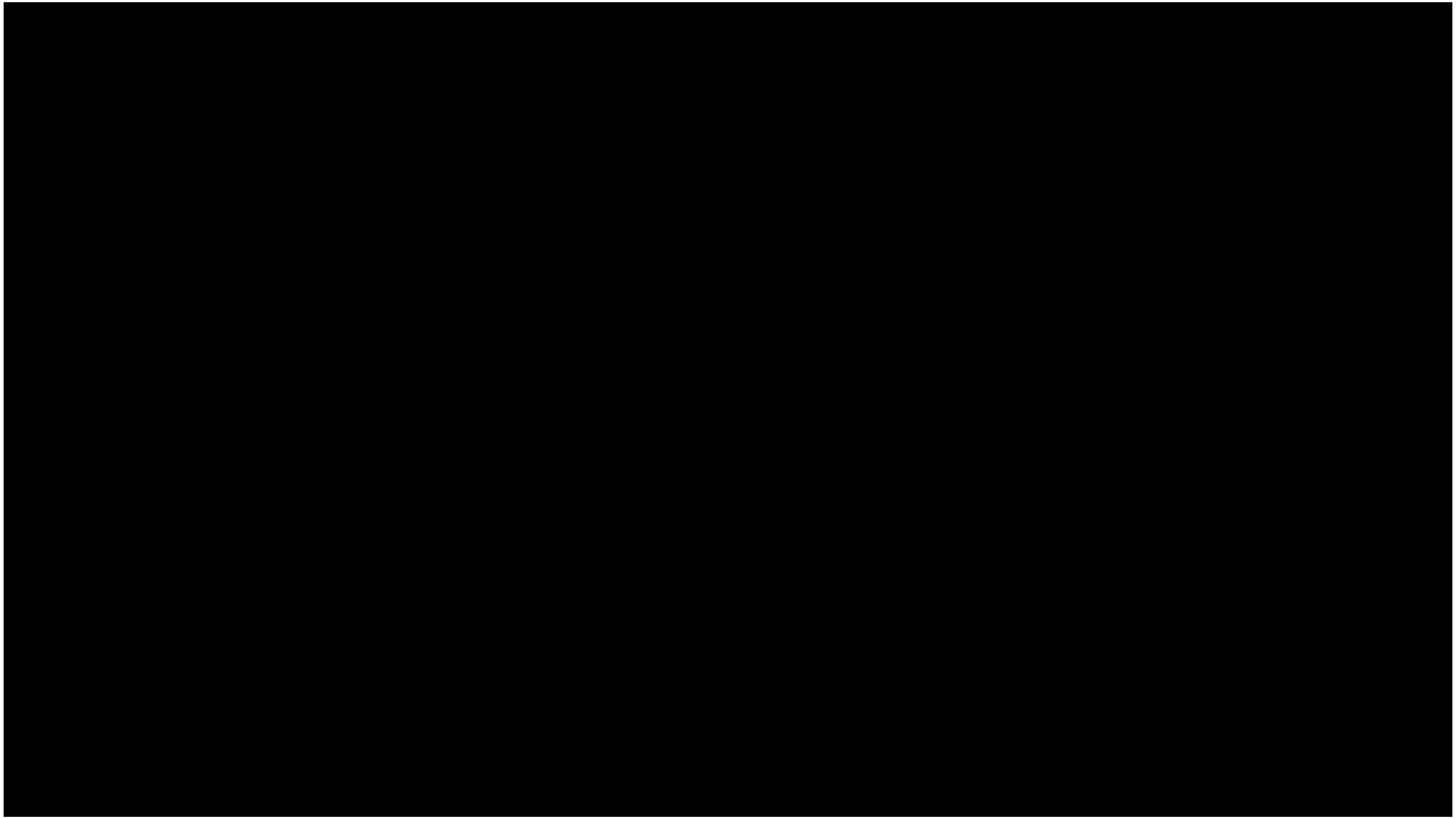
Orchestrator and multiple GBG instances
Additional GBG instance for mobERT
One Mobile planner instance for both MoMa’s



Takeda's global MoMa PoC – Simulation



MoMa interfacing with storage unit – Simulation



Pick-and-place SAT demo

Acknowledgements

PhD Supervisors

Péter Galambos

Károly Széll

DigiLab, Takeda

Patricia Wildberger

Brian Parkinson

Project TIAGo

Panna Zsoldos

SiLA

Stefan Koch

Mark Dörr

Lukas Bromig

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.

Better Health, Brighter Future