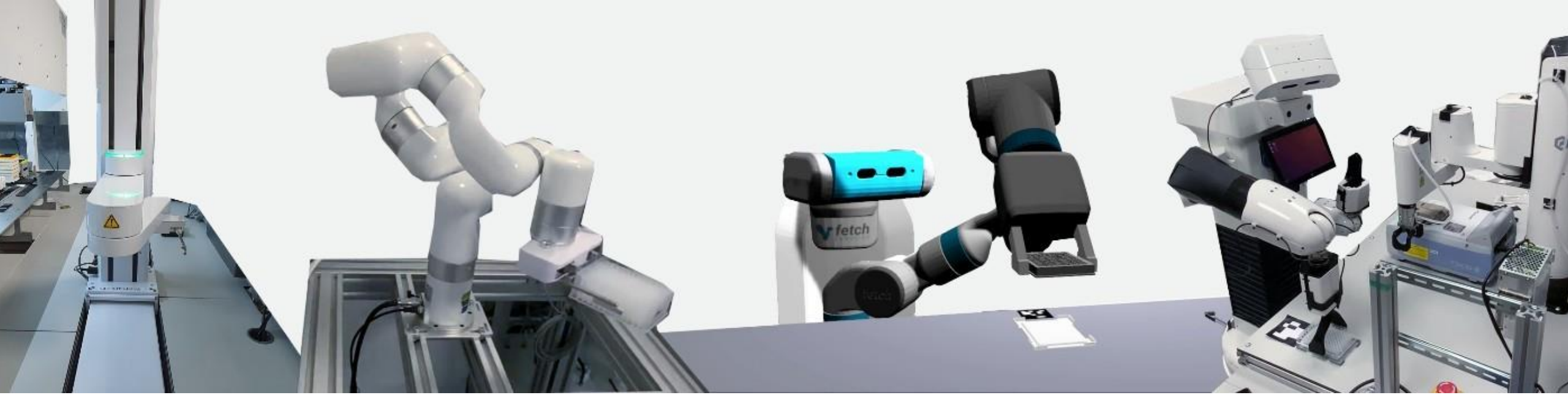

Reference Architecture Model for the Integration of Lab Robots

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Engineer, Digital Laboratory
Pharmaceutical Sciences, Sustainability & Technology
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Takeda

Better Health, Brighter Future

Agenda

- **Robotized lab automation systems**
  and their challenges
- **The Laboratory Automation Plug & Play (LAPP) framework**
  as a Reference Architecture Model
- **Hierarchical decomposition**
  of laboratory workflows
- **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
- **Proof-of-concept studies**
  Consortia & academia
- **How we approach this at Takeda**
  Our Global PoC project

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 these

Collaborative & mobile robotics

- Operate in human-designed (less-structured) environments
- Interface with modular and 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

The Laboratory Automation Plug & Play (LAPP) framework

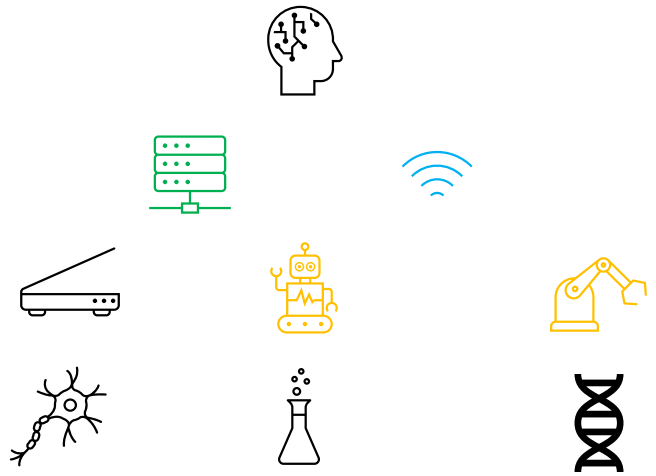
As a Reference Architecture Model

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

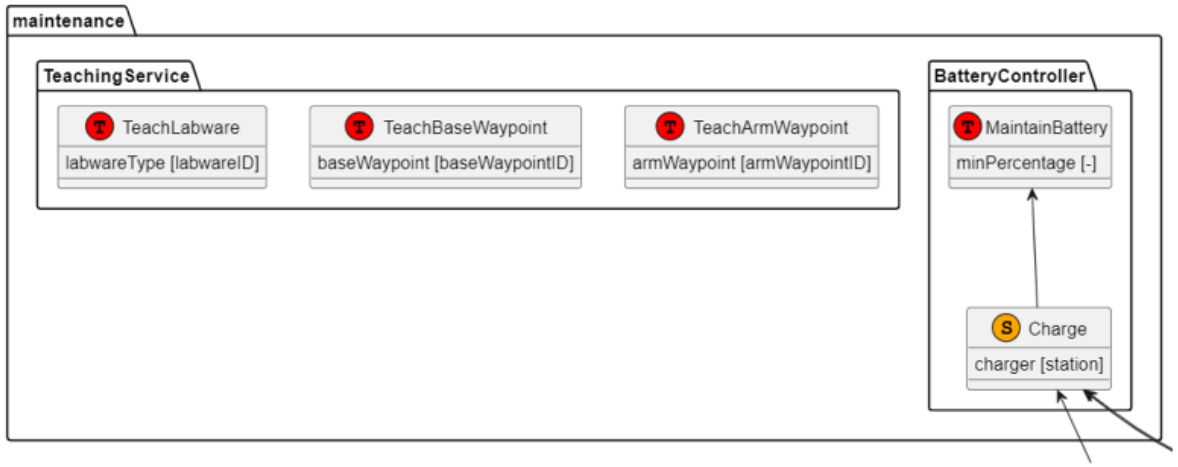
Hierarchical decomposition

of laboratory workflows

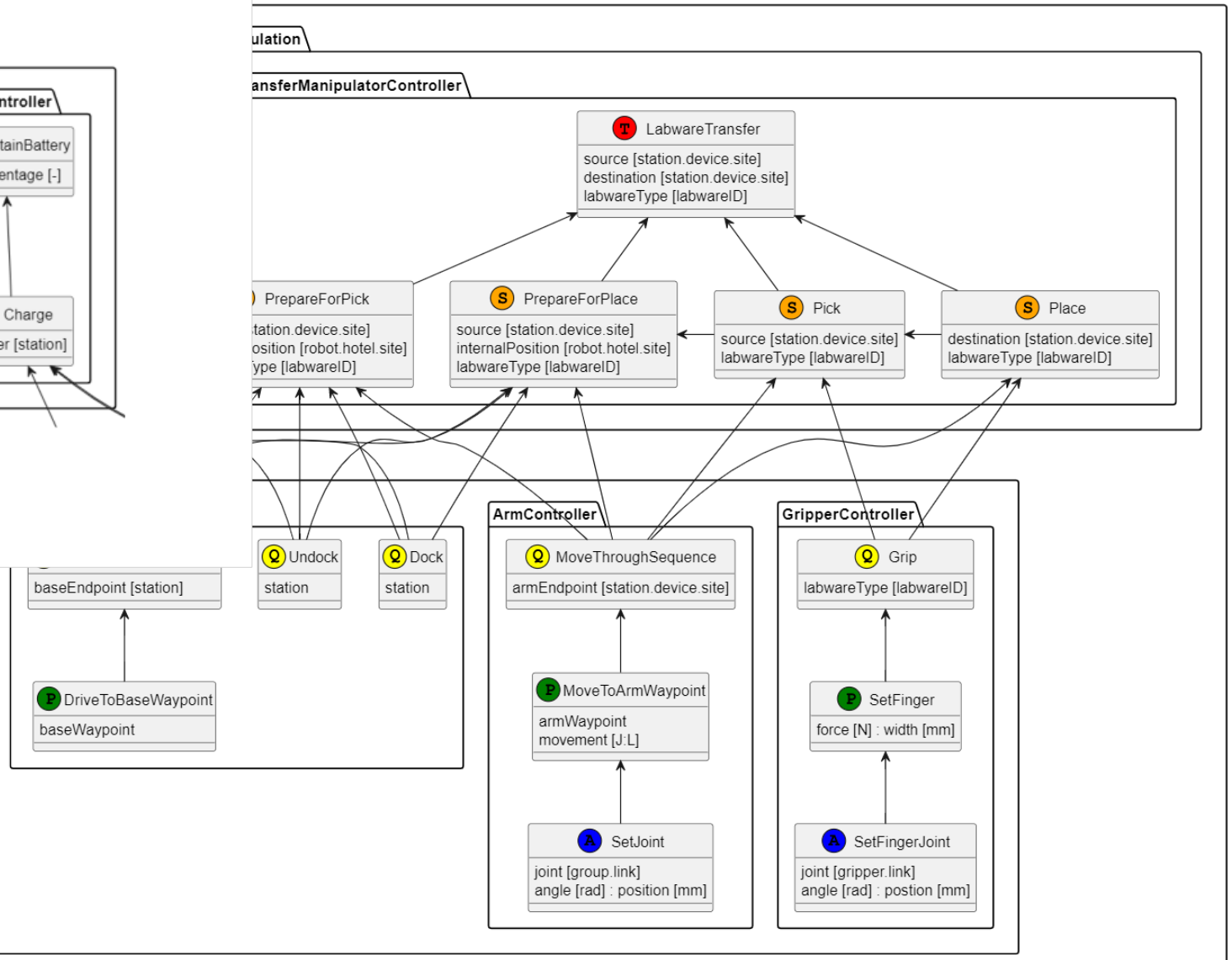
Hierarchical decomposition of lab workflows

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

Pick & place labware transfer – Maintenance activities

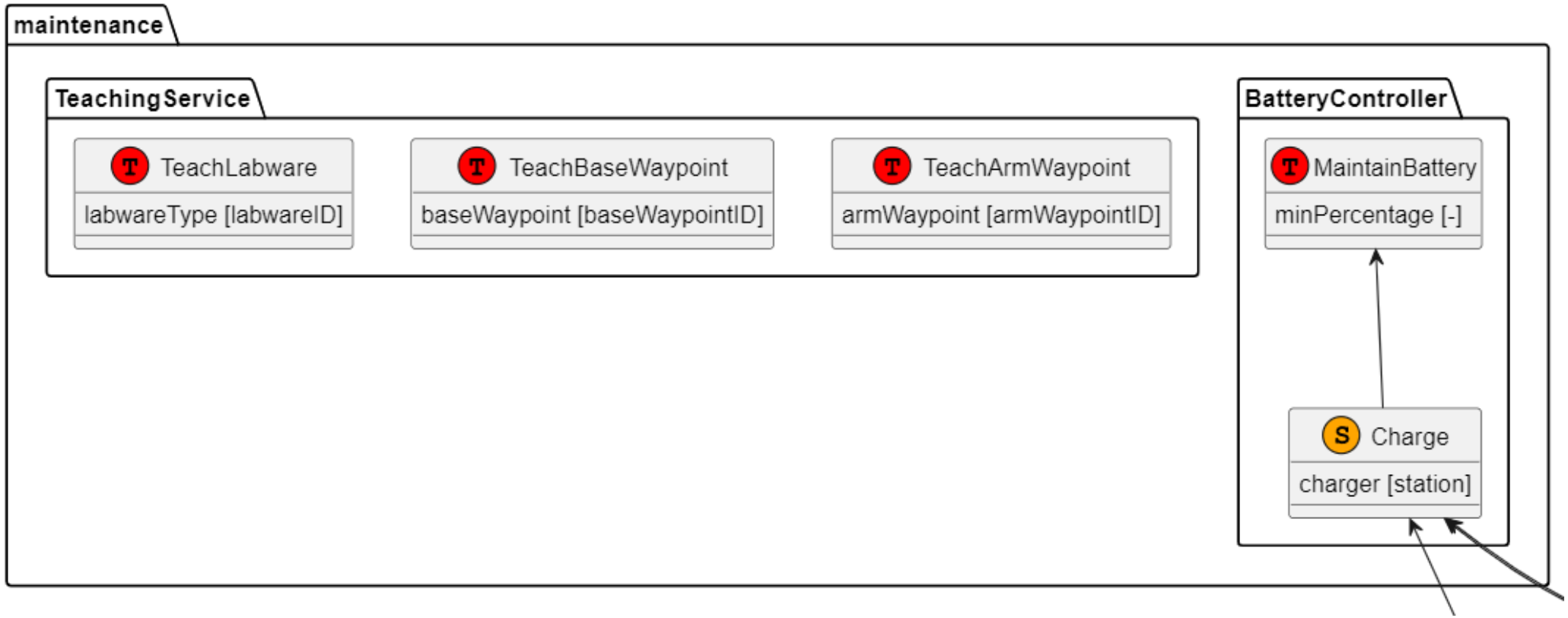


cal activity decomposition

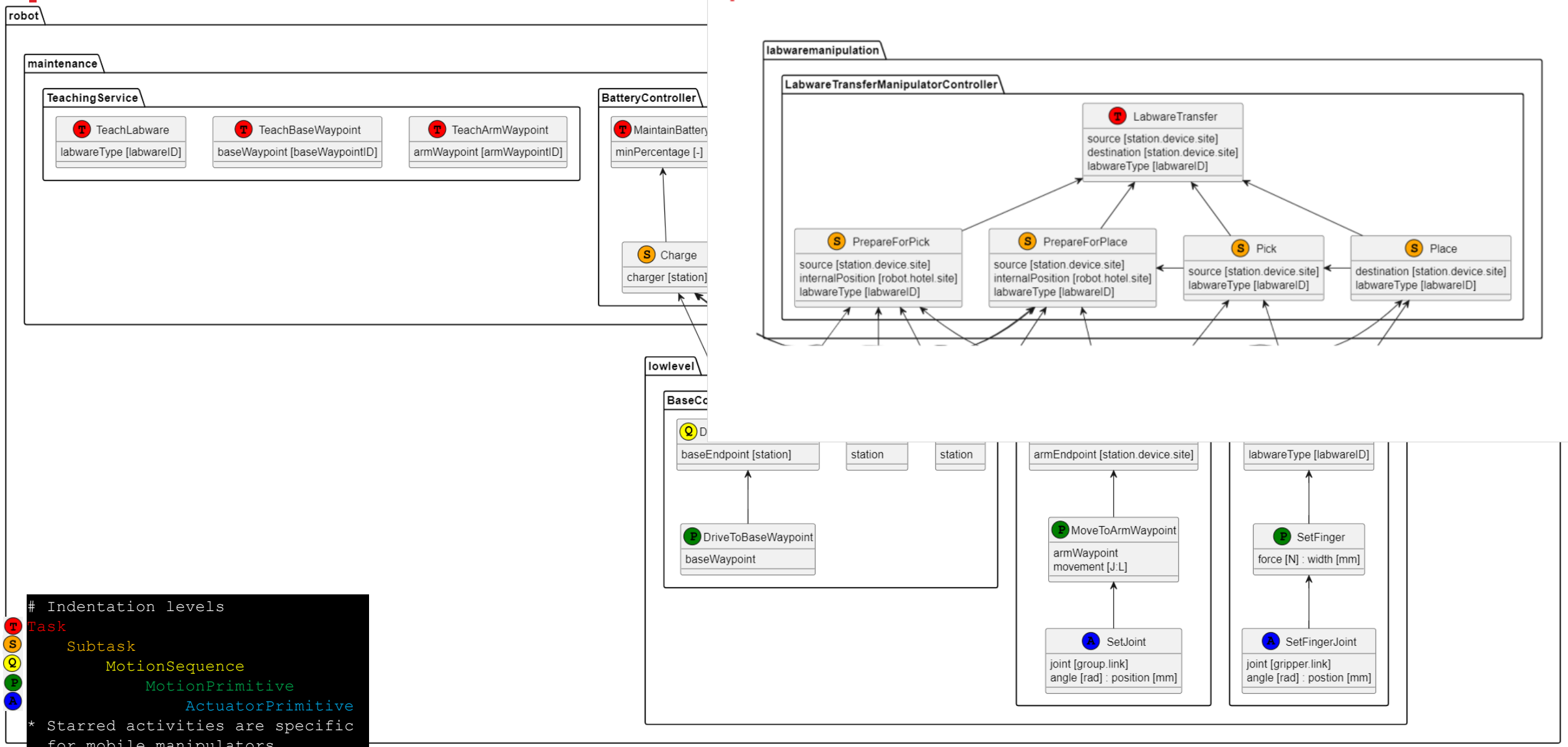



```
# Indentation levels
Task
    Subtask
        MotionSequence
            MotionPrimitive
                ActuatorPrimitive
* Starred activities are specific
  for mobile manipulators
```

Pick & place labware transfer – Maintenance activities



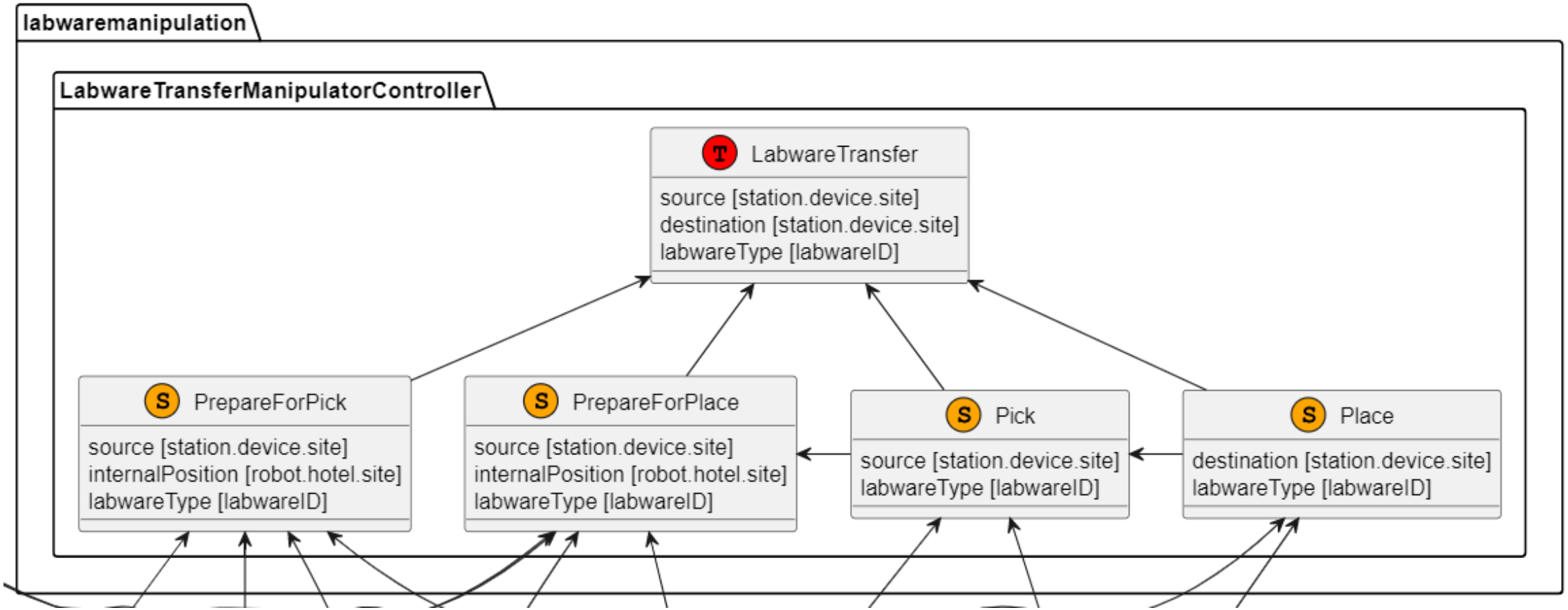
Pick & place labware transfer – Hi



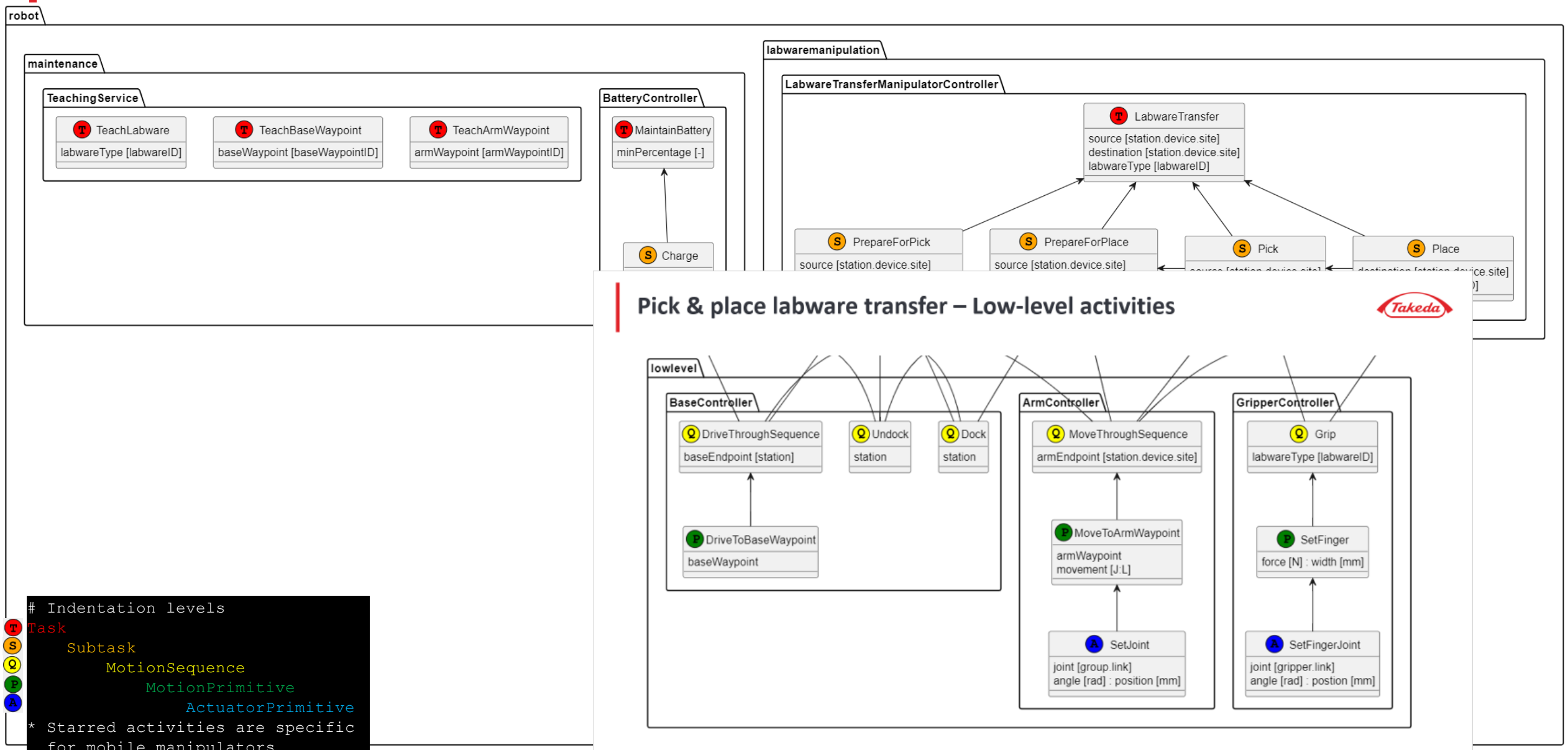
Pick & place labware transfer – High-level activities


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

Pick & place labware transfer – High-level activities



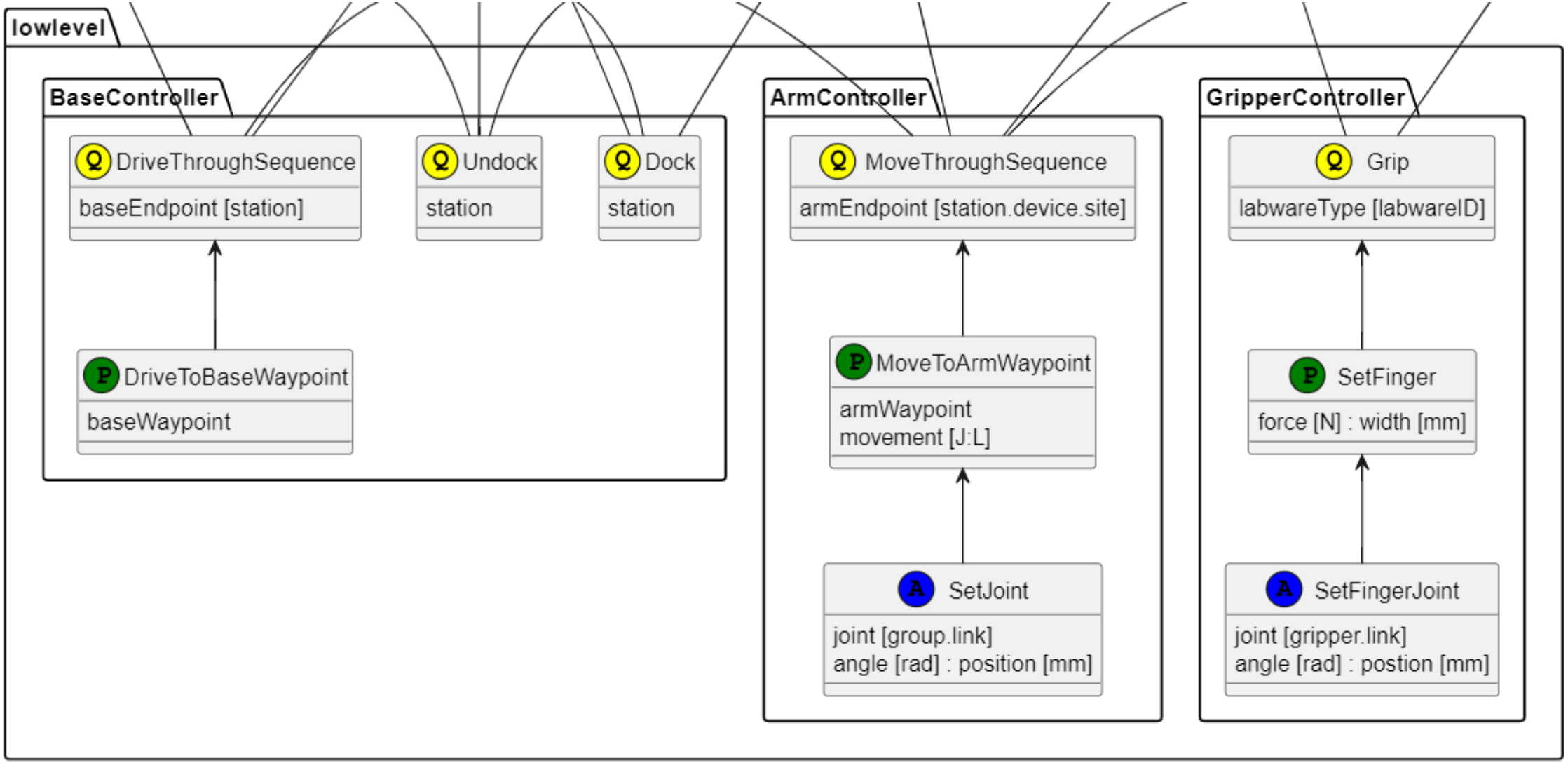
Pick & place labware transfer – Hierarchical activity decomposition



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



Hierarchical decomposition

Pick & place labware transfer activity

Pick & place labware transfer – Pseudocode

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

```
# Decomposition of a pick-and-place labware transfer task of a mobile manipulator robot
LabwareTransfer (station_1.device_1.site_1, station_2.device_1.site_1, DEEP96)
    PrepareForPick (self.site_1, DEEP96)
        *Undock (charger_1)
        *DriveThroughSequence (station_1)
            *DriveToBaseWaypoint (station_1.baseWaypoint_1)
            (...)
            *DriveToBaseWaypoint (station_1.baseWaypoint_n)  # Final baseWaypoint = station_1
        *Dock (station_1)
        MoveThroughSequence(station_1.device_1.site_1_safe)  # Safe position
            MoveToArmWaypoint (station_1.device_1.site_1.armWaypoint_1, J)
                SetJoint (joint_1, <angle>)
                (...)
                SetJoint (joint_n, <angle>)
            (...)
            MoveToArmWaypoint (station_1.device_1.site_1.armWaypoint_n-1, J)    # Safe position, aka. site_approach
    Pick (station_1.device_1.site_1, DEEP96)
        MoveThroughSequence(station_1.device_1.site_1)    # Handover position
            MoveToArmWaypoint (station_1.device_1.site_1.armWaypoint_n, L)  # Final armWaypoint = site_1
        Grip ()
            SetFingers (<force>)
        MoveThroughSequence(manipulation-ready)
            MoveL (device_1.site-approach_1)
            MoveL (device_1.device-approach)
            MoveL (manipulation-ready)
        *Place (self.hotel.site_1, DEEP96)
    PrepareForPlace (self.site_1, DEEP96)
        *Undock (station_1)
        *DriveThroughSequence (station_2)
            *DriveToBaseWaypoint (station_1.baseWaypoint_1)
            (...)
            *DriveToBaseWaypoint (station_1.baseWaypoint_n)  # Final baseWaypoint = station_2
        *Dock (station_2)
        *Pick (self.hotel.site_1, DEEP96)
        MoveThroughSequence(station_2.device_1.site_1_safe)  # Safe position
            MoveToArmWaypoint (station_2.device_1.site_1.armWaypoint_1, J)
            (...)
            MoveToArmWaypoint (station_1.device_1.site_1.armWaypoint_n-1, J)    # Safe position, aka. site_approach
    Place (station_2.device_1.site_1, DEEP96)
        MoveThroughSequence(station_2.device_1.site_1)    # Handover position
            MoveToArmWaypoint (station_2.device_1.site_1.armWaypoint_n, L)  # Final armWaypoint = site_1
        Release ()
        MoveThroughSequence(manipulation-ready)
            MoveL (device_1.site-approach_1)
            MoveL (device_1.device-approach)
            MoveL (manipulation-ready)
```

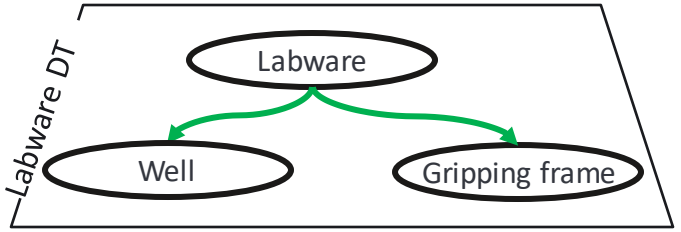
Ontologies

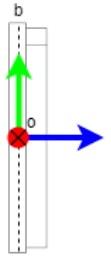
Pick & place labware transfer

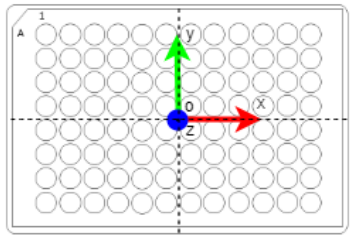
Labware ontologies

Motivation

- Represent robot-relevant information about the lab entities







The endeavor

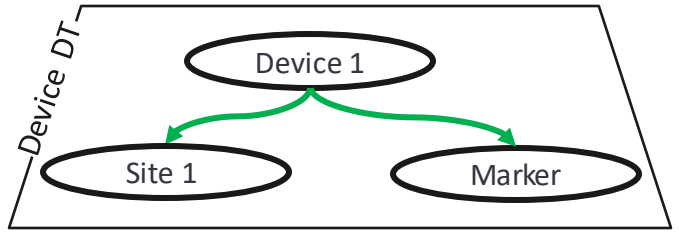
- Lead by Mark Dörr, Uni Greifswald
- Part of the Bits in Bio / Bioprotocols / LAB-OP group
- An SRWG subgroup to focus on the robot-related aspects

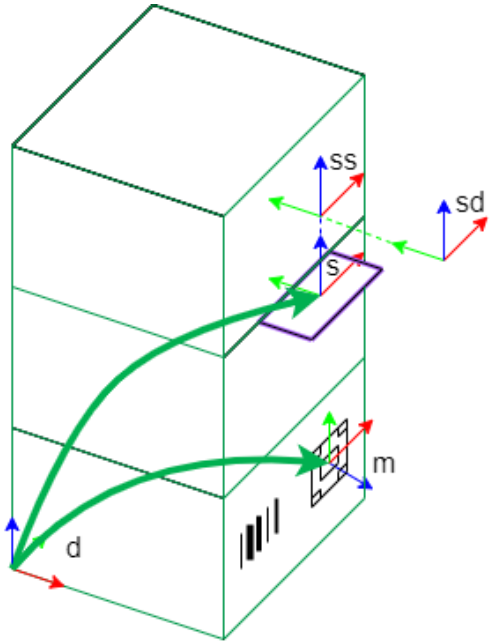
Stack

- 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





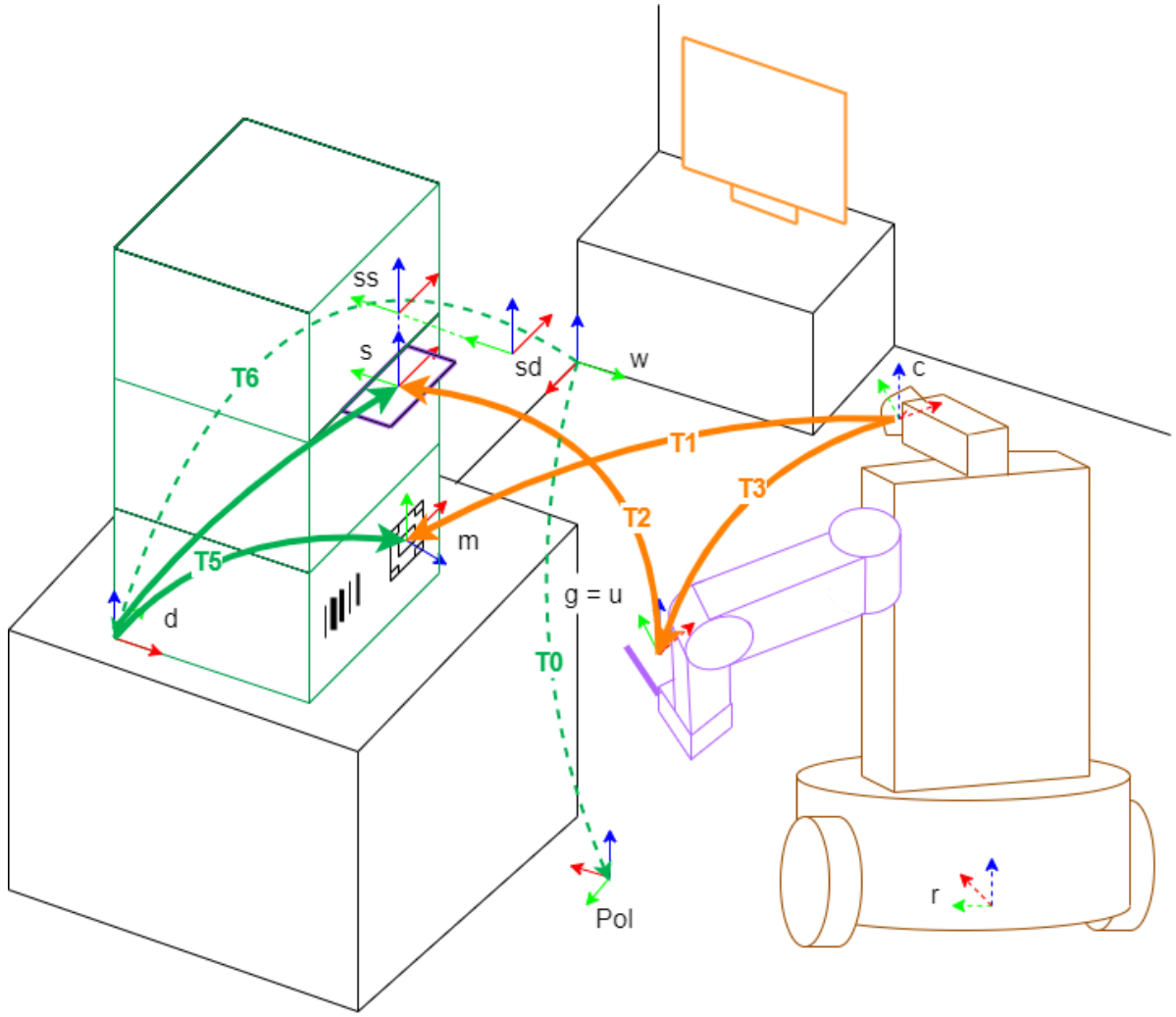
Position representations for mobile robots

with the LAPP Digital Twin

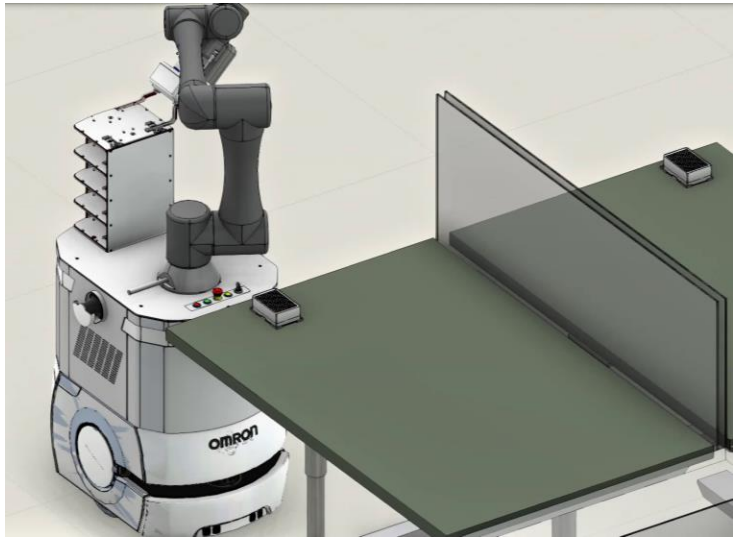
Position representations for mobile robots with the LAPP DT

- Top-down position definitions
- Stored in parent

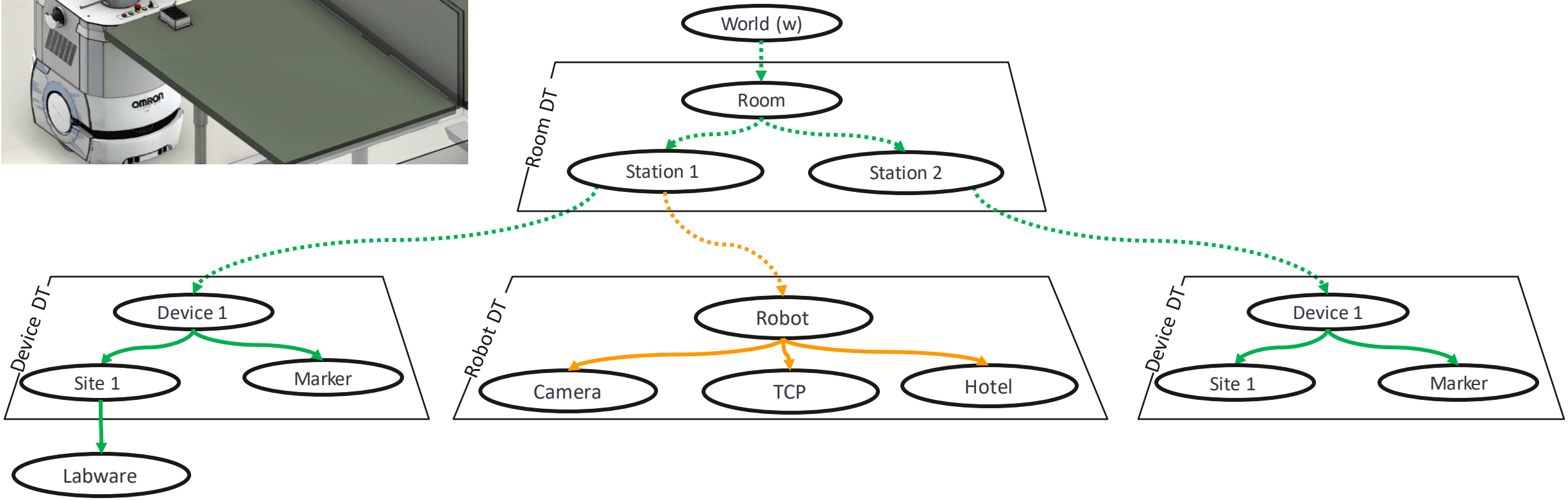
Legend	
	Live, robot-level, not exposed towards SiLA
	Stored in the LAPP DT Represented as high-level SiLA properties (references)
------	Transformation originates from inaccurate base odometry
———	Transformation originates from accurate sources • robot kinematics • marker detection • positions stored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



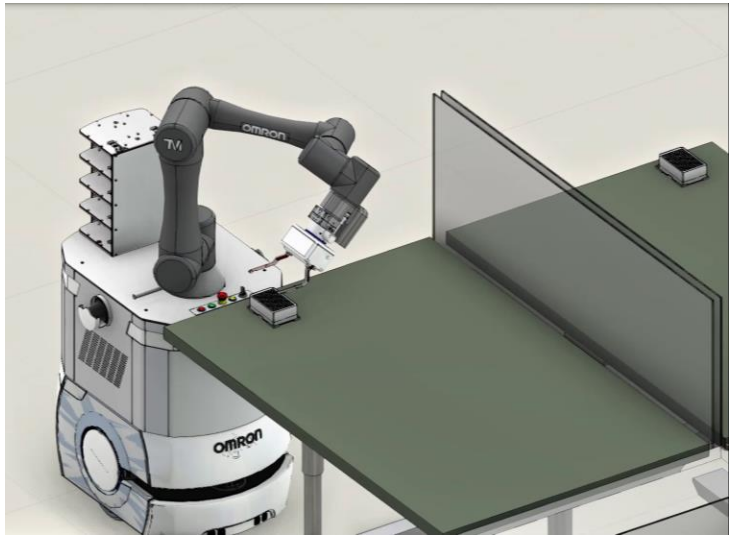
Robot docked to station 1



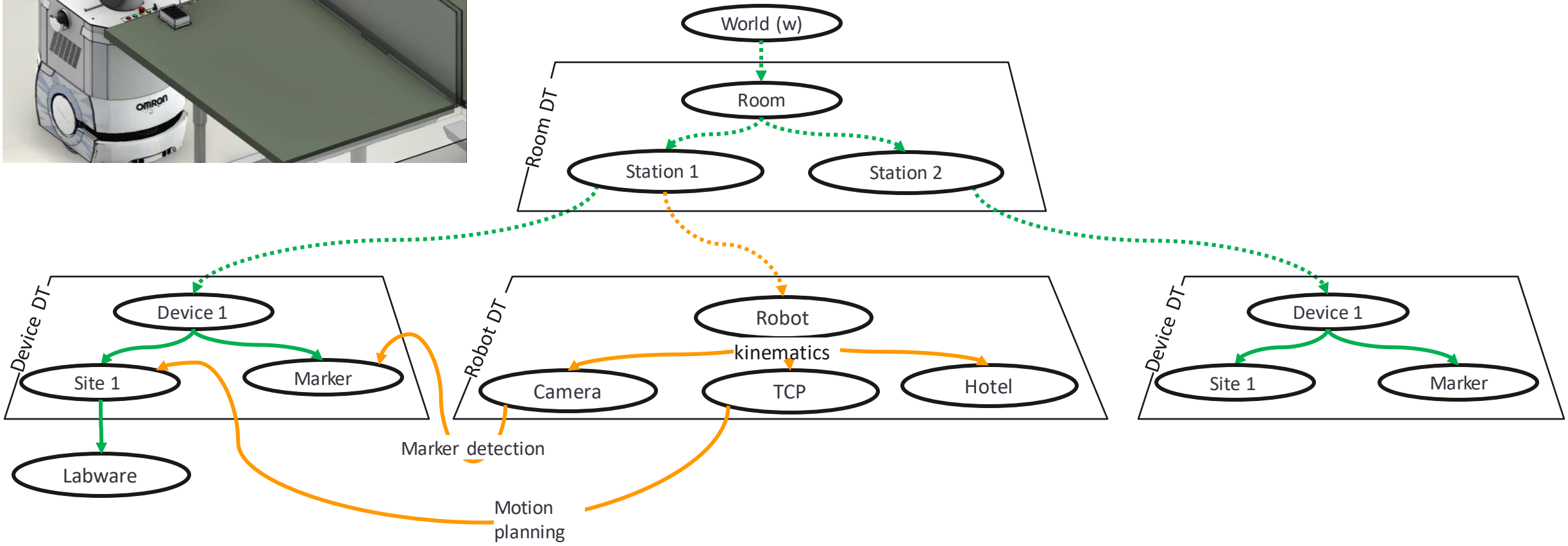

```
T LabwareTransfer (station_1.device_1.site_1, station_2.device_1.site_1, DEEP96)
S     PrepareForPick (self.site_1, DEEP96)
Q         Undock (charger_1)
Q         DriveThroughSequence (station_1)
Q         Dock (station_1)
```



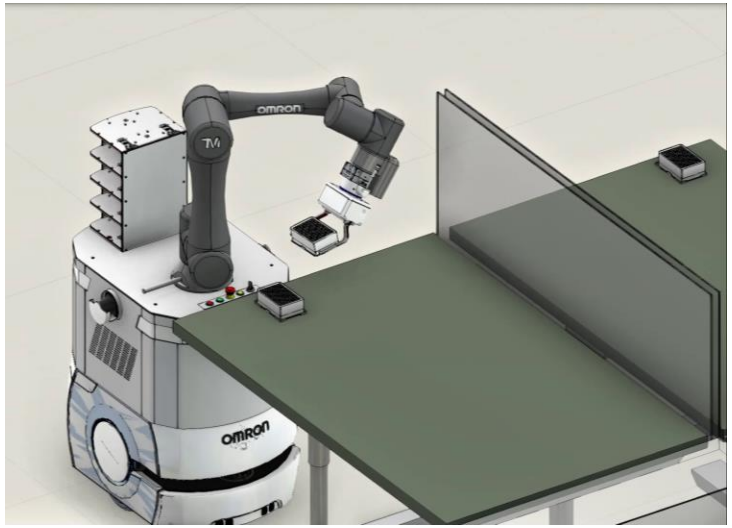
Pick from station_1.device_1.site_1



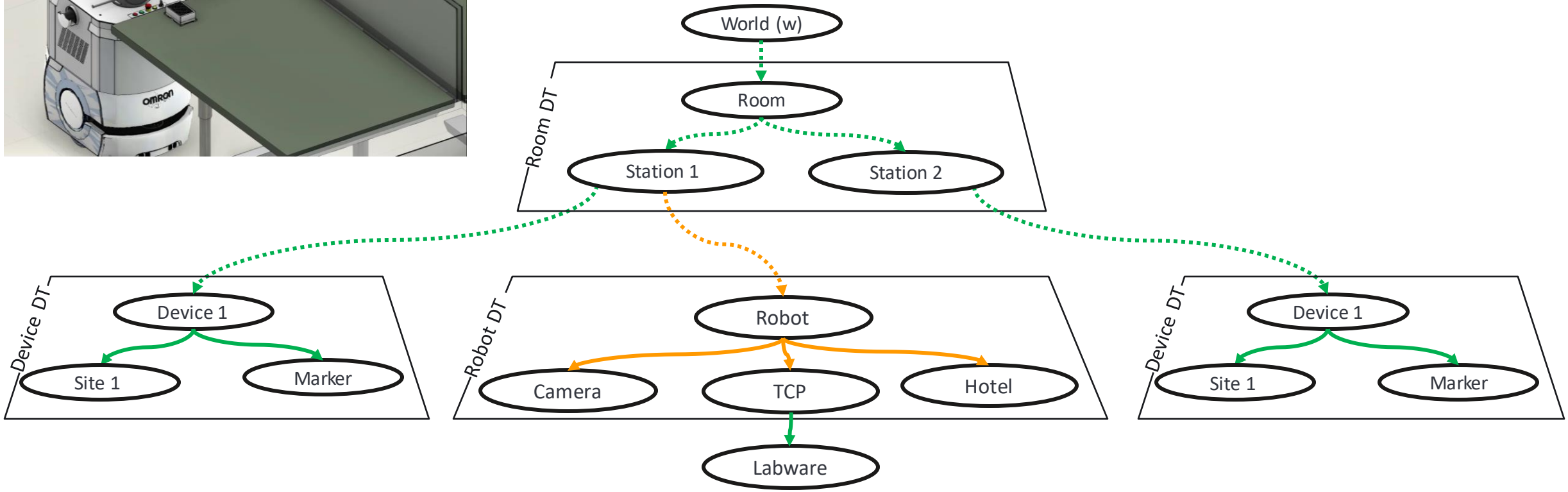
```
    MoveThroughSequence(station_1.device_1.site_1_safe)  # Safe position
Pick (station_1.device_1.site_1, DEEP96)
    MoveThroughSequence(station_1.device_1.site_1)   # Handover position
```



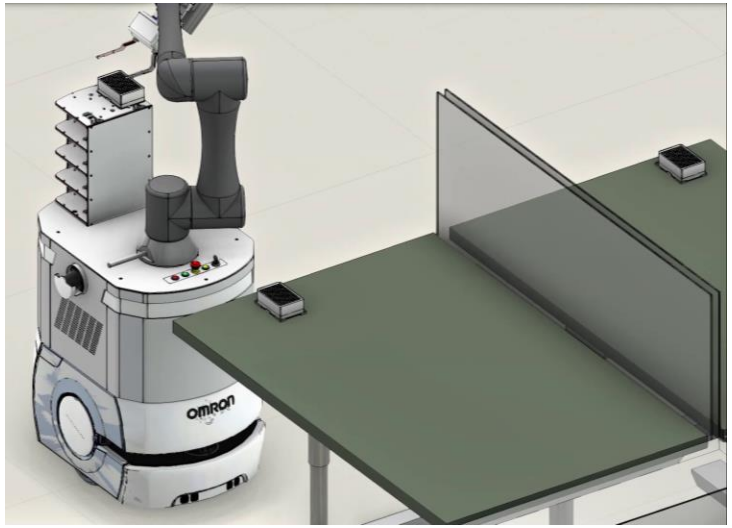
Pick from station_1.device_1.site_1 → Labware in gripper



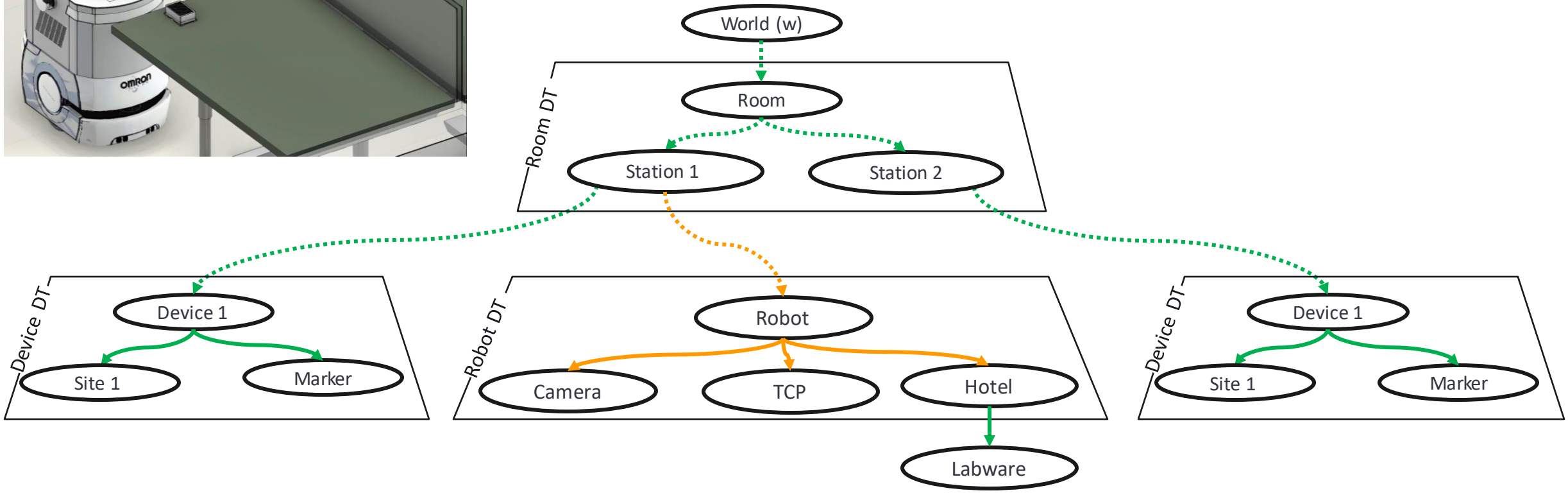
```
Grip ()
MoveThroughSequence(manipulation-ready)
```



Place on on-board hotel

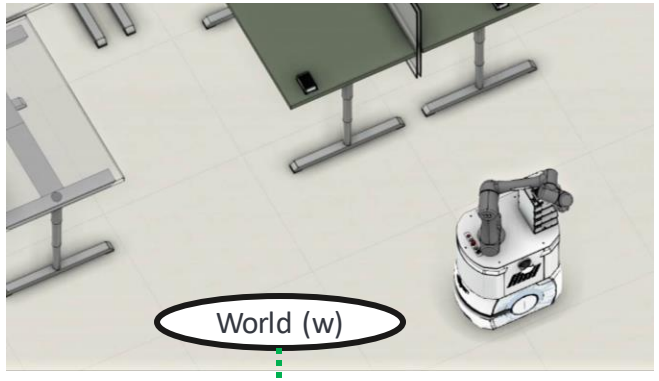


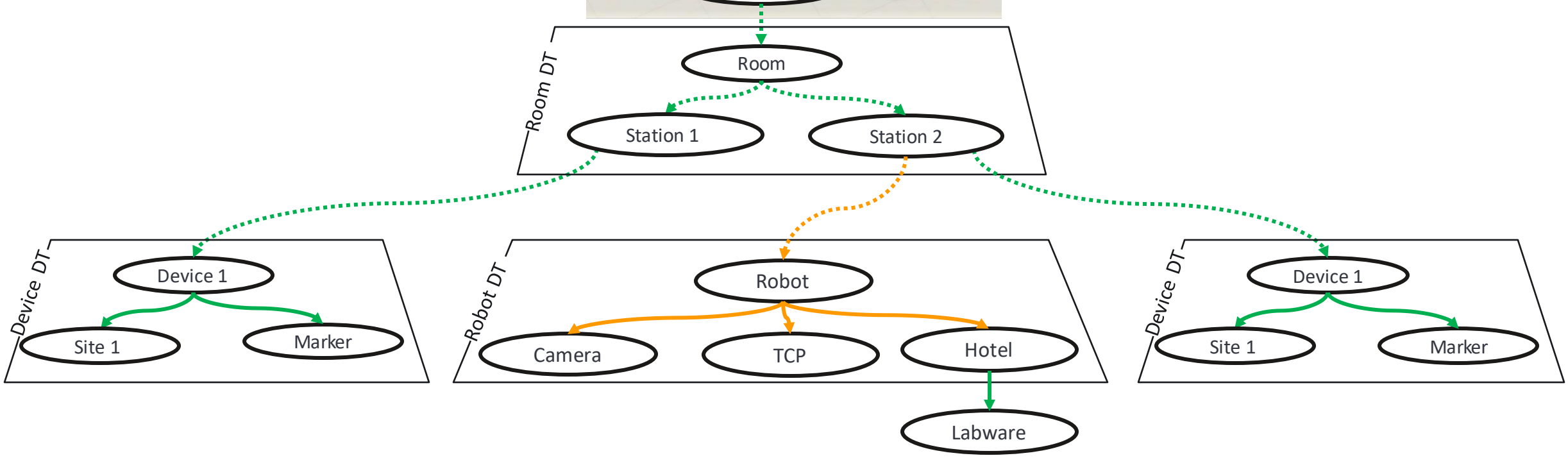

```
Place (self.hotel.site_1, DEEP96)
```



Switch to Station 2 → Undock, navigate and dock

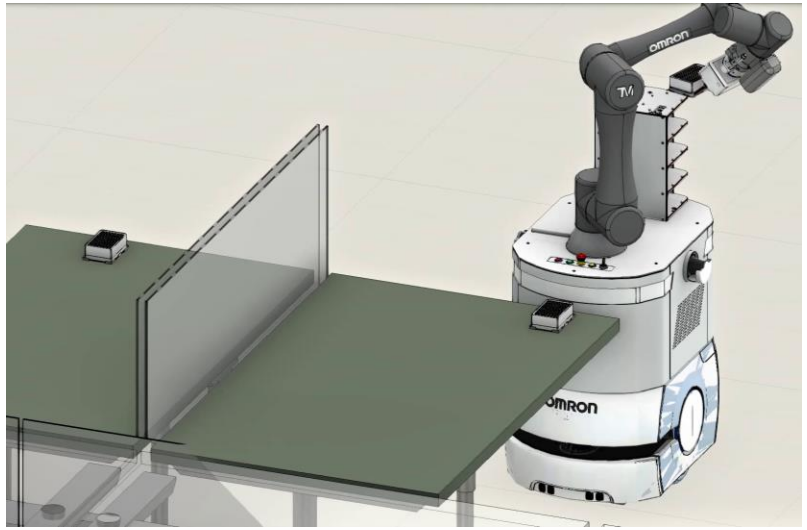
```
PrepareForPlace (self.site_1, DEEP96)
    Undock (station_1)
    DriveThroughSequence (station_2)
    Dock (station_2)
```

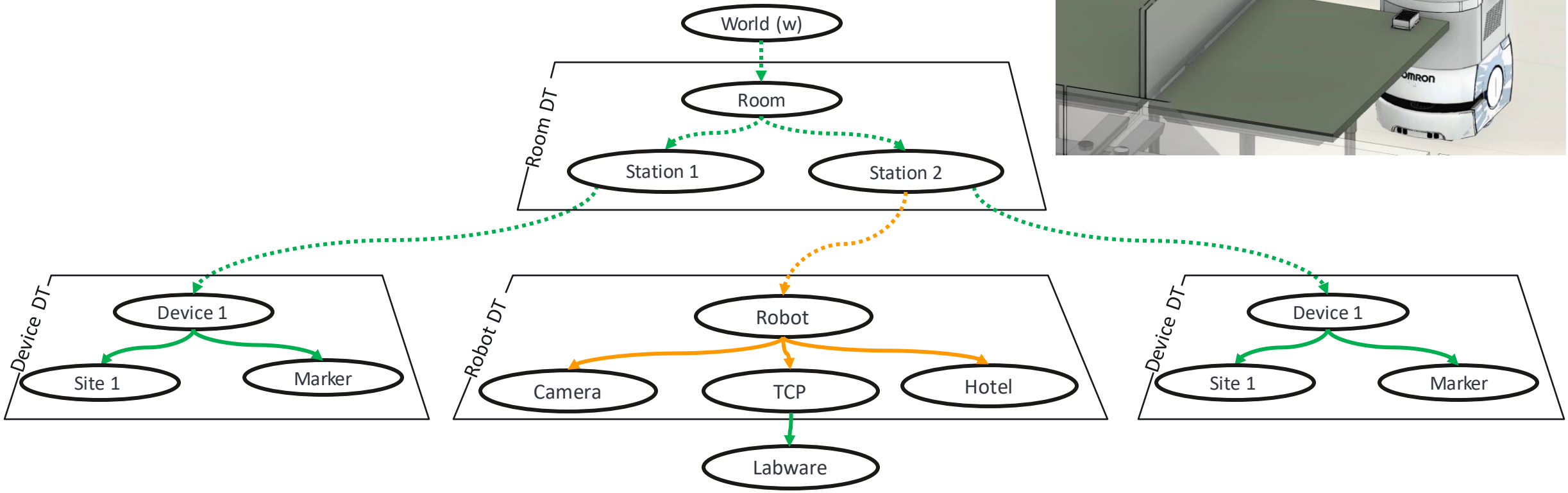




Pick from on-board hotel → Labware in gripper

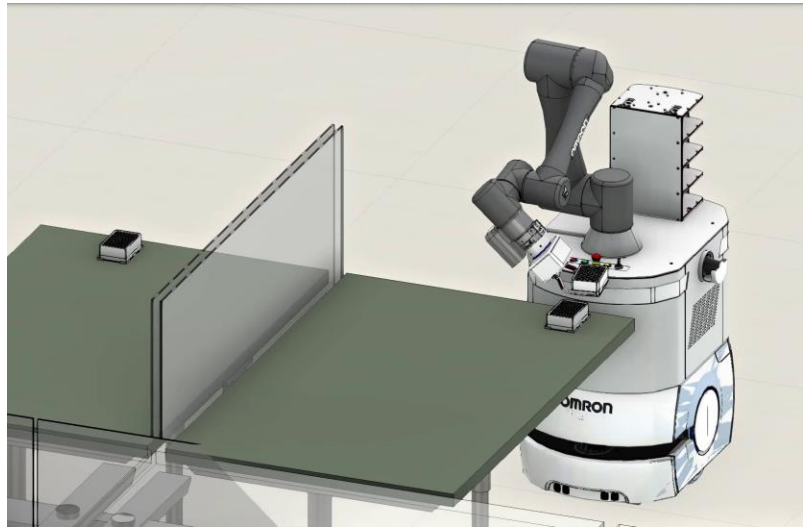
```
Pick (self.hotel.site_1, DEEP96)
```

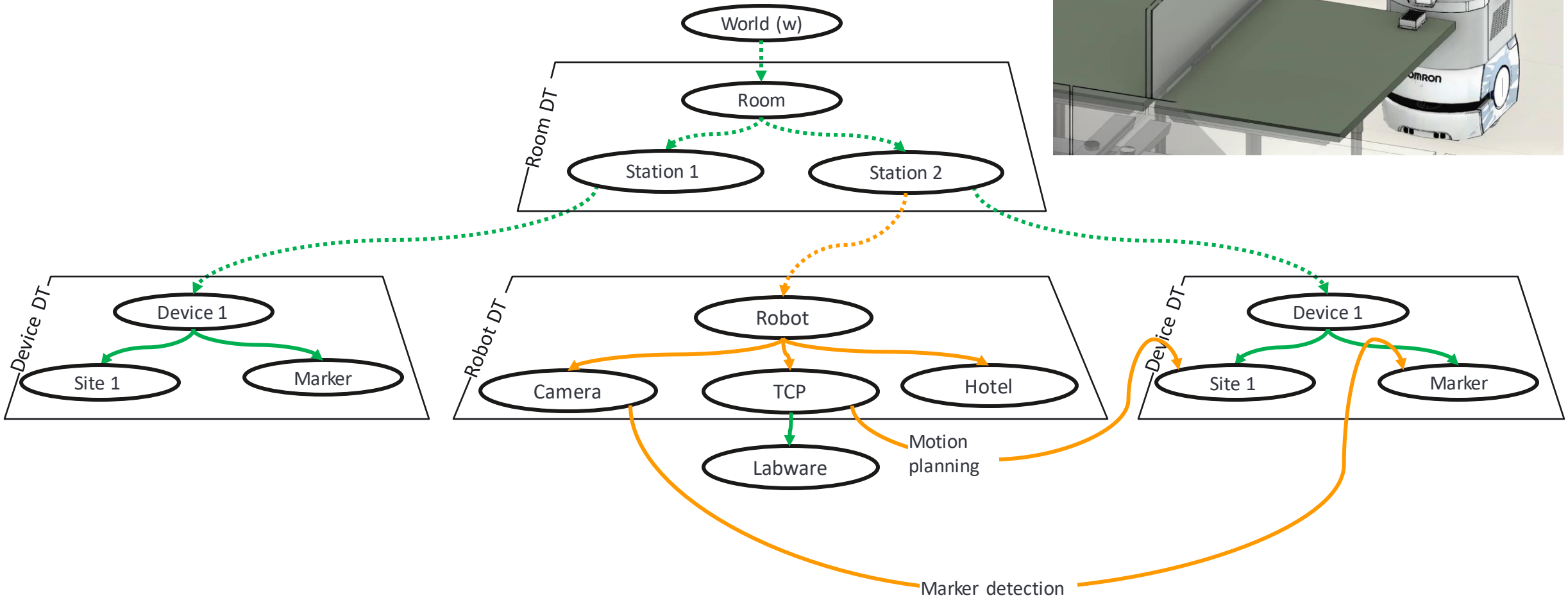




Place to station_2.device_1.site_1

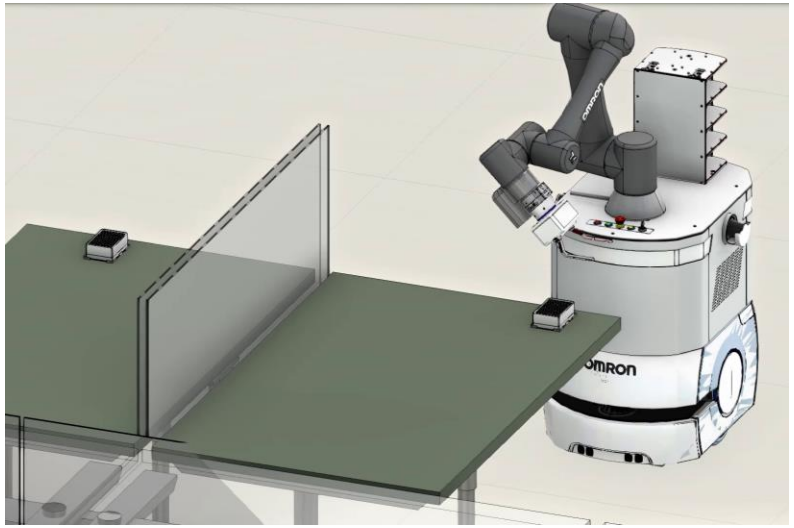
```
Place (station_2.device_1.site_1, DEEP96)
```

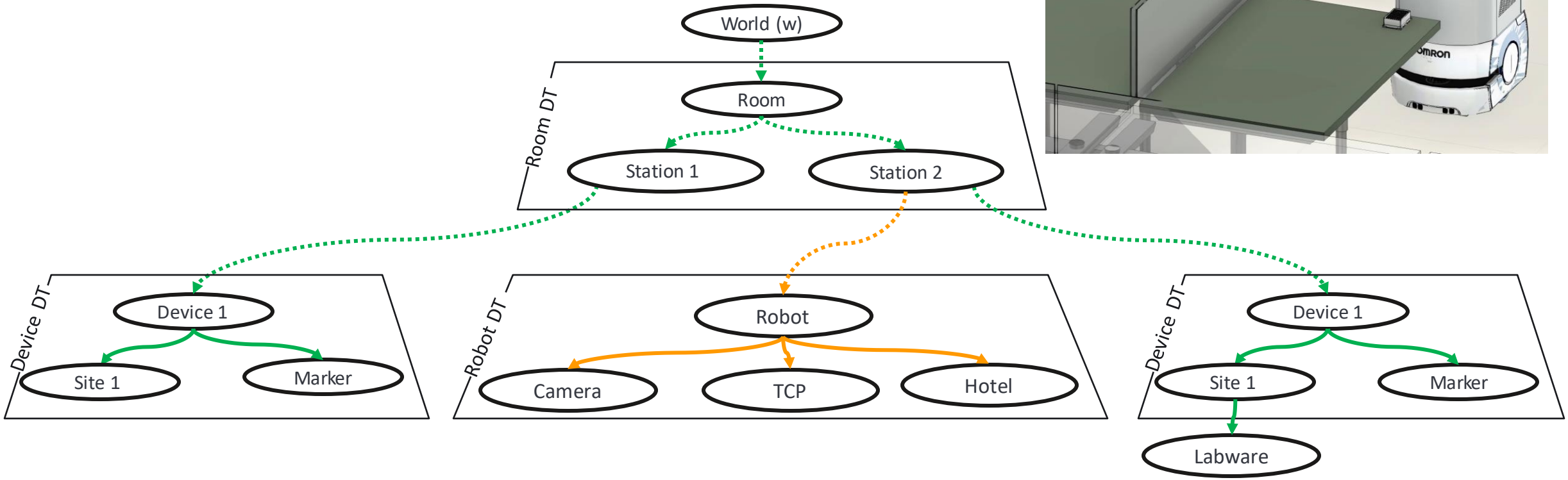




Placed to station_2.device_1.site_1

```
Release ()
MoveThroughSequence(manipulation-ready)
```





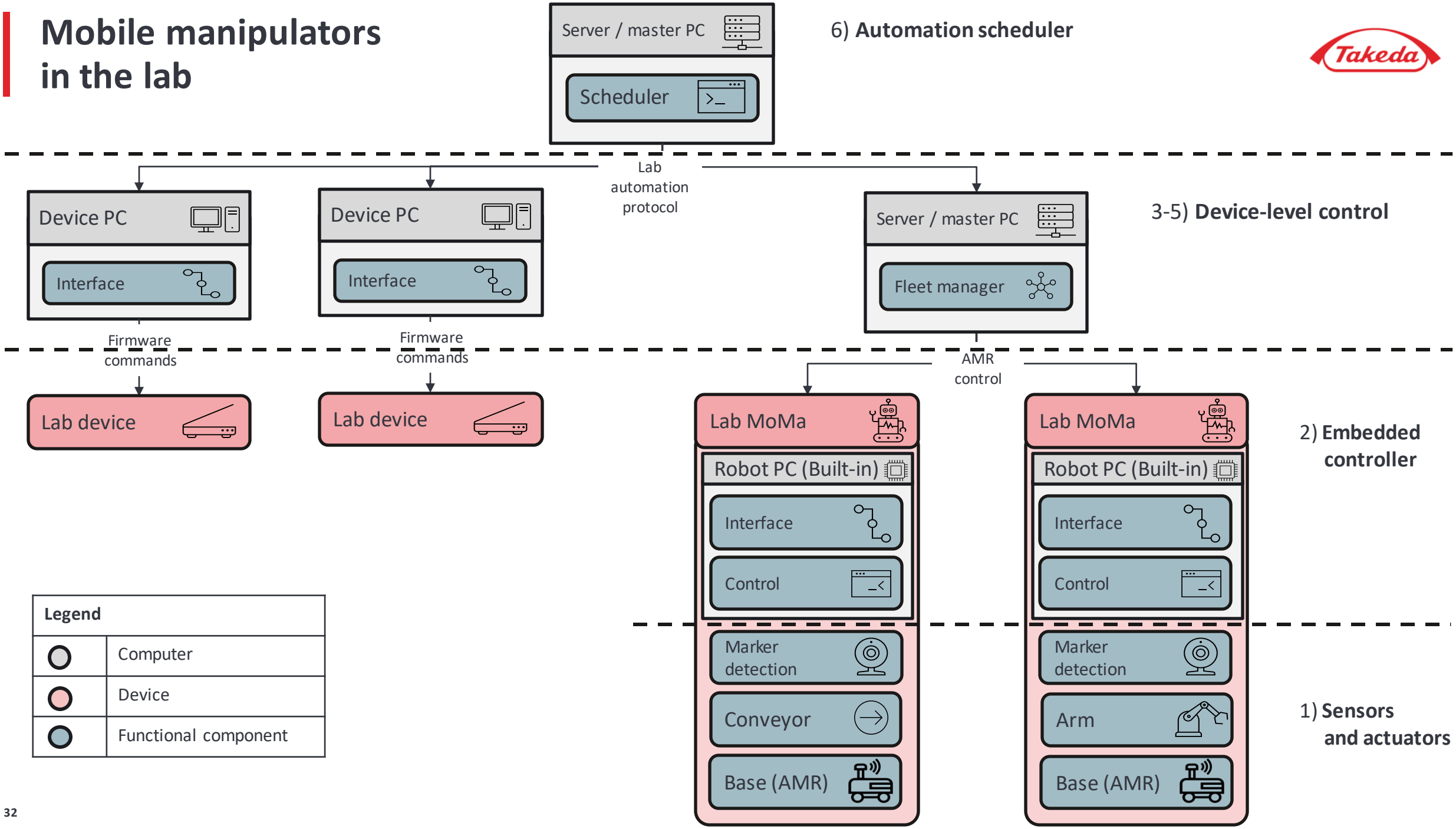
Control pyramid

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	

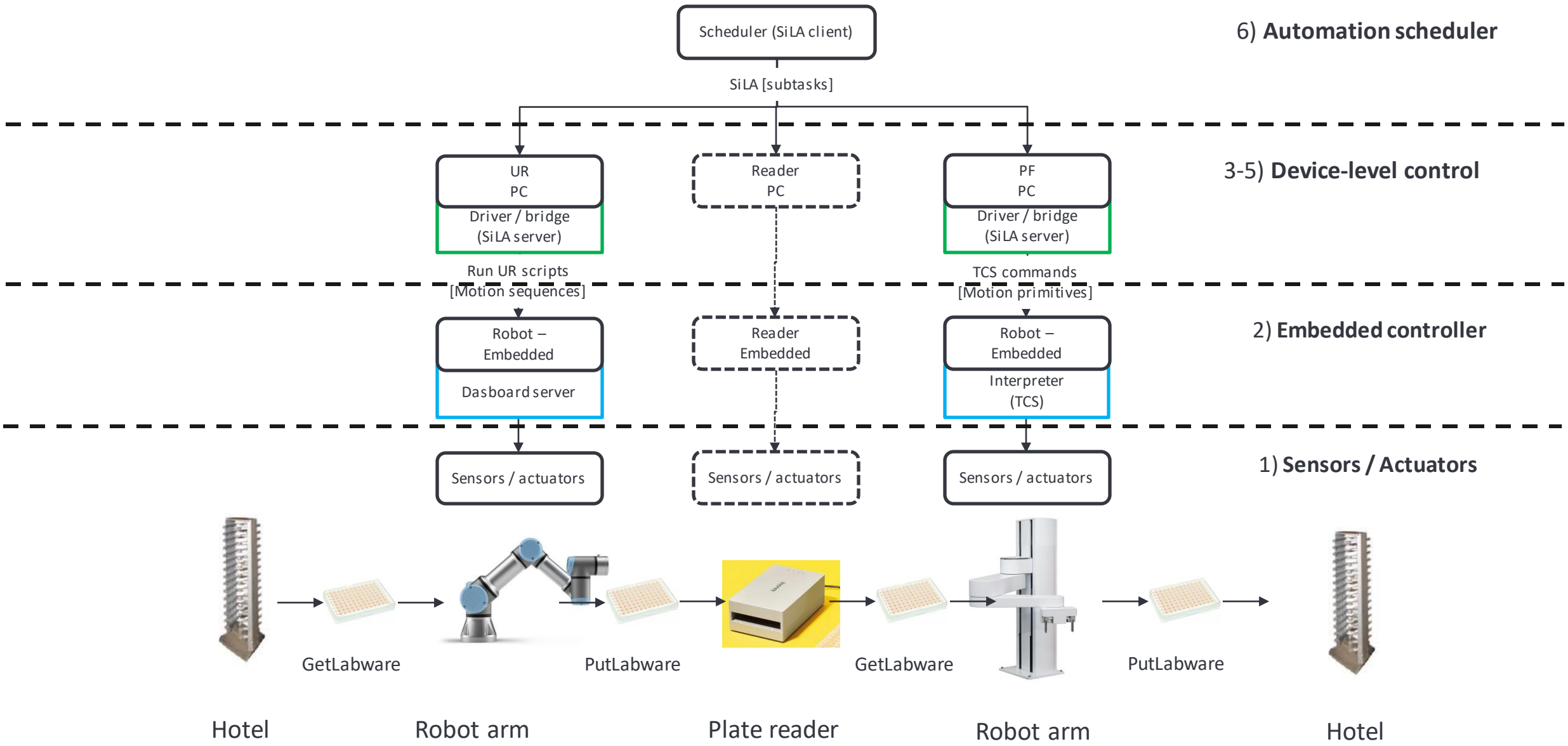
Mobile manipulators in the lab



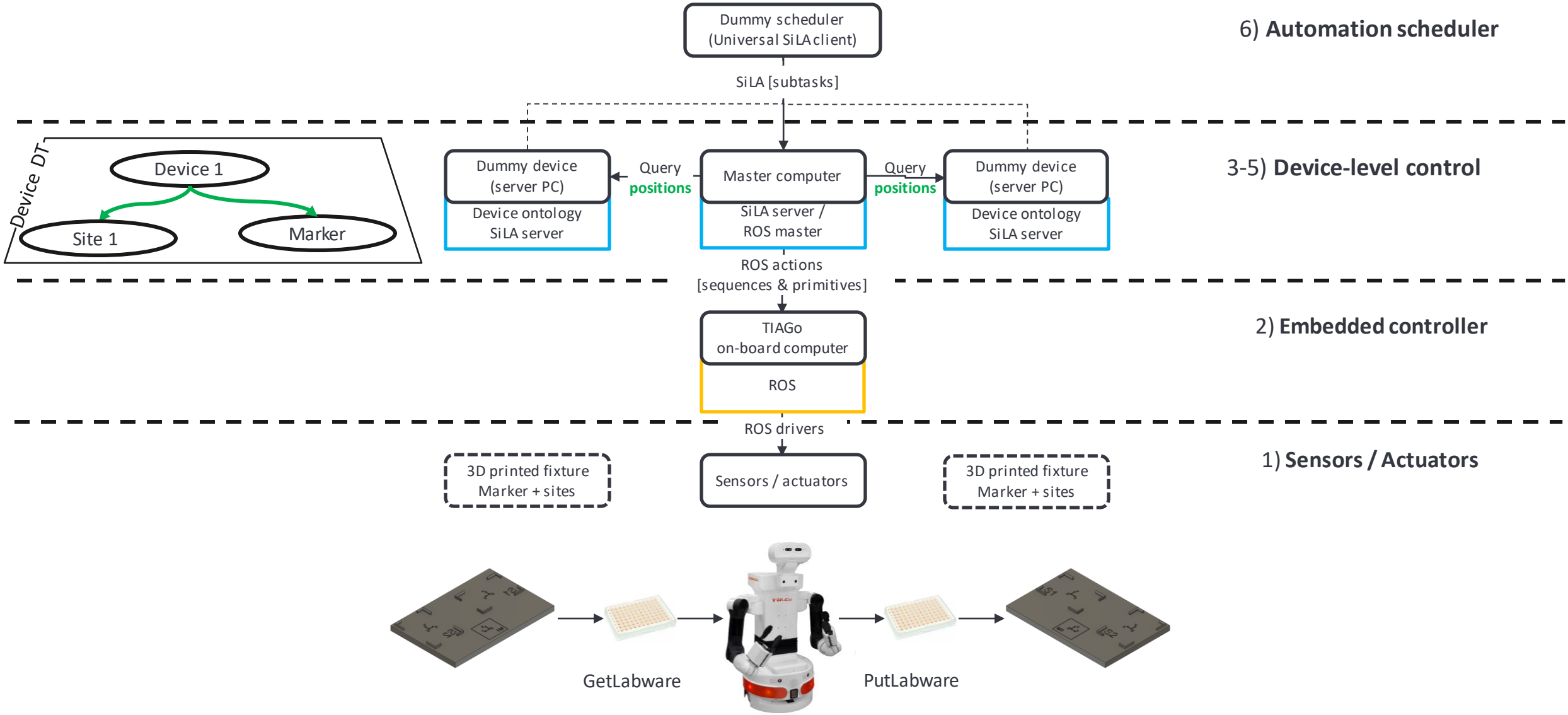
Proof-of-concept studies

Consortia & academia

Reference implementations – SiLA Hackathon

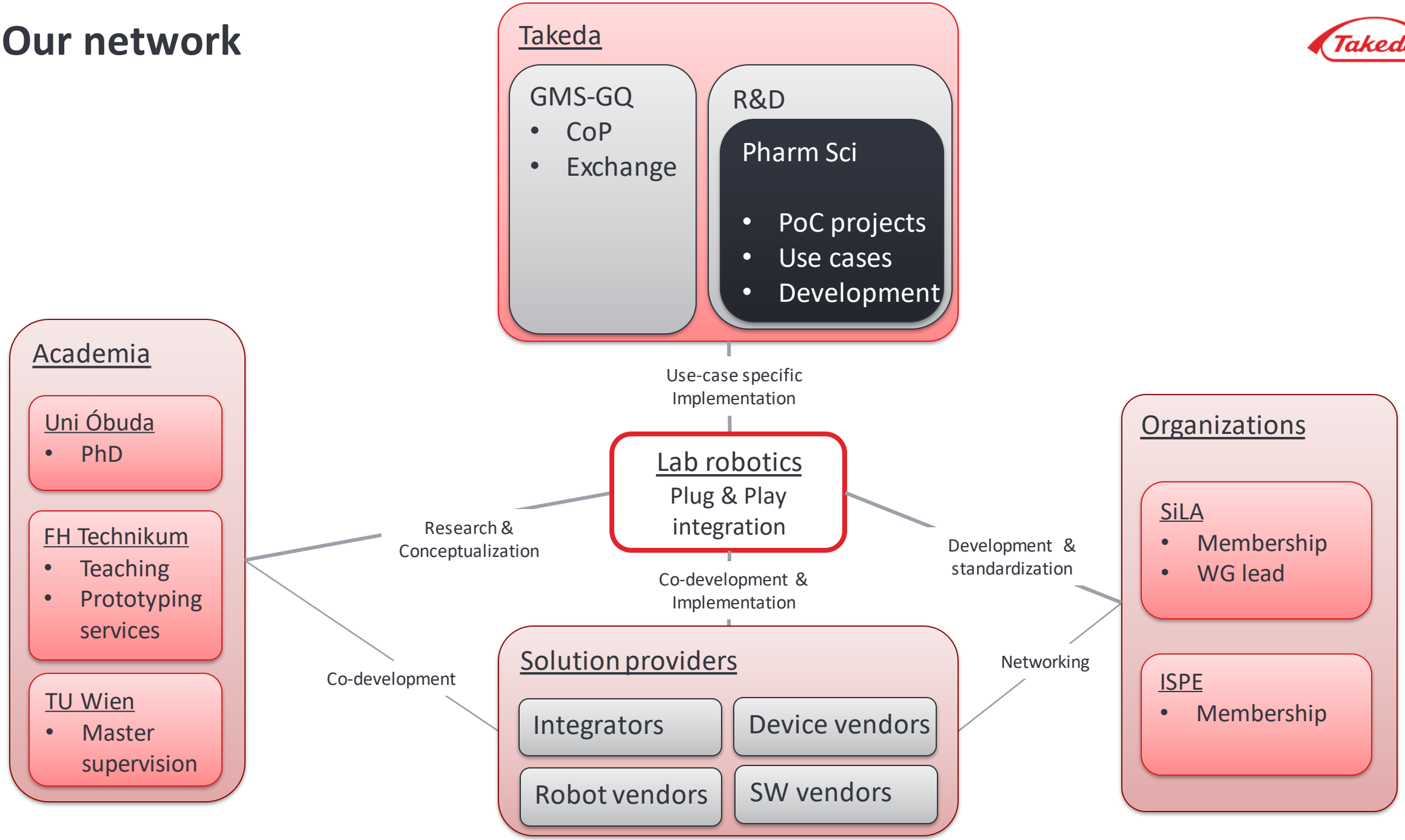


Reference implementations – TIAGo, Uni Óbuda, Panna Zsoldos

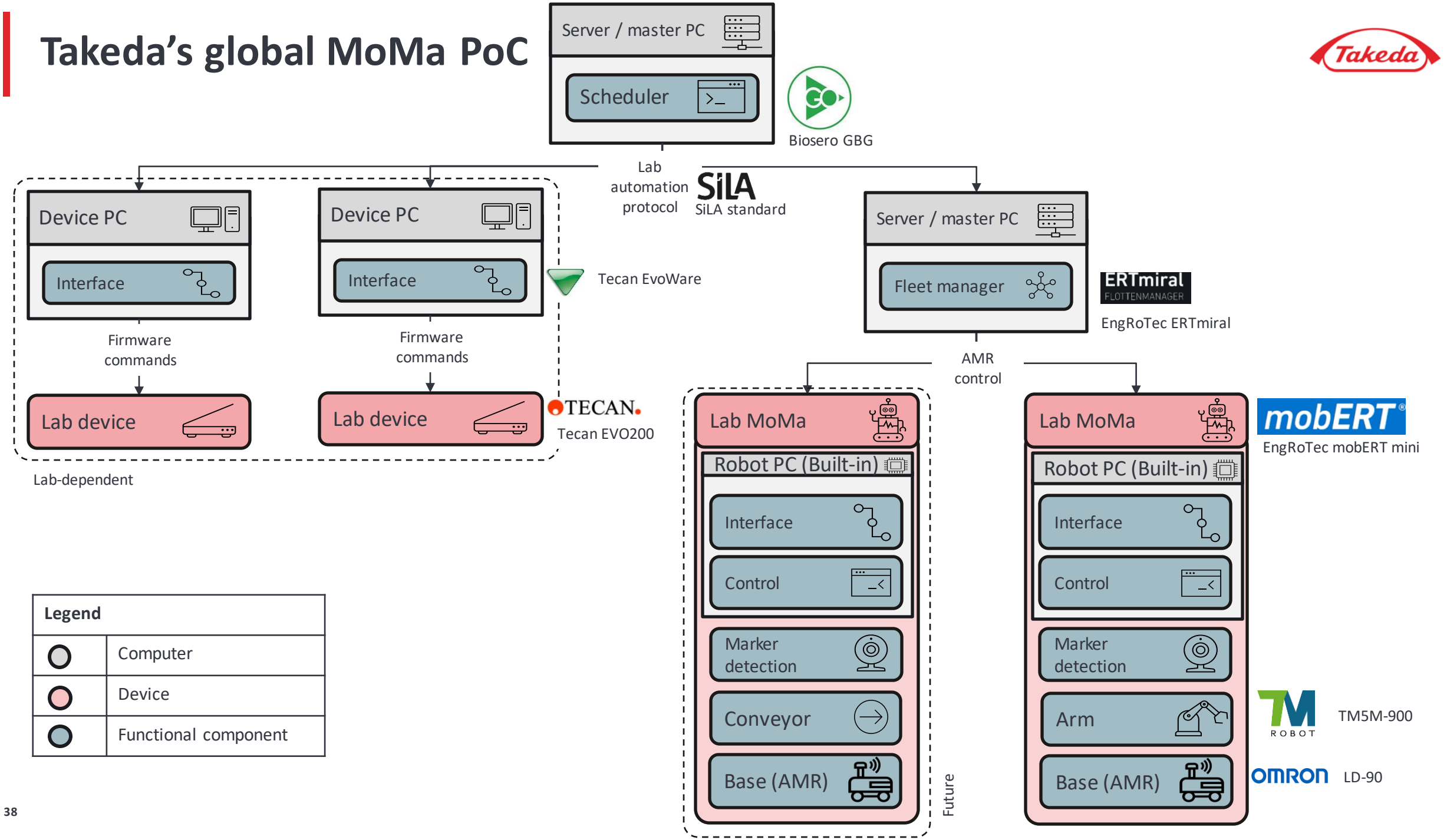


How we approach this at Takeda

Our network

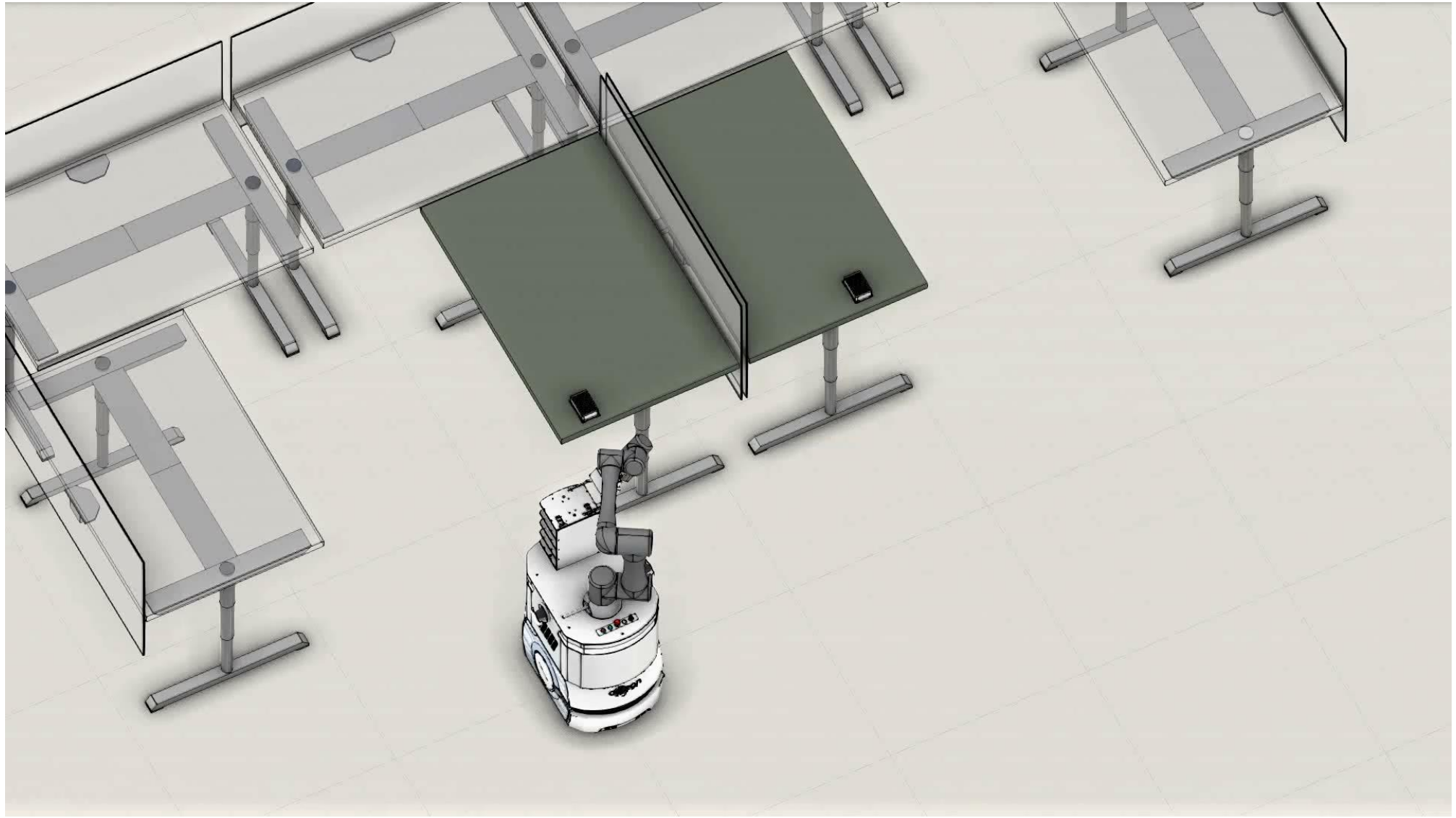

Takeda
GMS-GQ
• CoP
• Exchange
R&D
Pharm Sci
• PoC projects
• Use cases
• Development
Use-case specific Implementation
Academia
Uni Óbuda
• PhD
FH Technikum
• Teaching
• Prototyping services
TU Wien
• Master supervision
Research & Conceptualization
Lab robotics
Plug & Play integration
Co-development & Implementation
Development & standardization
Co-development
Solution providers
Integrators
Device vendors
Robot vendors
SW vendors
Networking
Organizations
SiLA
• Membership
• WG lead
ISPE
• Membership

Takeda's global MoMa PoC



Legend	
	Computer
	Device
	Functional component

Takeda’s global MoMa PoC – Simulation



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PAL Robotics

Public LAPP project website

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

Thank you for your attention.

Better Health, Brighter Future

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