2022 ISPE
PHARMA 4.0™
AND ANNEX 1 CONFERENCE

ISPE®

7-8 December | Vienna, Austria and Virtual

Standardized Integration for Lab Robots

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Takeda

State of the art lab robotics and their limitations

The lab robotics landscape - Present

Color code
- Established product
- Fresh on the market
- Emerging/under development

Liquid handling

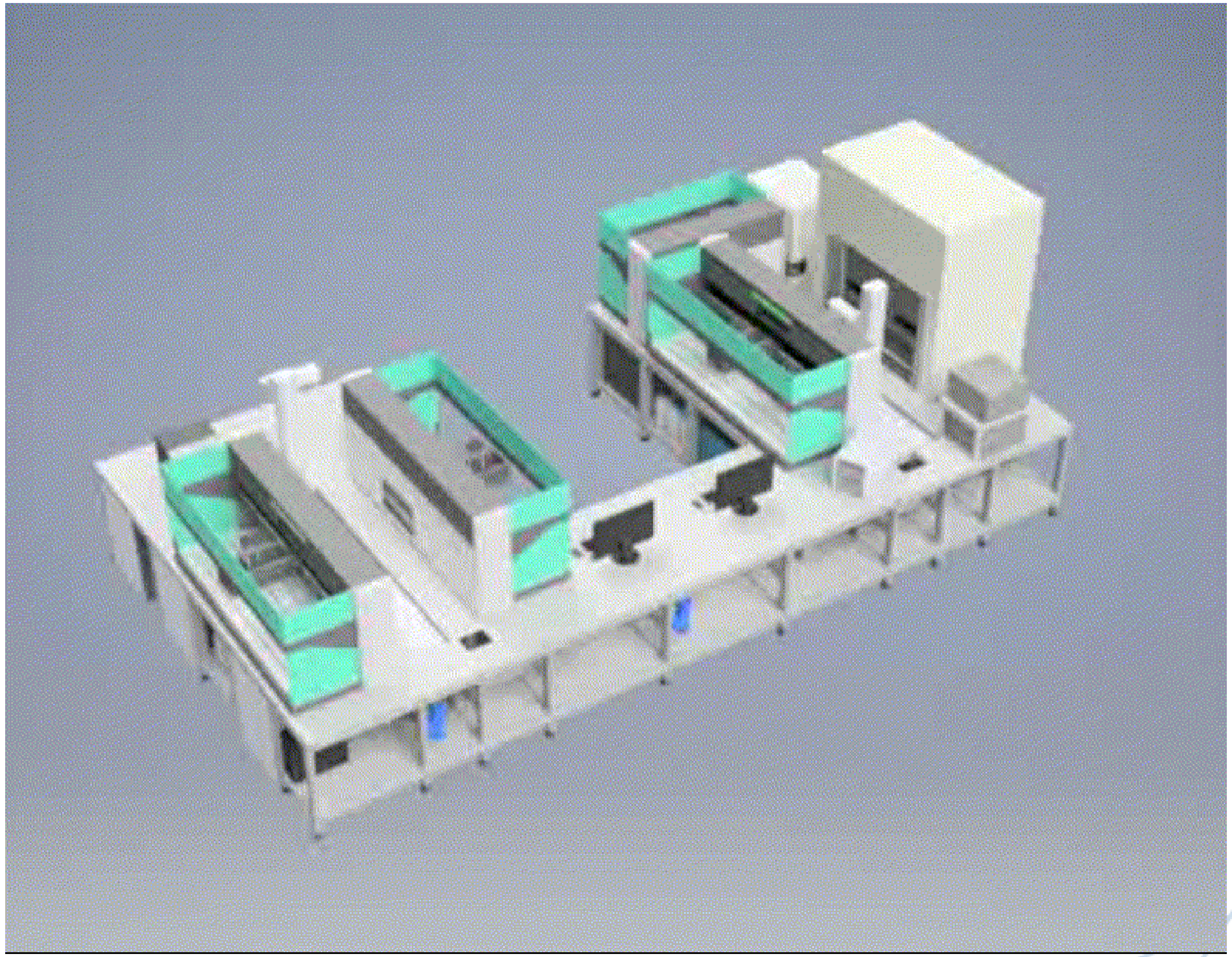
- Use Case
  - Parallel pipetting
  - Flexible pipetting
- Technologies
  - Gantry-type liquid handler robots
    - Tecan
    - Beckman Coulter
    - Hamilton
    - Opentron
  - Robots handling hand-held pipettes
    - Andrew+
    - Research

Sample transportation

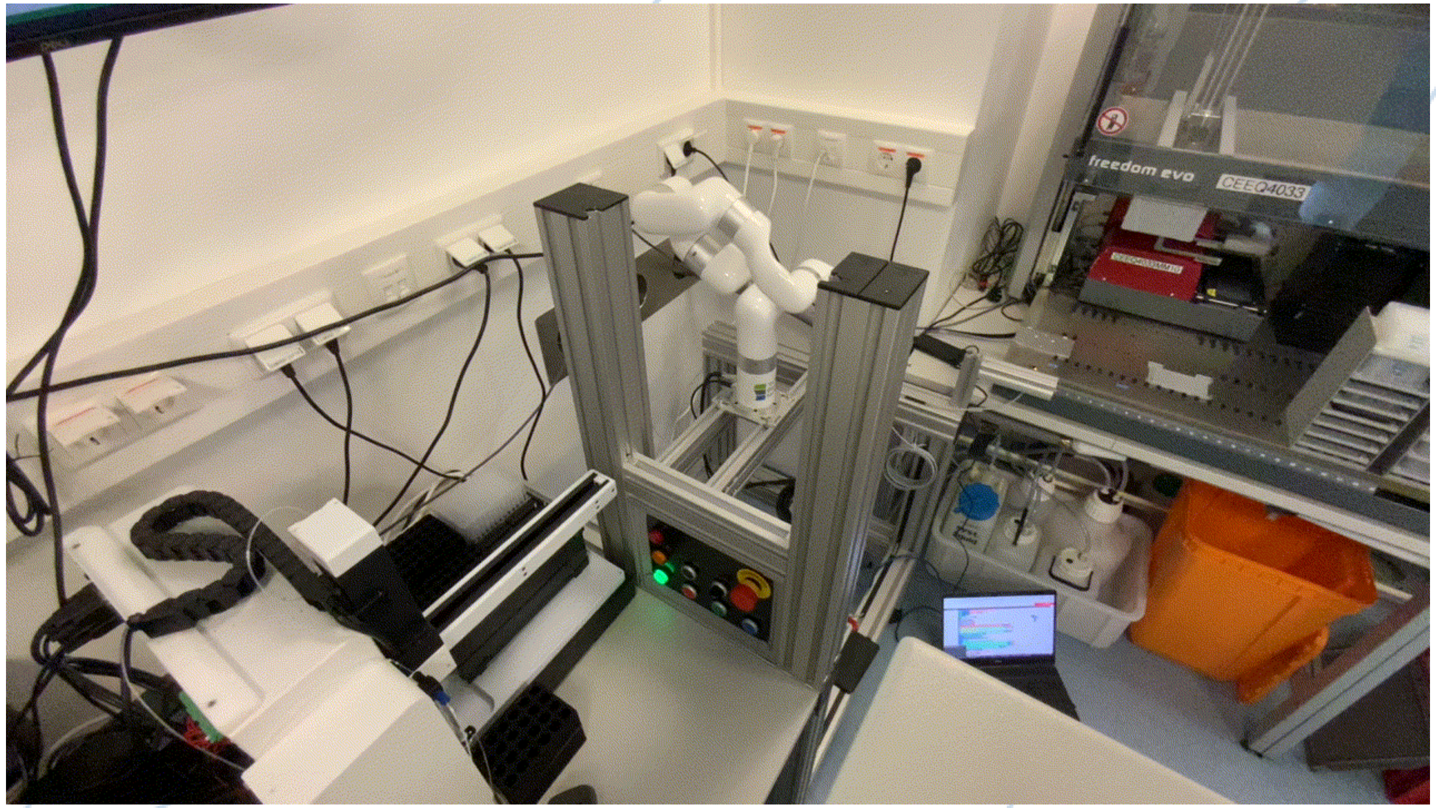
- Use Case
  - Pick and place
  - Standard objects
  - Physical device interactions
- Technologies
  - Benchtop robots
    - PreciseFlex
    - xArm
    - Denso Cobotta
    - UR
  - Mobile manipulators (floor)
    - Kevin
    - Biosero
    - Astech Projects
    - United Robotics Group
    - Gearu
    - Omron, Stäubli, Kuka
  - Mobile manipulators (bench/track)
    - Formulatrix ROVER
  - Drones (Research)

Our projects:
Sample transportation with bench-top robots

Automated microscale purification platform



At-line analytics



Sample transportation robots

Stationary robot arms

uFactory

PreciseFlex ®

Mobile manipulators

KEVIN, Fraunhofer IPA

OMRON – Biosero

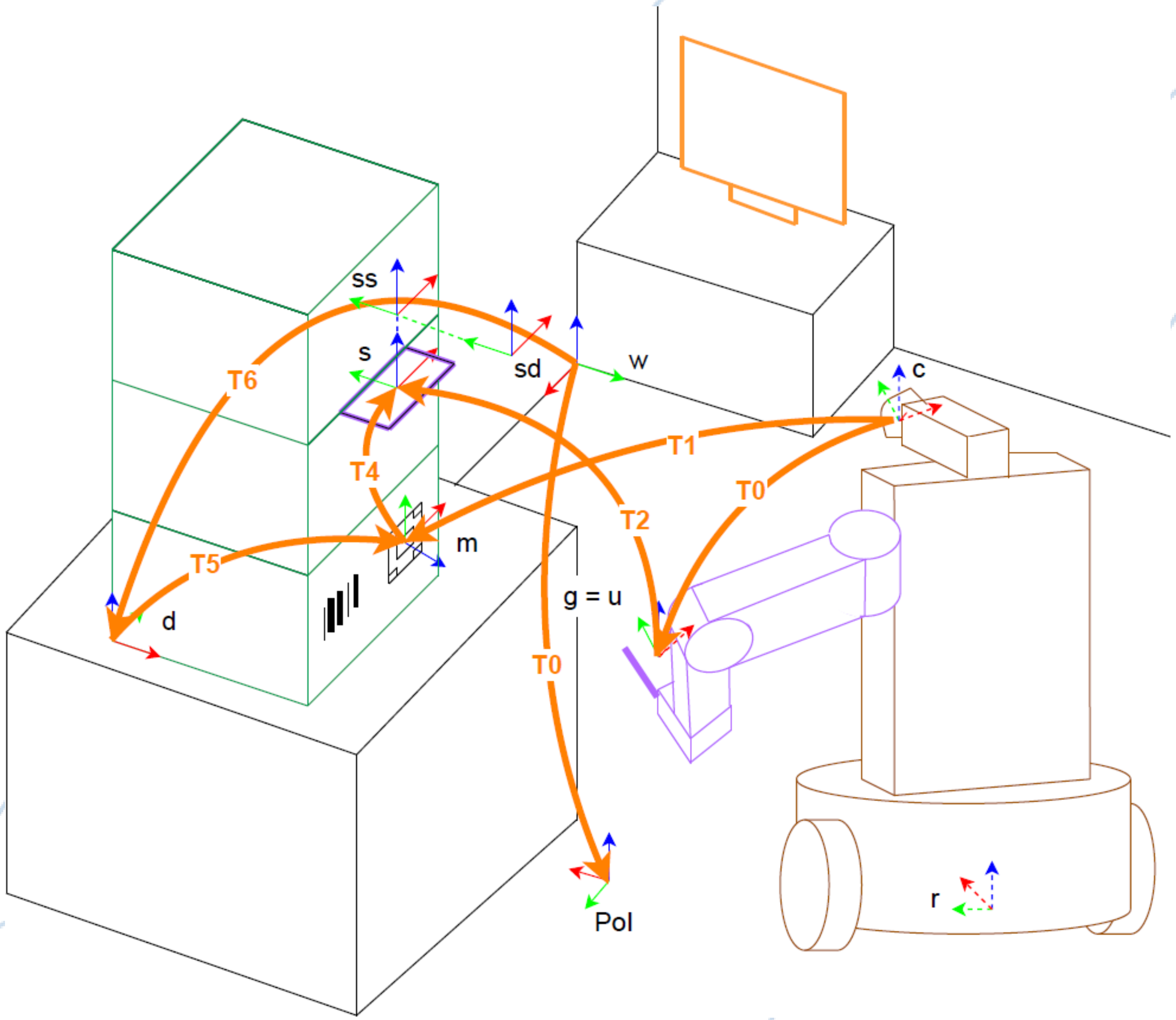
KUKA – University of Liverpool

UniteLabs – Astech Projects

Coordinate frames and robot positions

Teaching of vision-based robots [15]

- Manually drive the robot to station, make sure marker visible
- Base's location on the map is stored as the PoI of the station
- Camera-to-marker transformation is stored (T1)
- Manually move the arm to the site position (s)
- The marker-to-nest transformation is stored (T4)



The Laboratory Automation Plug & Play (LAPP) framework

Motivation

The three pillars of plug & play lab robotics

Communication

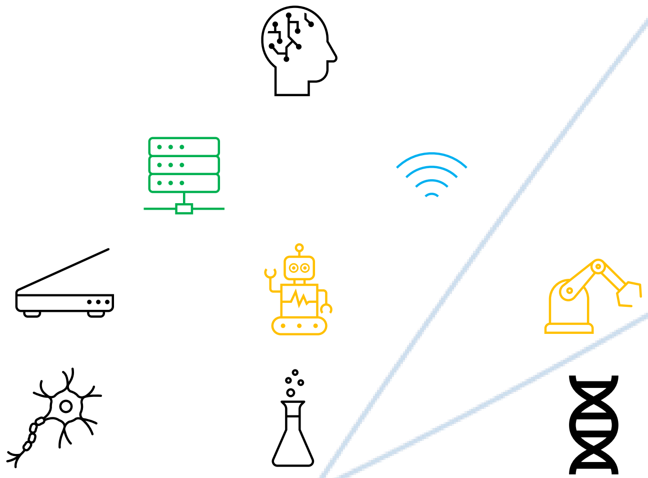
- Standardized interoperability for lab devices
- Peer-to-peer communication between:
  - LIMS/Scheduler
  - Lab equipment: Liquid handlers, analytics
- **Standardization in Laboratory Automation (SiLA)**

Digital Twin

- Information layer for the various components of the system
- Enables plug & play setup
- Laboratory Automation Plug & Play (LAPP)

Robot level

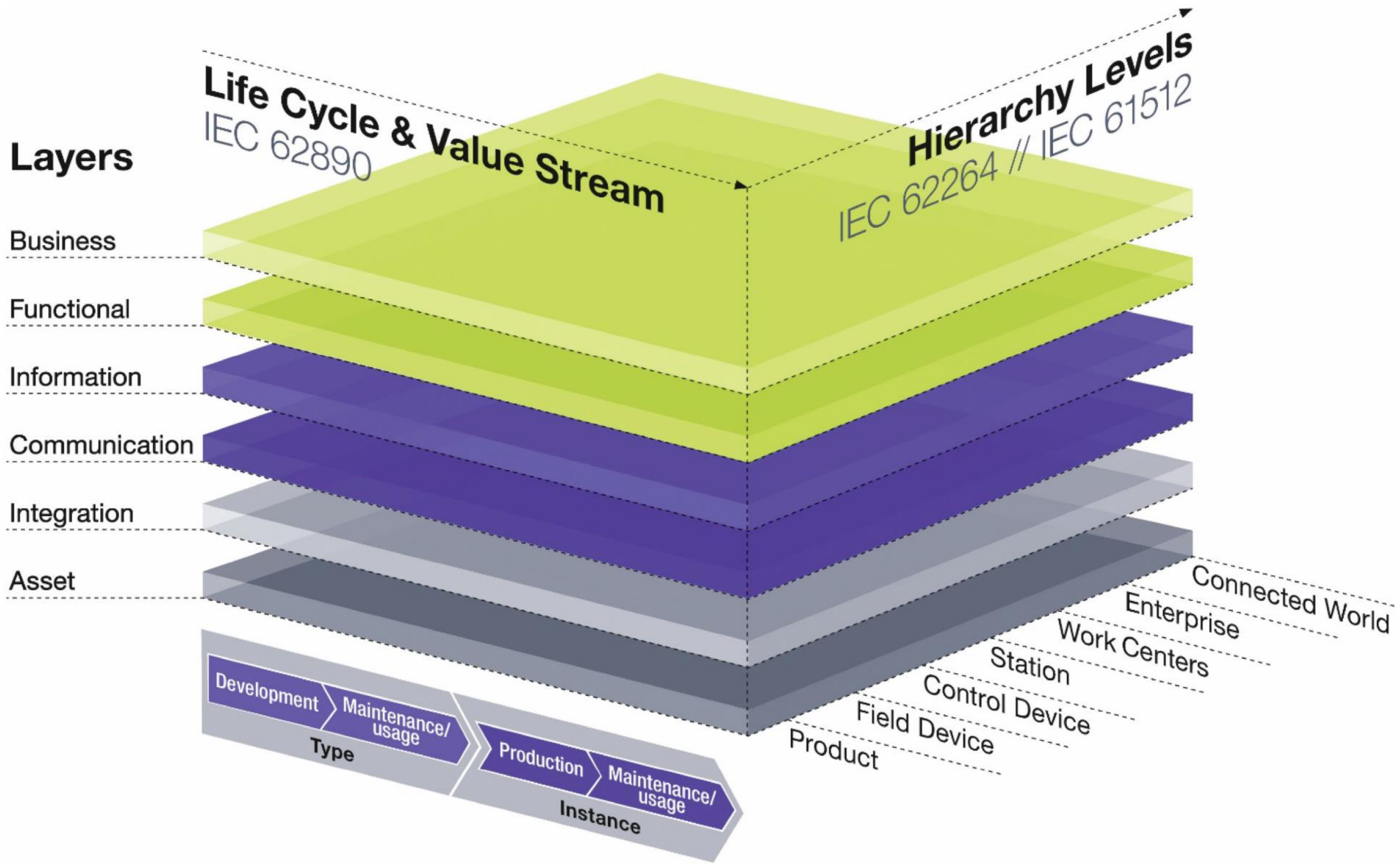
- Advanced robot implementations
- Robot Operating System (ROS)



SiLA Robotics Working Group

- **Unify feature definitions**
  - Today's topic
- SiLA-ROS interface
  - Hackathons
- Reference implementations
  - TIAGo → Panna
  - MIR + UR
- Incorporate new concepts
  - Digital twin
  - Robotic action templates
  - Labware library
  - Advanced robotic technologies: Perception, manipulation Human-machine collaboration

Reference Architecture Model Industry 4.0 (RAMI4.0) [30]



Hierarchical levels of laboratory processes

Process		Lab examples			
Level nr	Level name	Examples, liquid handler	Examples, robot arm	Examples, mobile robot	Examples, conveyor
7	Service	microscale services			
6	Procedure (Experiment / assay)	microscale chromatography workflow			
5	Task	liquid transfer	labware transfer		
4	Subtask	aspirate	get labware, put labware		
3	Motion sequence	approach site with pipettor arm	approach site	navigate to target	-
2	Motion primitive	motion vectors	linear move, close gripper	navigate to intermediary	move tray to desired position
1	Actuator primitive	joint control, pump control	joint control	base velocity commands	motor or magnet control

Hierarchical levels of workflow representation and control architecture

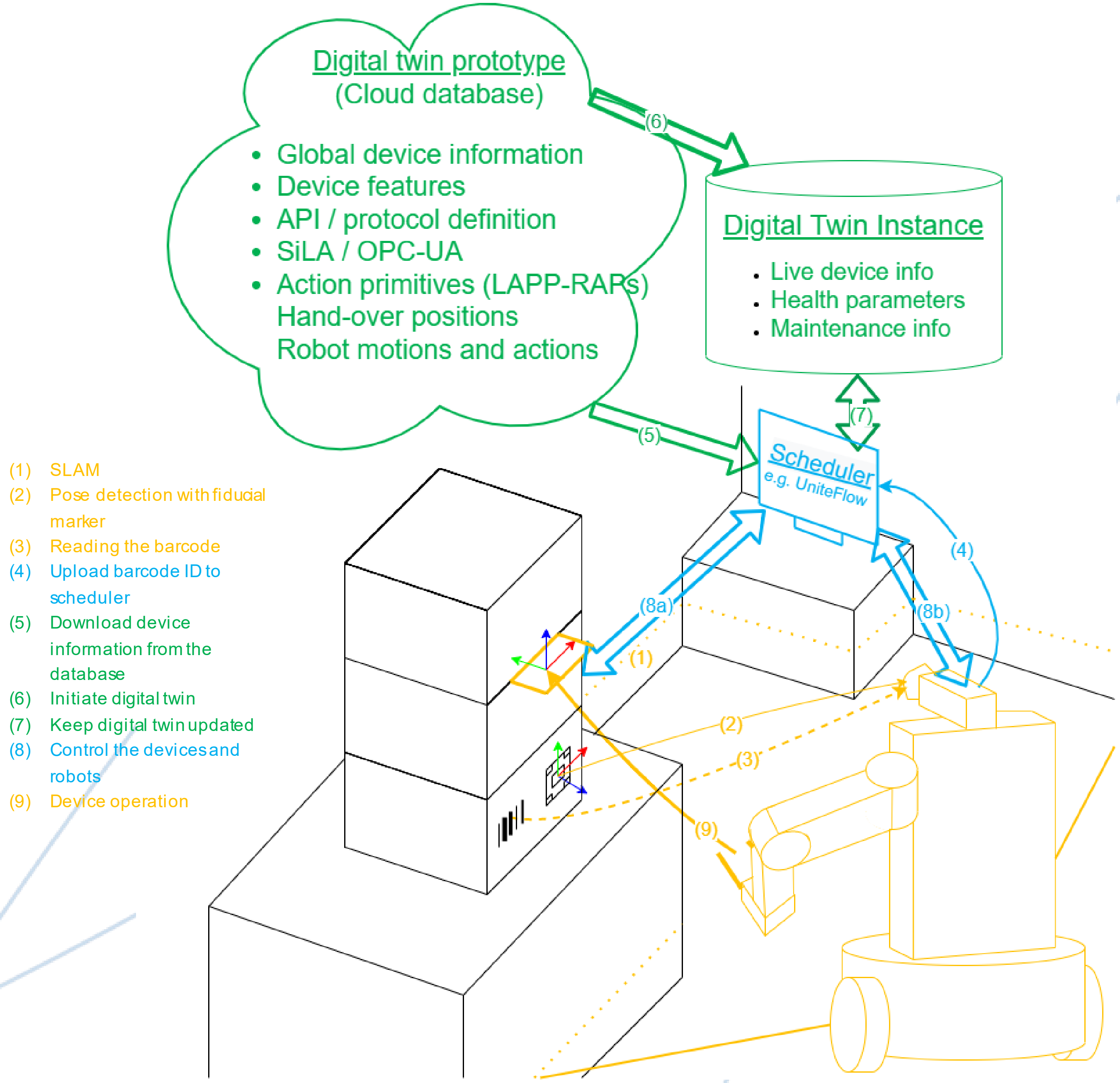
Process		Protocols and languages		Control architecture	
Level nr	Level name	Liquid handling	Robotics	Liquid handling	Robotics
7	Service	Service protocol		Lab management (LIMS, LES)	
6	Procedure (Experiment / assay)	Experiment design language Laboratory process language		Automation Scheduler (E.g. GBG, niceLabs, PharmaMV)	
5	Task	High-level liquid handling script	Modular robot program	EVO PC	Robot controller PC
4	Subtask	Low-level liquid handling script			
3	Motion sequence		Low-level robot program		
2	Motion primitive	Device firmware		Embedded controller	Robot controller
1	Actuator primitive		Joint trajectories, IO control		

The Laboratory Automation Plug & Play (LAPP) framework

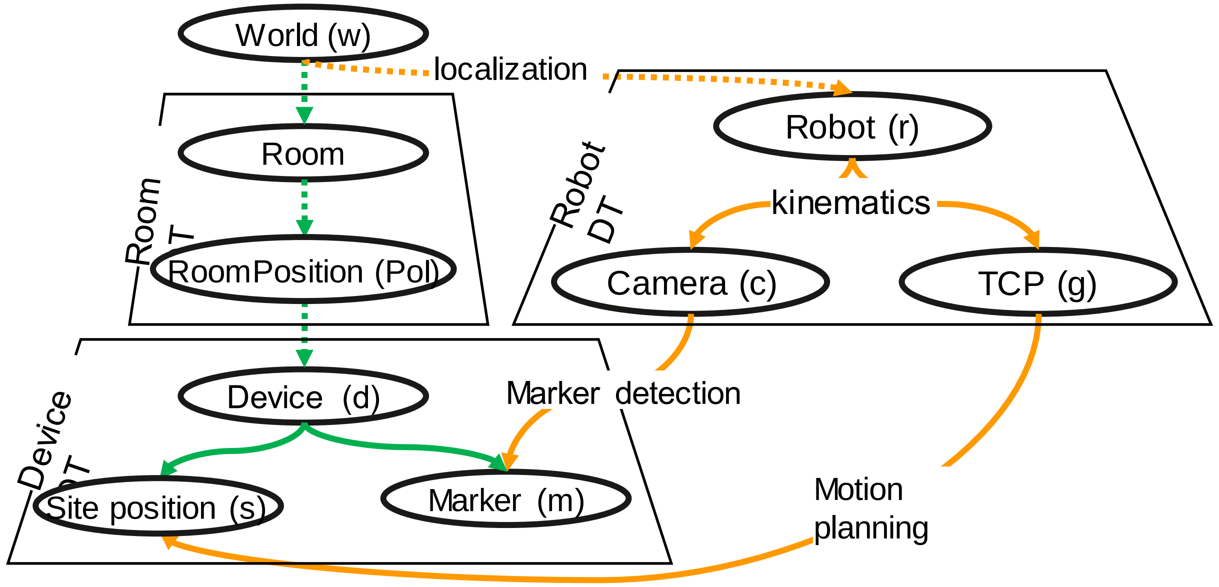
Why:
To enable a fully autonomous setup sequence for:
- Navigation
- Motion planning
- Device interactions

What:
A comprehensive all-round integration framework for manipulator robots in the lab

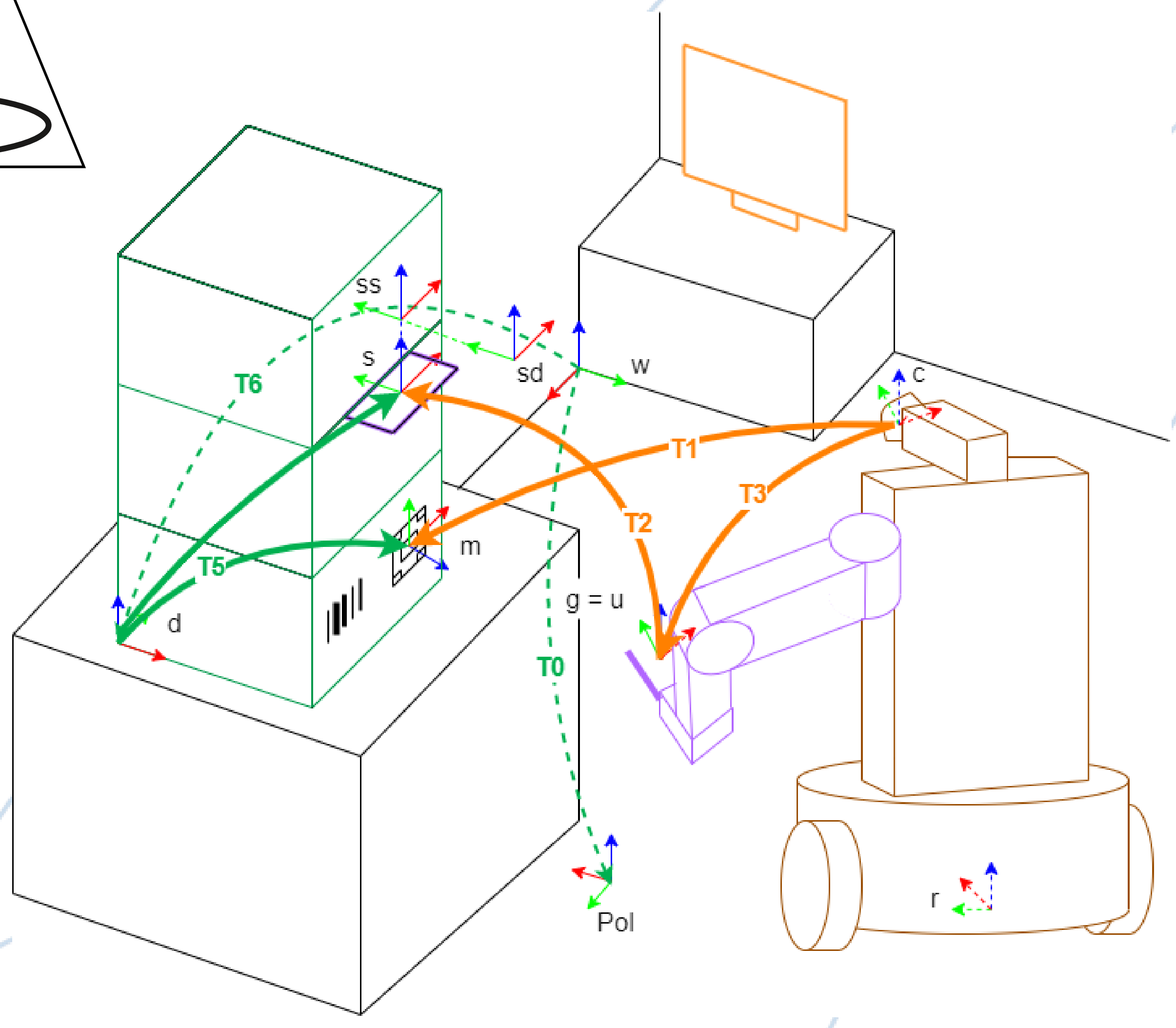
How:
- Combine existing building blocks
  - SLAM, Fiducial markers, kinematics, vision
- Add semantic and ontological layer:
  - The digital twin
- Provide a systematic approach:
  - Distinguish the components and layers of the system



Position representation for mobile robots with the LAPP DT

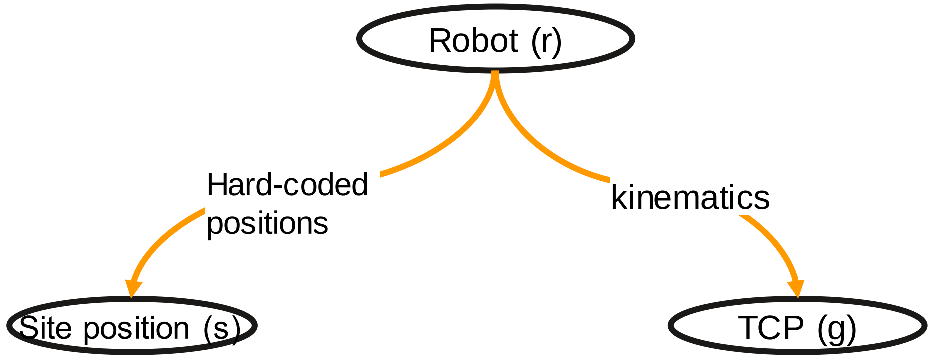


- Top-down position definitions
- Stored in parent



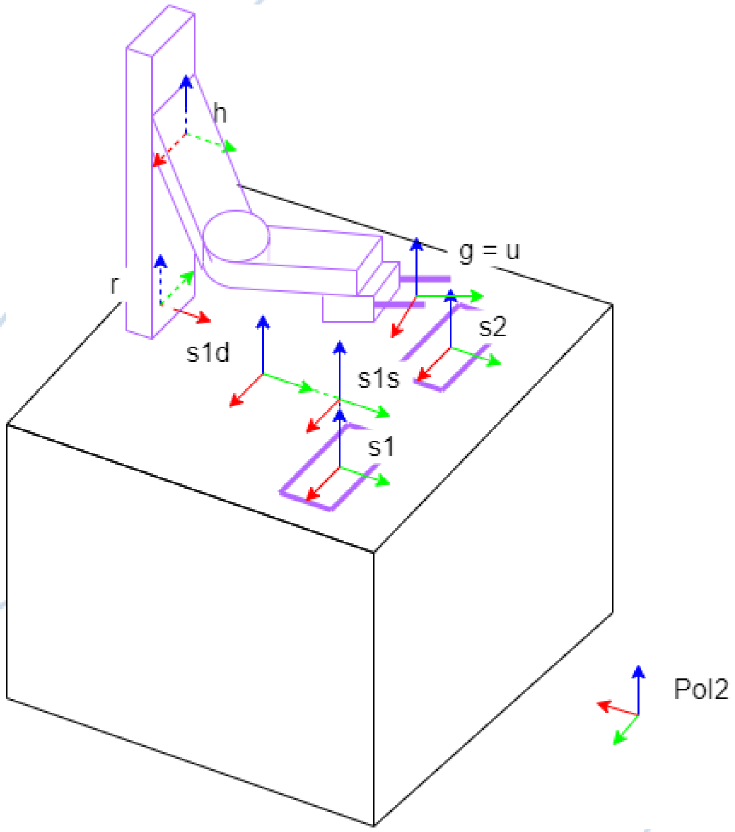
	Legend
	Live, robot-level, not exposed towards SiLA
	Stored in the LAPP DT Represented as high-level SiLA properties (references)
	Transformation originates from inaccurate base odometry
	Transformation originates from accurate sources • robot kinematics • marker detection • positions stored in the digital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

Position representation for stationary robots with the LAPP DT



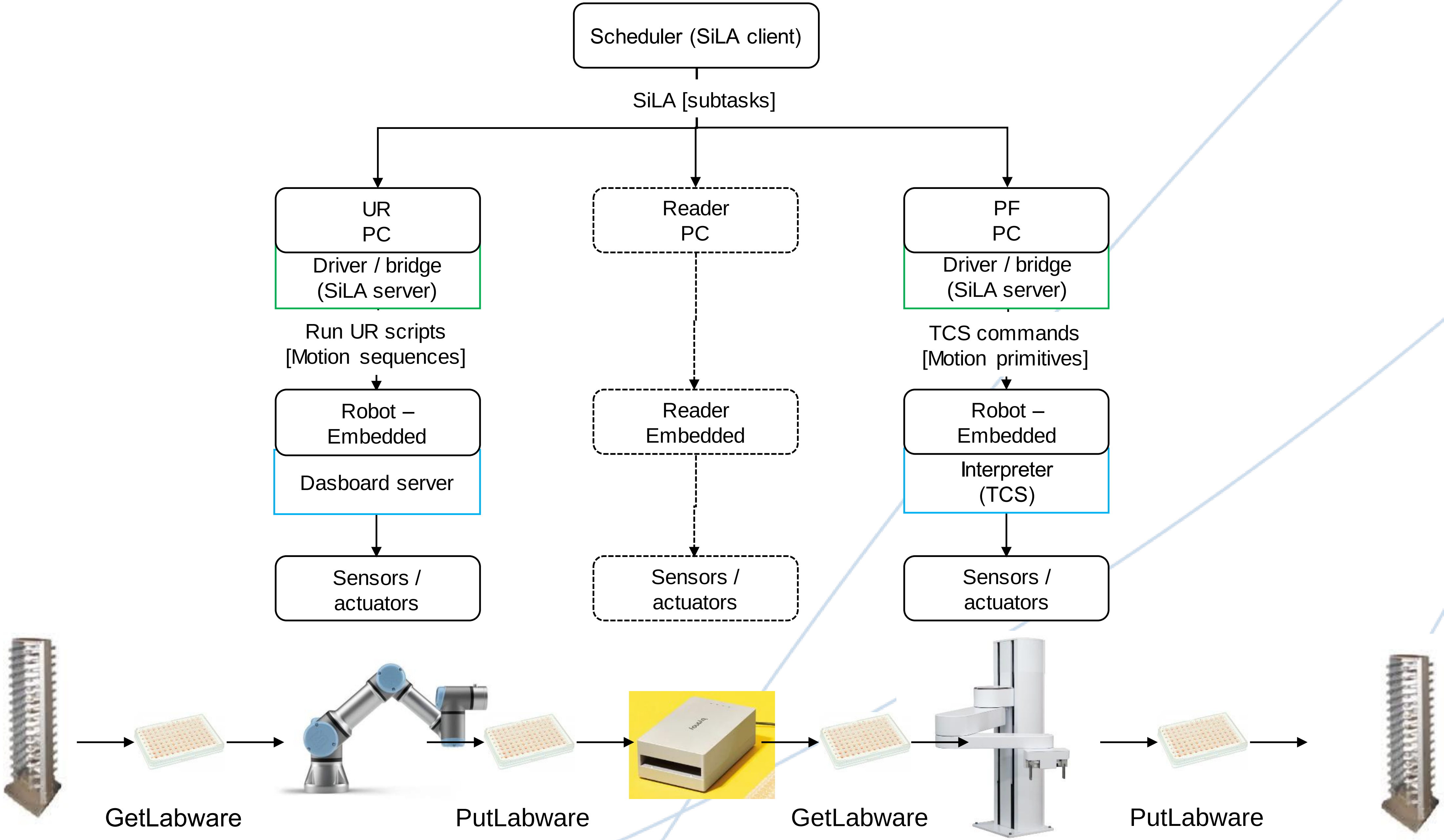
Legend	
	Live, robot-level, not exposed towards SiLA

- Positions defined in robot coordinate system
- Defined by on-line programming (manual teaching)

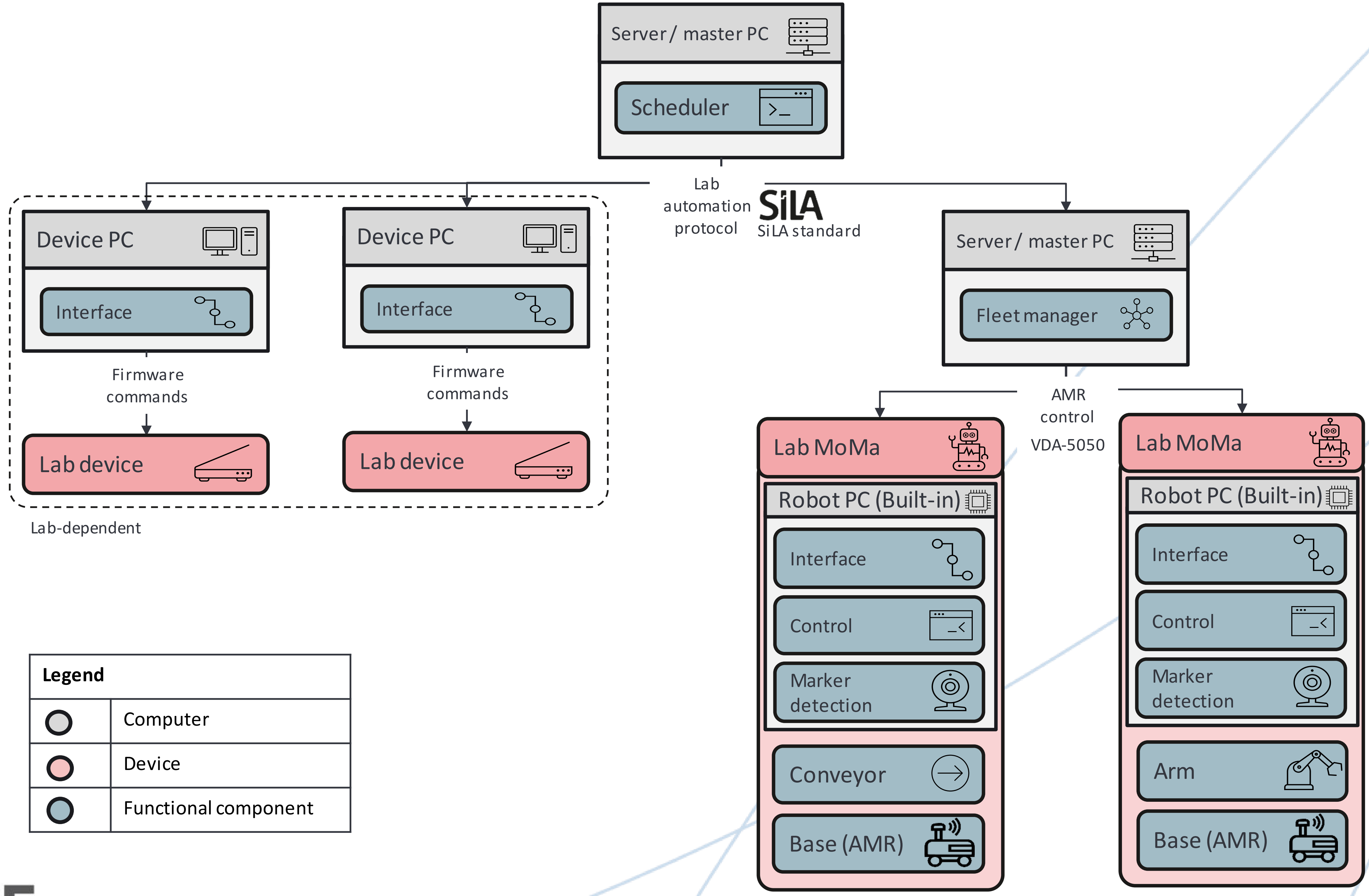


Proof-of-concept studies

Reference implementations - The last SiLA hackathon



Reference implementations – Takeda's PoC



Legend	
○	Computer
○	Device
○	Functional component

Reference implementations - TIAGo

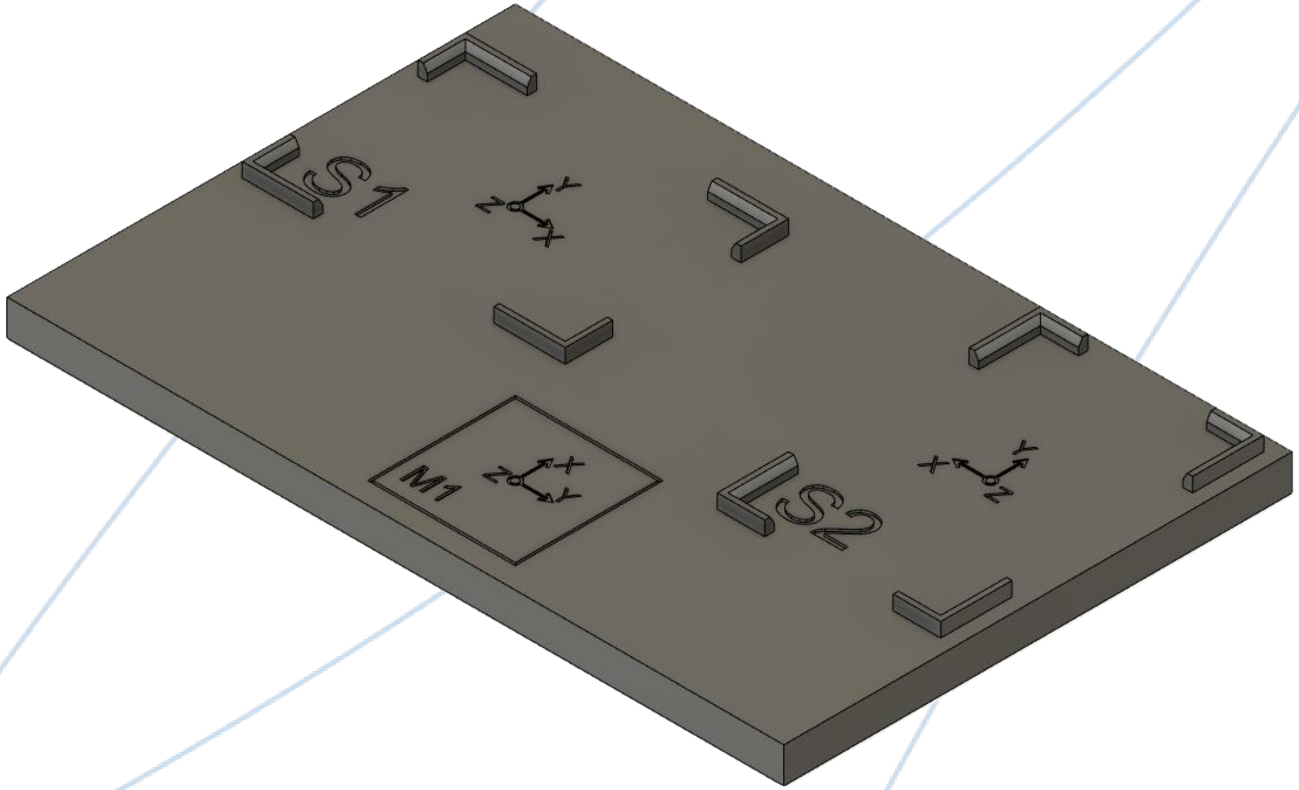
Panna Zsoldos, summer intern

- Take part in the SiLA Robotics Working Group’s effort to unify the feature definitions
- Apply the reference SiLA-ROS bridge implementation to TIAGo’s framework
- Implement the basic marker-based pick-and-place sample transportation
- Prepare TIAGo for a PoC on LAPP

Reference implementations – Plans

Collaborative proof-of-concept study for Teaching-free Robot Integration with the LAPP Digital Twin

- Implement the concept for multiple different robots (stationary and mobile)
- Design the information models and database infrastructure
- Design a replicable mockup device with fixed marker and hand-over positions
- Test and benchmark the solution
- **This is a call for participation!**



Simplified integration of qualified laboratory devices

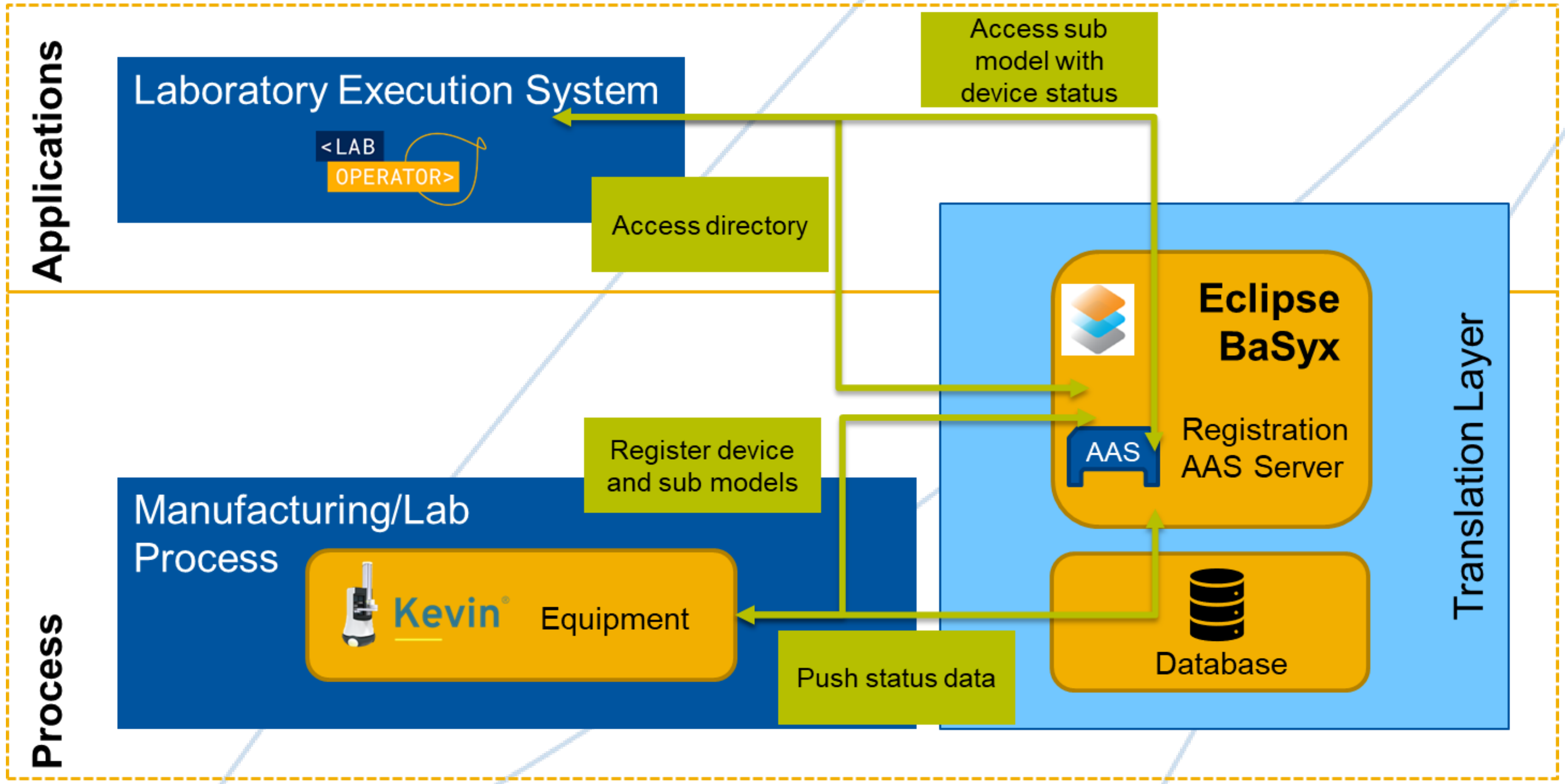
with the Asset Administration Shell as the Digital Twin

Use Case:

- Laboratory COBOT connected to LES
- In case of a failure, I can exchange the prequalified COBOT or another instrument
- Without any configuration in any system
- Continue the work immediately and
- Reduce the requalification efforts to zero

Benefits:

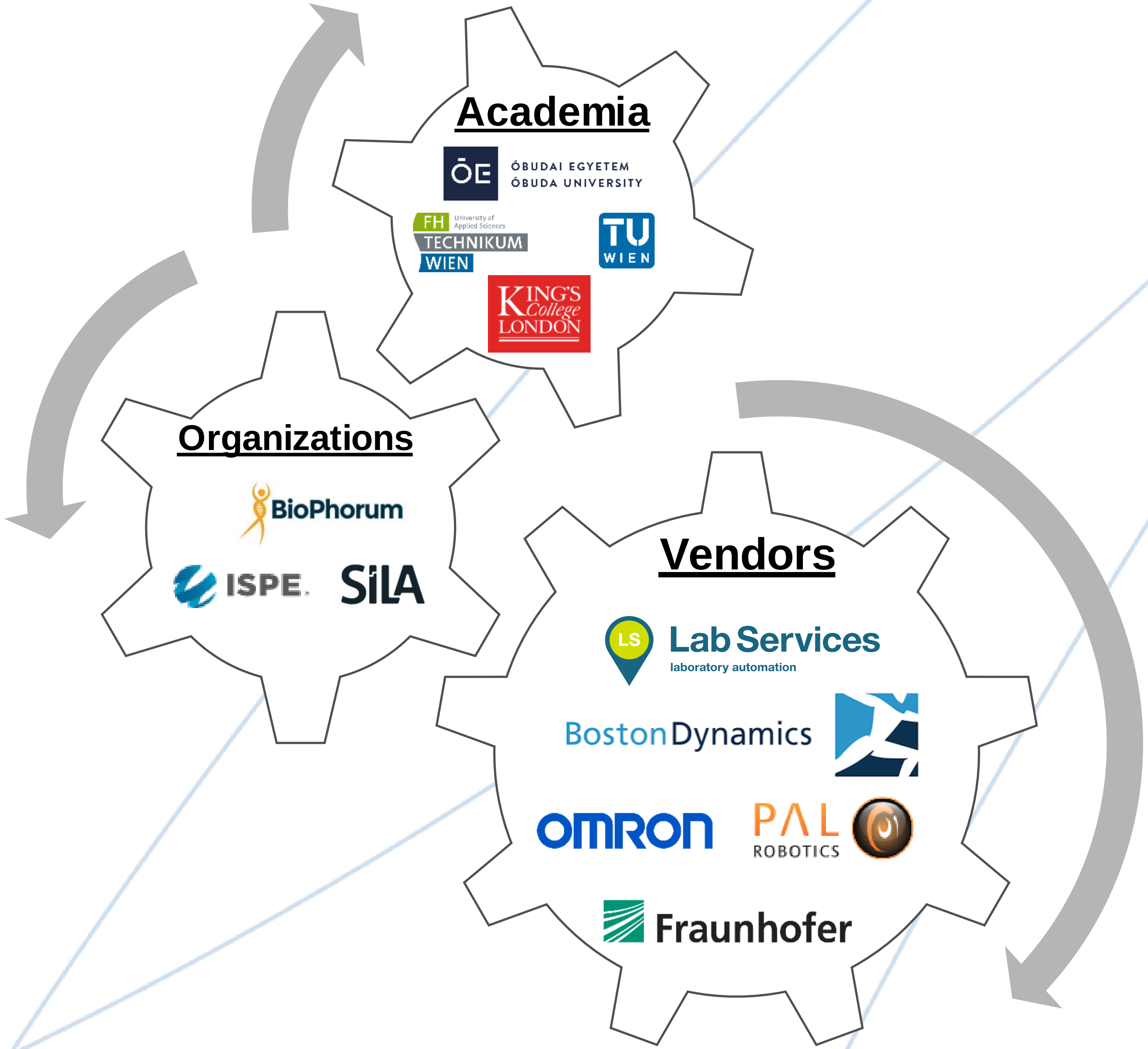
- Scalable concept to support the Industry 4.0 global multidimensional model (RAMI4.0)
- Bi-directional communication capability
- Integrated “validation 4.0” approach to support Plug & Produce concepts
- Reduce implementation & update costs
- Can be Integrated into Pharma 4.0 concepts, IDTA concepts, and international standardization activities like NAMUR.



Community & Future work

Our network

- Expand the capabilities and resources by the means of external collaborations
- Be up-to-date with the latest developments by maintaining a close connection to academia
- Maintain good relations with solution providers
- Co-develop solutions
- Actively influence the industry through cross-company organizations
- Networking with other users



The SiLA Robotics Working Group

Organization

- Domain-specific working group
- Reports back to the core WG
- Open group
- Bi-weekly meetings

Mission

- Combine existing established technologies in a comprehensive framework
- SiLA as the central element of the tech stack
- Unify, scale-up and extend functionality
- Incorporate new concepts
- Facilitate exchange in the lab robotics community

Vision

- Foster the SiLA-based plug & play integration of lab robots
- Unify the communication standard
- Provide vendor-independent solutions

Milestones

- SiLA-ROS interface
  - Hackathons
- Unify feature definitions
  - Structure to incorporate present and future lab robot capabilities
  - Identify candidates as standard definitions for specific capabilities
- Reference implementations
  - TIAGo → Panna
  - MIR + UR
  - **4th BioSASH Hackathon**
- Incorporate new concepts (LAPP)
  - Digital twin
  - Robotic action templates
  - Labware library
  - Advanced robotic technologies: Perception, manipulation, Human-machine collaboration
- Bi-weekly meetings on-going
  - Discussions: workflow representations, labware ontologies, etc.
  - Contact adam.wolf@sila-standard.org to join

Future applications and new topics

Color code
- Established product
- Fresh on the market
- Emerging/under development

Collaborative assistance

- Use Case
  - Fetch consumables and labware
  - Prepare worktable for human
  - Collaborative pipetting
- Technologies
  - Benchtop robots
  - Mobile manipulators
    - ABB

[24]

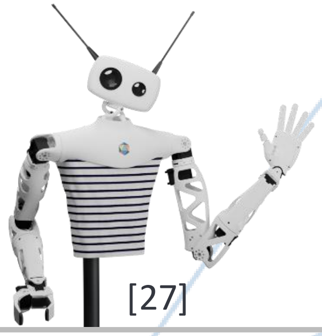
State monitoring

- Technologies
  - Mobile robots (wheeled)
  - Mobile robots (quadruped)

[25]

Telemanipulation

- Use Case
  - Remote error handling
    - Drive the robot to the error site,
    - Use on-board camera to evaluate
    - Remote control the arms to resolve
  - Remote work
- Technologies
  - Benchtop robots
    - Shadow Robot
    - Reachy
  - Mobile manipulators



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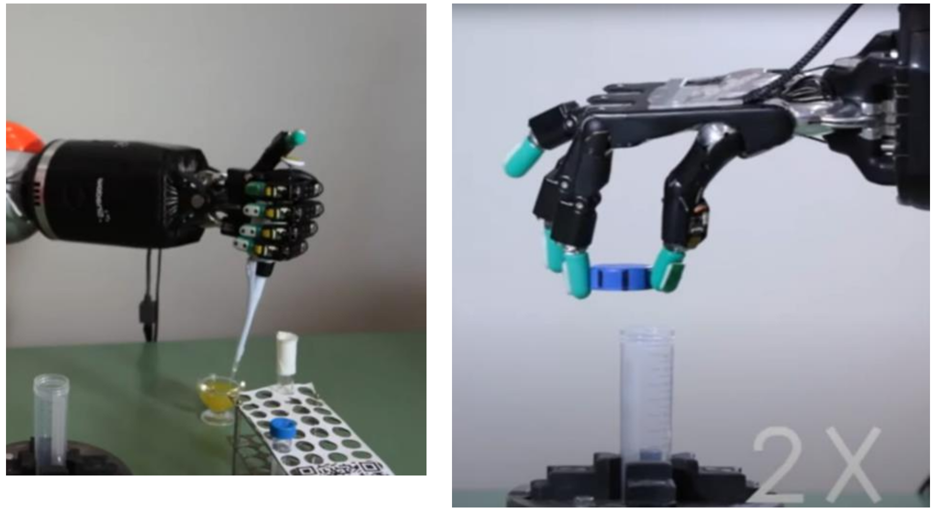
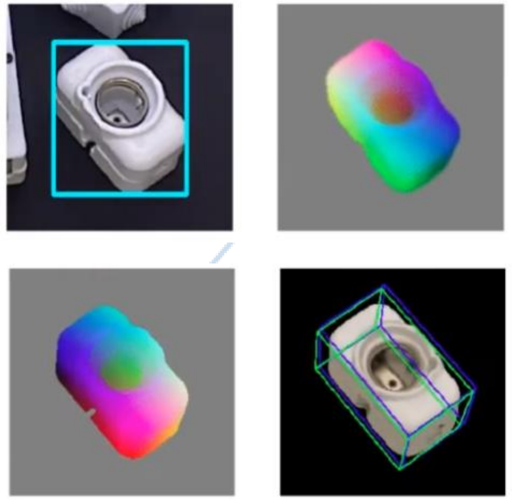
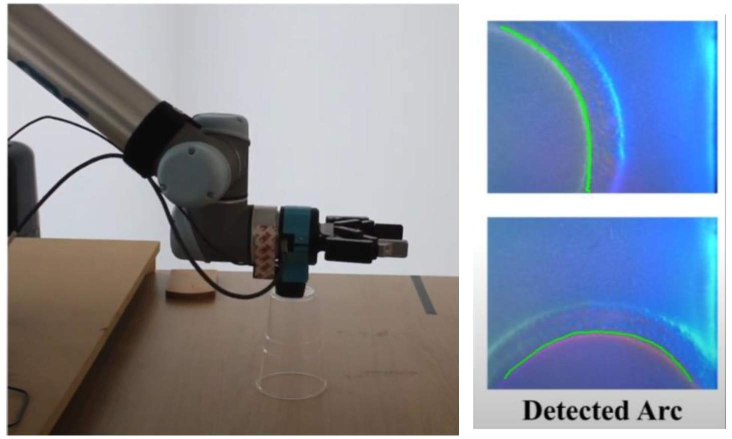
[26]

Incorporating new concepts – Advanced perception



Shadow Robot


V4R, ACIN, TU Wien

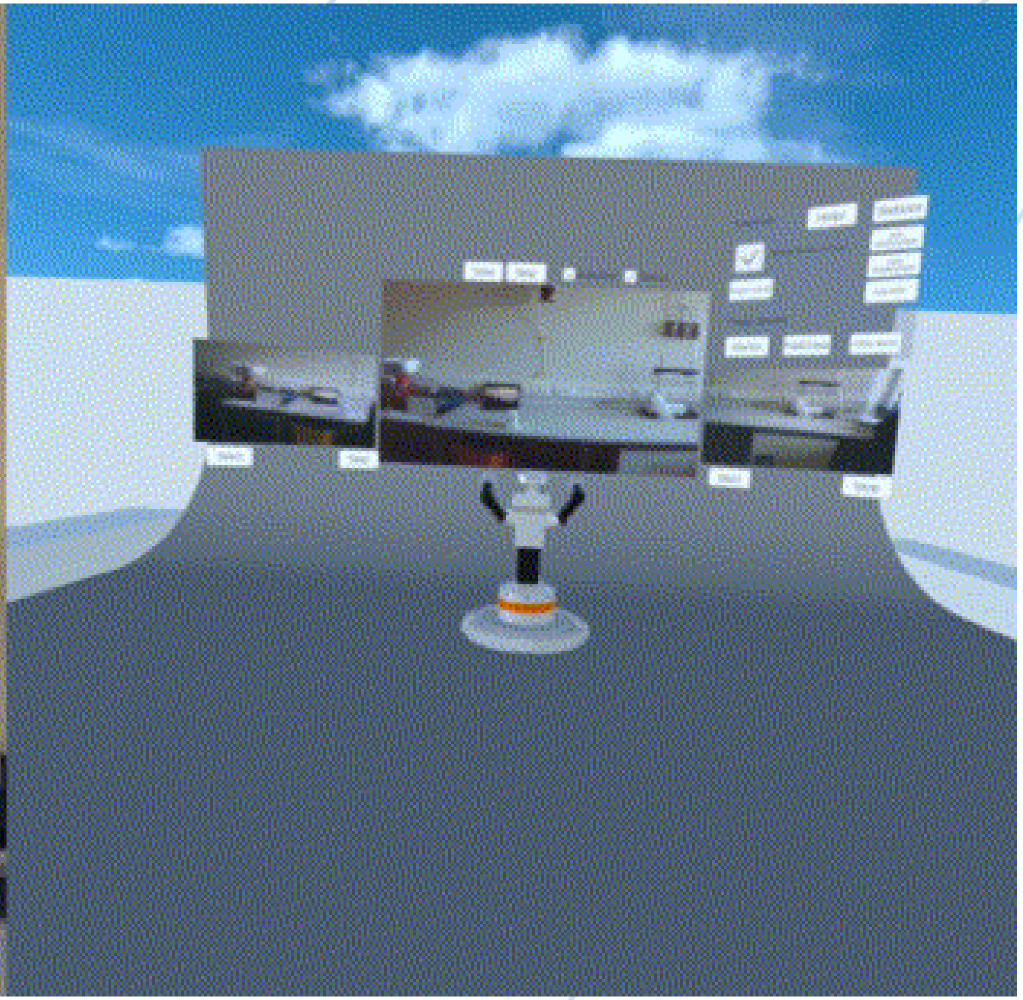


Jiang et al.

V4R, ACIN, TU Wien

Our projects:
VR telemanipulation with mobile manipulator

Master thesis	Project of Janek Janßen	**Technology:**	Oculus + Unity
Use case:	Remote error handling		TIAGo + ROS



Public LAPP project website

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

Literature

(1) Wolf, Á; Wolton, D.; Trapl, J.; Janda, J.; Romeder-Finger, S.; Gatternig, T.; Farcet, J.- B.; Galambos, P.; Sz´ell, K. Towards Robotic Laboratory Automation Plug & Play: The "LAPP" Framework. SLAS Technology 2021,

(2) Jones, D.; Snider, C.; Nassehi, A.; Yon, J.; Hicks, B. Characterising the Digital Twin: A systematic literature review. CIRP Journal of Manufacturing Science and Technology 2020, 29, 36–52.

(3) Erdős, G.; Paniti, I.; Tipary, B. Transformation of robotic workcells to digital twins. CIRP Annals 2020, 69, 149–152.

(4) Tipary, B.; Erdős, G. Generic development methodology for flexible robotic pick-and-place workcells based on Digital Twin. Robotics and Computer-Integrated Manufactur-ing 2021, 71, 102140.

(5) Tipary, B. Assembly plan calibration using sensor networks. Ph.D. thesis, 2022.

(6) Bartley, B.; Beal, J.; Rogers, M.; Technologies, R. B. B. N.; Bryce, D.; Goldman, R. P. Building an Open Representation for Biological Protocols. [Preprint] 2022, 1 .

(7) Chu, X. Automation Strategies for Sample Preparation in Life Science Applications. Ph.D. thesis, 2016.

(8) Nagy, T. D.; Haidegger, T. A DVRK-based Framework for Surgical Subtask Automation. Acta Polytechnica Hungarica 2019, 16 .

(9) Vedula, S. S.; Malpani, A. O.; Tao, L.; Chen, G.; Gao, Y.; Poddar, P.; Ahmidi, N.; Paxton, C.; Vidal, R.; Khudanpur, S.; Hager, G. D.; Chen, C. C. G. Analysis of the structure of surgical activity for a suturing and knot-tying task. PLoS ONE 2016, 11 .

(10) Fleischer, H.; Thurow, K. Automation Solutions for Analytical Measurements: Concepts and Applications; John Wiley & Sons, 2017; p 272.

(11) Fleischer, H.; Baumann, D.; Chu, X.; Roddelkopf, T.; Klos, M.; Thurow, K. Integration of Electronic Pipettes into a Dual-arm Robotic System for Automated Analytical Measurement Processes Behaviors. IEEE International Conference on Automation Science and Engineering 2018, 2018-Augus, 22–27.

(12) Wolf, A.; Galambos, P.; Sz´ell, K. Device Integration Concepts in Laboratory Automation. INES 2020 - IEEE 24th International Conference on Intelligent Engineering Systems, Proceedings. 2020; pp 171–177.

(13) Garrido-Jurado, S.; Mu˜noz-Salinas, R.; Madrid-Cuevas, F. J.; Mar´ın-Jim´enez, M. J. Automatic generation and detection of highly reliable fiducial markers under occlusion. Pattern Recognition 2014, 47, 2280–2292.

(14) feature definitions/ch/unitelabs · master · SiLA2 / sila base · GitLab. https://gitlab.com/SiLA2/sila_base/-/tree/master/feature_definitions/ch/unitelabs.

(15) (224) Webinar Kevin - YouTube. https://www.youtube.com/watch?v=HfZCNi841Oo&t=27s.

(16) ANSI/SLAS, ANSI SLAS 4-2004 (R2012): Microplate Standards, Well Positions. 2004,

(17) SiLA2 / sila ros · GitLab. https://gitlab.com/SiLA2/sila_ros

(18) Details of the Asset Administration Shell. Part 1 – The exchange of information between partners in the value chain of Industrie 4.0 (Version 1.0). [cited 2021 June 09]., https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/2018-verwaltungsschale-im-detail.html.

(19) Kim, D.; Oh, P. Y. Lab automation drones for mobile manipulation in high throughput systems. 2018 IEEE International Conference on Consumer Electronics, ICCE 2018-January, 1–5.

(20) Pharmaceuticals & Biomedical – Shadow Robot Company. https://www.shadowrobot.com/pharmaceuticals-biomedical/.

(21) Vincze, M.; Bajones, M.; Suchi, M.; Wolf, D.; Weiss, A.; Fischinger, D.; Da La Puente, P. Learning and detecting objects with a mobile robot to assist older adults in their homes. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) 2016, 9914 LNCS, 316–330.

(22) Gomes, D. F.; Lin, Z.; Luo, S. GelTip: A finger-shaped optical tactile sensor for robotic manipulation. IEEE International Conference on Intelligent Robots and Systems 2020, 9903–9909.

(23) Thalhammer, S.; Leitner, M.; Patten, T.; Vincze, M. PyraPose: Feature Pyramids for Fast and Accurate Object Pose Estimation under Domain Shift. 2021, 13909–13915.

(24) abb-conversations.com/au/2020/09/robots-are-lending-a-hand-in-laboratories-worldwide-making-healthcare-and-handling-safer-and-more-productive/

(25) bostondynamics.com/products/spot

(26) shadowrobot.com

(27) pollen-robotics.com

(28) D. Leidner, C. Borst and G. Hirzinger, "Things are made for what they are: Solving manipulation tasks by using functional object classes," 2012 12th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2012), 2012, pp. 429-435, doi: 10.1109/HUMANOIDS.2012.6651555.

(29) Schnicke, Frank, Thomas Kuhn, and Pablo Oliveira Antonino. "Enabling industry 4.0 service-oriented architecture through digital twins." European Conference on Software Architecture. Springer, Cham, 2020.

(30) Reference Architecture Model Industrie 4.0 (RAMI4.0) English translation of DIN SPEC 91345:2016-04 (2016)

Thank you for your attention.