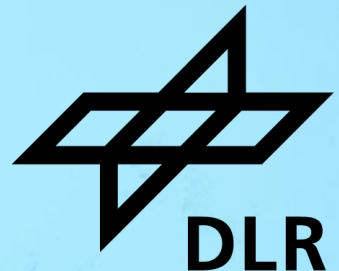


ADAPTIVE MONTAGEPLANUNG FÜR DYNAMISCHE ENTWICKLUNGSUMGEBUNGEN AUF BASIS EINEN KNOWLEDGE GRAPHEN UND PDDL

Roland Glück, Tobias Andreas Köhler, Roshan Shibu, Holger Weber, Korbinian Nottensteiner, DLRK 2026, 10.09.2026



- Teil des Projekts ASPIRO
- **Aerospace Production using Intelligent Robotic Systems**
- Work in progress
- Intermediate report
- Overall project introduced by Korbinian Nottensteiner tomorrow, September 10, 14:20 in room K3

Motivation

Dynamic Development Environments



- Varianten, kleine Losgrößen und kurze Produktlebenszyklen verlangen häufig neue Montagefolgen
- CAD enthält bereits Produktstruktur und Geometrie, aber noch keinen ausführbaren Montageprozess
- Manuelle Planung ist zeitaufwendig und nicht skalierbar

Ziel:

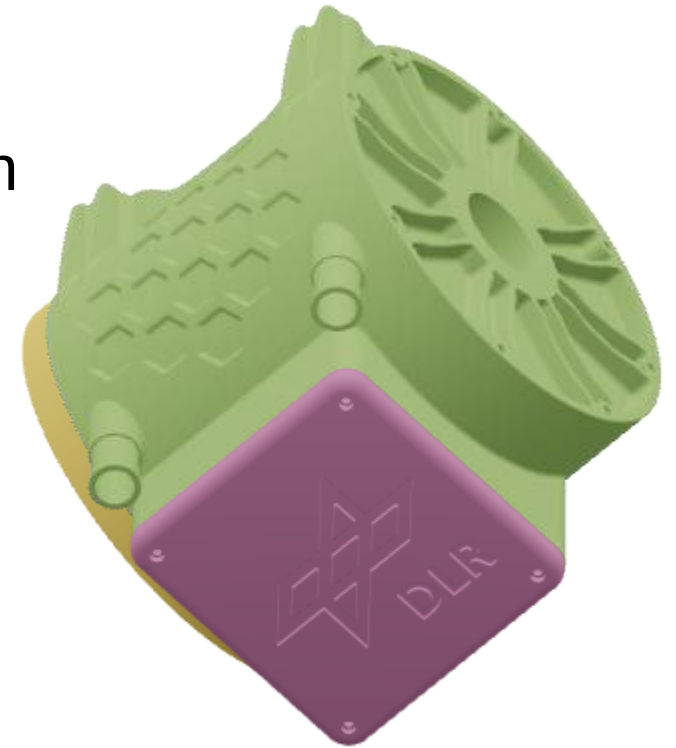
1. **Automatisierte Extraktion von Montagebedingungen auf Basis der CAD-Geometrie**
2. **Ableitung von Entscheidungen und Montageplänen**



Problemstellung

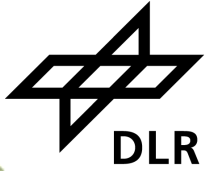


- CAD-Daten nicht maschinenlesbar für Montageplanung
 - Keine formale Brücke zwischen Produktanforderungen und Roboterfähigkeiten
-
- Kein durchgängiger Workflow
 - Geringe Adaptivität
 - Manueller Aufwand

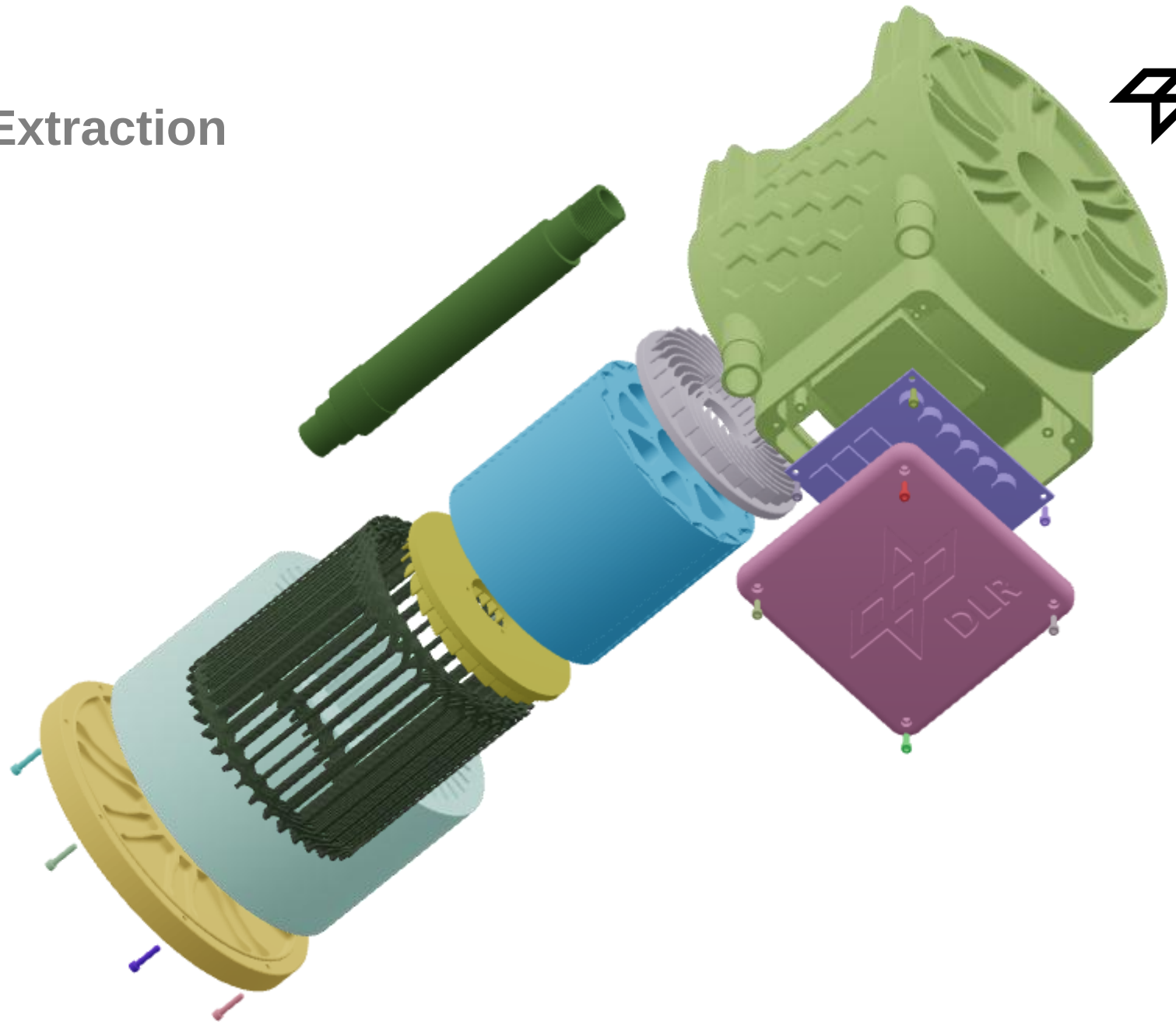


Problemstellung

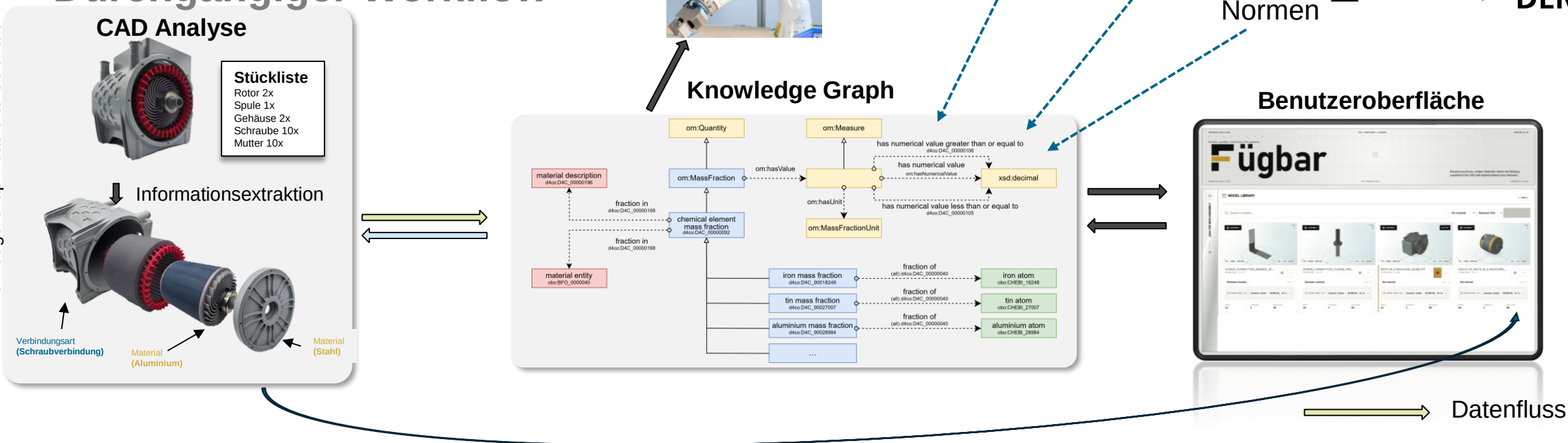
Assembly Constraints Extraction



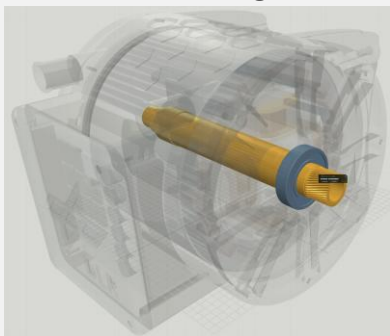
- Baugruppenstruktur
- Werkstoffe
- Anzahl
- Normteile
- Verbindungen
- Verbindungsarten
- Montagereihenfolge



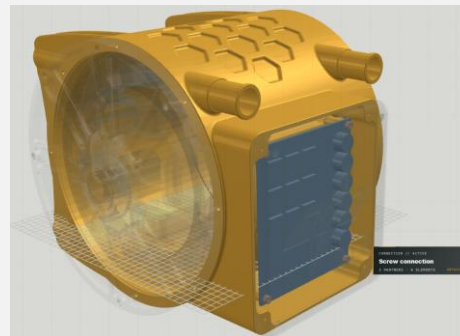
Unser Ansatz Durchgängiger Workflow



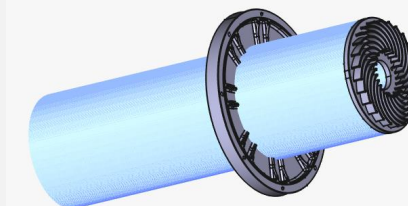
Verbindungen



Verbindungsarten

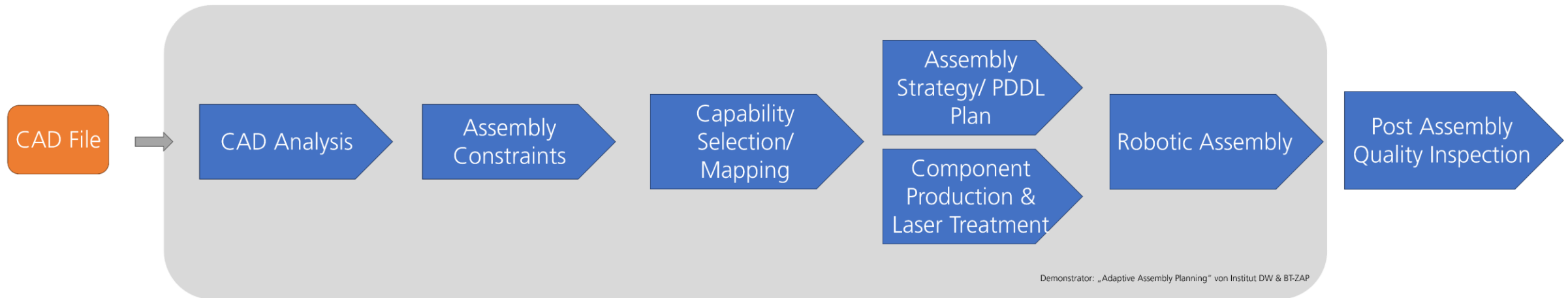


Vorrangbeziehungen

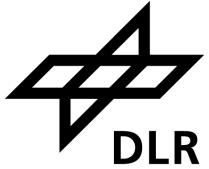


Data Extraction Methods

- CAD Analysis using Connection Extractor
- Constraints and sequences computed by Assembly Sequence Generator
- Capability Mapping by End-Effector Matcher



Connection Extractor

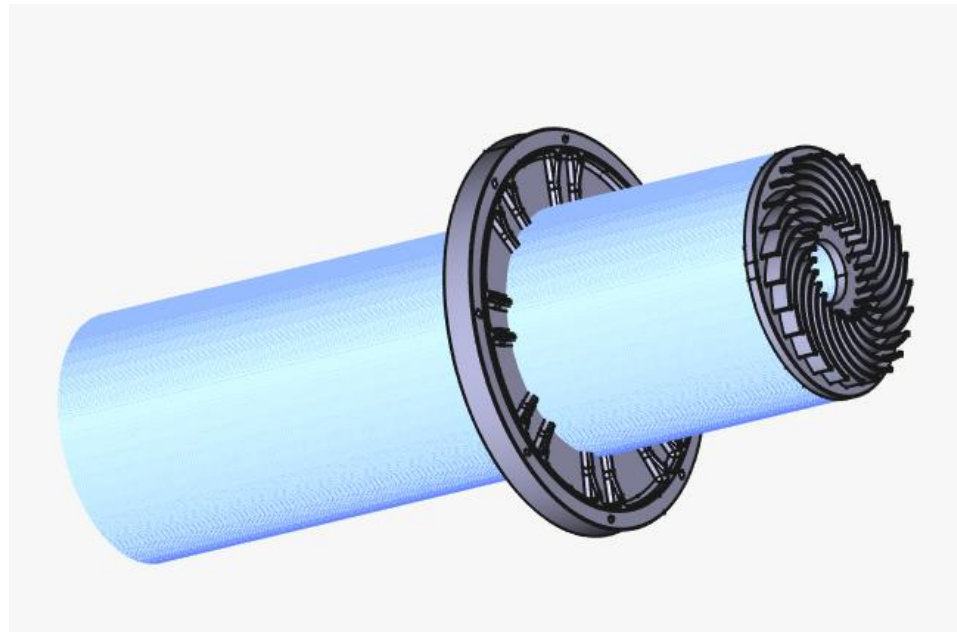


- Library to extract hierarchy, connections and connection elements

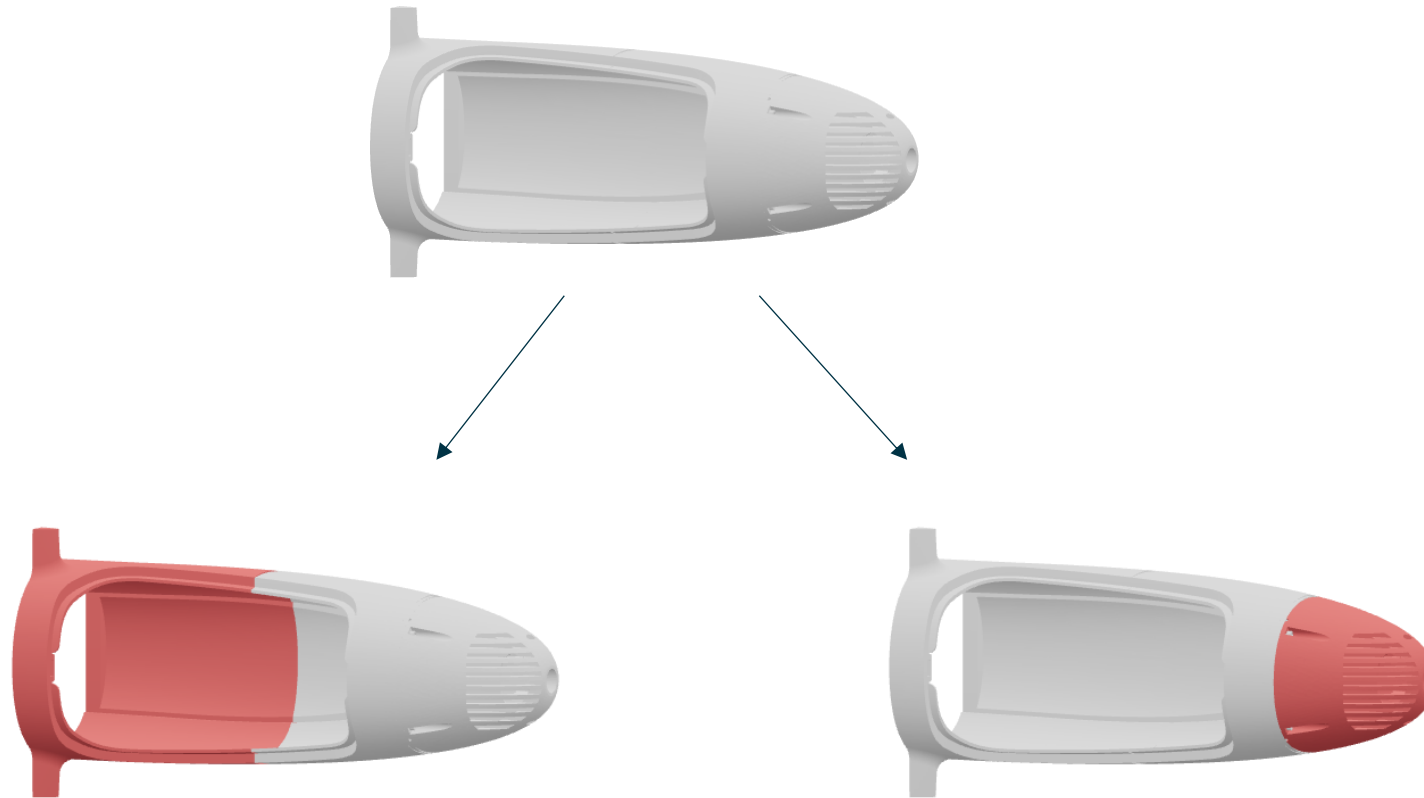


Assembly Sequence Generator Approach (Ongoing work)

- Swept volume calculated by computing projection and extruding
- Broad-phase collision detections
- Physics based collision free path finding also considered

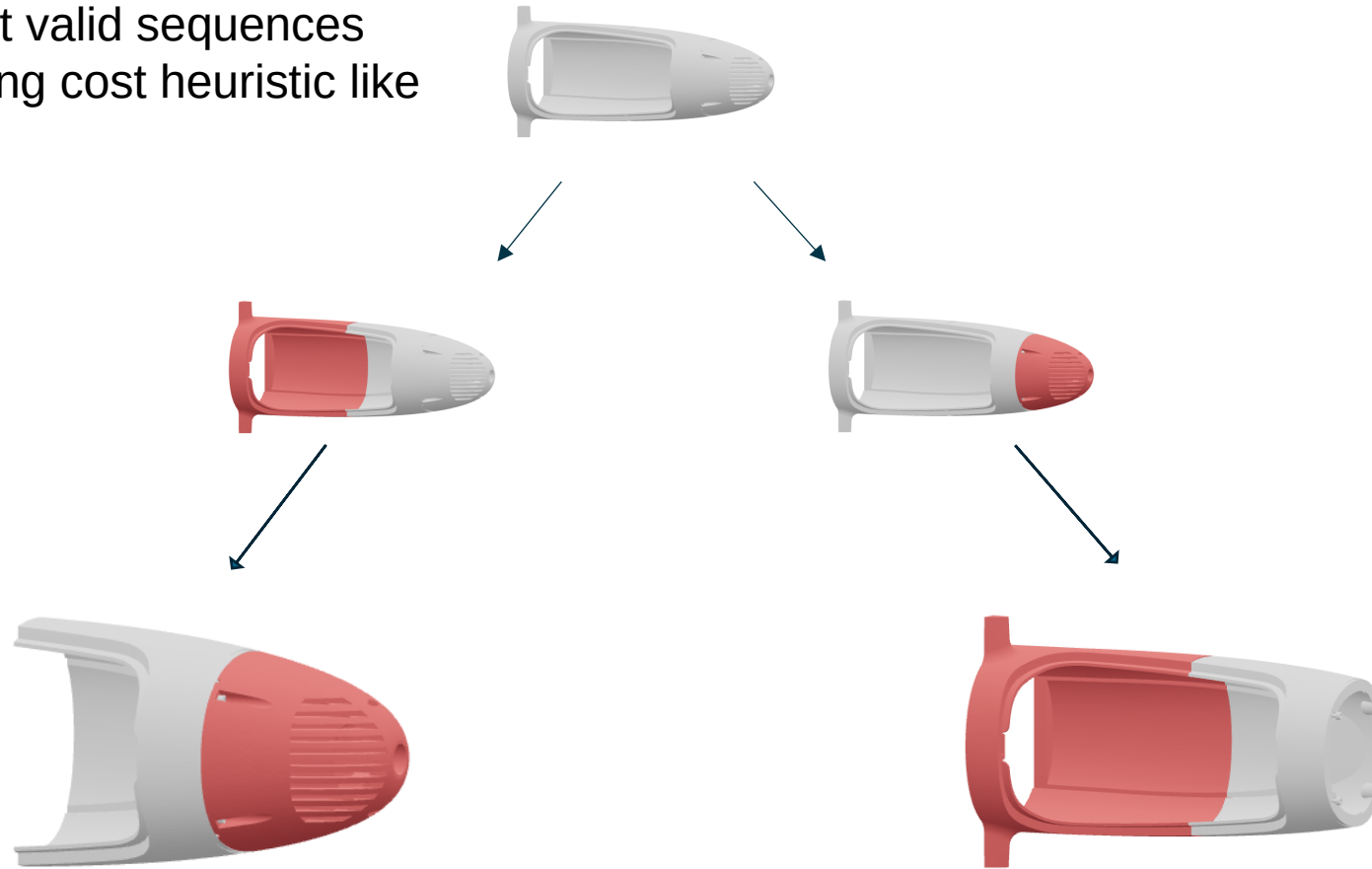


Assembly Sequence Generator Approach (Ongoing work)



Assembly Sequence Generator Approach (Ongoing work)

- DAG traversal to get valid sequences
- Edges weighted using cost heuristic like path complexity



PDDL in a nutshell



- **P**lanning **D**omain **D**efinition **L**anguage
- Instance consists of **problem file** and **domain file**
- Domain file:
 - Defines types
 - Defines predicates
 - Defines actions
 - Precondition
 - Action
 - Postcondition
- Problem file:
 - Defines concrete instances of the types
 - Defines initial configuration
 - Defines goal configuration

Domain File



```
(:types robot, nose)
(:predicates isFree ?r - robot isAtGripPosition ?n - nose
              canVacuumPick ?r - robot isPlaced ?n - nose
              holdsNose ?r - robot ?n - nose)
(:action pickNose
  :parameters (?r - robot ?n - nose)
  :precondition (and (isFree ?r) (isAtGripPosition ?n)
                    (canVacuumPick ?r))
  :effect ((not (isFree ?r) (holdsNose ?r ?n)))
)
(:action placeNose
  :parameters (?r - robot ?n -nose)
  ....
```

Problem File



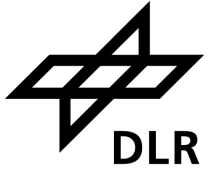
```
(:objects UR10 - robot LBR - robot nose1 - nose  
        nose2 - nose)  
(:init (isFree UR10) (isFree LBR) (isAtGripPosition nose1)  
      (canVacuumGrip UR10))  
(:goal (isPlaced nose1))
```

Solving PDDL



- Bunch of solvers for PDDL problems available
- Solvers find sequence of actions to reach goal state from init state
- Domain file allows also for indicating duration of actions
- Minimization of process time
- Transfer of PDDL actions to robot: follows

The standardised Digital Twin Asset Administration Shell State of the art



■ Issues:

- Vendor lock-in
- No semantics
- No IT-grade interface
- Fragmented Information for assets: commonly fragmented across CAD/PLM, commissioning tools, controller configuration, maintenance records and shop-floor applications.

As exemplary design use case we will reference here the Universal Robot UR10!

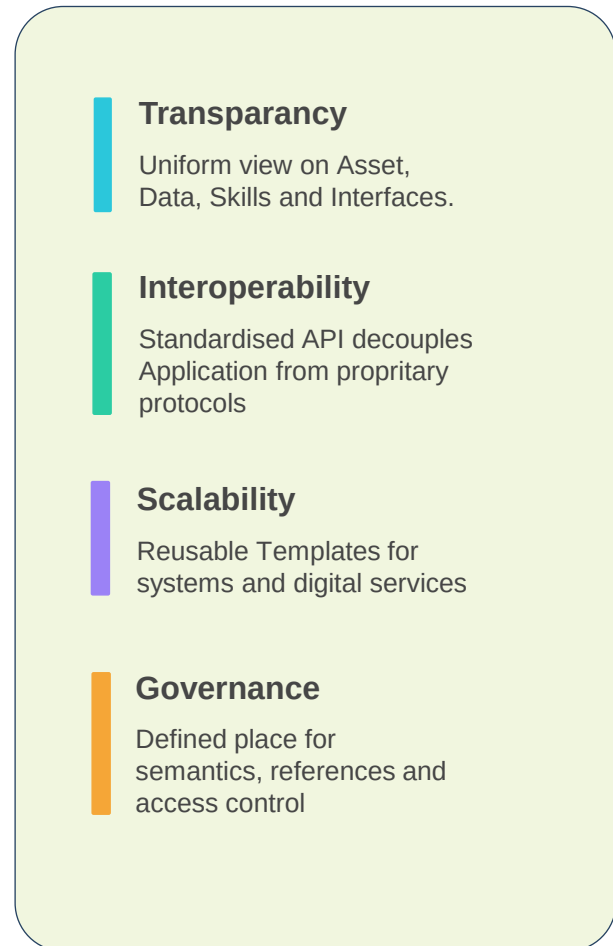
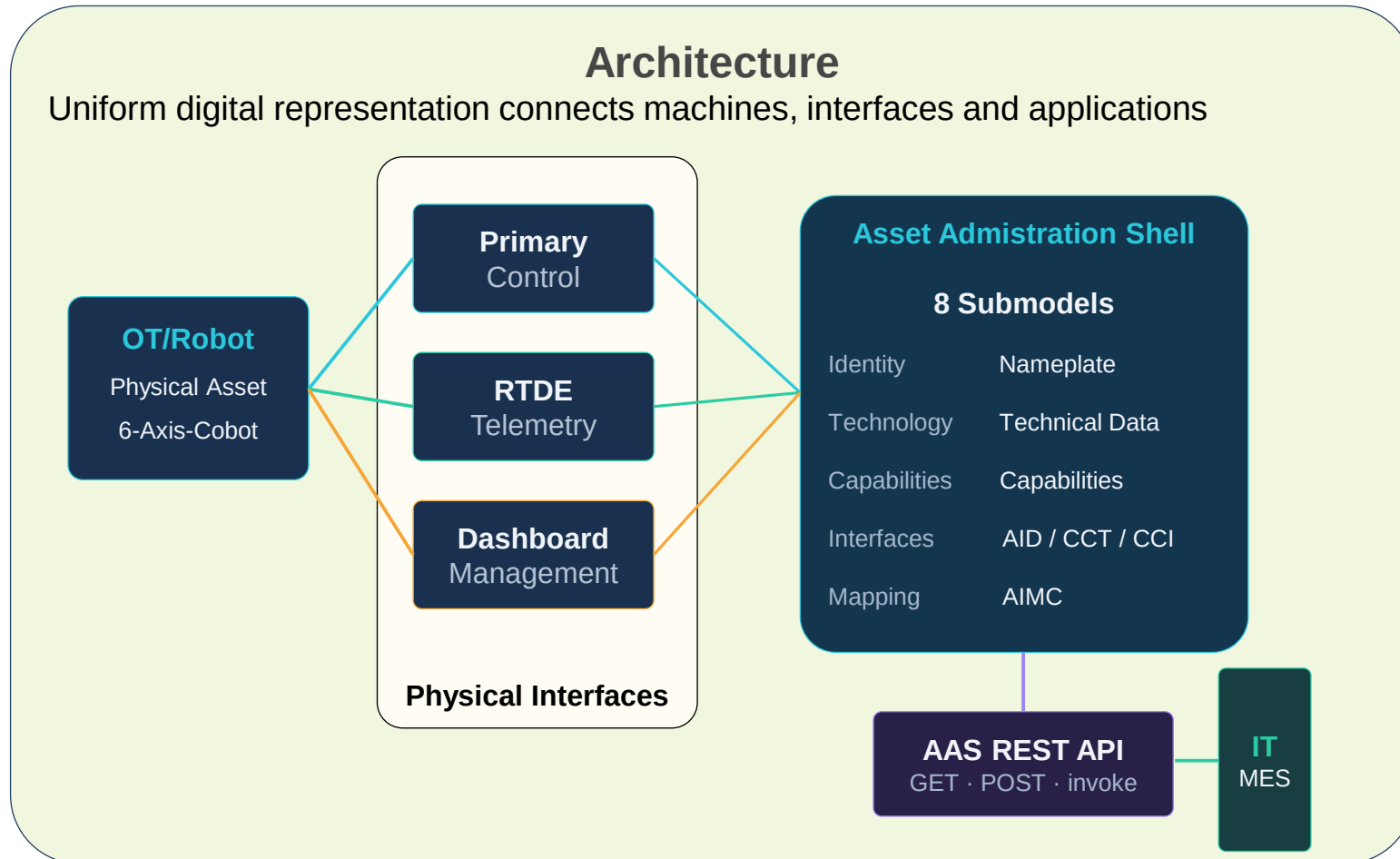
■ Solution:

- The AAS as the standardised digital representation of the asset and standardised interfaces; organise information in purpose-specific submodels, link them by semantic references and make them easy accessible.
- Faster integration and change impact analysis, less manual data reconciliation, and a foundation for scalable digital services and assurance.

From Roboter to controllable, interoperable database



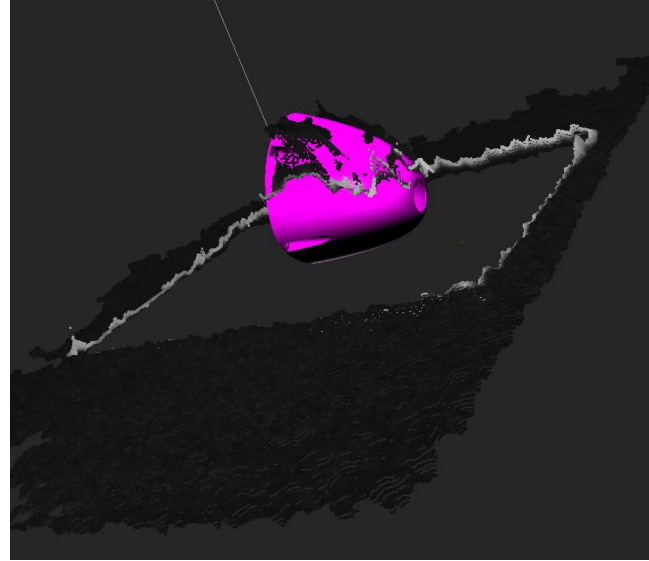
AAS bundles technical data, capabilities and interfaces making them accessible through a standardised API



6D-Pose Pipeline

T_camera_part

SAM +
FoundationPose



STEP 1

Capture

rc_visard 65:
RGB + depth +
Intrinsic



STEP 2

Preprocessing

ROI-Crop,
Voxel –
Downsampling,
Statistical outlier
removal



STEP 3

Mask

FastSAM



STEP 4

Registration

FoundationPose
render-and-compare

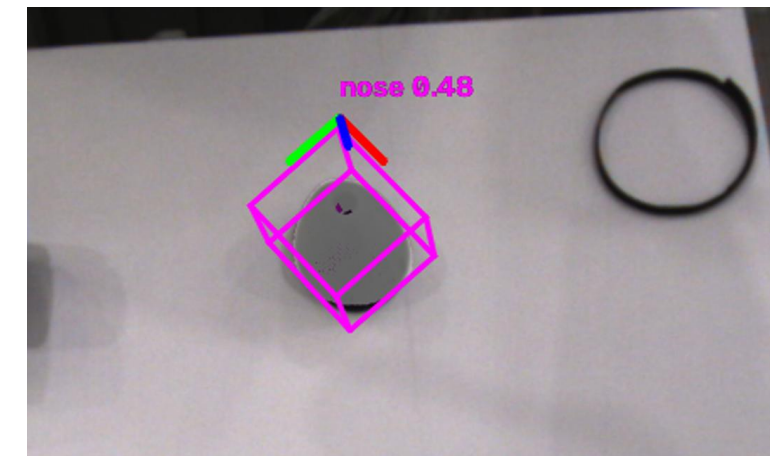
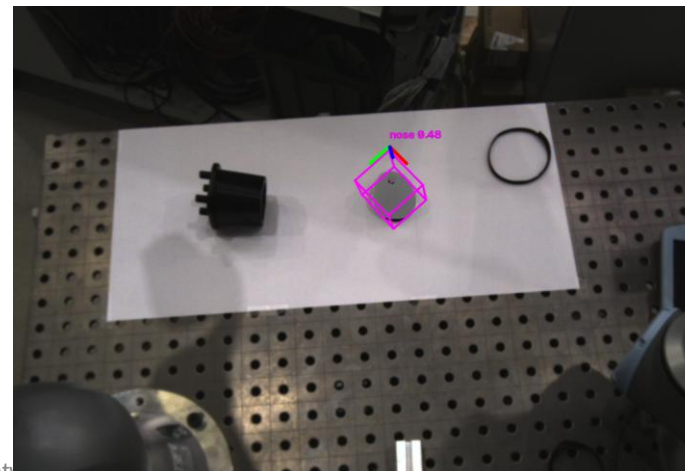


STEP 5

Validation

Fitness,
RMSE

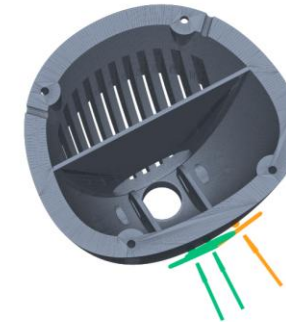
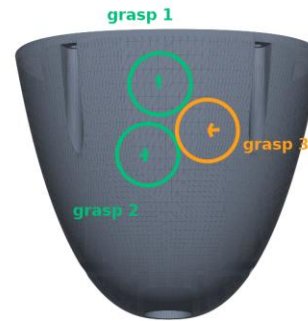
- **Fitness:** completeness. A measured point has a corresponding partner in the CAD model, subject to a threshold. Note that the camera captures only approximately 50% of the object.
- **RMSE:** goodness of fit. It indicates how closely the identified point pairs align (based on the fitness correspondences).



Kinematic chain

- Kinematic chain of gripping
 - $T_{\text{robot_tcp}} = T_{\text{base_camera}}$

Vacuum grasp points on the drone nose



along the approach direction

from above

— primary grasp (priority 1-2) — fallback grasp (priority 3)
circle = suction cup footprint (Ø 20 mm) · arrow = approach, along +z of the TCP frame into the surface

grasping points derived by



Offline from CAD

Samples candidate points over the CAD point cloud.

Criteria:

- **Occupancy:** Missing points indicate an edge or a bore within the safety distance.
- **Normal consistency:** Excludes changes in curvature.
- **Planarity:** RMS distance to the local best-fit plane.

Online at runtime

Use the mesh with the estimated pose, then apply two steps:

- **Normal filtering:** Retain only surfaces whose normal direction roughly aligns with the approach direction.
- **Lever-arm minimisation:** From these candidate surfaces, select the one with the smallest distance to the center of mass.

- **Automated extraktion** of assembly conditions out of the CAD
- **Semantic enrichment** of the extracted data
- **Storage in central knowledge graph** for structured utilization
- **Deduction of actions** from the knowledge graph
 - *examples:*
 - „connection X releasable with tool Y“
 - „order: assemble part X before part Y“
- **Transferring the conditions into the PDDL**
- **Approach for automated und geometry based assembly planning**

Thank you for your attention

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