TU Clausthal

You've Got a Plan?

A Domain Modelling Approach for Collaborative Product Disassembly Planning with PDDL

ADVCOMP 2024, 2nd of October

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Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

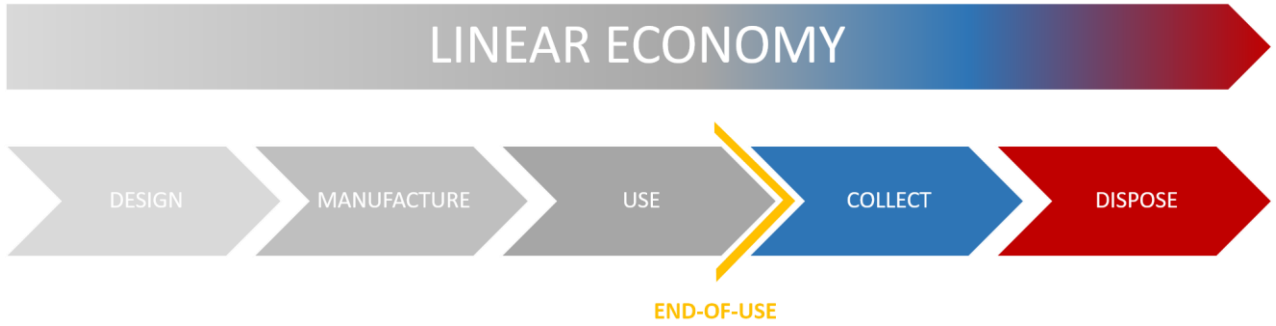
TU Clausthal

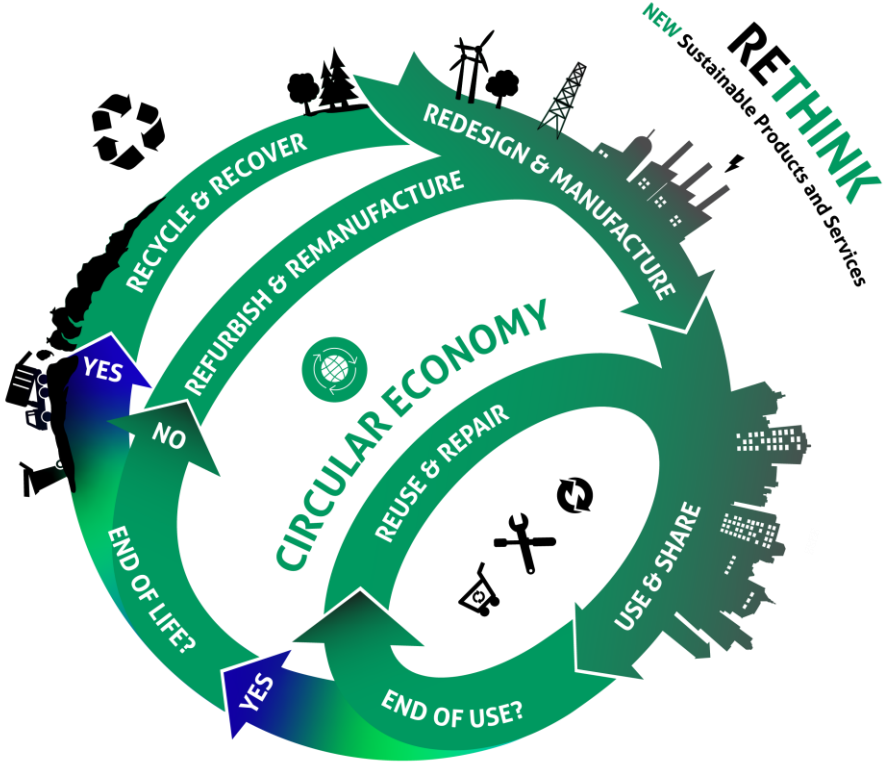
Dominique Briechle, M.Sc.

- **Research Interest:**
  - Digitized Circular Economy
  - AI-Planning Systems for Automation Processes
  - Digital Twin & Cyber-Physical Systems Design
  - Software Engineering for Robotics
- **CV:**
  - 2019: B.Sc. Energy and Raw Materials
  - 2021: M.Sc. Petroleum Engineering
  - 2021: Academic Researcher Center for Digital Technologies TU Clausthal & Ostfalia
  - 2022: Academic Researcher Institute for Software and Systems Engineering

Relevance of the Research

- Resource scarcity is increasing with every year!
- Linear Economy is still in place in industries
- Circular Economy keeps resources in a cycle
- We need a shift, from LE to CE!
- Especially production is energy and resource consuming
- Repairing, Refurbishing and Remanufacturing (3Rs) of products can mitigate these consumption
- **But how?**





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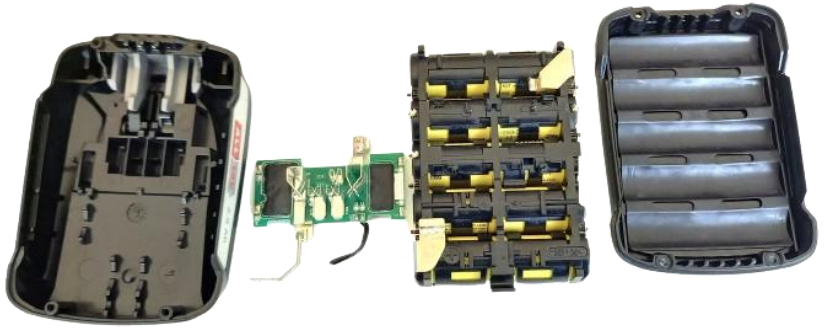
Problem Statement

- Discarding of products is nowadays easy
- On the opposite 3R operations are hard to conduct
- Reasons are, among others:
  - Economic Factors
  - Lack of skilled laborer
  - Technical obsolesces and inability to upgrade
  - Inability of companies to cope high amount and variety of used incoming products
- ➢ Automated Systems can mitigate some of those effects
- ➢ However, adaptivity is key and automated systems must be enabled to act in an adaptive manner

Problem Statement

So how can we enable Automated Systems to get from here…

to here and be adaptive at the same time?



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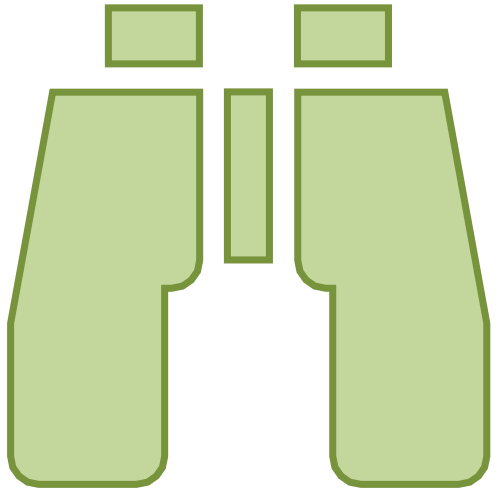
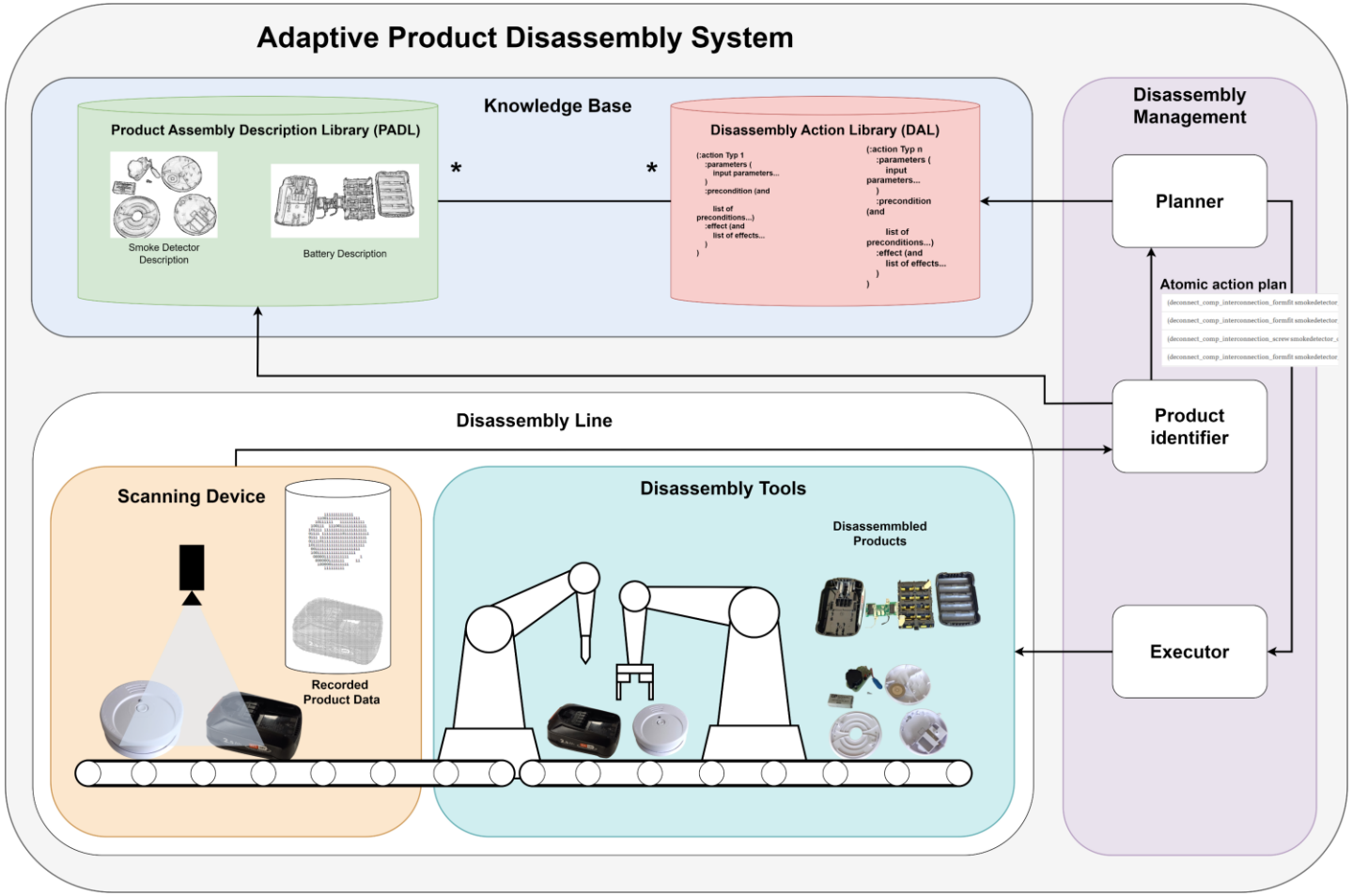
Scope of the Paper

- Two central subjects:
  - Conception of a model which takes the structural hierarchy and variety of products into account
  - Implementation and Testing of an AI-based sequence Planner

- Contribution to the research question:
  - Contribution of a meta-model, suitable to describe compositional structure in a modular and flexible way
  - Formulated PDDL-Domain derived from the meta-model to generate AI-based sequence plans for robotic disassembly systems
  - Evaluation and Testing with two product models, defined as PDDL-Problem on a Planner-based level



Overall Concept



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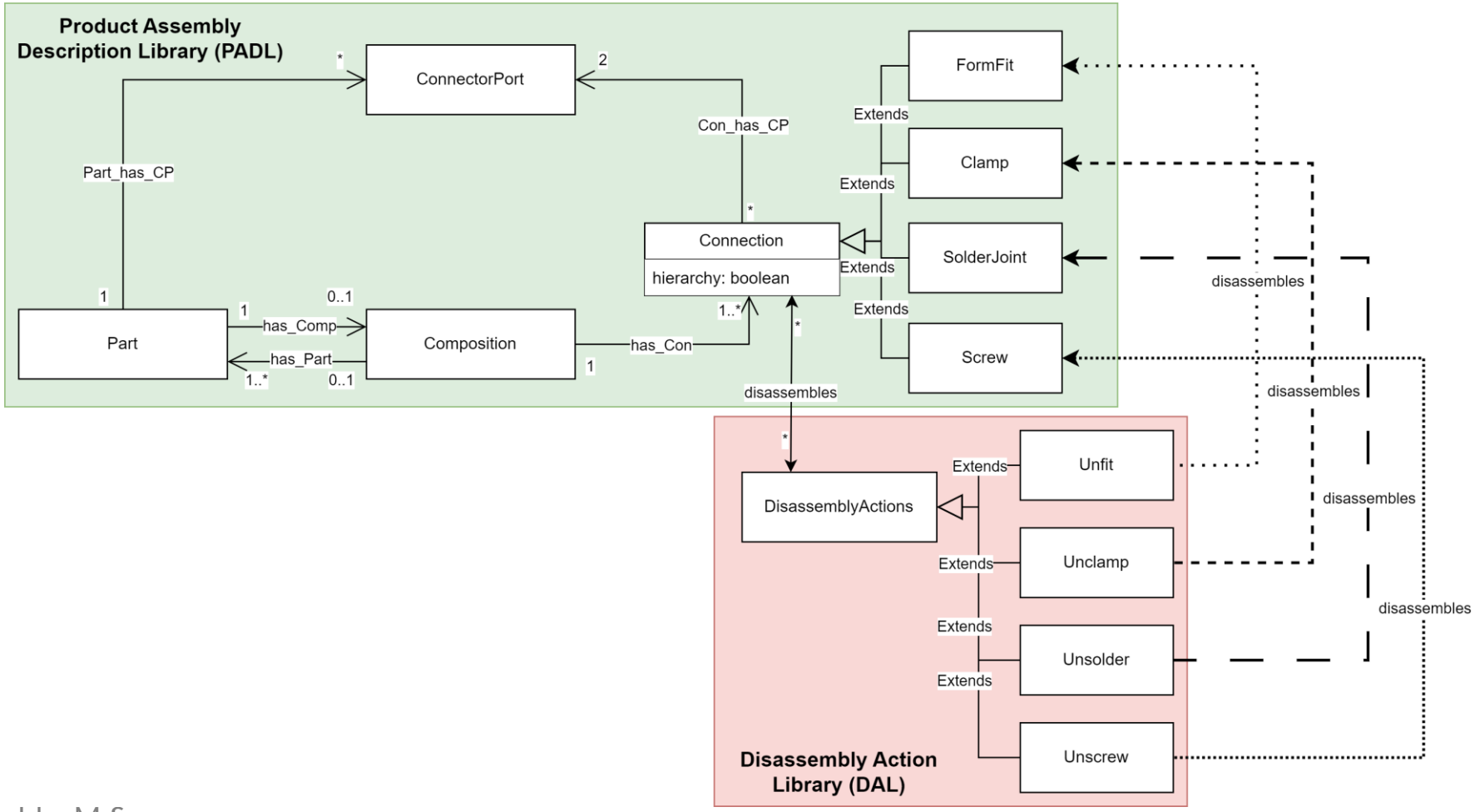
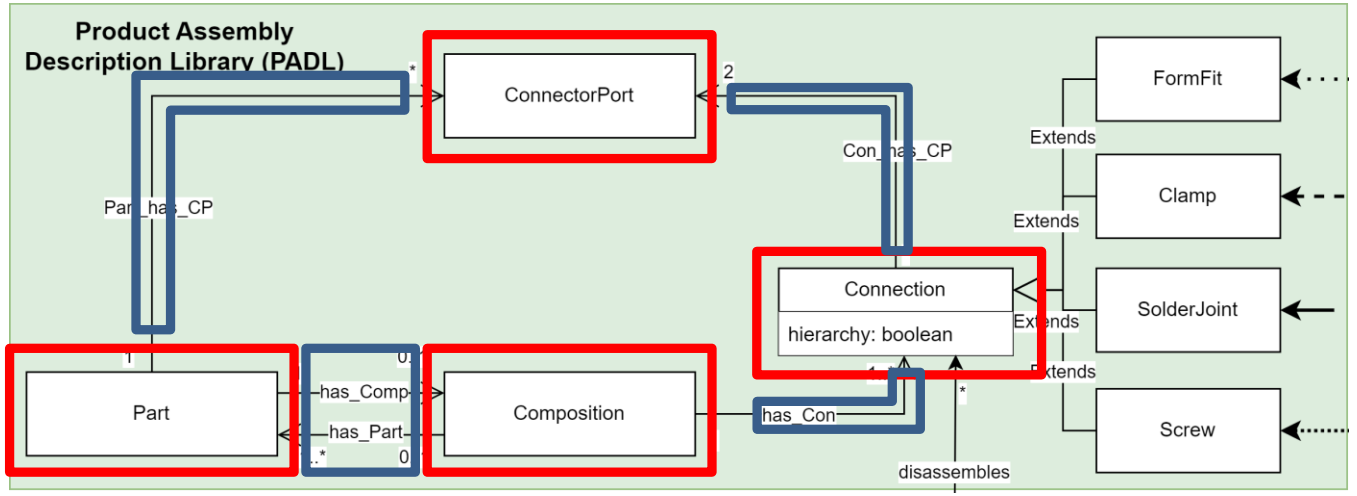
Meta-Model


Product Assembly Description Library (PADL)
ConnectorPort
Part_has_CP
Con_has_CP
Connection
hierarchy: boolean
Part
has_Comp
has_Part
Composition
has_Con
disassembles
FormFit
Clamp
SolderJoint
Screw
Extends
DisassemblyActions
Unfit
Unclamp
Unsolder
Unscrew
Disassembly Action Library (DAL)

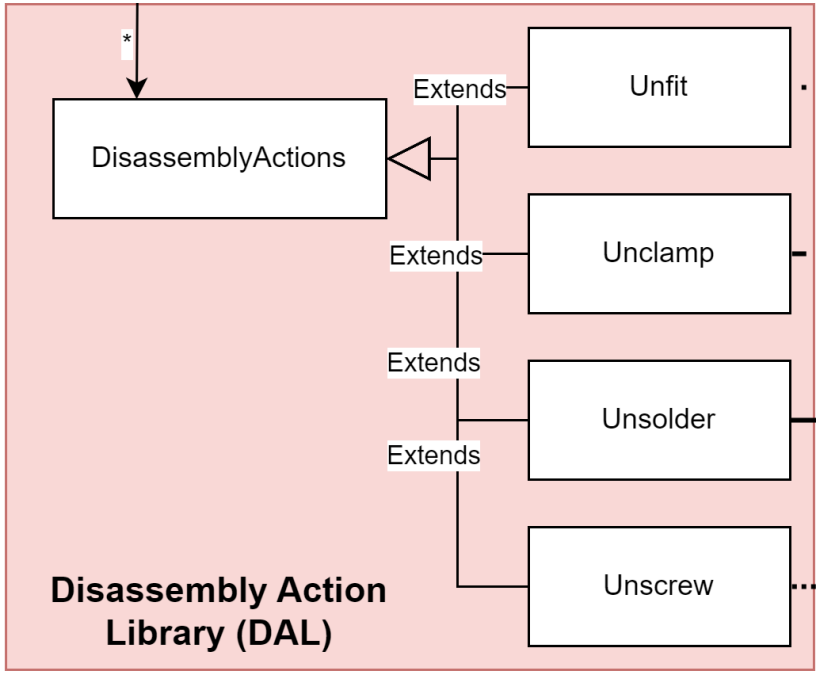
Product Assembly Description Library (PADL)

- PADL contains the general objects of our Meta-Model
- It is used to describe the compositional structure of the products
- Link establishes systematic connection between system entities
- Extensions of *Connection* act as specifications



Disassembly Action Library (DAL)

- DAL contains the model of the *DisassemblyActions,* required to disconnect the corresponding links
- Extensions enable the specification of disassembly operations



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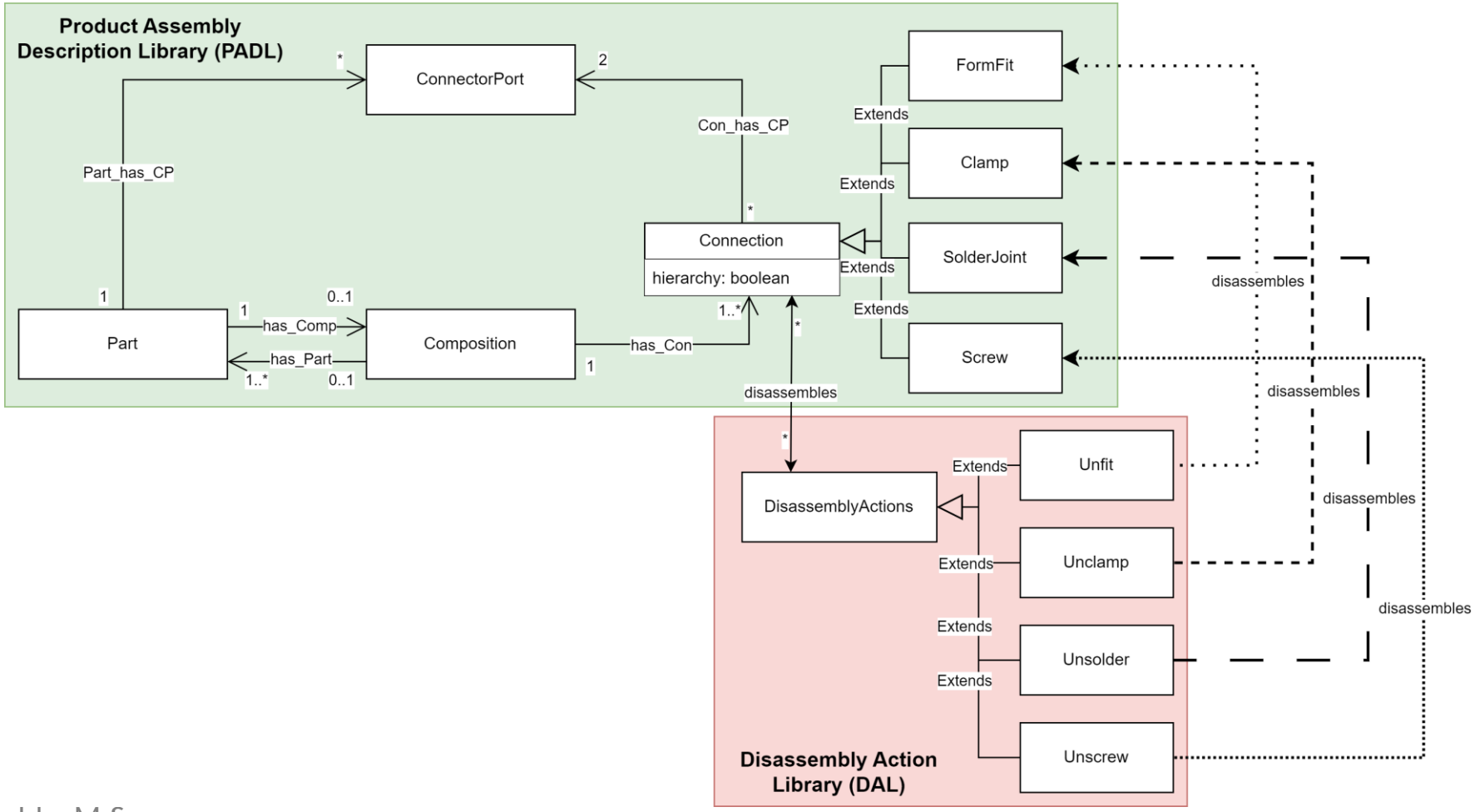
Meta-Model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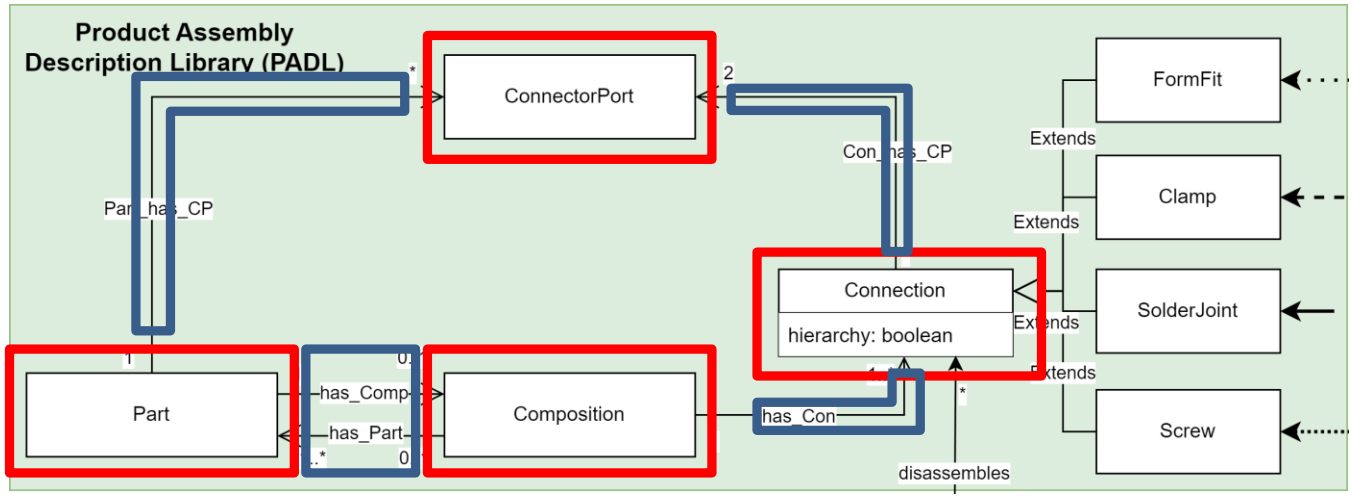
Implementation in PDDL

- Planning Domain Definition Language (PDDL) is used to implement the model
- PDDL is a descriptive language for AI-based Planning, which allows the formulation…
  - …of the meta-model entities as types
  - …the meta-model links as predicates
  - …the *DisassemblyActions* as Actions in the Domain
- Domain contains the information for the generation of Problems, which are then solved by a Solver/Parser combination

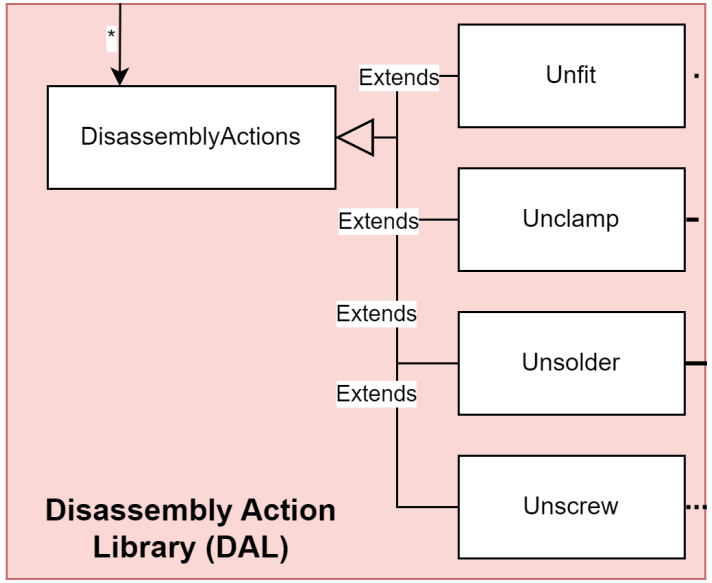
PDDL Domain – Types & Predicates




```
(:requirements :typing)
(:types
part - object
connectorport - object
connection - object
composition - object
interconnection - connection
transconnection - connection
)
```

```
(:predicates
(comp_has_cp ?part - part ?connectorport - connectorport)

(has_comp ?part – part ?composition - composition)

(has_part ?composition – composition ?part - part)

(has_con ?composition – composition ?connection - connection )

(con_has_cp ?connection – connection ?connectorport -
connectorport)
)
```

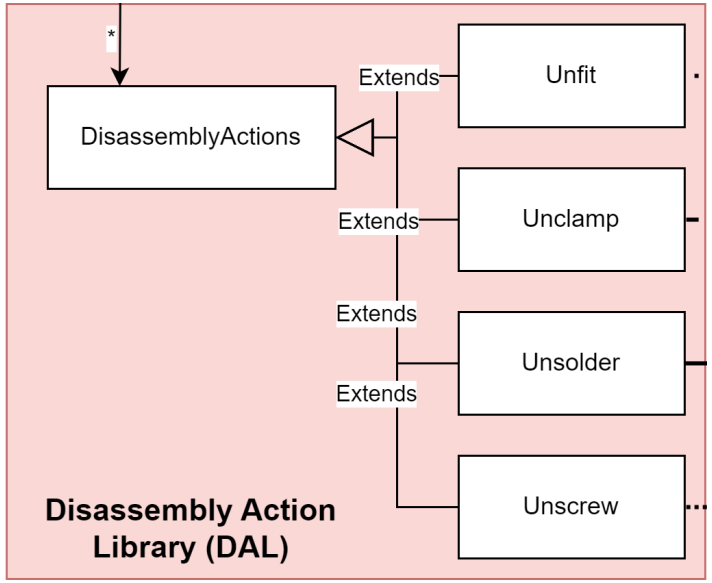
PDDL Domain - Actions




```
(:action disconnect_composition-interconnection
:parameters (
?comp - composition
?i1 - interconnection
?p1 - part
?p2 - part
?c1 - connectorport
?c2 - connectorport
 )
 :precondition (and
 (has_con ?comp ?i1)

 (forall (?deleg - transconnection)
 (not(has_con ?comp ?deleg))
 )
 (forall (?parts - part)
 (not(has_comp ?parts ?comp))
 )
 (part_has_cp ?p1 ?c1)
 (part_has_cp ?p2 ?c2)
 (has_part ?comp ?p2)
 (has_part ?comp ?p1)

 (con_has_cp ?i1 ?c1)
 (con_has_cp ?i1 ?c2)
 (not(= ?c1 ?c2))
 (not(= ?p1 ?p2))
 )
 :effect (and
 (not(has_con ?comp ?i1))
 (not(con_has_cp ?i1 ?c1))
 (not(con_has_cp ?i1 ?c2))))
```

```
(:action
disconnect_composition-transconnection
:parameters (
?comp - composition
?t1 - transconnection
?p1 - part
?p2 - part
?c1 - connectorport
?c2 - connectorport
)
:precondition (and
(has_con ?comp ?t1)
(forall (?allcomp - composition)
 (not(has_part ?allcomp ?p1))
 )
(has_comp ?p1 ?comp)
(has_part ?comp ?p2)
(part_has_cp ?p1 ?c1)
(part_has_cp ?p2 ?c2)
(not(con_has_cp ?t1 ?c1))
(not(con_has_cp ?t1 ?c2))
(not(= ?c1 ?c2))
(not(= ?p1 ?p2))
)
:effect (and
(not(has_con ?comp ?t1))
(not(con_has_cp ?t1 ?c1))
(not(con_has_cp ?t1 ?c2))
)
)
```

PDDL Domain - Actions




```
(:action disconnect_part-composition
:parameters (
?part - part
?comp - composition
?c1 - connectorport
?c2 - connectorport
?i1 - interconnection
)
:precondition (and
(forall (?over - composition)
(not(has_part ?over ?part))
)
(has_comp ?part ?comp)
(part_has_cp ?part ?c1)
(part_has_cp ?part ?c2)
(not(con_has_cp ?i1 ?c1))
(not(con_has_cp ?i1 ?c2))
(not(= ?c1 ?c2))
)
:effect (and
(not(has_comp ?part ?comp))
)
)
```

```
(:action
disconnect_composition-part
:parameters (
?comp - composition
?part - part
?c1 - connectorport
?c2 - connectorport
?i1 - connection
?i2 - connection
)
:precondition (and
(part_has_cp ?part ?c1)
(part_has_cp ?part ?c2)
(has_part ?comp ?part)
(forall (?links - connection)
(not(has_con ?comp ?links)
)
)
(not(con_has_cp ?i1 ?c1))
(not(con_has_cp ?i2 ?c2))
(not(= ?c1 ?c2))
(not(= ?i1 ?i2))
)
:effect (and
(not(has_part ?comp ?part))
)
)
```

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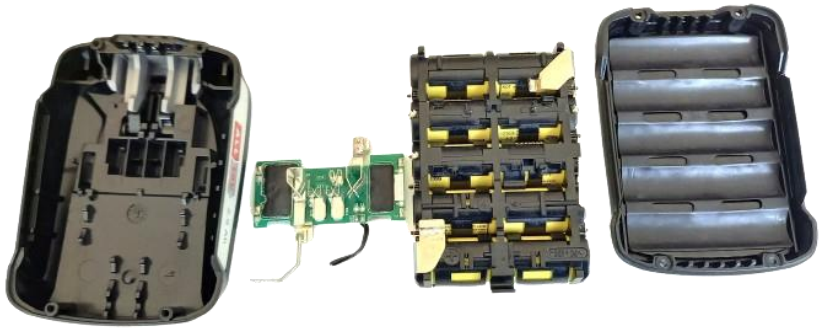
Problem Statement

Can we now get from here…

to here with our automated system?



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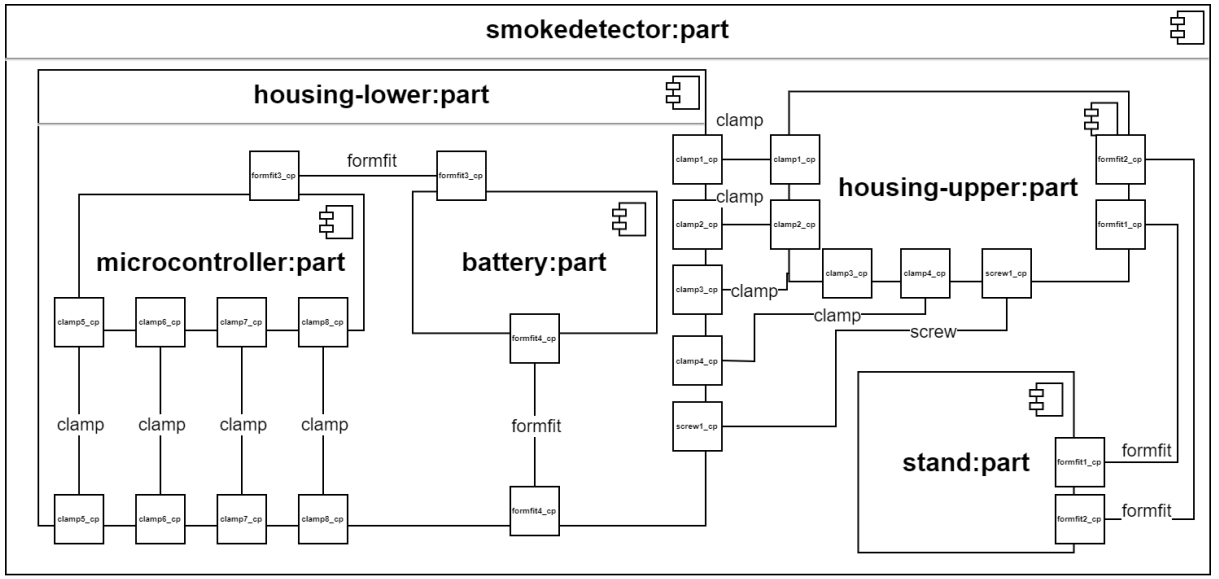
Test Scenario

- PDDL implementation was tested with two different Use-Cases on a planning base:
  - Smoke detector
  - Power Tool Battery
- Problems were drafted as Composition Structure Diagrams
- Composition Structure Diagrams captures the assembled state, that is used to define the initial state of the Problem



Results

- Solving was carried out via the tool: https://editor.planning.domains/
- As Solver, out of the standard implementation solvers, the BFWS Solver with an ff Parser was the most suitable option
- Plans were generated by the solver according to the Composition Structure Diagrams
- Application of different specified Actions were conducted in accordance to the preconditions

	Smoke Detector	Power Tool Battery
Total time:	1.05921 sec.	1.24214 sec.
Nodes generated during search:	332	429
Nodes expanded during search:	312	169
Plan found with cost:	15	25

Conclusion

- Definition of a Meta-Model allows the description of product assemblies and the according disassembly environment
- Disassembly planning is conducted via PDDL and showed, how such systems can generate sequence-based disassembly plans
- However, model has certain Limitations:
  - Condition is not regarded as a factor
  - Cost-based considerations have not played a part in the selection of actions
- Future Outlook:
  - Implement identified limitations into the Meta-Model and the according PDDL System
  - Test planner-based disassembly structure on Robot system with defined interfaces

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