

Design for Disassembly Guideline



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Introduction

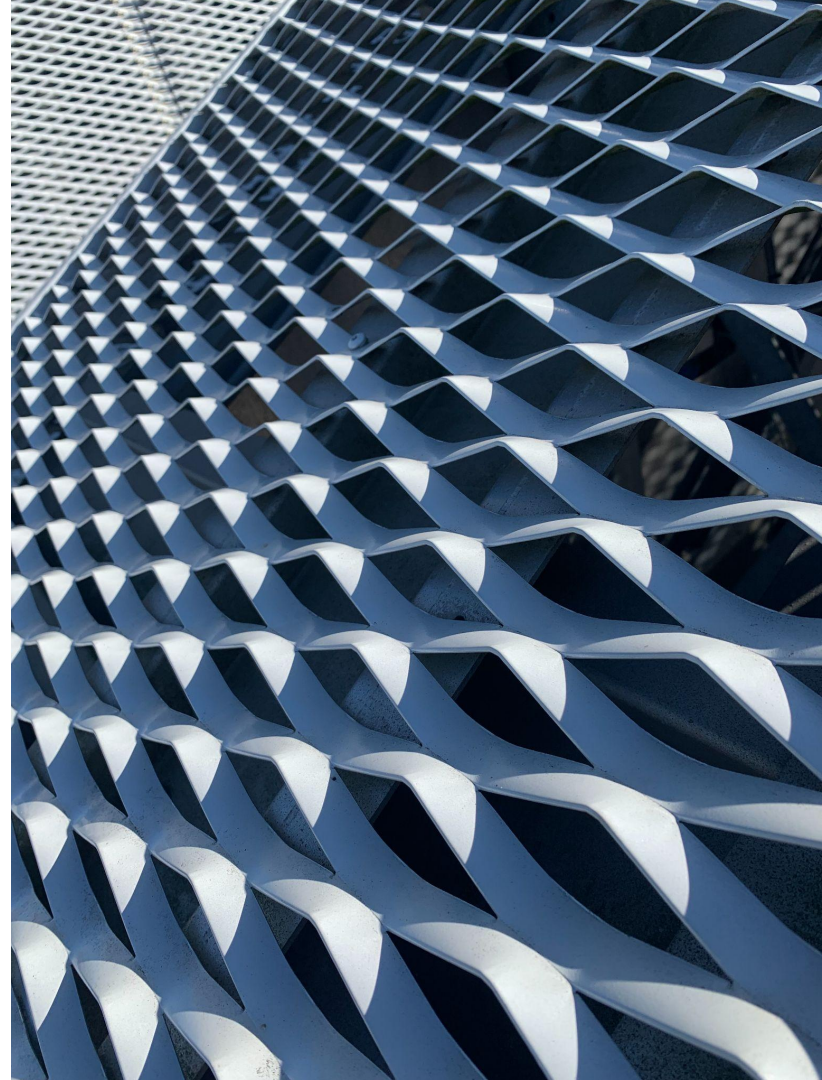
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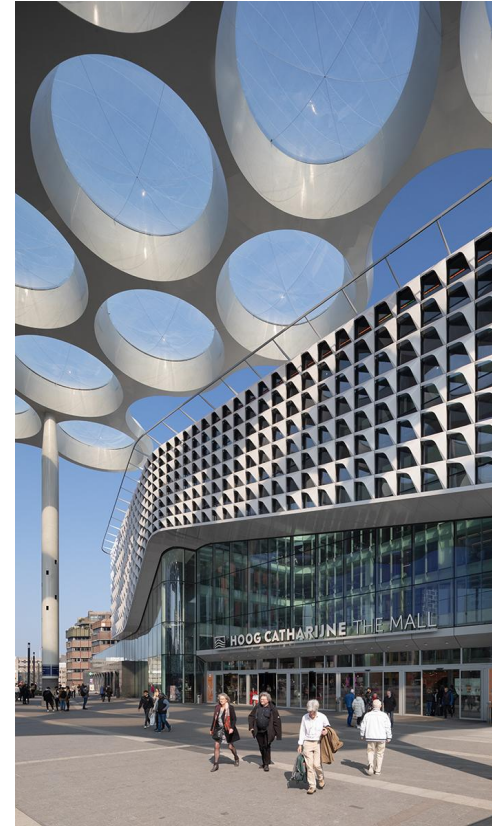
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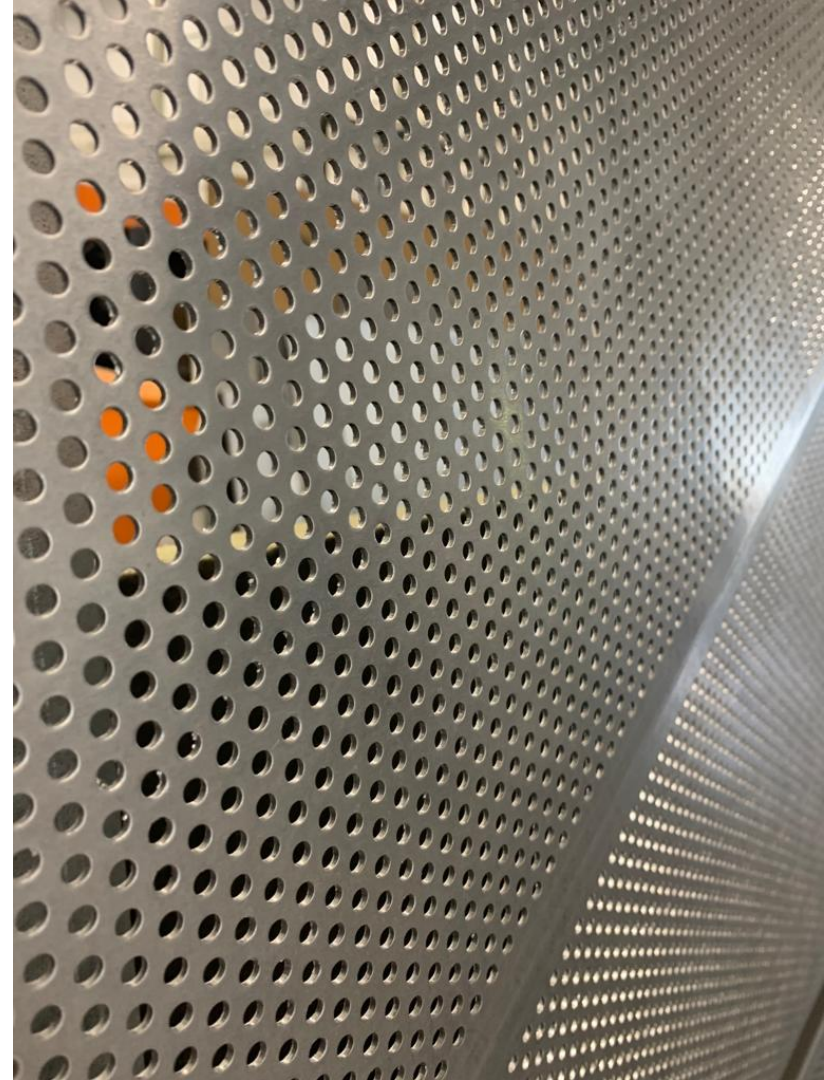
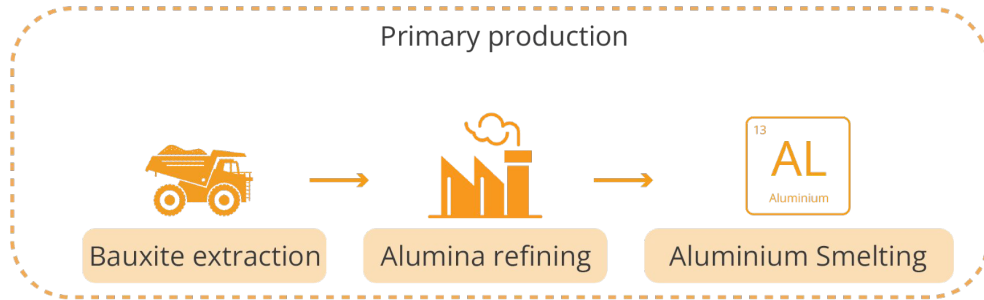
Aluminium



Aluminium Cladding

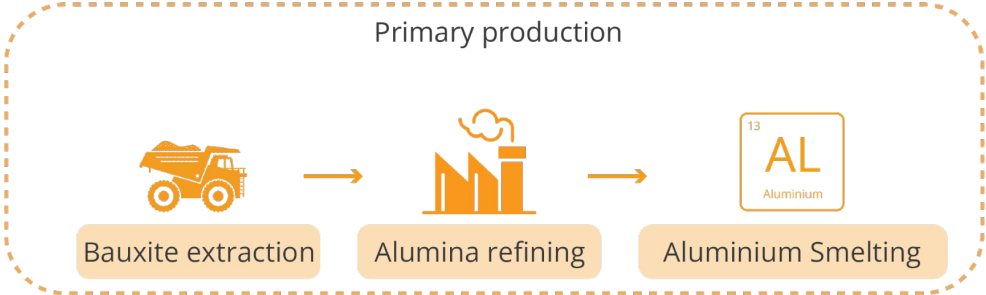


Primary Aluminium Production



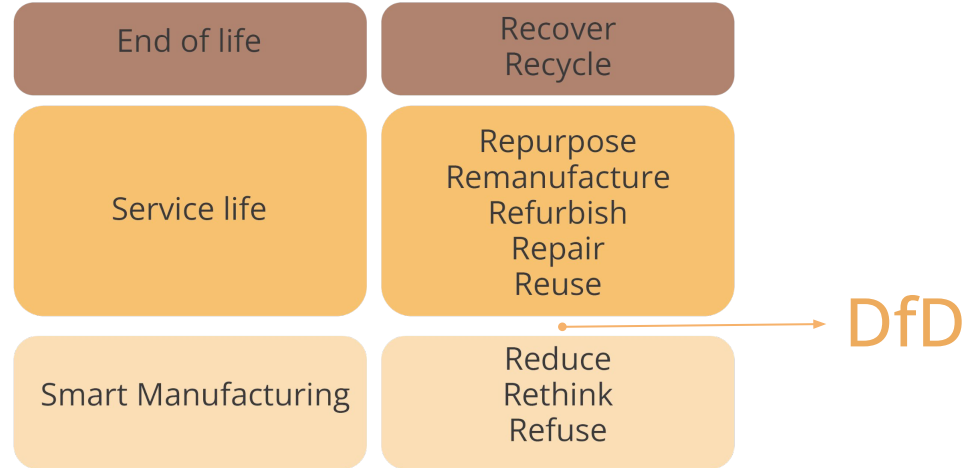


Aluminium Recycling



(European Aluminium, 2020) (Hydro, 2023) (Roba, 2023)

Cycling pathways



Problem statement

Linear Model



Resources

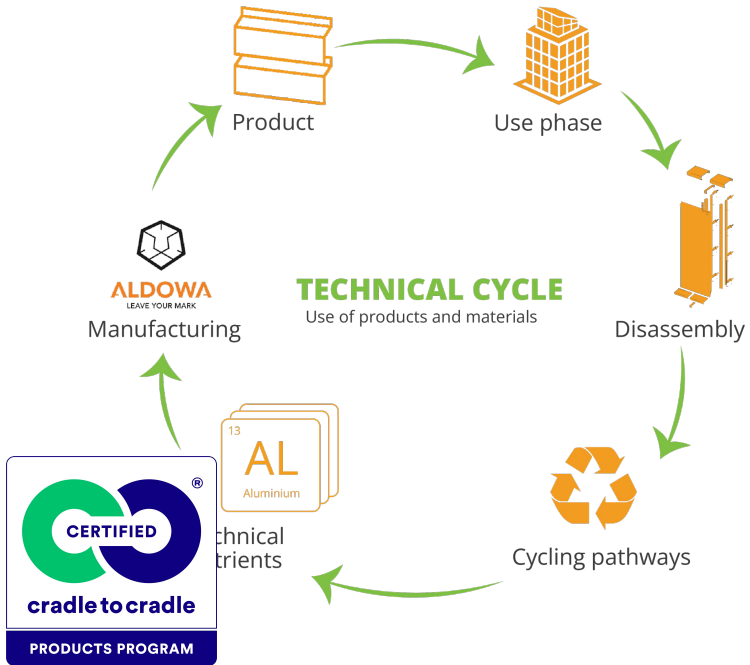


Use phase



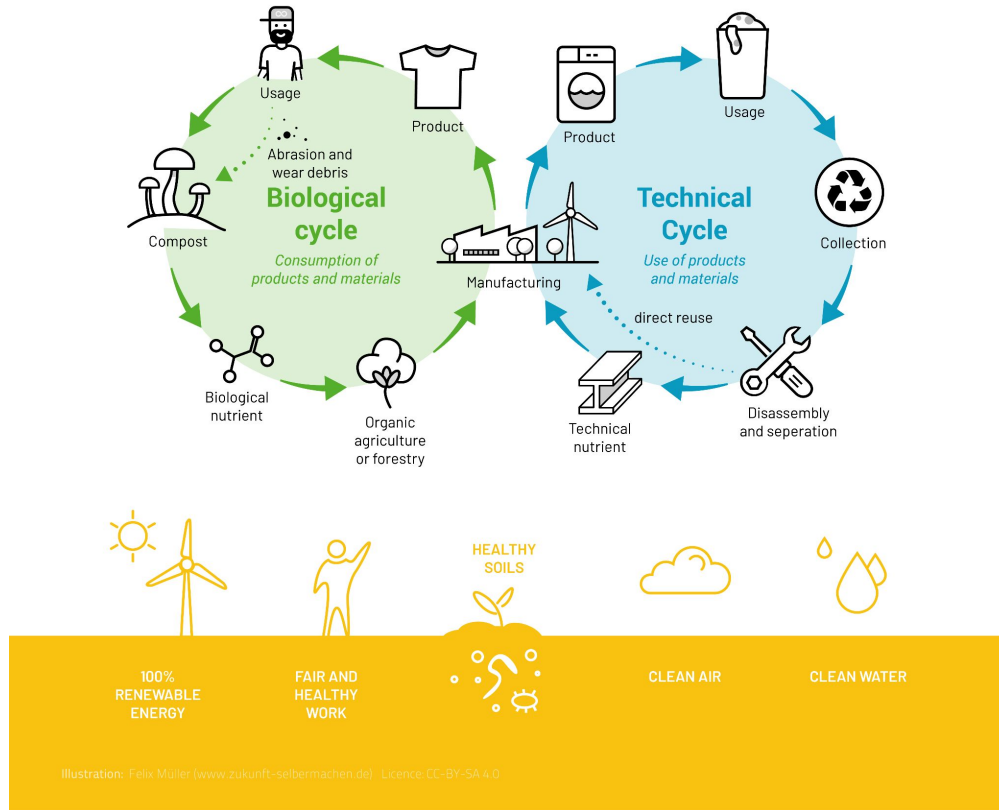
Disposal

Single used product



Closed loop system

Cradle to Cradle



Cradle to Cradle Certification



Material
Health



Product
Circularity



Clean Air &
Climate protection



Water & Soil
Stewardship



Social
Fairness

Cradle to Cradle Levels



Research question

How can the **disassembly potential** of Aldowa's cladding products be **assessed**, and what **design guideline** can be proposed to comply with the **design for disassembly requirements** of the **Cradle-to-Cradle** certification?

Literature research

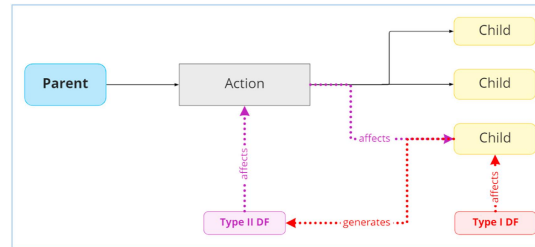
How can the **disassembly potential** of Aldowa's cassette panel be **assessed**?

Detachability score



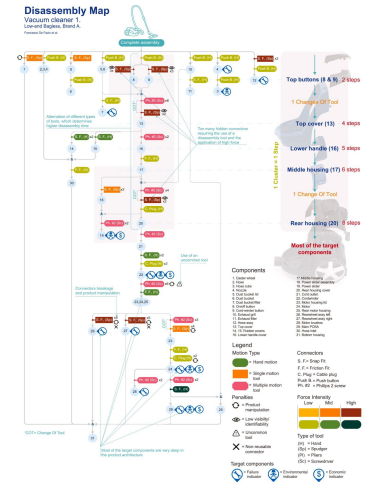
(BCI, 2023)

PAC Model



(Formentini & Ramanujan, 2023)

Disassembly Map

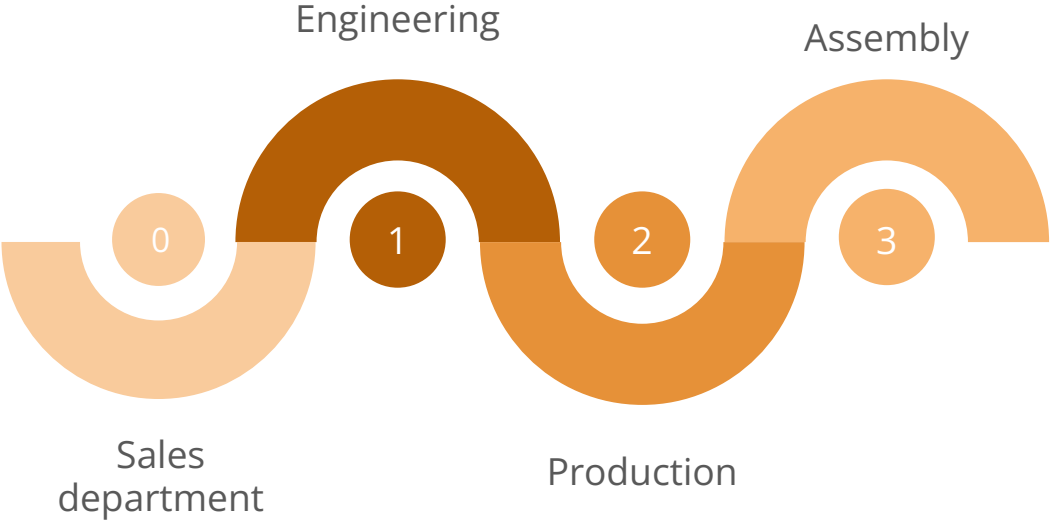


(De Fazio et al., 2021)

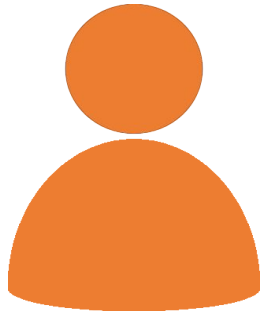
Practical research

What **design guideline** can be proposed to comply with the **design for disassembly requirements** of the **Cradle-to-Cradle** certification?

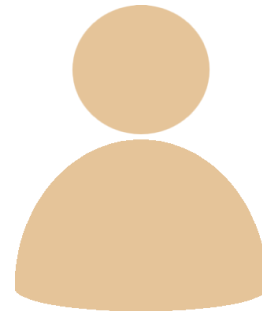
Project Workflow in Aldowa



Who are the main stakeholders in Aldowa involved in the decision making of design for disassembly?



Sales department



Engineering department

When and how can the guideline be used?

When can the guideline be used?



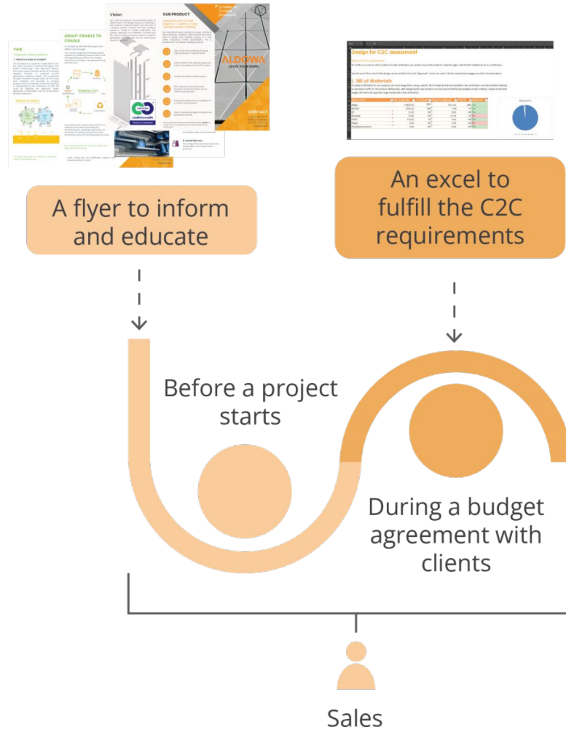
A flyer to inform and educate



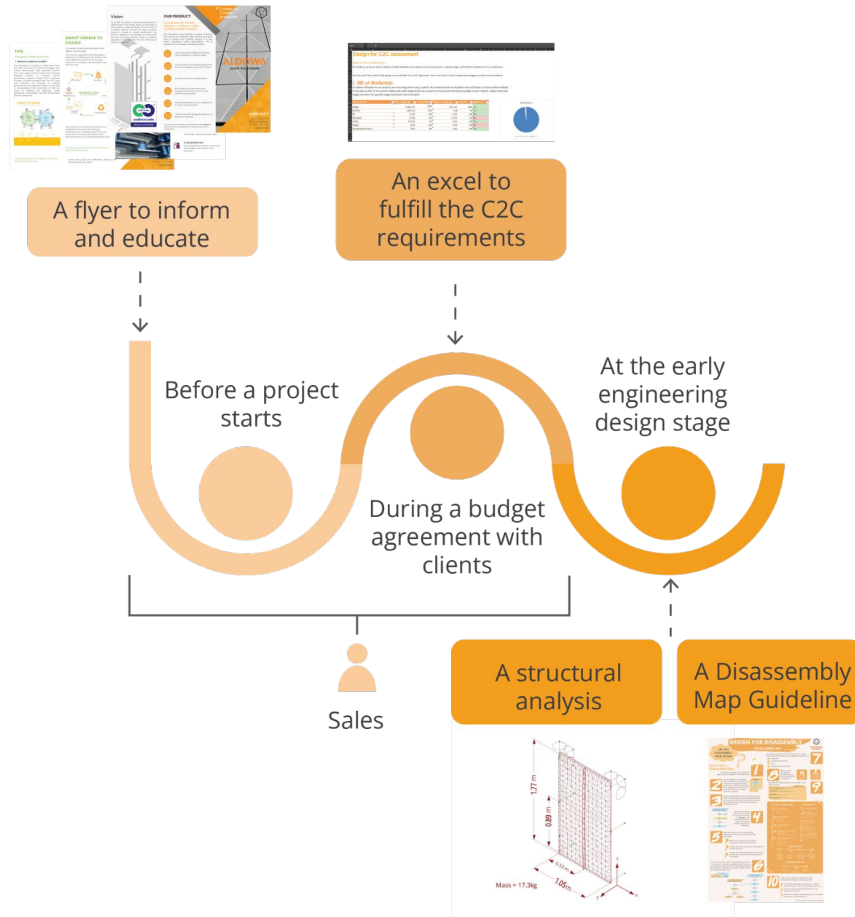
Before a project starts



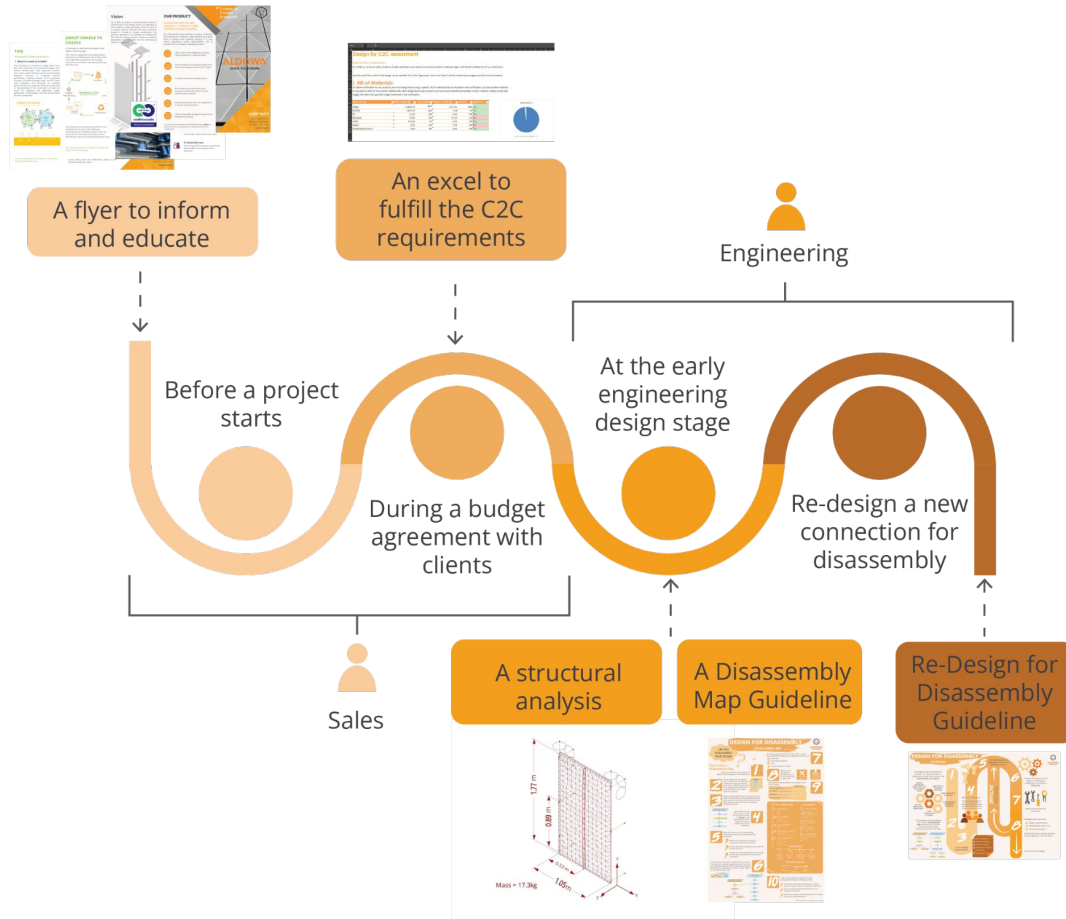
When can the guideline be used?



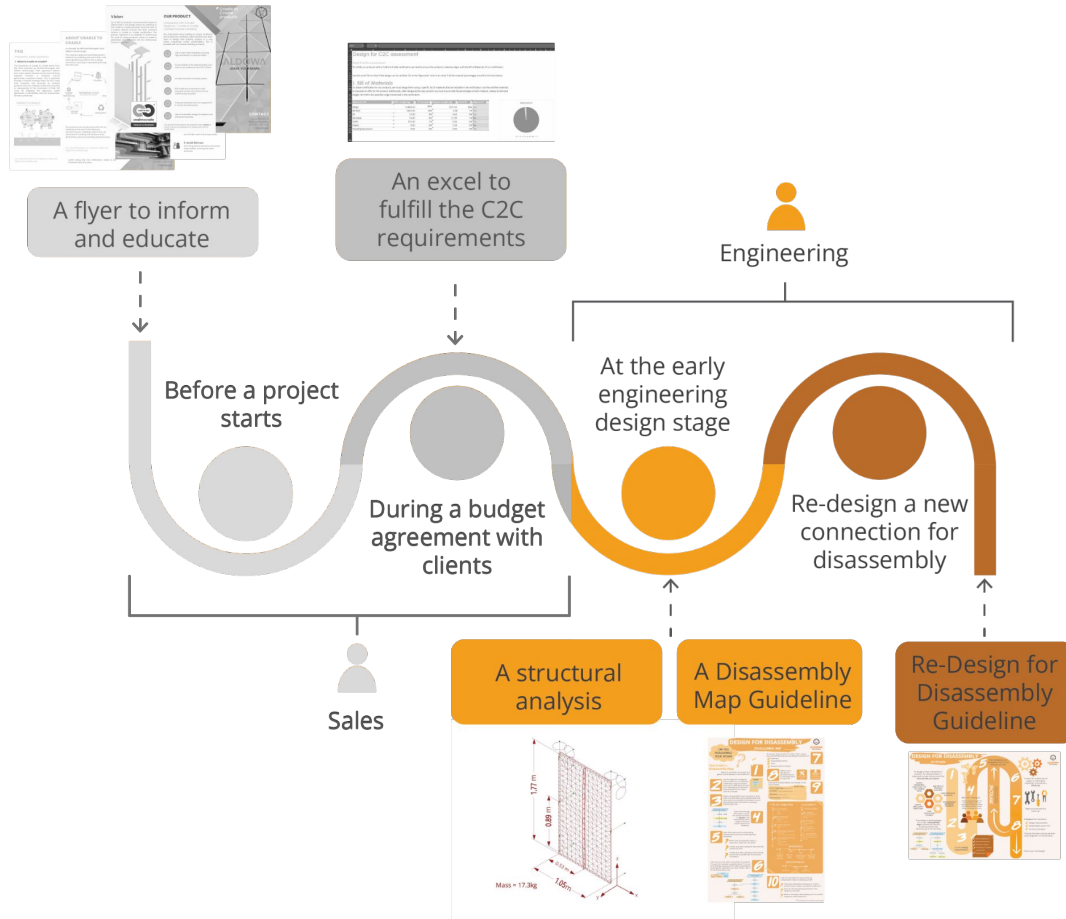
When can the guideline be used?



When can the guideline be used?



When can the guideline be used?



DfD Guideline

Introduction

DfD Guideline

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Before a project starts

FAQ

Frequently asked questions

1. What is Cradle to Cradle?

The foundation of Cradle to Cradle stems from the book authored by Michael Braungart and William McDonough. Their approach, distinct from other system theories aimed at minimizing negative impacts, is centered around generating a positive impact. This is achieved through a twofold strategy: firstly, by NOT using toxic materials, and secondly, by creating products that can undergo continuous recycling or repurposing at the conclusion of their life cycle. By adopting this approach, waste generation is eliminated, and the environment remains unharmed.

CRADLE TO CRADLE

A concept by Michael Braungart and William McDonough



For more information on Cradle to Cradle visit:
<https://c2ccertified.org/>

2. What does a Cradle-to-cradle Certification mean?

The Cradle to Cradle Products Innovation Institute (C2CPII), located in San Francisco, has developed an evaluation system aimed at creating, assessing, and certifying products that meet the C2C requirements. In response to the increasing demand for building certifications like LEED, BREEAM, and DGNB in recent years, there has been a corresponding rise in the need for sustainable materials and products.

C2C certification serves as an independent confirmation of a product's quality, encompassing various aspects. It verifies compliance with harmful emissions throughout installation, usage, and dismantling processes. Moreover, the certificate holds weight as evidence of sustainability, making it valuable for use in tender specifications that prioritize eco-friendly solutions.

3. Why do the products need to be demountable?

Design for disassembly means that the product is designed in such a way that the product can be demounted from the building and dismantled into assemblies and further into parts in a non-destructive way. After the disassembly process the parts can be recovered, sorted and inspected to apply an R-strategy (Reuse, refurbish, repair, remanufacture or repurpose) to extend its service life.

4. How does the certification work?

To achieve the certification, Aldowa must demonstrate strict adherence to all the certification standards, documenting and providing corresponding certificates and measurements as evidence. The certification body conducts a conformity check based on the submitted documents. Only upon meeting all the requirements, Aldowa is granted the certificate. It's worth noting that the certification needs to be renewed every two years.

If any materials are found to be in the RSL (Restricted substances list), Aldowa must replace them with other material alternatives. This process ensures that the company's facade products meet the highest environmental and sustainability standards. Due to the strict analysis of the composition of materials, which extends deep into the supply chain, Aldowa involves suppliers and subcontractors in the process. To protect sensitive information, such as production processes, suppliers may use non-disclosure agreements (NDAs) to safeguard their business secrets.

5. What is the difference between general recycling and Cradle to cradle recycling?

Recycling, especially aluminium recycling, faces challenges due to impurities, leading to "downcycling" where materials lose their technical quality. Cradle to Cradle recycling aims for consistent, high-quality circulation by proper disassembly, separating materials to prevent contamination and preserve their value from manufacturing and finishing processes.

CONTACT

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During a budget agreement with clients

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51										1-stu(NORFF) 7-RVS-staal 8-SY-staal			co-composit	e-estruis												15.33%	m2 composiet	148.73	133182		

27 non-destructive way. This ensures that the part being dismantled remains intact and can be reassembled or used

28

< > | aldowa | uitwerking | **C2C Check** | Bijlage tbv Klant | Budgetten | Bruterung plaatmaten | Coaten

During a budget agreement with clients

O15

Design for C2C assessment

Read this for explanation:

To certify our products with a Cradle to Cradle certification we need to ensure the product's materials aligns with the Bill of Materials of our certification.

Use this excel file to check if the design can be certified. Go to the "Approved" column to check if all the material percentages are within the boundaries.

I. Bill of Materials

To obtain certification for our products, we must design them using a specific list of materials that are included in the certification. Use the certified materials to calculate an offer for the product. Additionally, after designing the new product, we must ensure that the percentages of each material, relative to the total weight, fall within the specified range mentioned in the certification.

Material List	C2C weight [g]	% Accepted	Project weight [g]	Total %	Approved
AlMg1	14869.20	80%	1331.82	98%	Yes
RVS304	3365.60	18%	6.98	1%	Yes
PE	15.00	0%	0.00	0%	Yes
Bimetaal	74.80	0%	12.99	1%	No
HDPE	152.00	1%	0.00	0%	Yes
Plastic	0.00	0%	5.94	0%	No
Polyethylenschuim	0.00	0%	0.00	0%	Yes

Material %

• 1 • 2 • 3 • 4 • 5 • 6 • 7

1. Bill of materials check
2. Right quantities (kg)

During a budget agreement with clients

K39

II. Connections

To design for disassembly it is necessary to choose connections that are detachable. In this way we can disassemble all the parts in a non-destructive way. This ensures that the part being dismantled remains intact and can be reassembled or used again, if needed.

For a circular design we should strive to use connections with a **score above 0.5!**

Type of connection	Detachability score	Quantity
Dry	1.00	
Click	1.00	
Velcro strap	1.00	
Magnet	1.00	
Bolt and nut connection	0.80	669.23
Ferry screw connection	0.80	
Corner	0.80	
Screw	0.80	794.15
Connection with extra connective elements	0.80	
Direct integral connection	0.60	
Spike/nail connection	0.60	0.00
Kit connection	0.20	0.00
Pur connection (Polyurethaan)	0.20	
Glue connection	0.10	
Poured connection	0.10	
Laser connection	0.10	0.00
Cement connected	0.10	
Chemical anchors	0.10	
Hard chemical connection	0.10	

Total score= 0.80

aldowa uitwerking C2C Check Bijlage tbv Klant Budgetten Bruterung plaatmaten Coaten Perforatie+clusters Alumet



BUILDING
CIRCULARITY
INDEX®

At the early engineering design stage

DESIGN FOR DISASSEMBLY



CAN YOU DISASSEMBLE YOUR DESIGN

DISASSEMBLY MAP

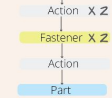
Test it with a Disassembly Map

Select an assembly of a project and gather a 2D drawing or a 3D model of it.

2 Use this legend to categorize each component. An assembly is defined as a group of parts and a part is defined as an item of an assembly and cannot be disassembled further down, such as a bracket.

3 Make a disassembly map to visualize in what order the assembly can be disassembled and what actions are needed. Remember to use a disassembly action box before reaching a fastener/part box:

Assembly name

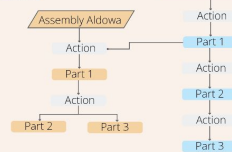
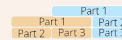


If you have enough information, record the amount of times (X AMOUNT) the disassembly action needs to be done and the amount of fasteners.

5 Map all the parts and corresponding disassembly actions by answering these questions:

- Which next disassembly step(s) is required to reach the next part?
- Is there any other operation that could be carried out first?
- Is there any other operation that could be carried out in parallel with the one just completed?

Take into account other assemblies of products. If a part from another assembly (even if it is not from Aldowa) needs to be first dismantled before accessing the assembly you have chosen, add it to the disassembly map.



1 START

LEGEND
Assembly
Parts
Fasteners
Disassembly action

4

6

Draw your map by hand or in Mira. Then, assess your disassembly map by calculating the amount of:

- Fasteners
- Disassembly actions
- Parts
- Amount and list of tools

8 Make sure to identify the penalties and try to eliminate them in step 10!!!!



Calculate the detachability score based on the scores below:

TYPE OF CONNECTION (Action boxes)	AVERAGE SCORE
ACCESSIBILITY (Part & fastener boxes)	
ROBUSTNESS (Part boxes)	
INTERDEPENDENCE (Assemblies)	

TYPE OF CONNECTION



ACCESSIBILITY



ROBUSTNESS



INTERDEPENDENCE

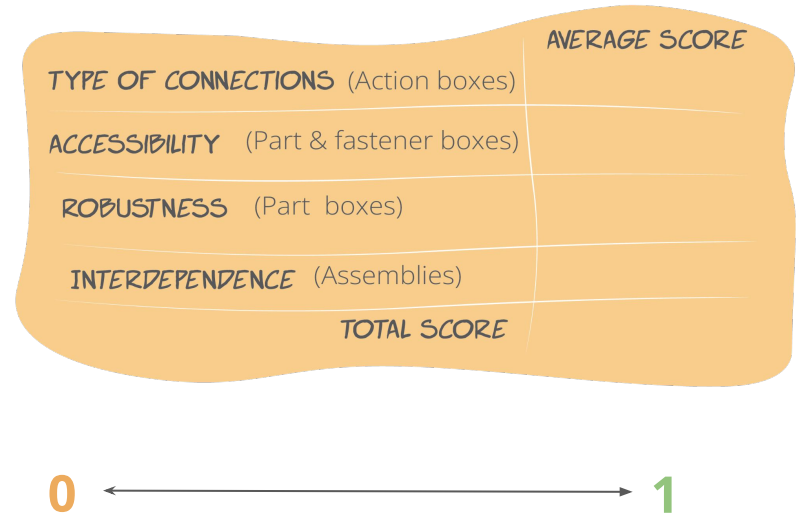
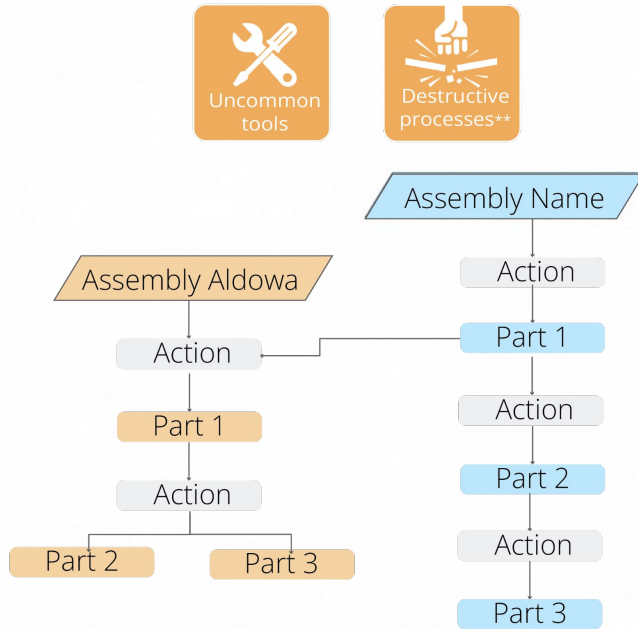


10 Improve the design for disassembly by analysing the map and asking yourself:

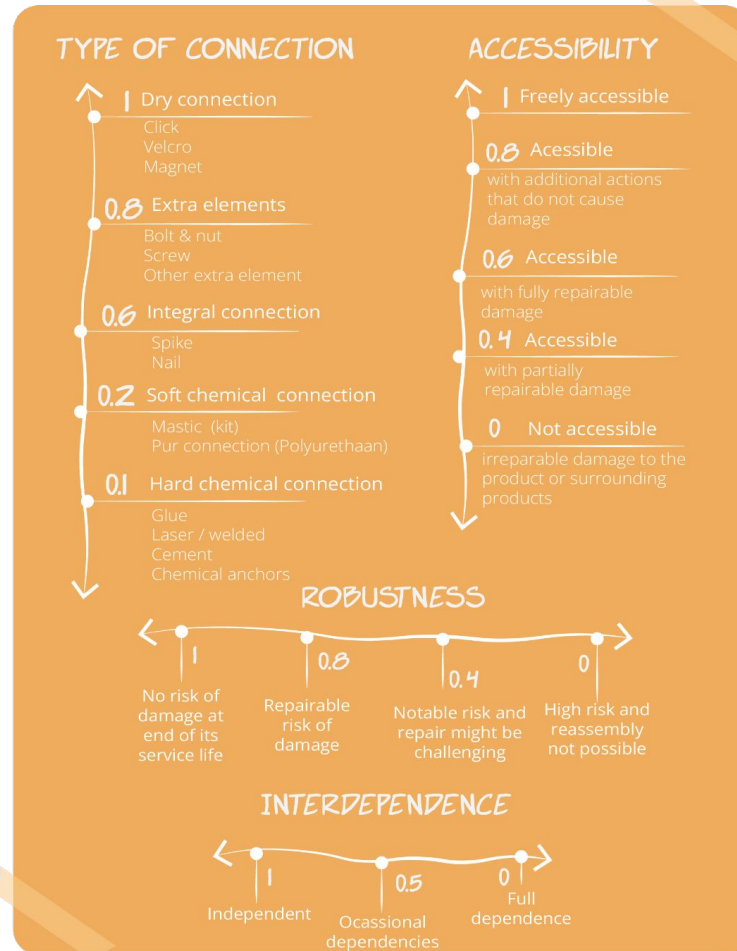
- Is this part absolutely necessary or is there another way to make a connection without it?
- How can the disassembly penalties in the design be reduced?
- What is the lowest detachability score and what measures could improve it?

**dismantling a part in a way that causes damage

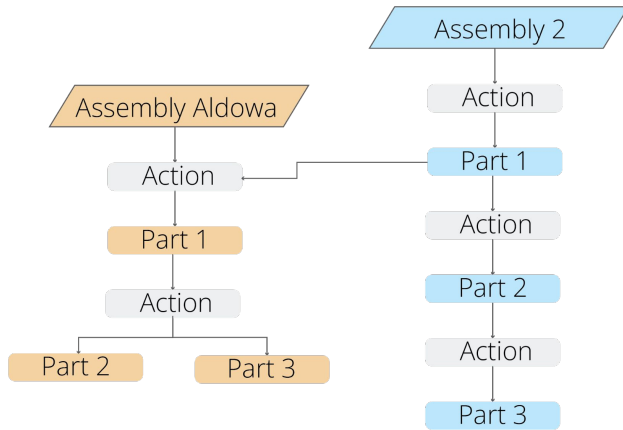
What is a disassembly map?



Detachability score



Findings



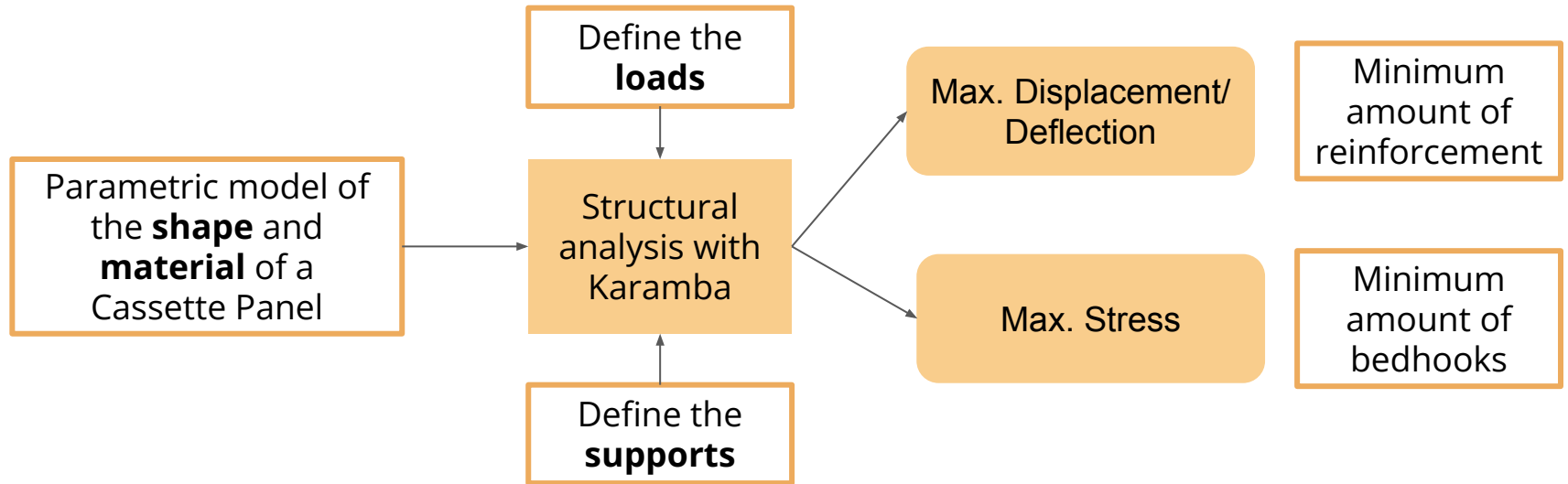
- It can be used in the **early design stages**: when an engineer receives the drawings from sales
- **Quick** way to assess the disassembly potential of an assembly
- **Disassembly barriers** can be **detected** easier in a visual map
- An initial **disassembly score** can be set as a **base** to **improve or compare** the re-design
- It has a degree of **subjectivity**

Design for Disassembly requirements for C2C

- 1 **Reduce** fasteners
- 2 **Decrease** disassembly steps
- 3 Eliminate destructive processes
- 4 **Minimize** tools
- 5 Use detachable fasteners
- 6 Accessible critical parts
- 7 **Increase automation** of disassembly

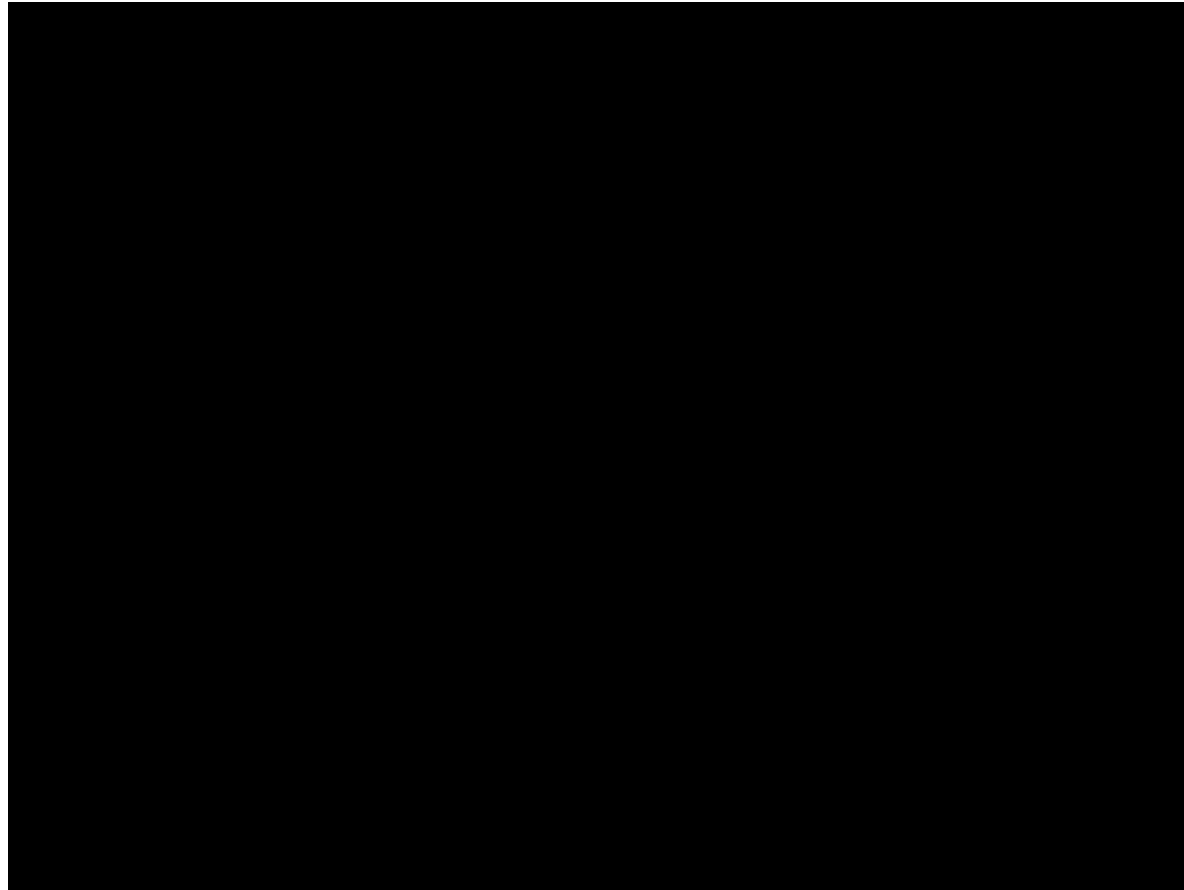
SAFE STRUCTURE

At the early engineering design stage





At the early engineering design stage



Benefits of minimizing connections



Reduce
disassembly time



Lower risk of
damage



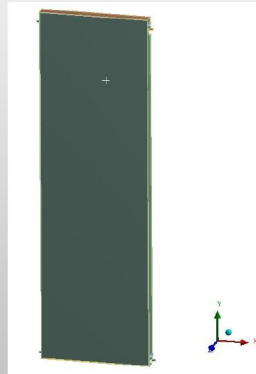
Easier to
separate & user
friendly



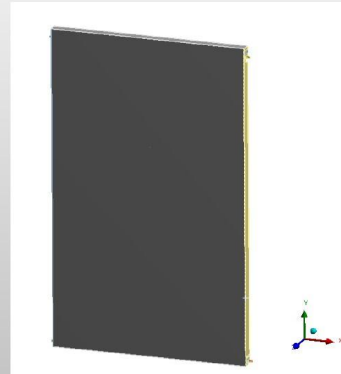
Costs savings in
material and
labour

Comparing results with Ansys Model

Geometry



3mm(527x1775mm)



3mm(1054x1775mm)

Comparing results with Ansys Model

	Panel A		Panel B	
	Highrise BV	Grasshopper Simulation	Highrise BV	Grasshopper Simulation
Total displacement [mm]	8.48	14.0	8.58	17.0

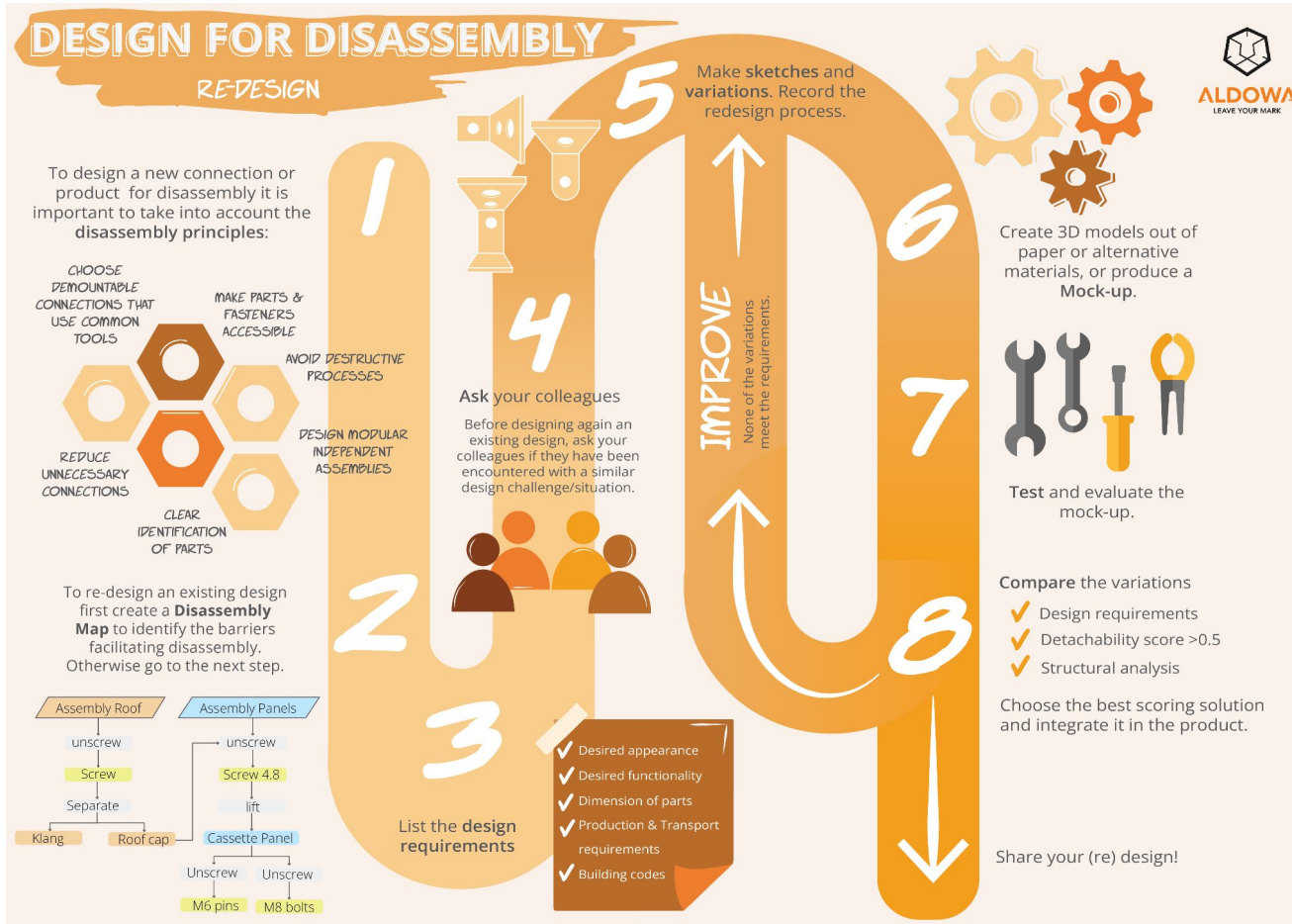
+/- 6.8 mm

Comparing results with Ansys Model

	Panel A		Panel B	
	Highrise BV	Grasshopper Simulation	Highrise BV	Grasshopper Simulation
Total displacement [mm]	8.48	14.0	8.58	17.0
Total displacement [mm]	8.48	10.9	8.58	9.8

+/- 1.2 mm

Redesign a new connection



Cradle-to-Cradle Case study

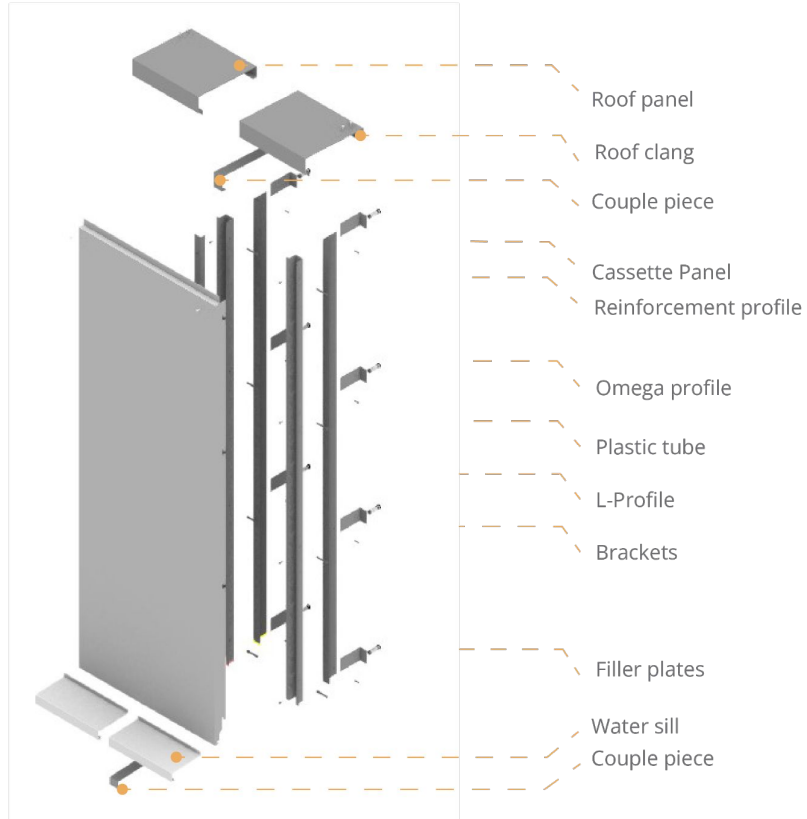
Introduction

DfD Guideline

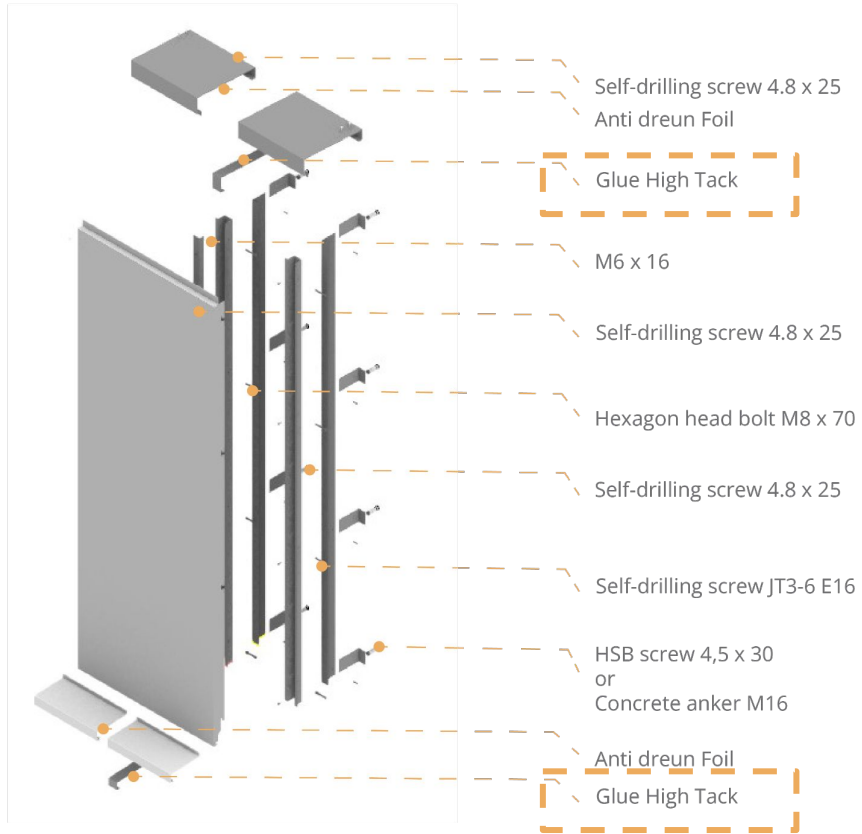
Case study

Conclusion

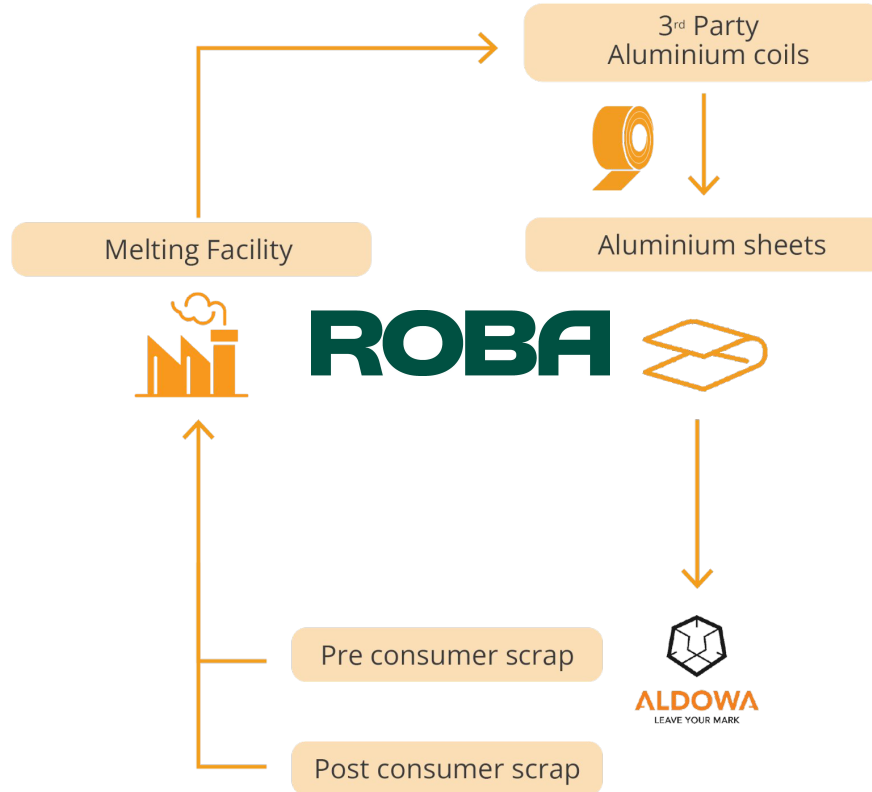
Case study



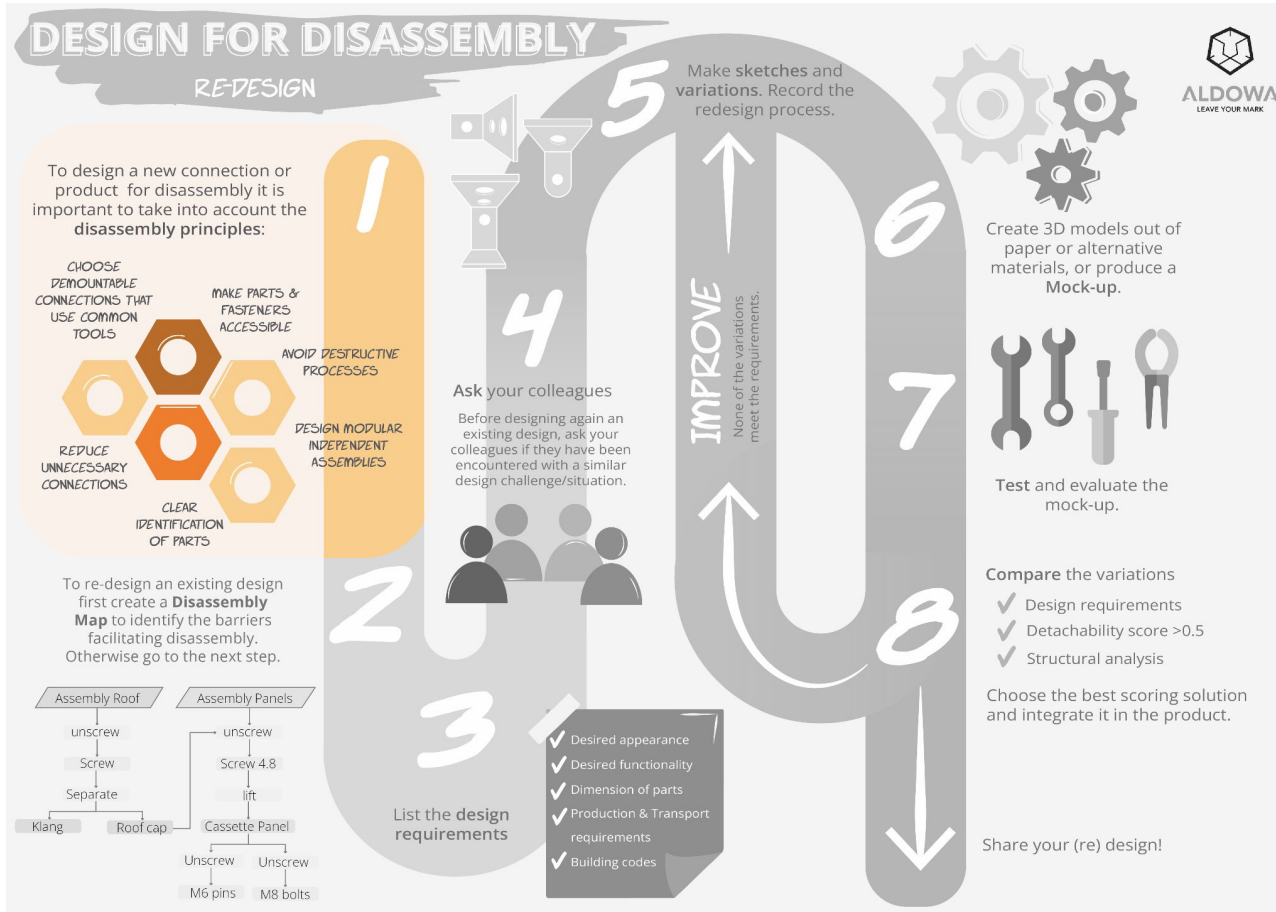
Fasteners



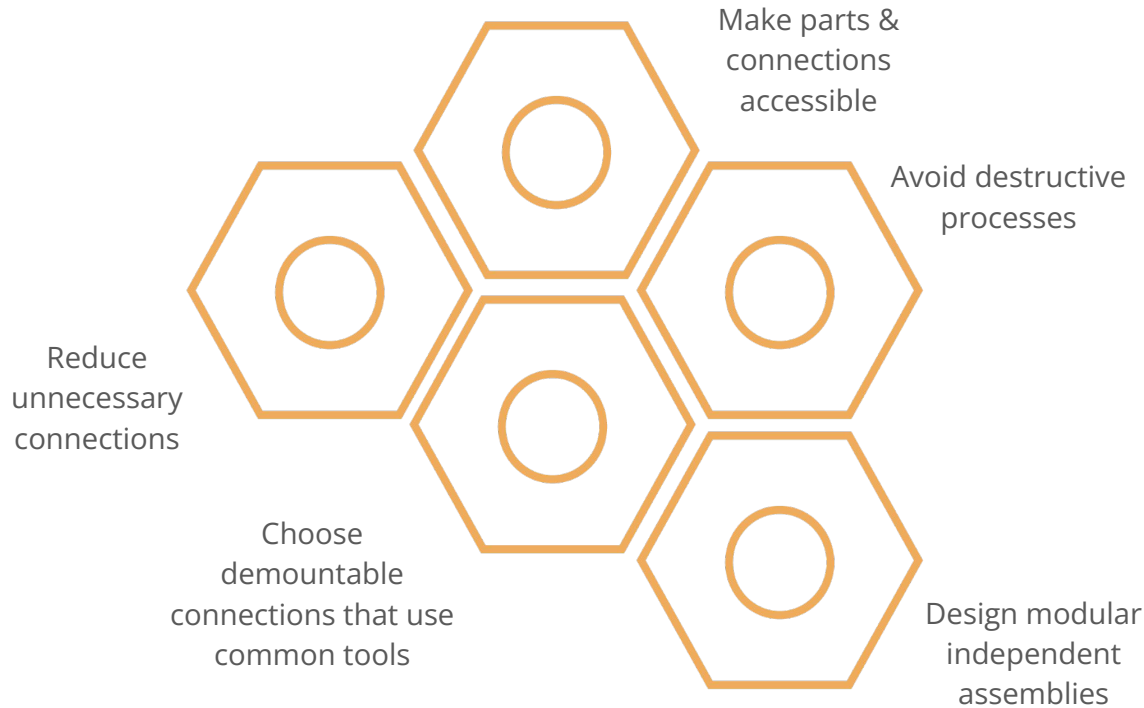
Recovery scenario



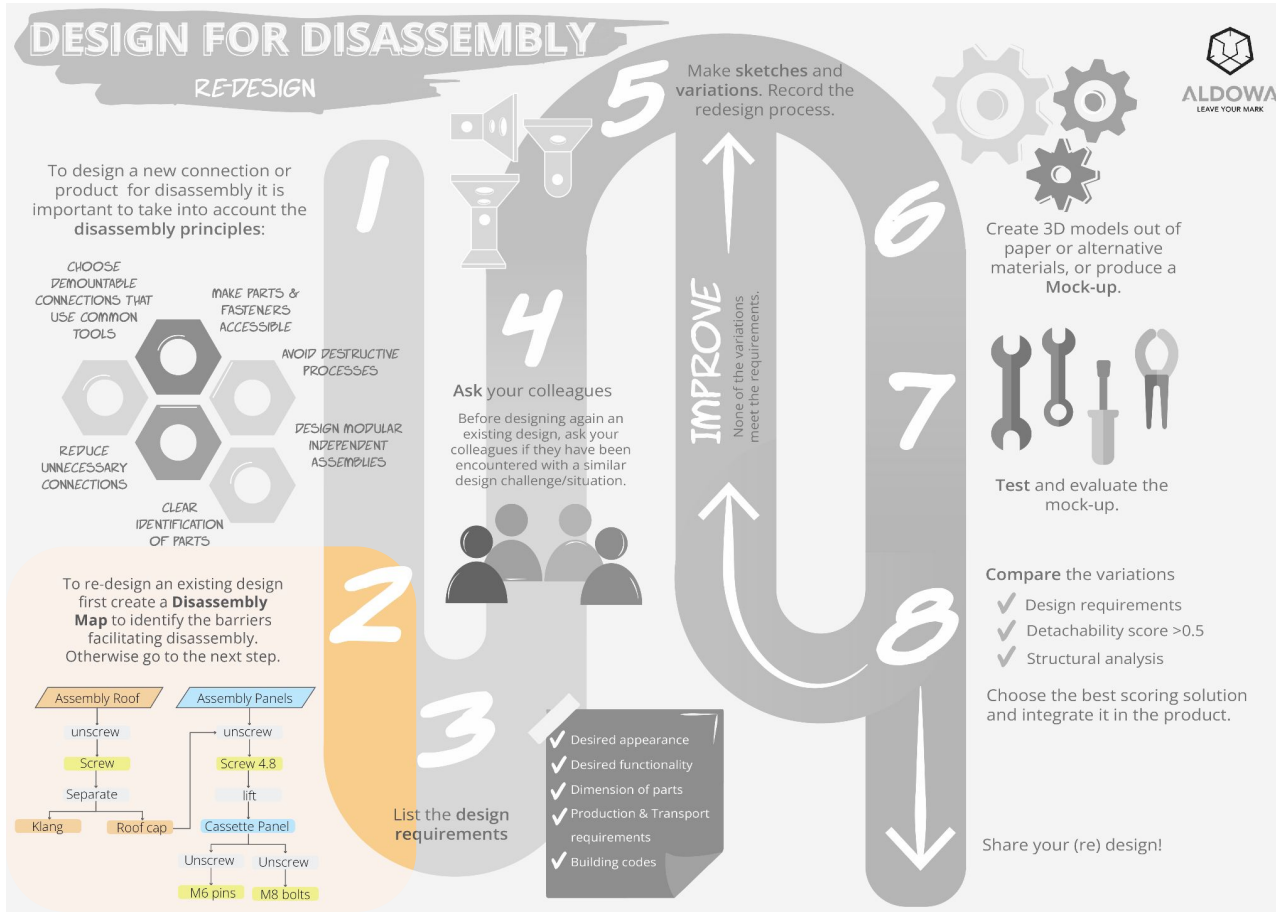
Overview of the guideline



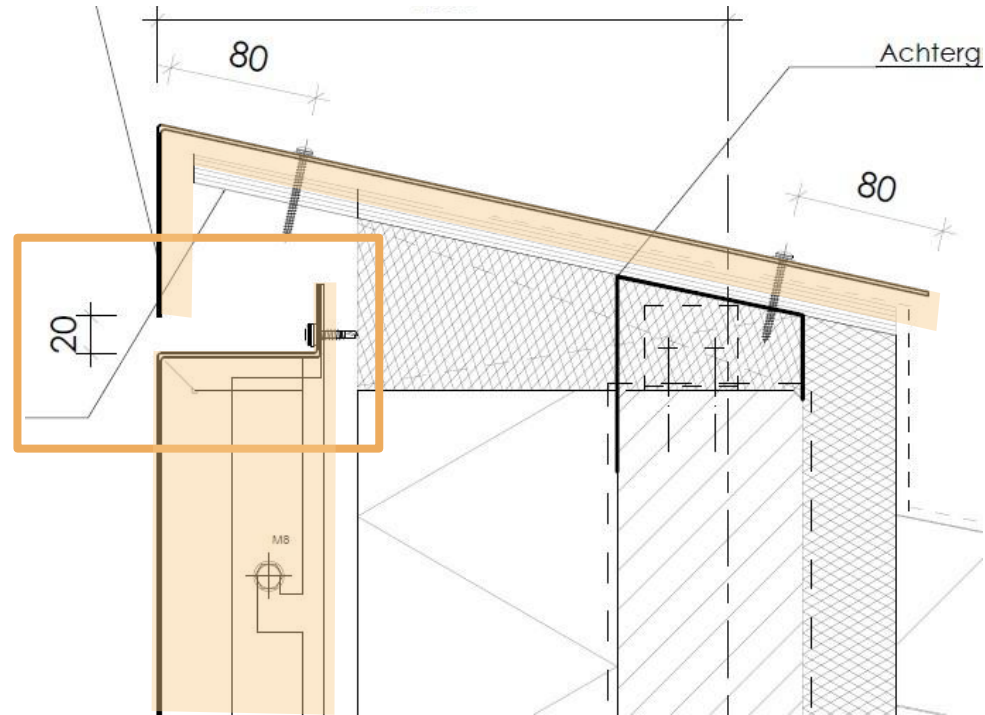
1. Take into account the disassembly principles



Overview of the guideline

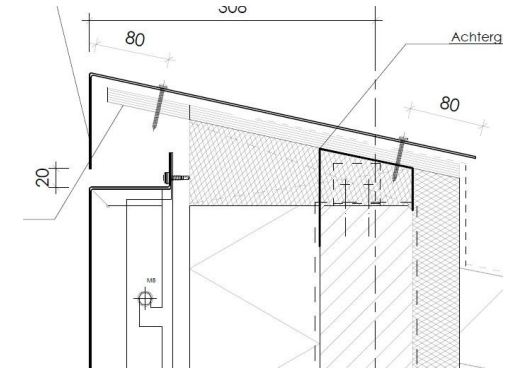
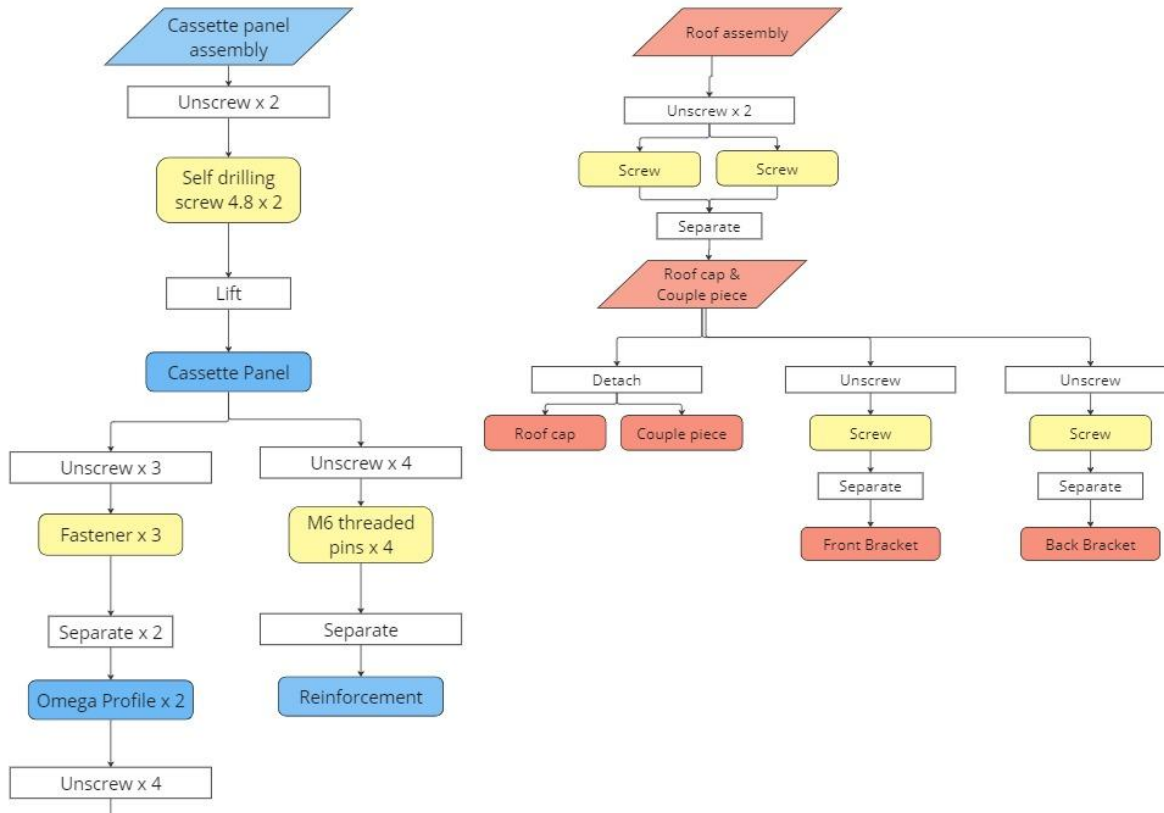


2. Create a disassembly map to identify the barriers



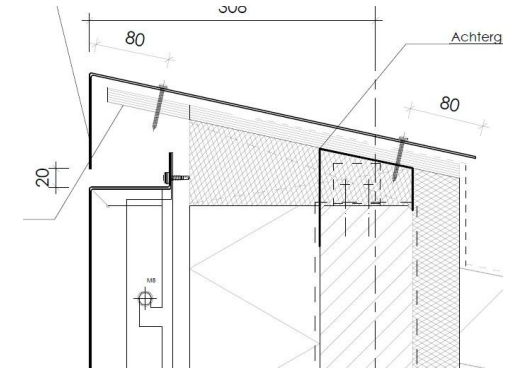
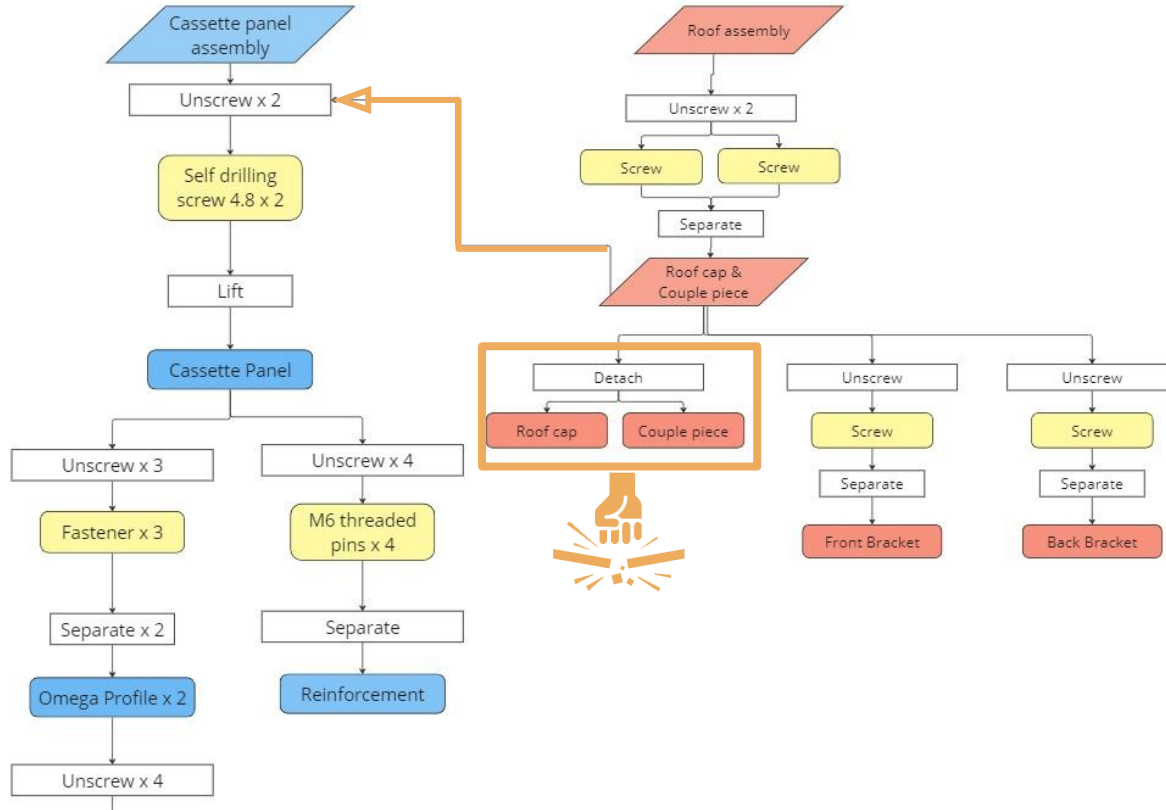
Case study: Project Logistiek & Milieu

2. Create a disassembly map to identify the barriers



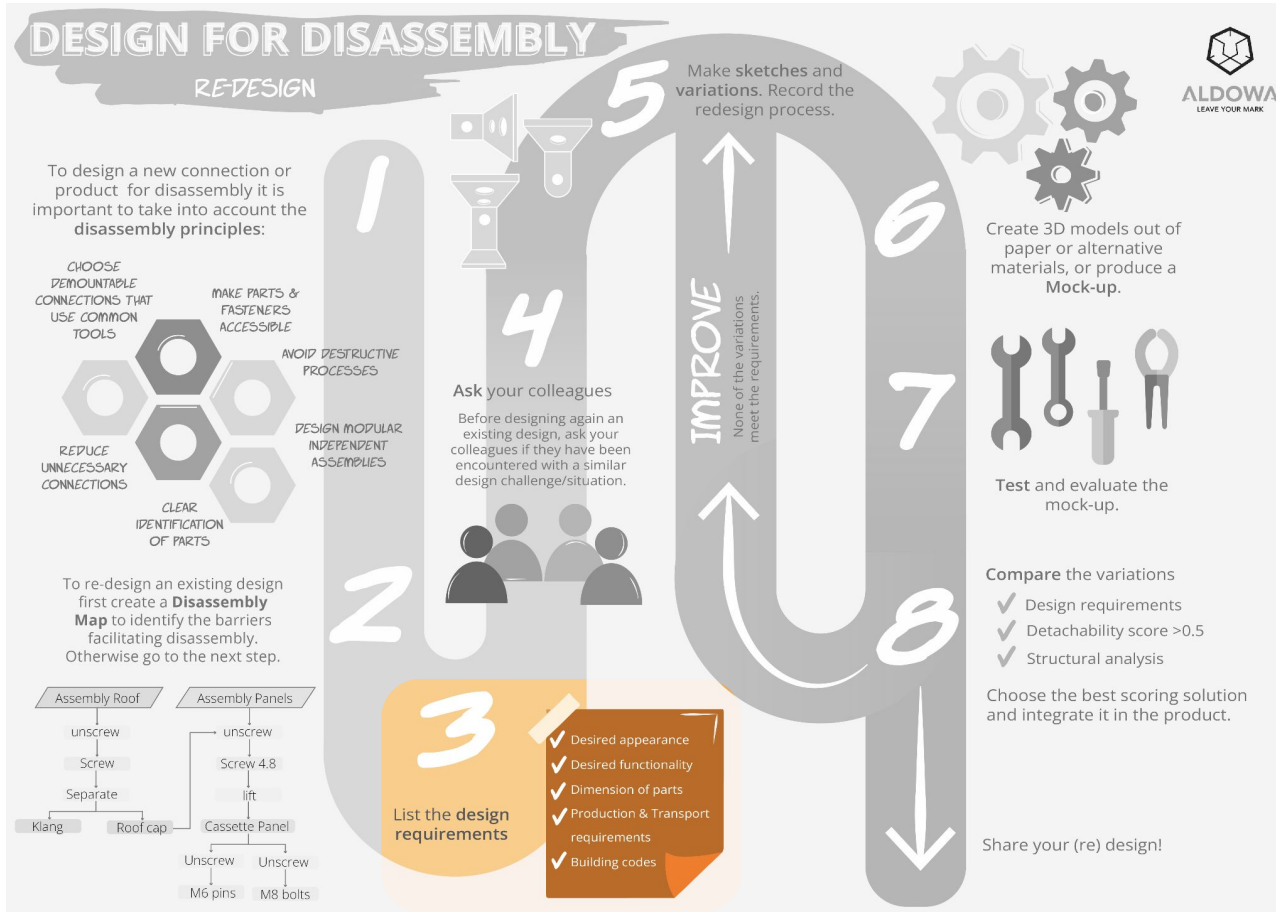
Case study: Project
Logistiek & Milieu

2. Create a disassembly map to identify the barriers

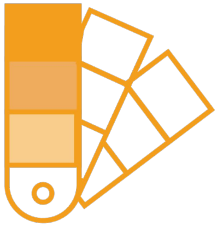


Case study: Project
Logistiek & Milieu

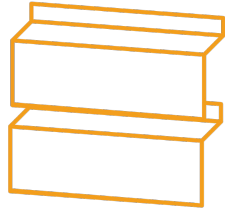
Overview of the guideline



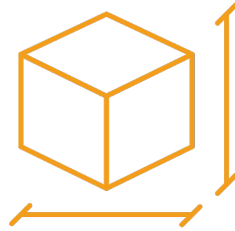
3. List the design requirements



Desired
appearance



Desired
functionality
& recovery
scenario



Dimension of
parts

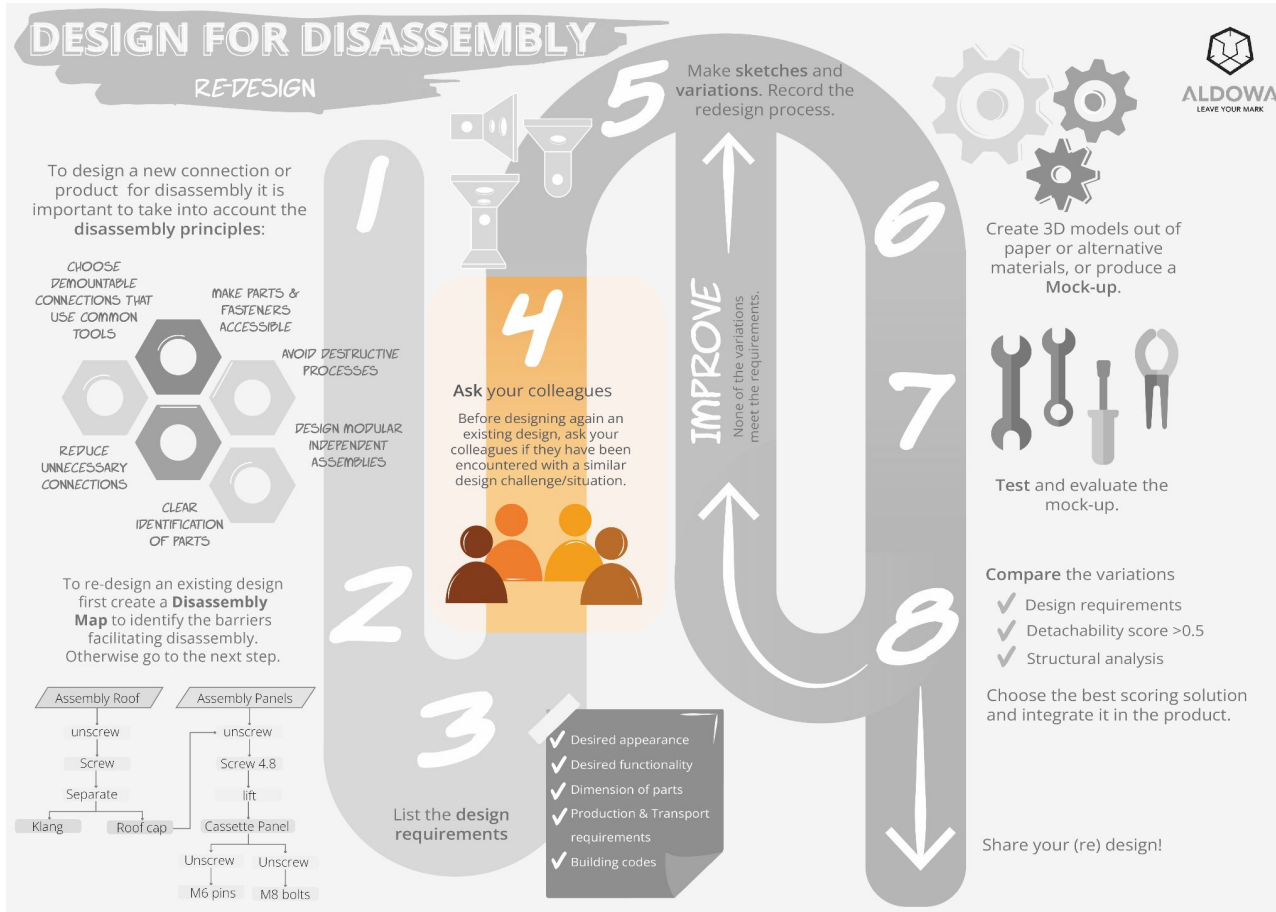


Production and
transportation
requirements

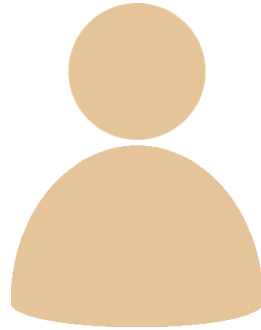


Building
codes

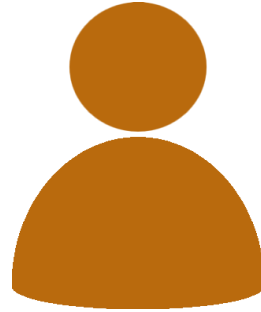
Overview of the guideline



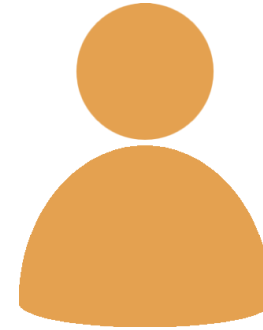
4. Ask colleagues



Engineers



Project Leaders



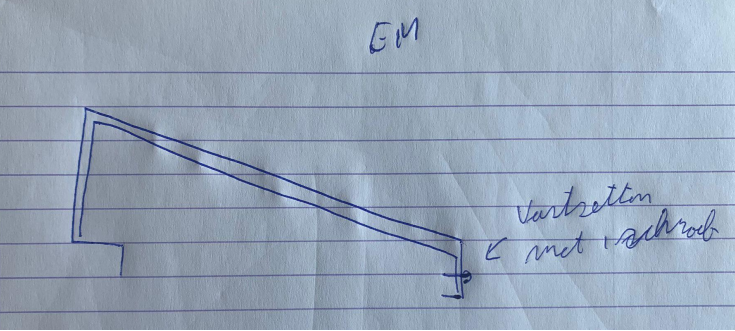
Production

Couple pieces are **loose pieces** without identification. They are mostly lost or **missing** at the building site.

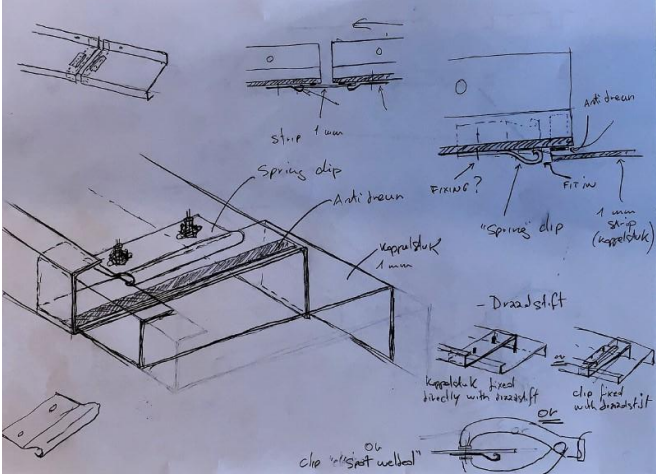
It takes **more time** to fix them here because it slows down the **production** process.

4. Ask colleagues - Couple pieces

Screwed at the back of the roof panel



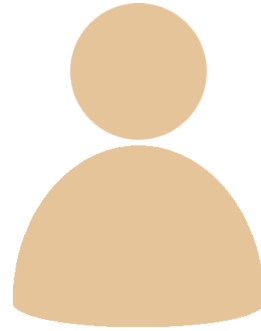
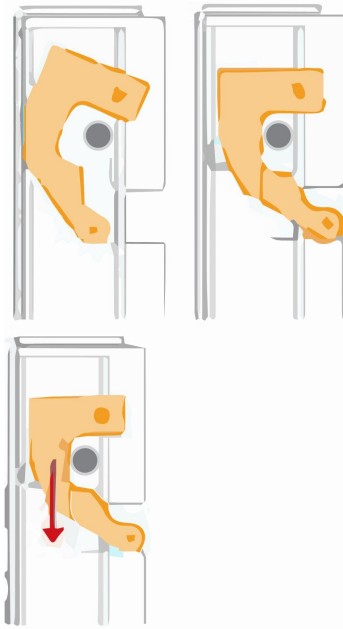
Clicking system



Drawings from Aldowa

4. Ask colleagues - Cassette Panels

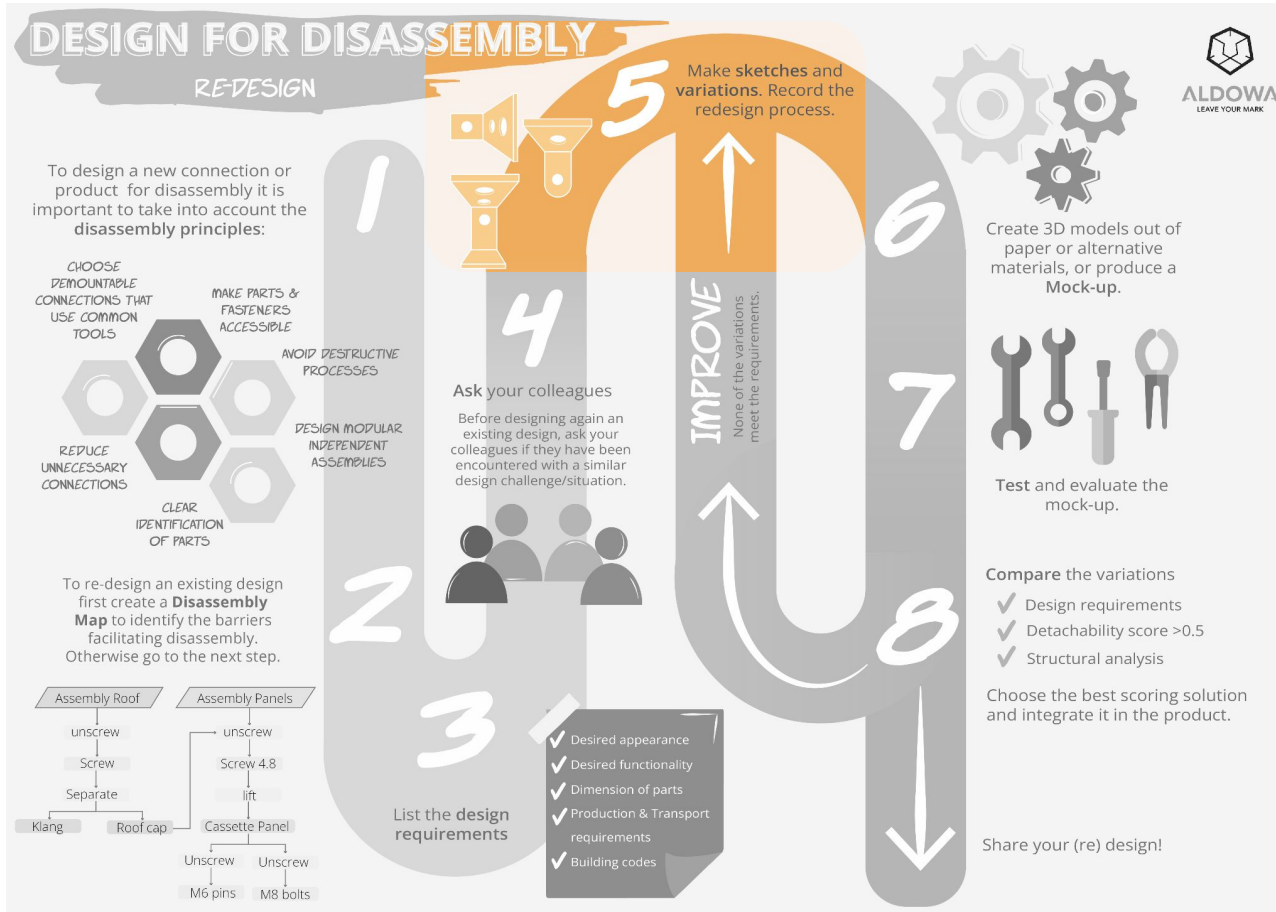
Click & Go



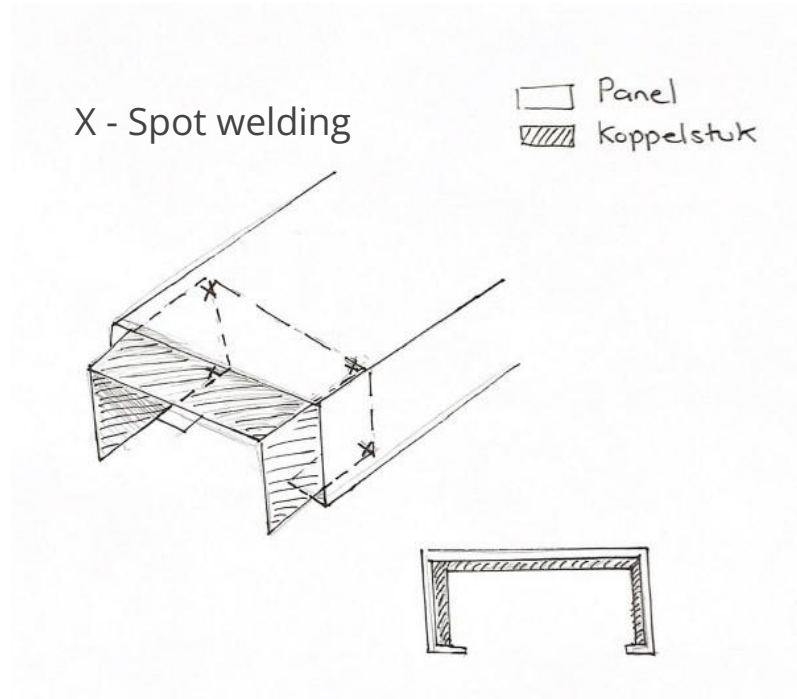
Engineers

(Aldowa, 2023)

Overview of the guideline

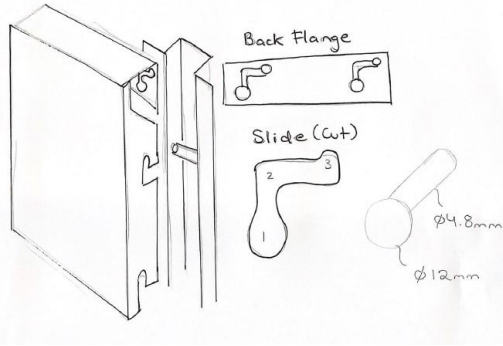


5. Make sketches and variations: Couple piece

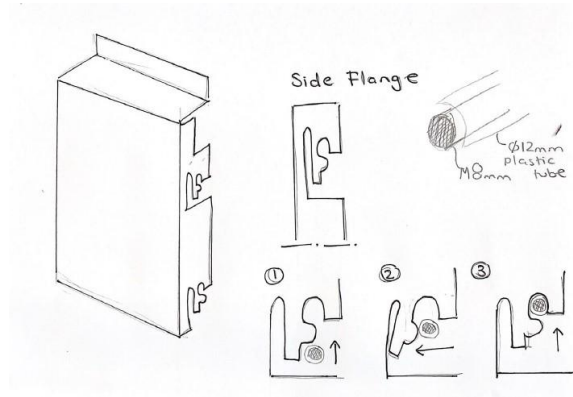


5. Make sketches and variations: Cassette panel

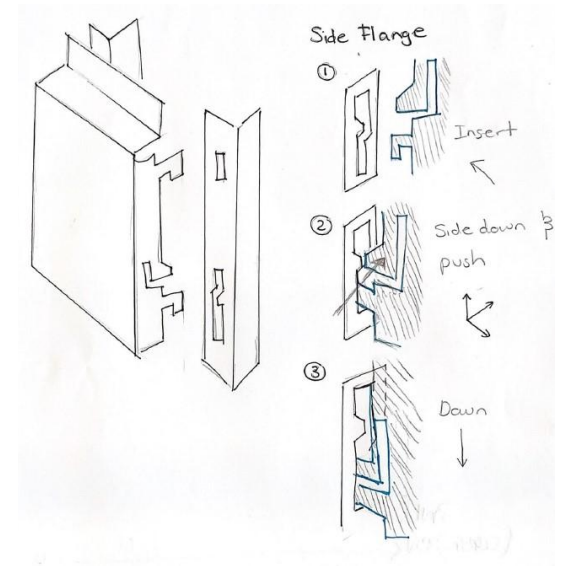
A. Sliding system



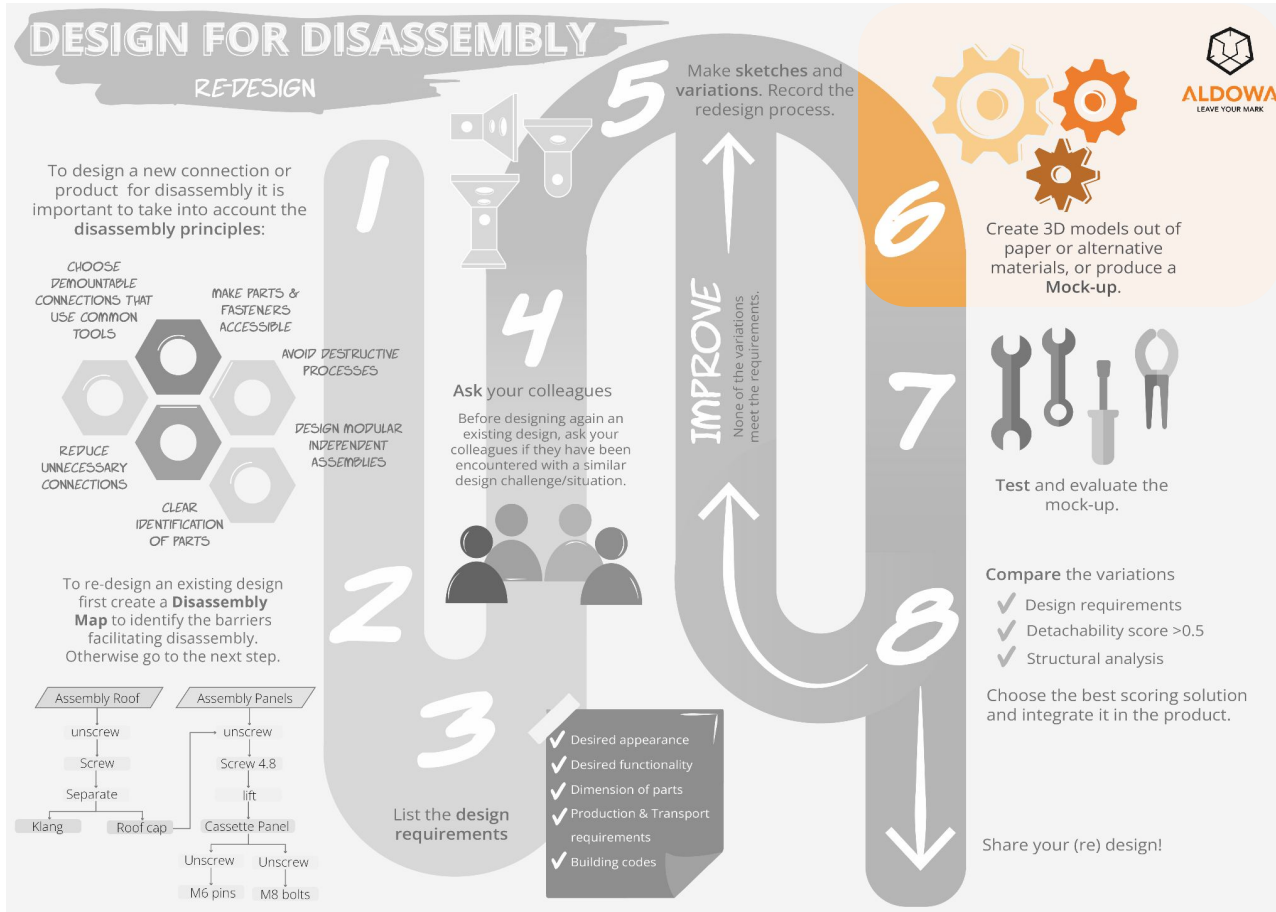
B. Clicking system



C. Snap fit system

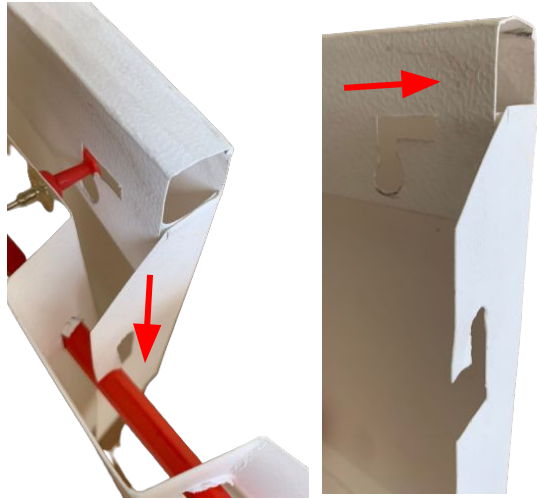


Overview of the guideline

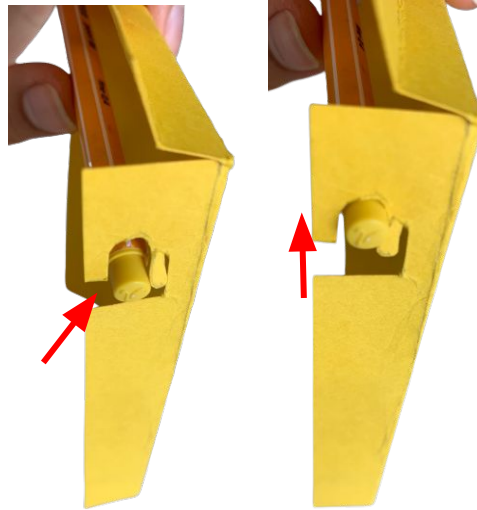


6. Create 3D models or a mock-up

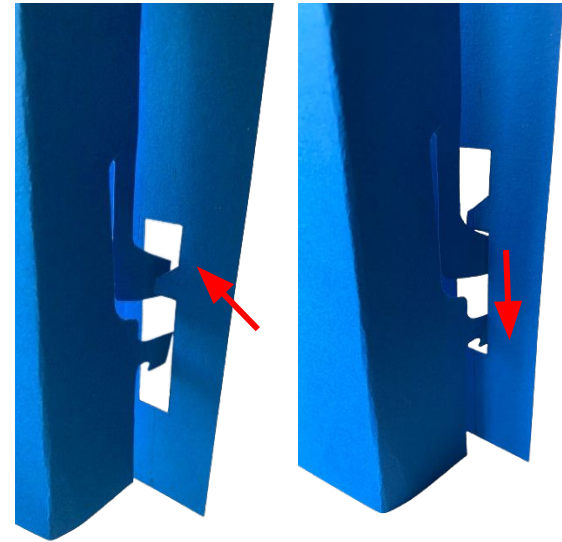
A. Sliding system



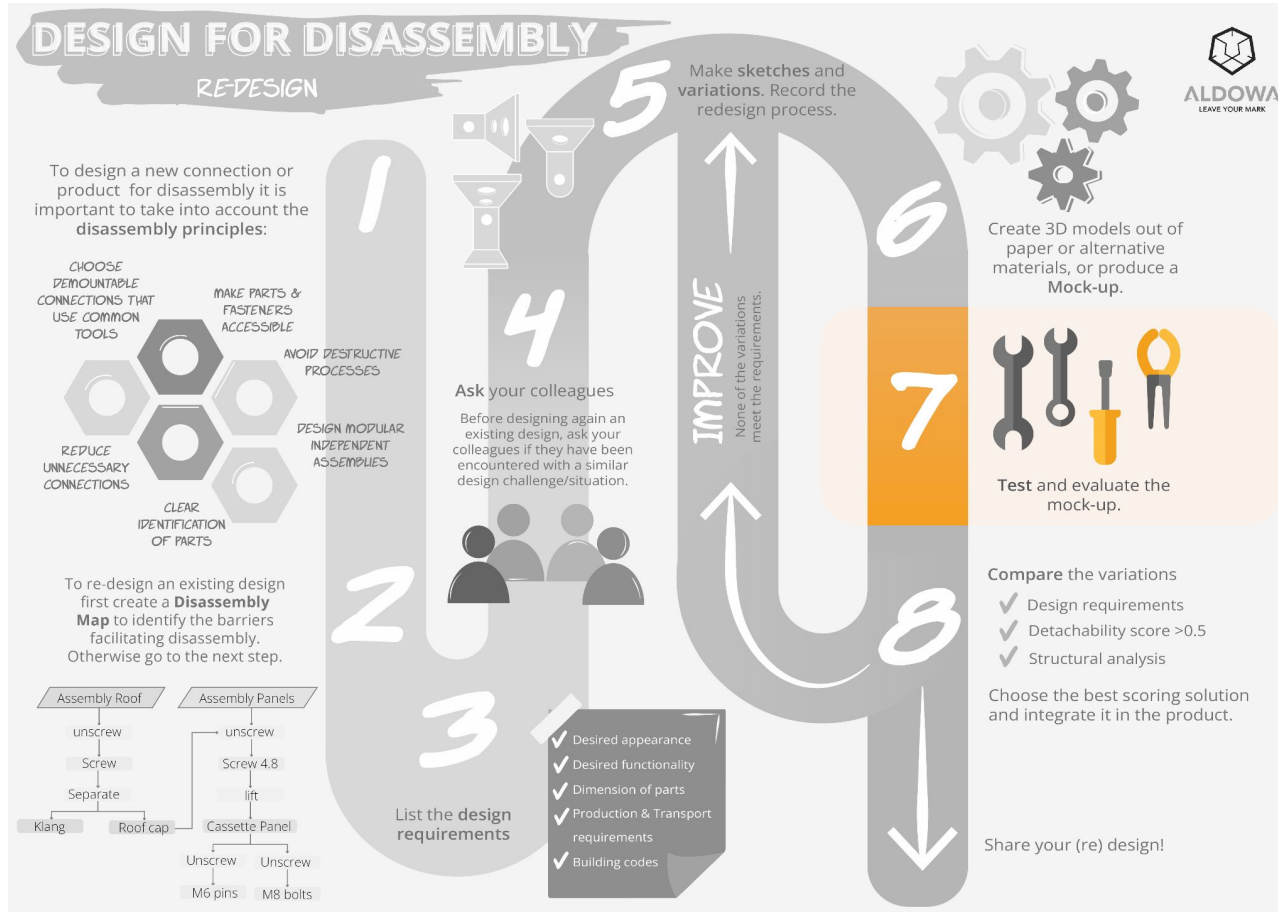
B. Clicking system



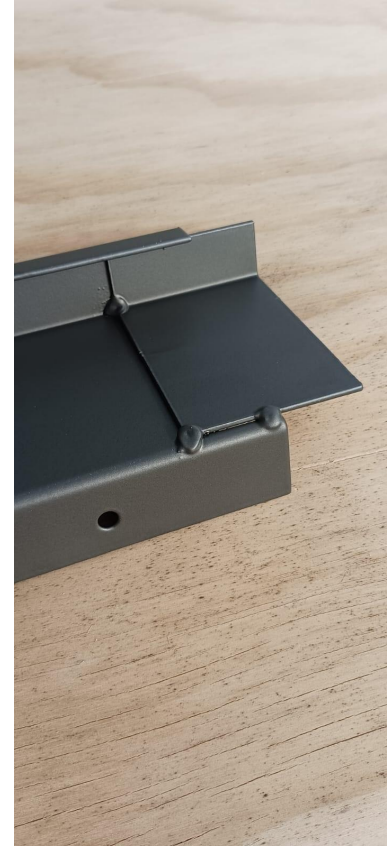
C. Snap-fit system



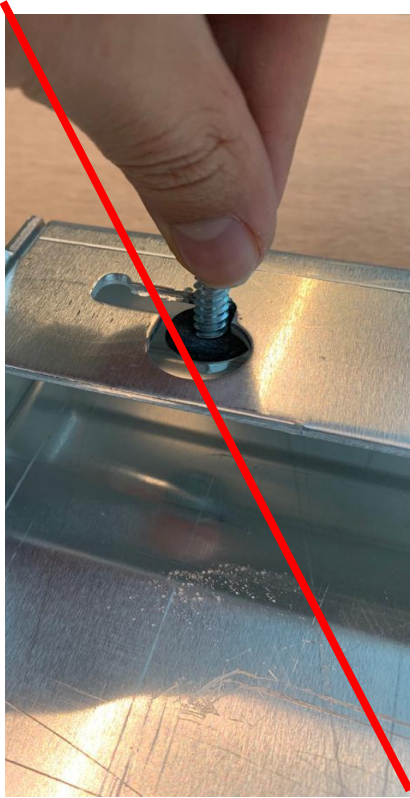
Overview of the guideline



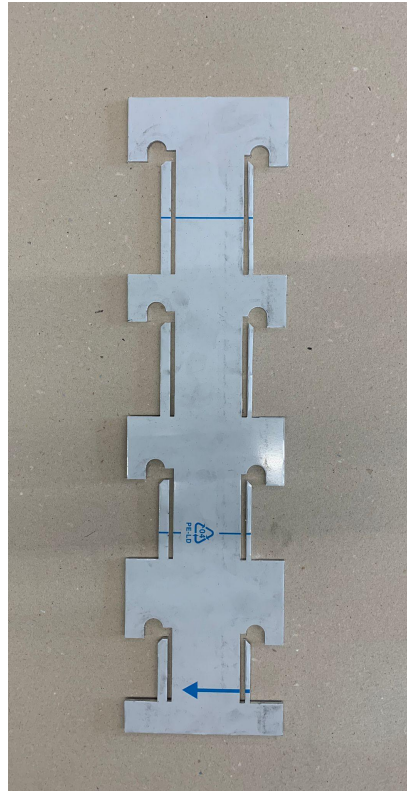
7. Test: Couple piece welded and coated connection



7. Test: Cassette Panel Connections



A. Sliding system

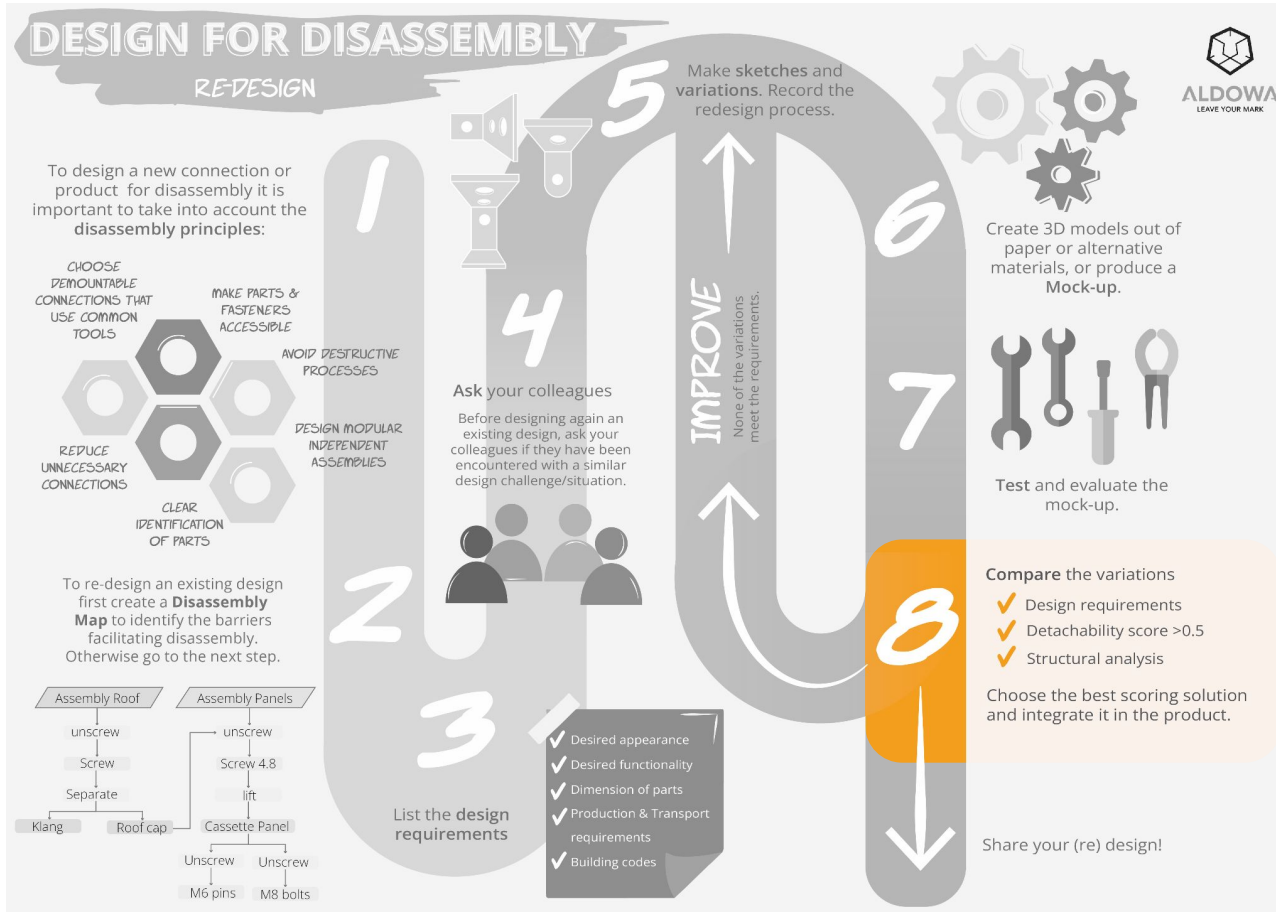


B. Clicking system



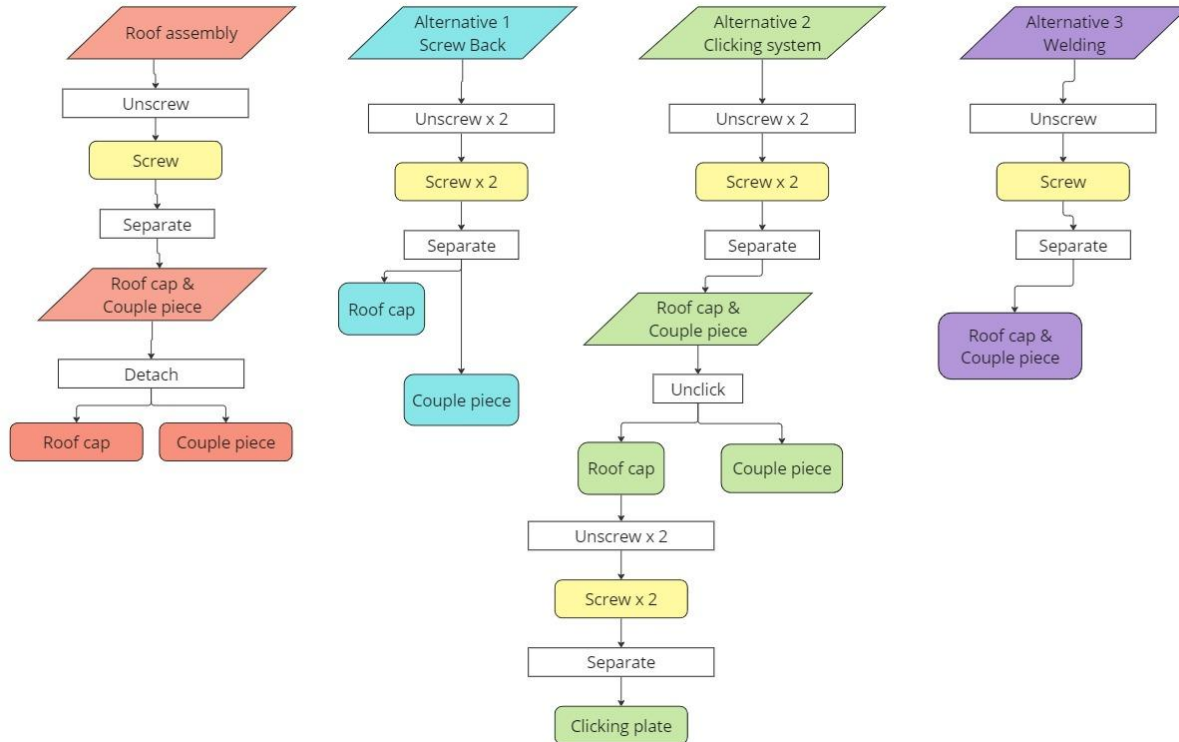
C. Snap-fit system

Overview of the guideline



8. Compare the variations: Detachability score

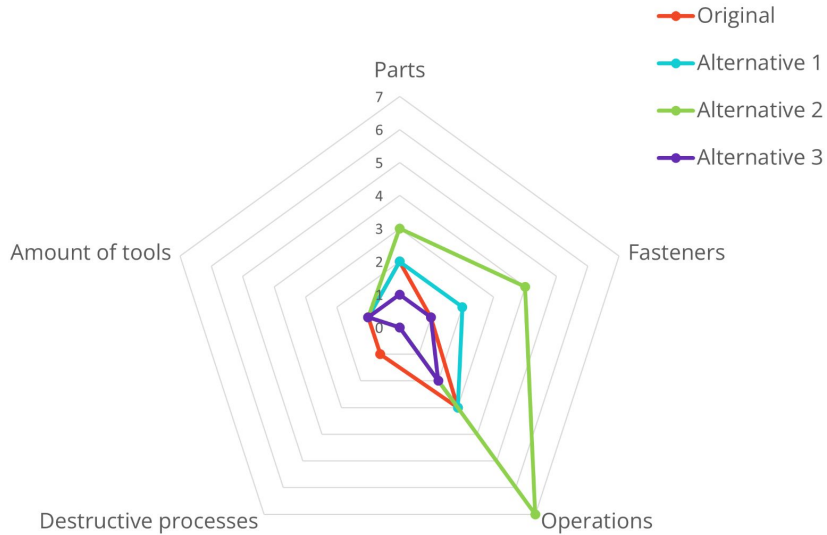
Couple pieces



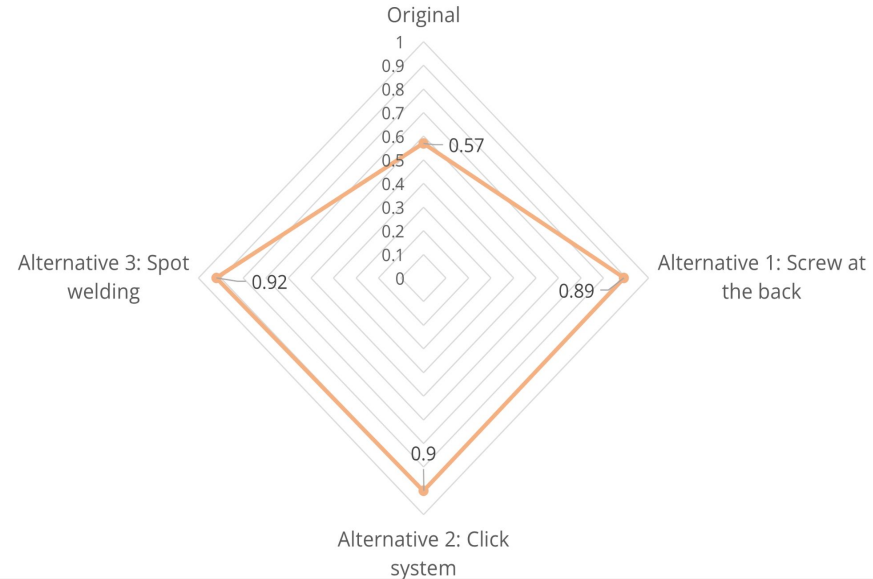
8. Compare the variations: Detachability score

Couple pieces

Disassembly Map Comparisons

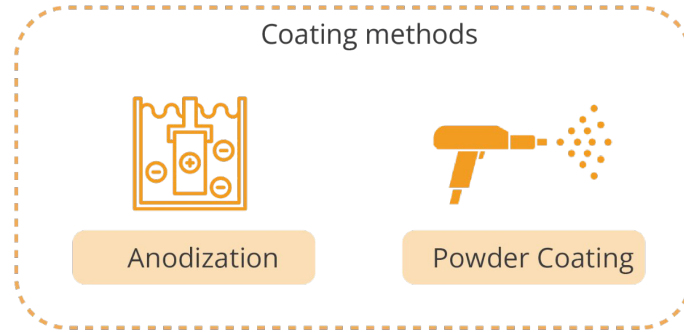


Detachability score

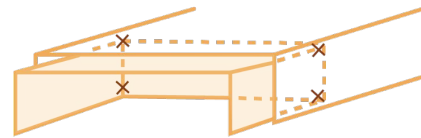
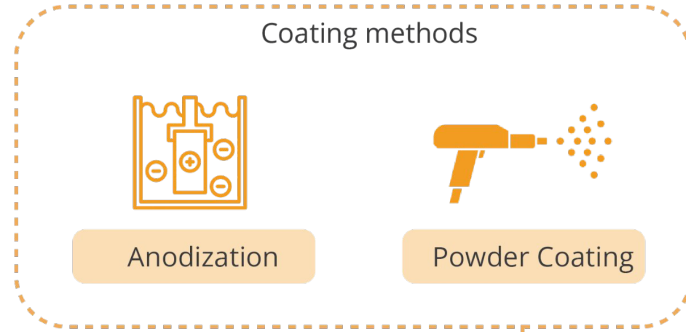


0 ← → 1

8. Evaluate - Couple piece connection

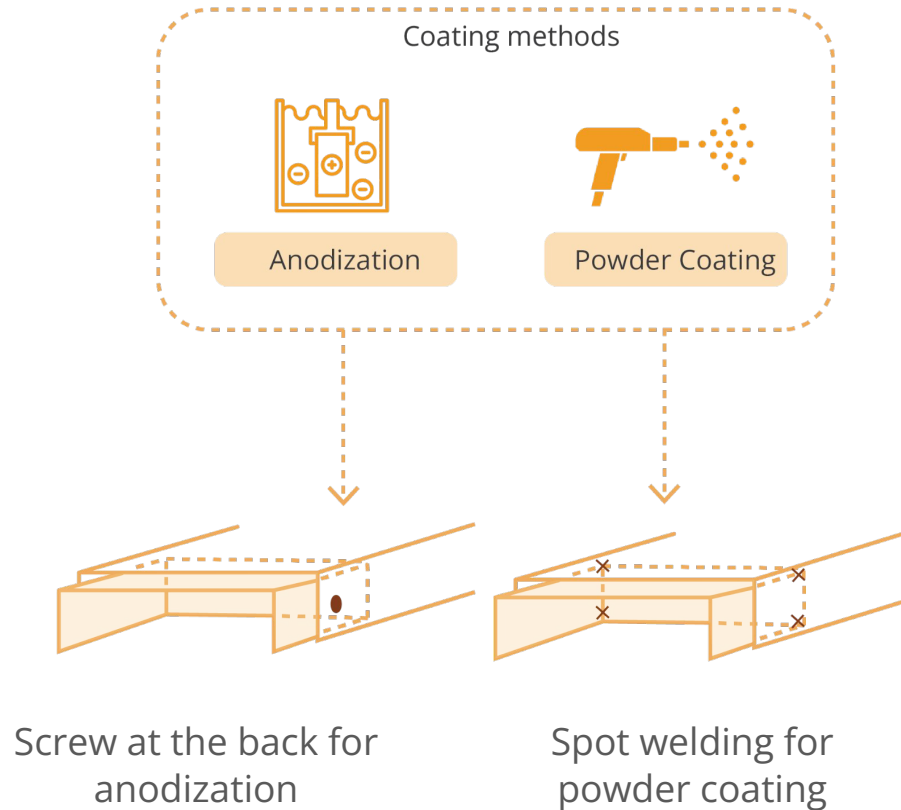


8. Evaluate - Couple piece connection

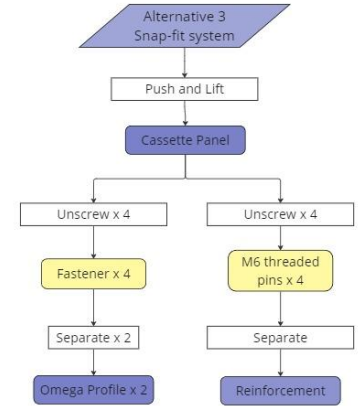
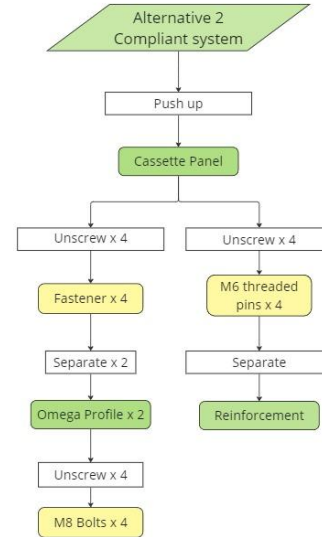
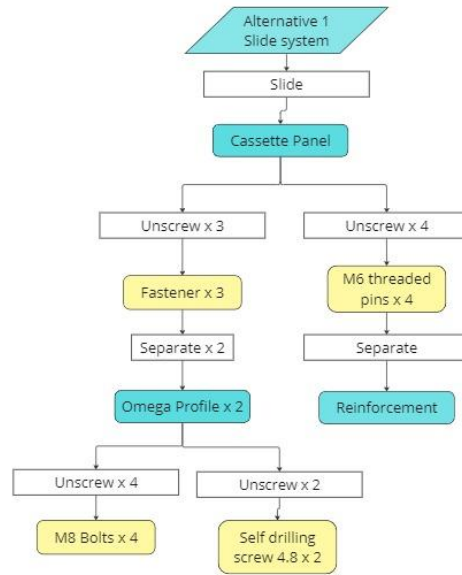
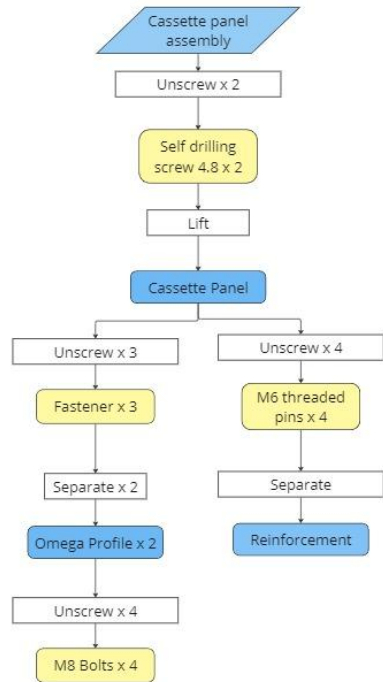


Spot welding for
powder coating

8. Evaluate - Couple piece connection

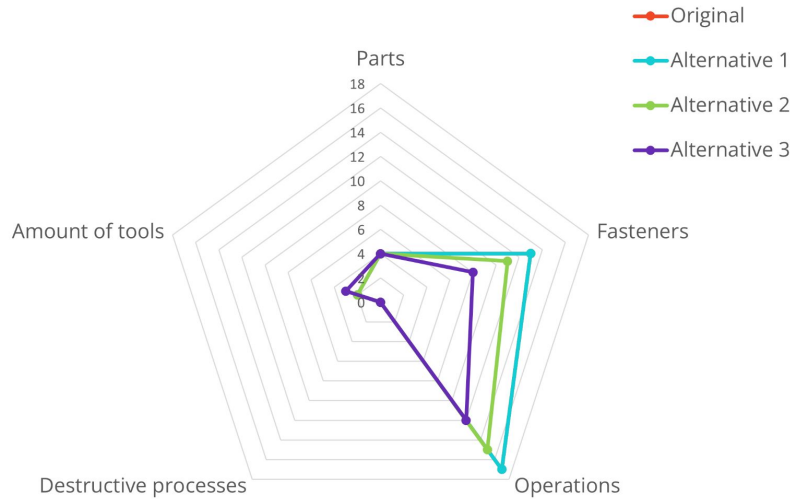


8. Compare the variations: Detachability score

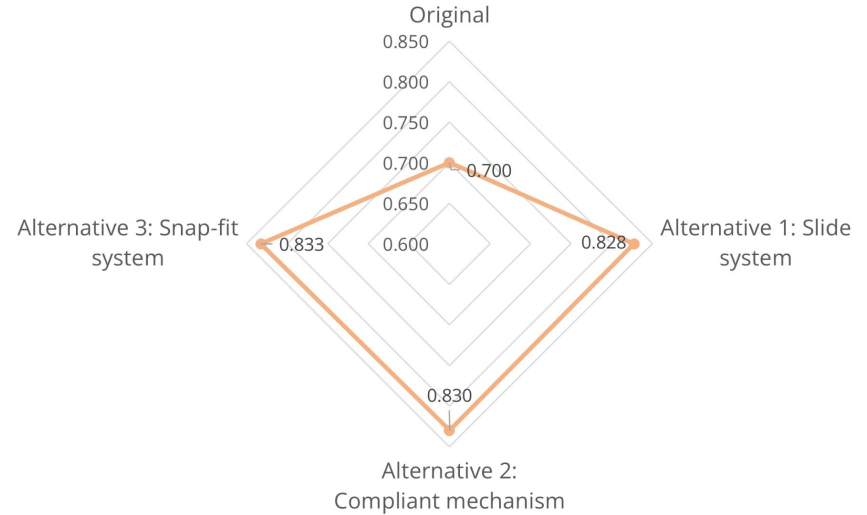


8. Compare the variations: Detachability score

Disassembly Map Comparisons

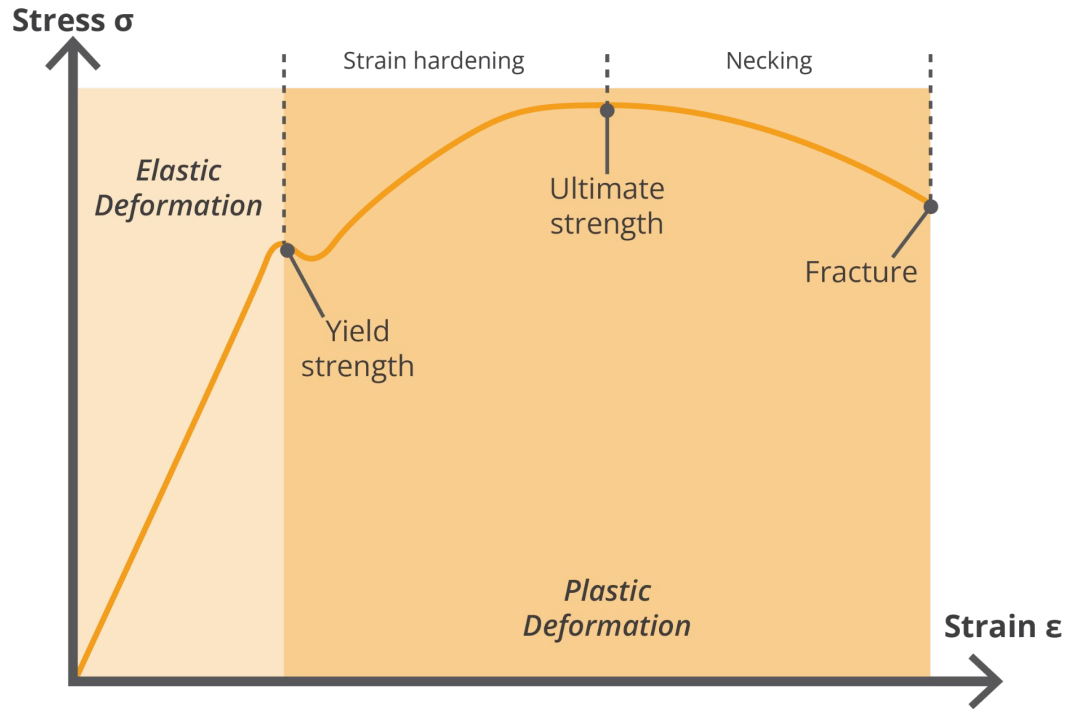


Detachability score



0 ←————→ 1

8. Compare the variations: Structural analysis



$$\sigma_{max} < \text{Yield strength}$$

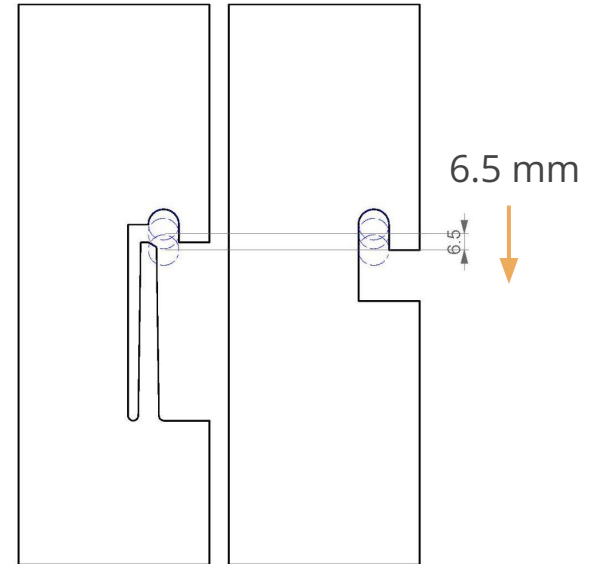
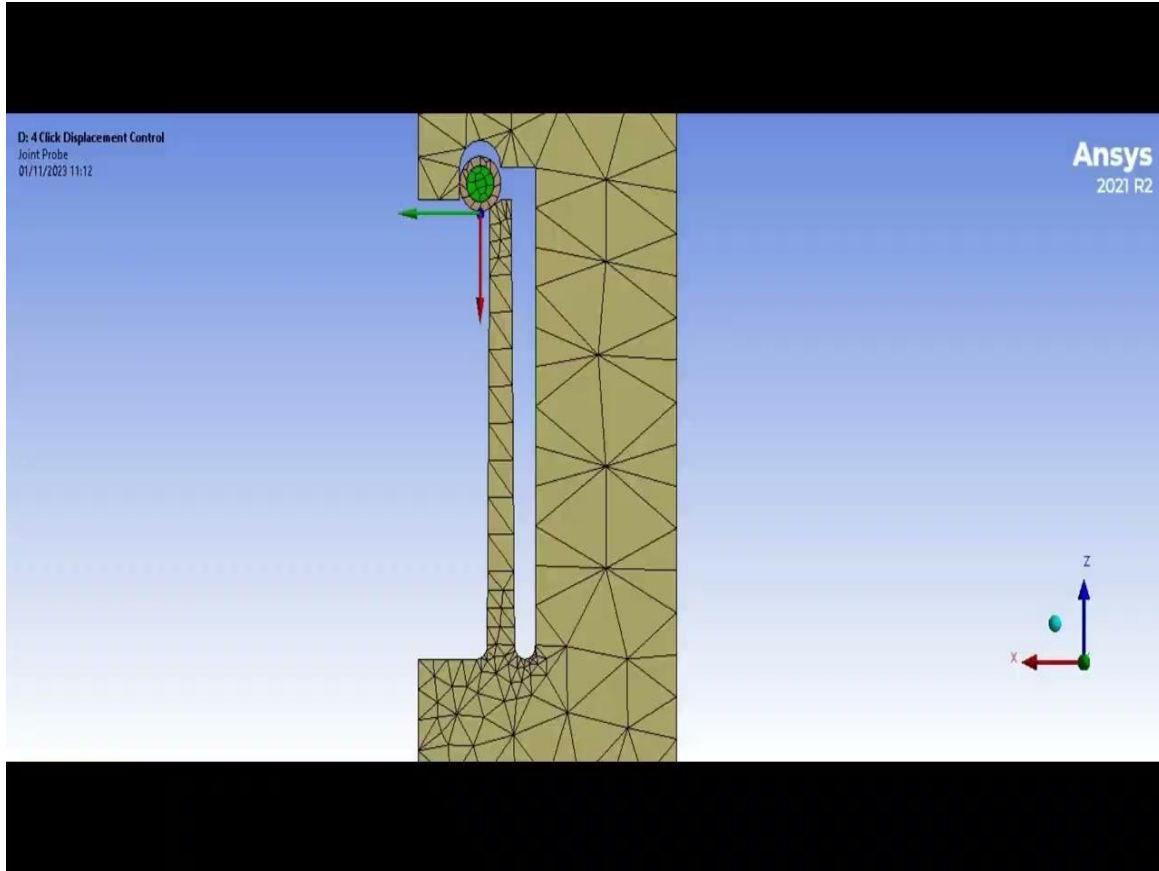
Calculation of the forces

WIND FORCE

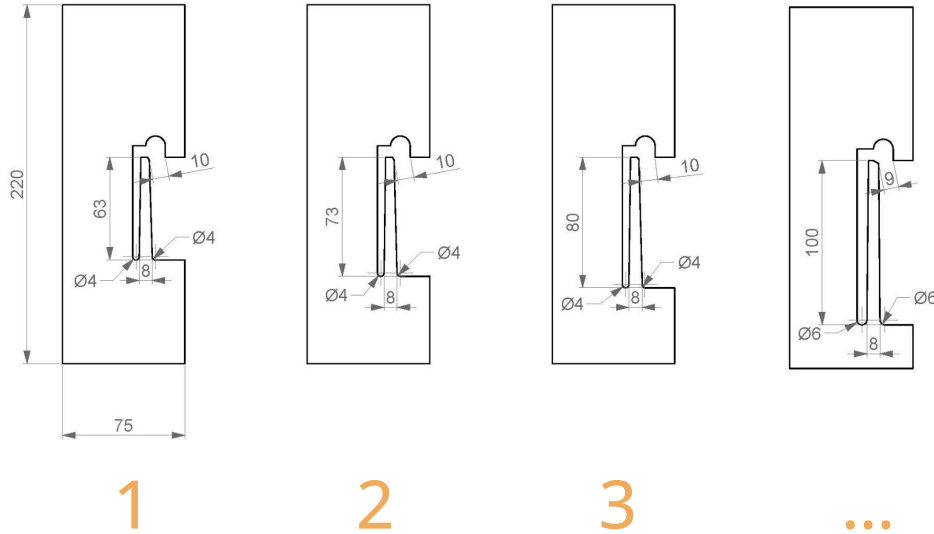
Height Building	65 m	
Area Panel	0.7 m ²	
Number of connections	6	Prevents horizontal motion
Number of connections	2	Prevents vertical motion
Peak velocity pressure	1.86	Coastal Area II
Cf coefficient	1.4	-
Safety Factor variable load	1.5	-
Wind pressure/suction (qp)	3.906 kN/m ²	
Wind upwards (qu)	0.078 kN/m ²	(2% of qp)
Qvertical	54.68 N	$qu / 1 * Area * 1000$
Qhorizontal	546.84 N	$qp / 5 * Area * 1000$

$$F_{\text{unlock}} > Q_{\text{vertical}} \quad 55 \text{ N}$$

Displacement Control



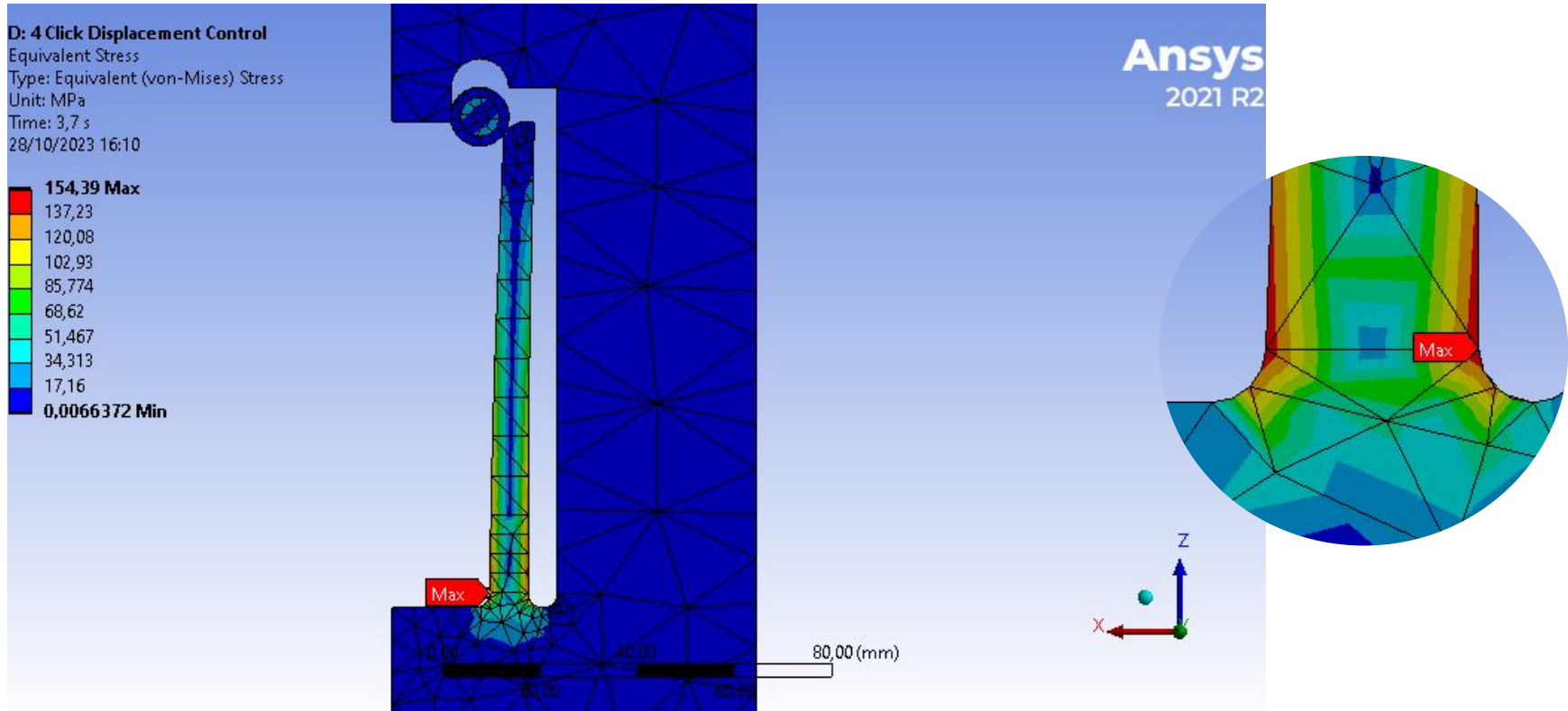
Iterations



Iteration	Force unlock (N)	Stress (MPa)
1	64	171
2	48	164
3	23	131
4	93	188
5	90	186
6	81	180
7	57	154
8	93	166

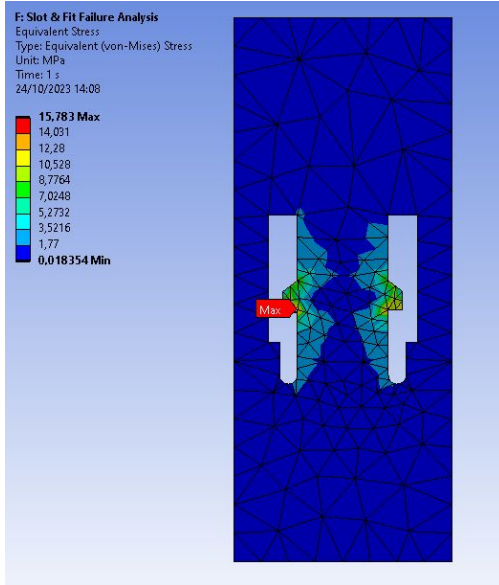
$$F_{\text{unlock}} > 55 \text{ N}$$

Finite Element Analysis: Clicking system

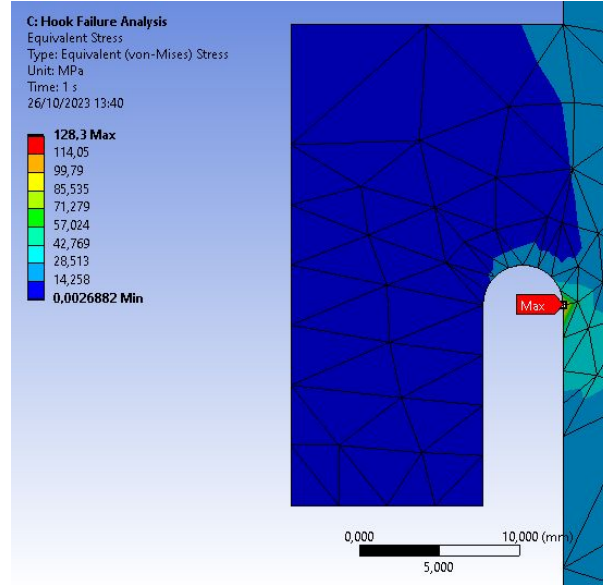


$$\sigma_{\max} < 132\text{MPa}$$

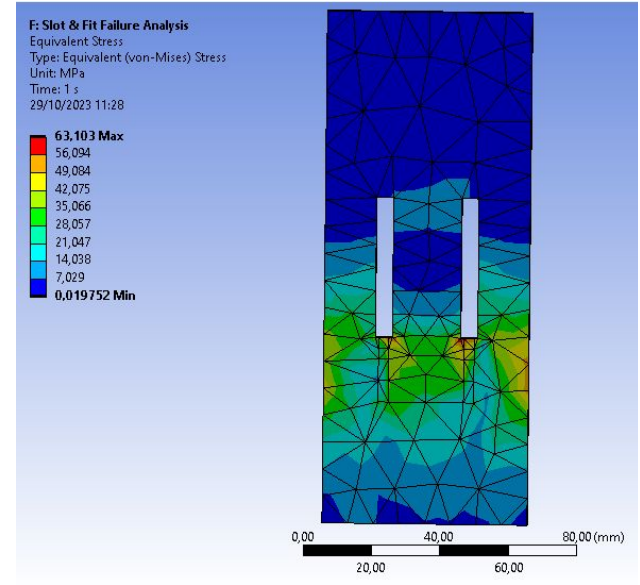
Finite Element Analysis: Snap-fit system



$\sigma_{\max} = 15 \text{ MPa}$



$\sigma_{\max} = 128 \text{ MPa}$

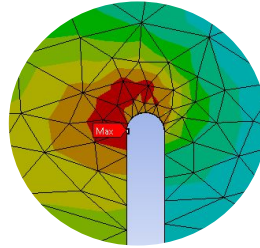
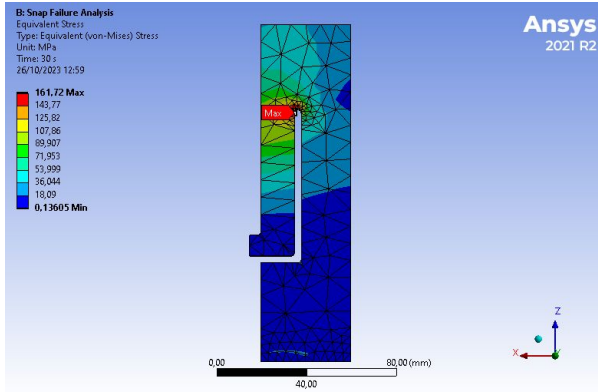


$\sigma_{\max} = 63 \text{ MPa}$

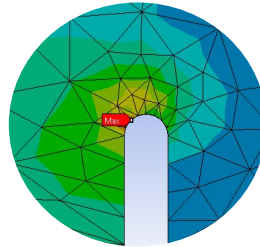
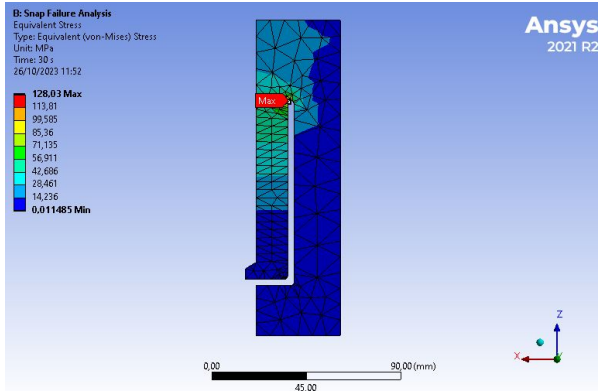
$\sigma_{\max} < 132 \text{ MPa}$

Finite Element Analysis: Snap-fit system

1.



3.



Iteration	Push Force (N)	Displacement (mm)	Max. Stress (MPa)
1	60	3,1	161
2	45	3,0	158
3	20	2,2	128

$\sigma_{max} < 132 \text{ MPa}$

Conclusion

Introduction

DfD Guideline

Case Study

Conclusion

Cassette panel connections



Less amount of:

- Fasteners
- Operations

Amount of	Original	Clicking system	Snap-fit system
Parts	4	4	4
Fasteners	13	11	8
Operations	17	15	12

Cassette panel connections



Less amount of:

- Fasteners
- Operations



Higher detachability
score

0.70 → 0.83

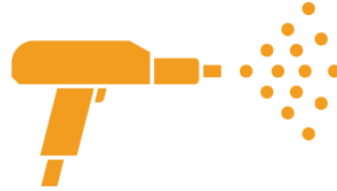


$F_{\text{unlock}} > Q_{\text{Vertical Wind}}$

Further research



Further iterations
necessary to
reduce peak
stresses at corners
and **vibrations**

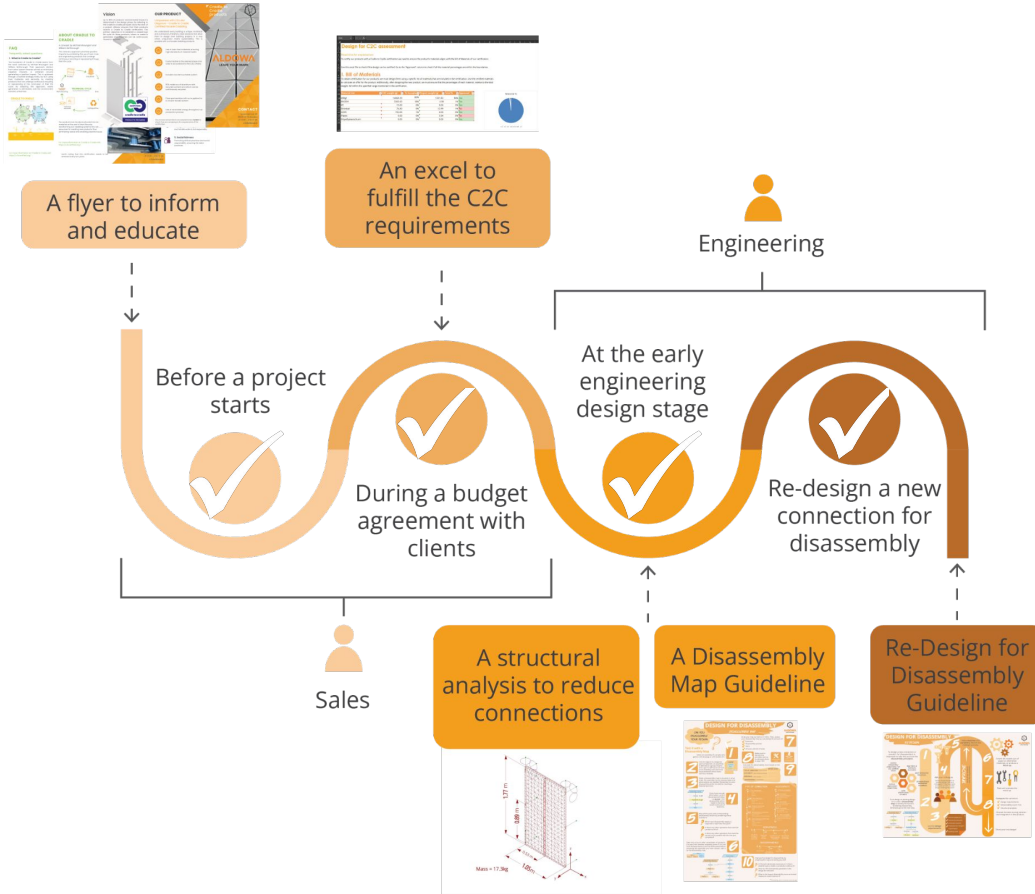


Include **tolerances**
for thermal
expansion and
coatings

Research question

How can the **disassembly potential** of Aldowa's cladding products be **assessed**, and what **design guideline** can be proposed to comply with the **design for disassembly requirements** of the **Cradle-to-Cradle** certification?

DfD Guideline



Facilitate maintenance
Reuse, Repair, Remanufacture...



Extend the service life of products



Reduce waste



C2C certificate

Thank you