KU LEUVEN

FLANDERS MAKE

Design for (Robotic) Ease of Disassembly

DESIGN GUIDELINE CARDS

WHAT? WHY? HOW? WHO?

DISASSEMBLY

is the planned, non-destructive separation of a product into its individual components, parts or materials.

R-STRATEGIES (R-X)

are circular economy approaches, ranging from Refuse, Rethink and Reduce to Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover, that guide product design to maximize resource efficiency and reduce negative environmental impacts.

DESIGN FOR EASE OF DISASSEMBLY

Product design that allows straightforward, non-destructive disassembly at the end of a product's (first) life and thereby enables R-strategies.

While disassembly is today performed manually, we can only hope the future will be different and so should be the product design.

Therefore, **20 DESIGN GUIDELINE CARDS** are developed around **4 KEY TOPICS** to facilitate the **EASE OF DISASSEMBLY IN A HUMAN-ROBOT COOPERATIVE SYSTEM.**

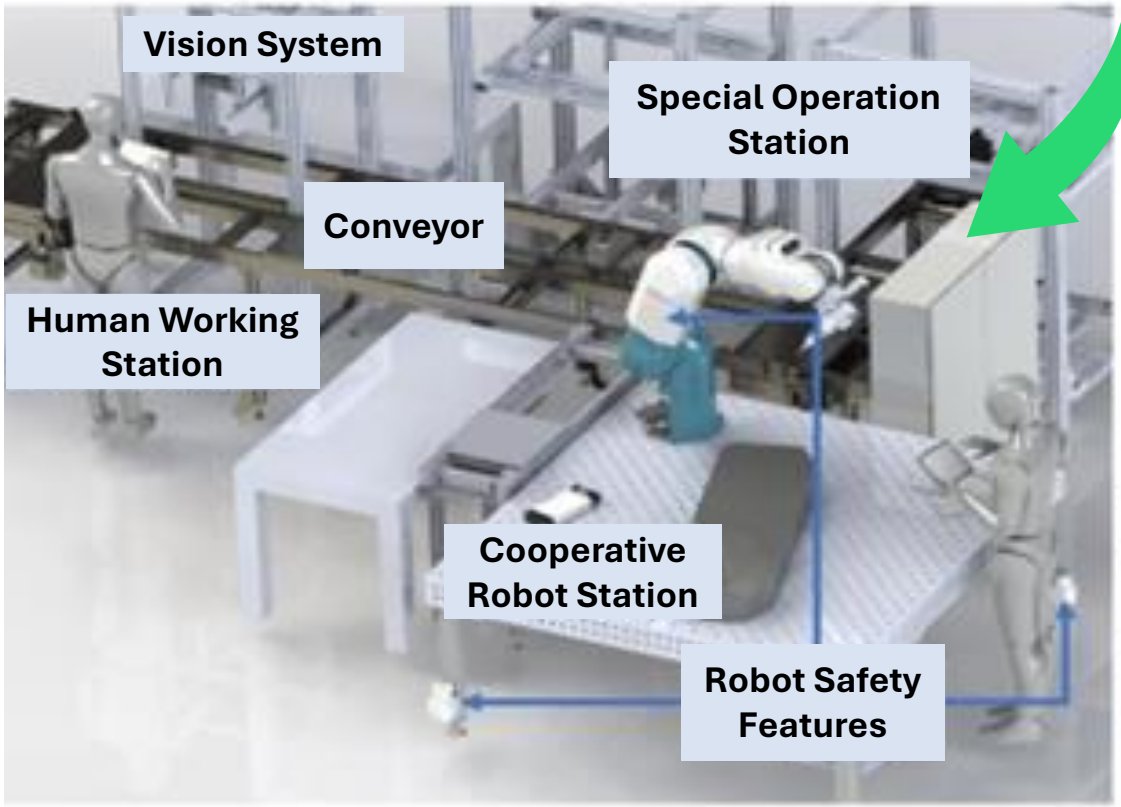
Geometry & Surface
1 - 3

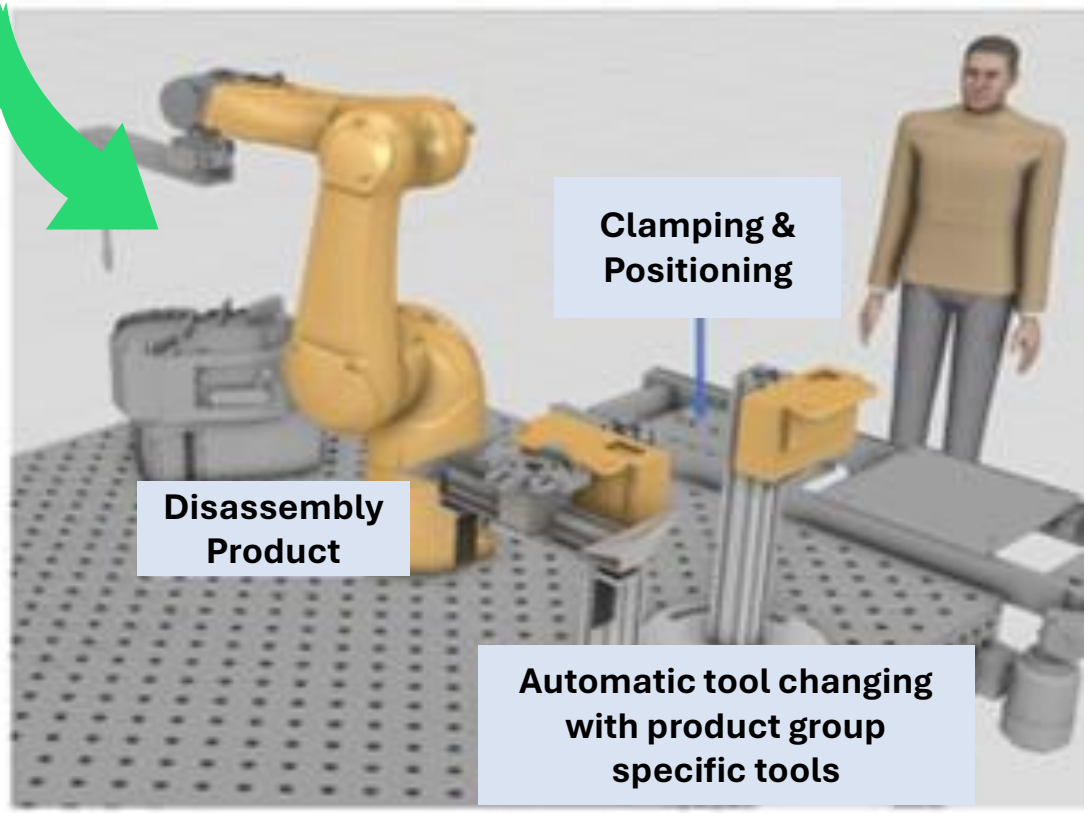
Diagnostic & Visibility
4 - 7

Product Composition
8 - 11

Connectors
12 - 20

Compared with centralized mass manufacturing, **DEMANUFACTURING** products at their end-of-(first) life will be **DECENTRALIZED**, requiring **HUMAN-ROBOT COOPERATION** to handle the high variation across different generations of products under different conditions in an economically viable manner, **WITHOUT DEDICATED TOOLING**.

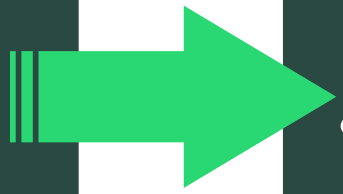




Limitations of a human-robot cooperative demanufacturing cell*

Manual

- Wide variety of tools
- Two-hand operations
- Easy product reorientation
- Parallel inspection and execution



Robotic cell

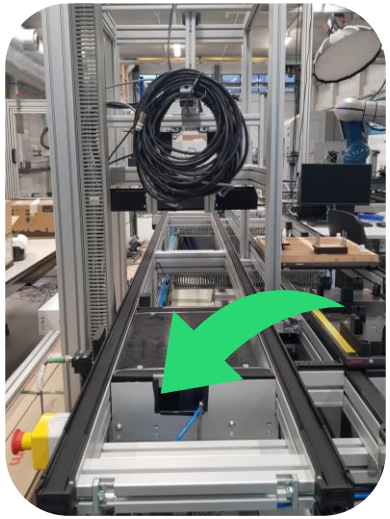
- Limited tooling available
- A single robot arm
- Product clamped
- Sequential inspection and operation

Always consider realistic TOOL ACCESS, SIZE, AND ORIENTATION when planning disassembly

***based on learnings in the KU Leuven Re- & Demanufacturing Lab**

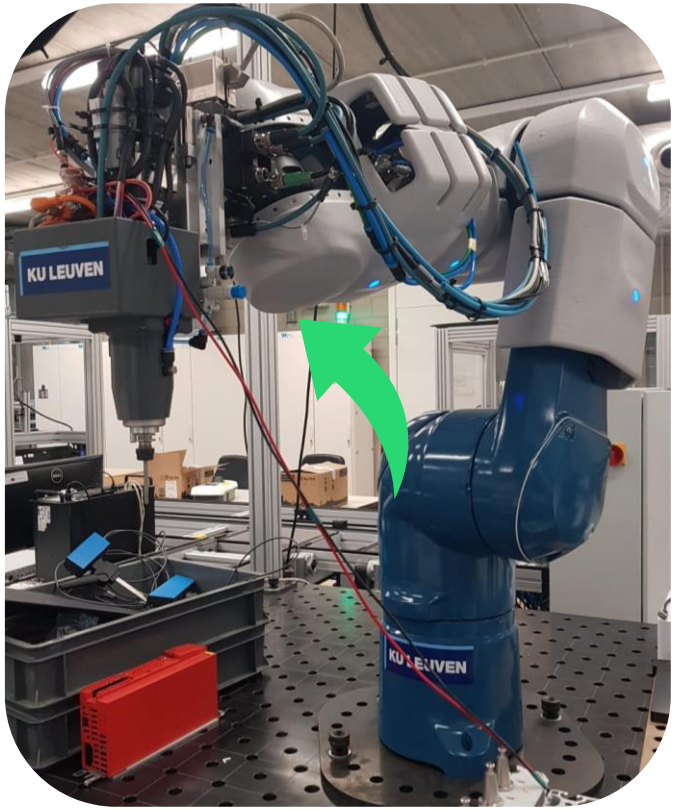
Tooling in a demanufacturing cell for electric and electronic equipment

Conveyor

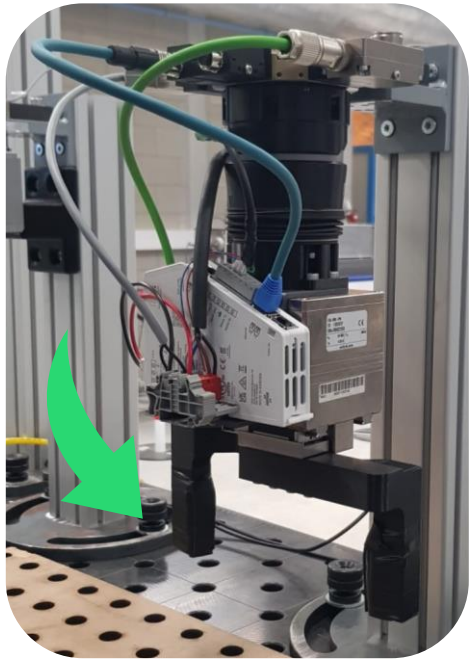


Vision system

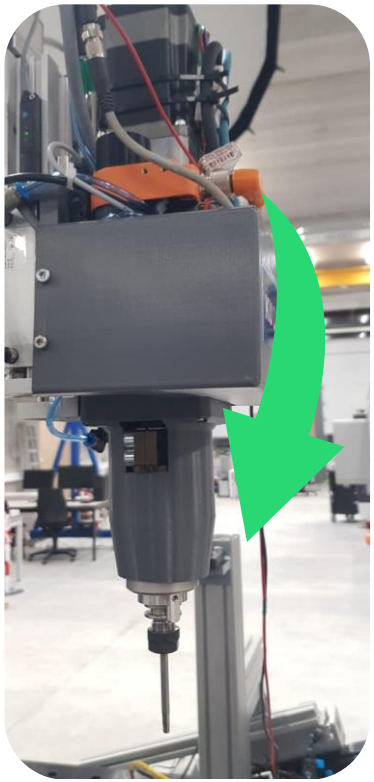
Robotic arm



Clamping



Unscrewing



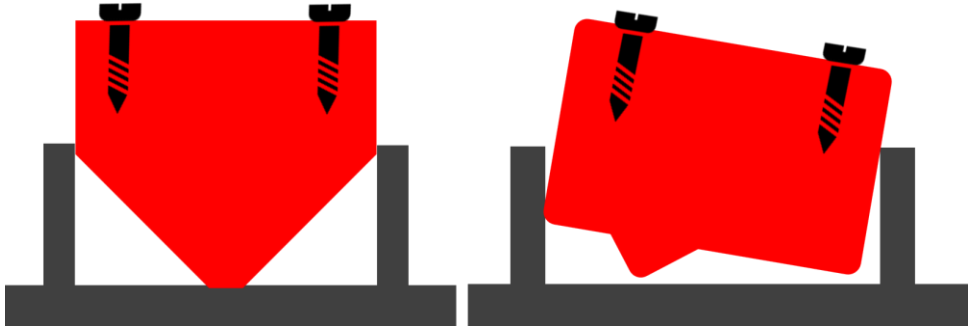
Parallel finger gripper

KU LEUVEN

FLANDERS MAKE

Restricted Clamping

The product’s geometry provides insufficient flat or accessible surfaces for secure clamping, hindering stable fixation



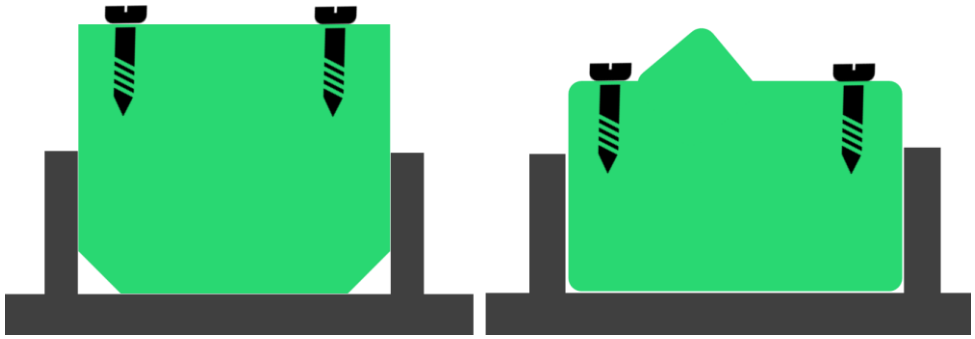
1

KU LEUVEN

FLANDERS MAKE

Feasible Clamping

Design the product with sufficient flat or accessible surfaces to allow secure clamping and stable positioning during disassembly



1

KU LEUVEN

FLANDERS MAKE

Limited Graspability

Components cannot be grasped by the robotic finger gripper due to shape, surface, or size

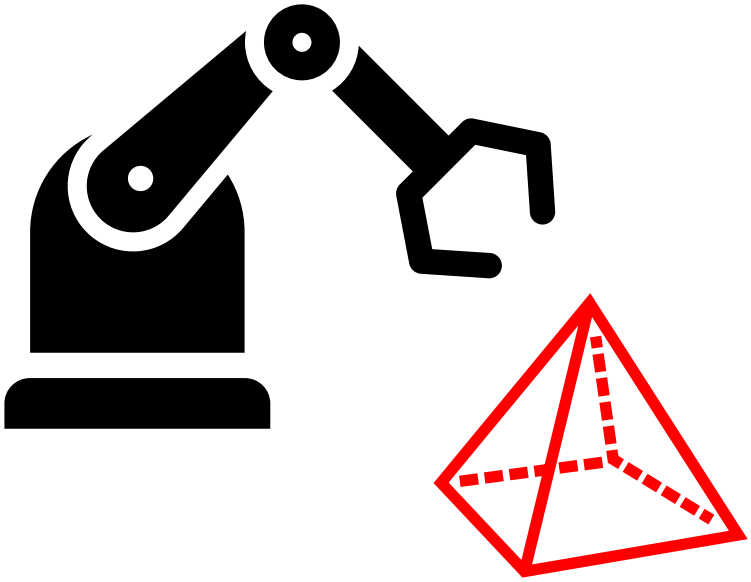


Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Robot Graspability

Redesign components to increase graspable surfaces, including flat areas and suitable size, ensuring compatibility with robotic grippers

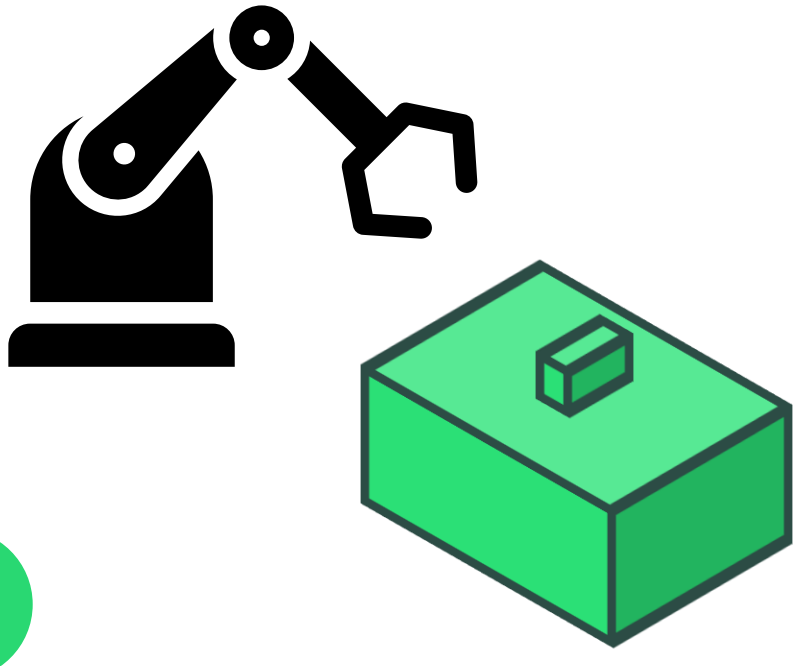


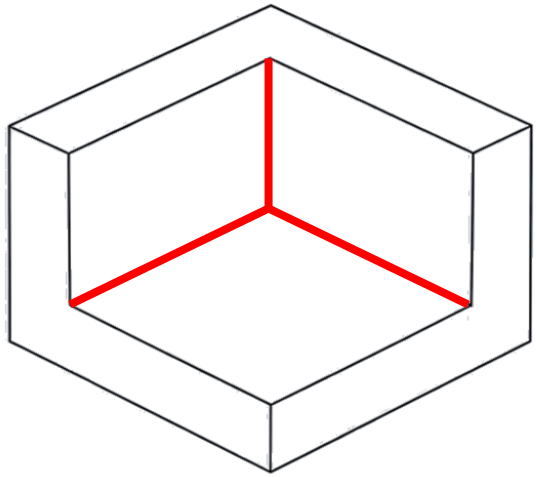
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Complicated Cleaning

Glossy, scratch-prone surfaces or sharp inner corners require extra cleaning after repair increasing turnaround time



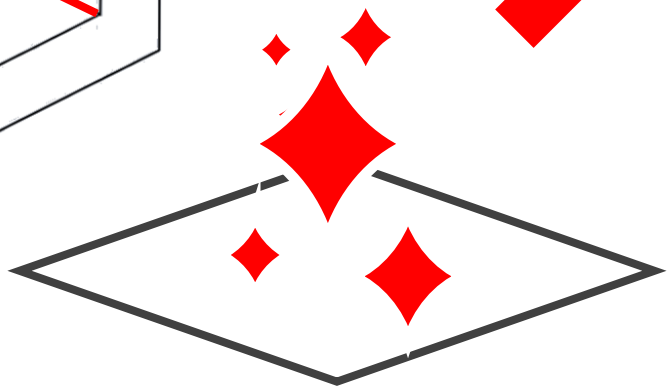


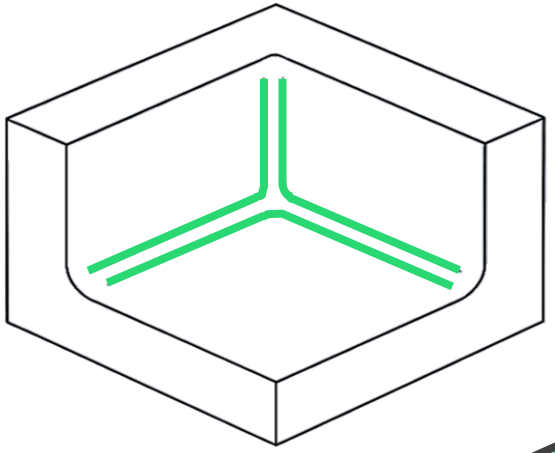
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Easy Cleaning

Use scratch-resistant, matte, non-porous surfaces or rounded inner corners to minimize cleaning efforts and aesthetic defects



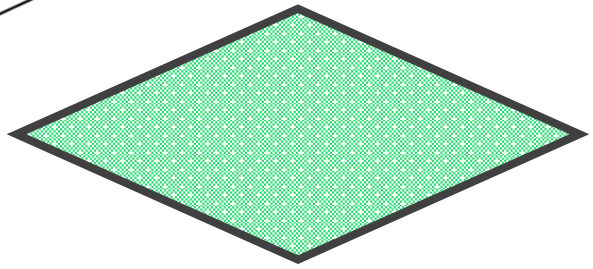


Image: HRE PolyCE Project

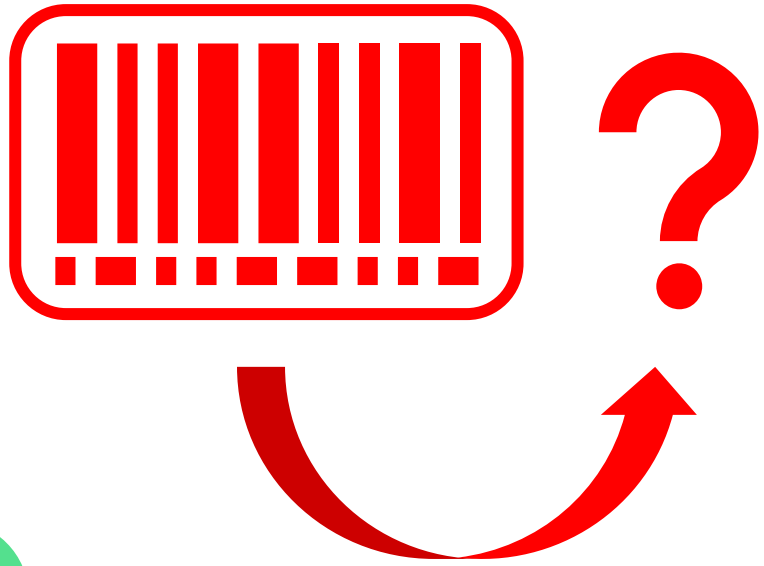
3

KU LEUVEN

FLANDERS MAKE

Insufficient Labeling

Missing, poor, or non-durable labels make components identification and disassembly harder



KU LEUVEN

FLANDERS MAKE

Clear Labeling

Use clear and durable labels to enable correct component identification and to retrieve updated product information online

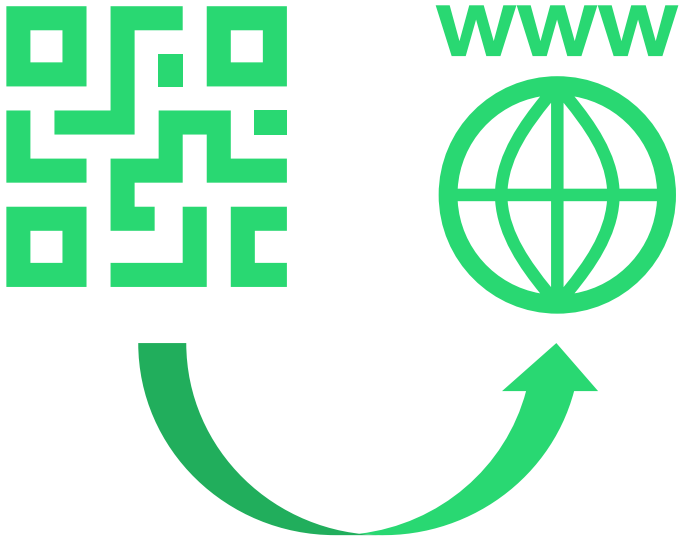


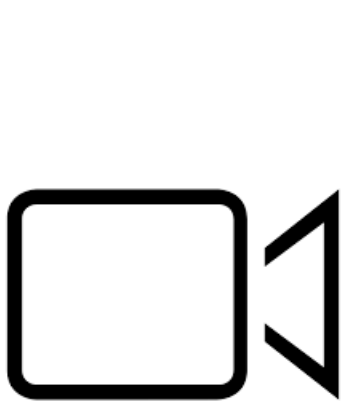
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Inaccessible Electronics

Critical electronic components are challenging to identify and/or to verify their condition visually or electrically



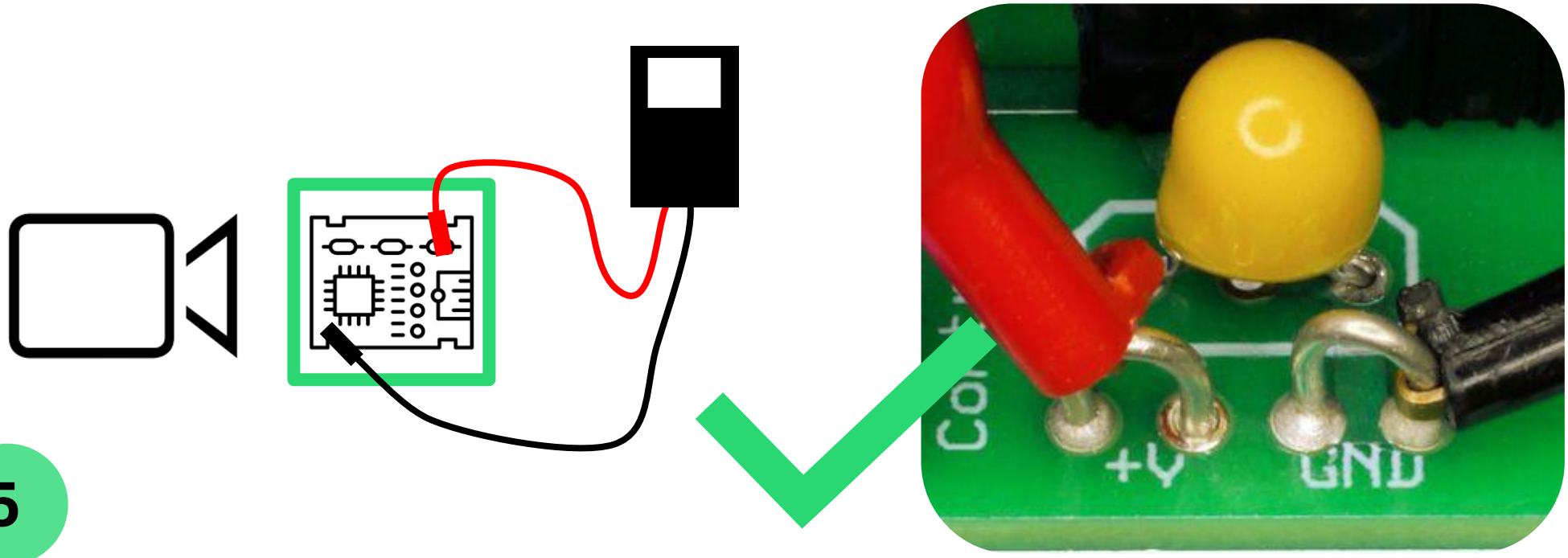
?

KU LEUVEN

FLANDERS MAKE

Accessibility of Electronics

Make critical electronic components accessible for visual inspection and provide markings to support electrical testing

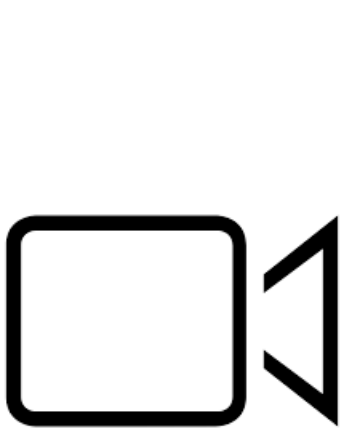


KU LEUVEN

FLANDERS MAKE

Difficult to Assess Wear

Critical components that are prone to wear, e.g., motor brushes and filters, require numerous steps to inspect their condition



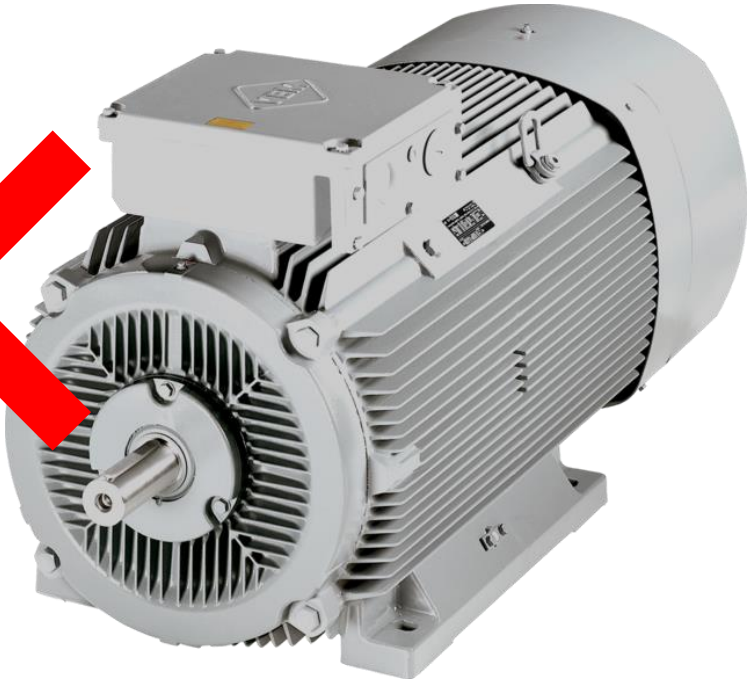


Image: VEM motors GmbH, Wikimedia Commons (CC BY-SA 4.0)

KU LEUVEN

FLANDERS MAKE

Ease to Assess Wear

Allow easy access to assess the condition of components prone to wear and to determine the severity of the wear

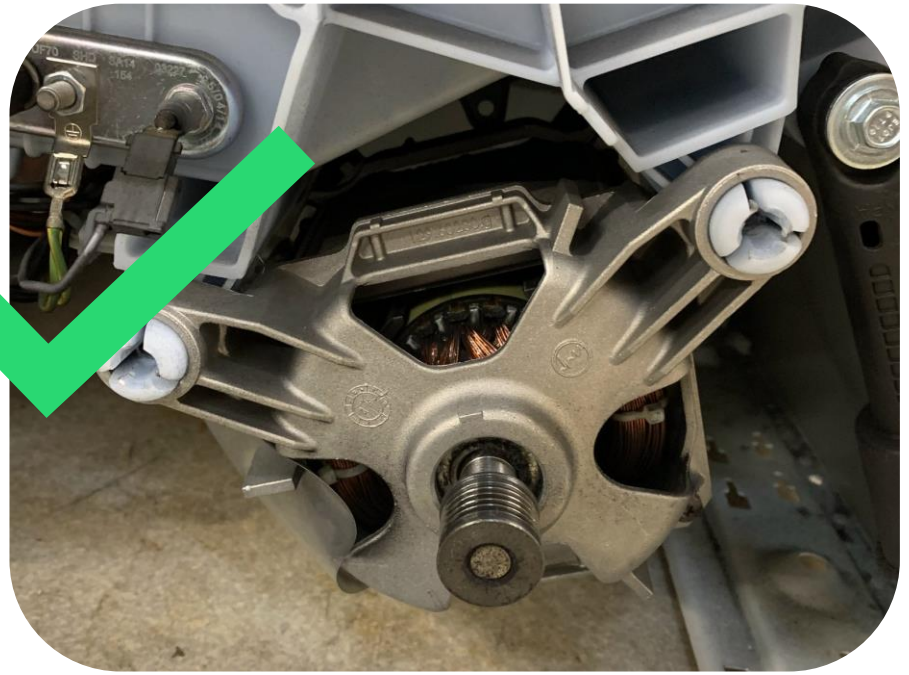


Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Limited Visibility

Components or connectors are not visible to a robot vision system, challenging automated detection and disassembly

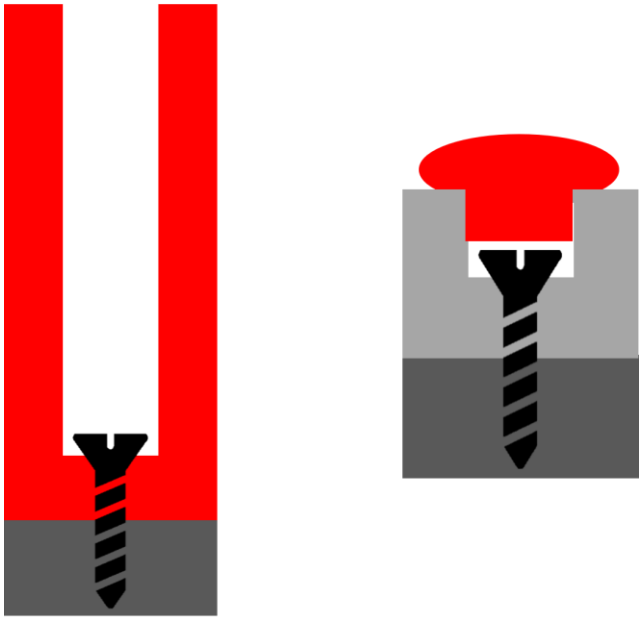


Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Full Visibility

Reposition or expose components and connectors to ensure a robot's vision system can detect them

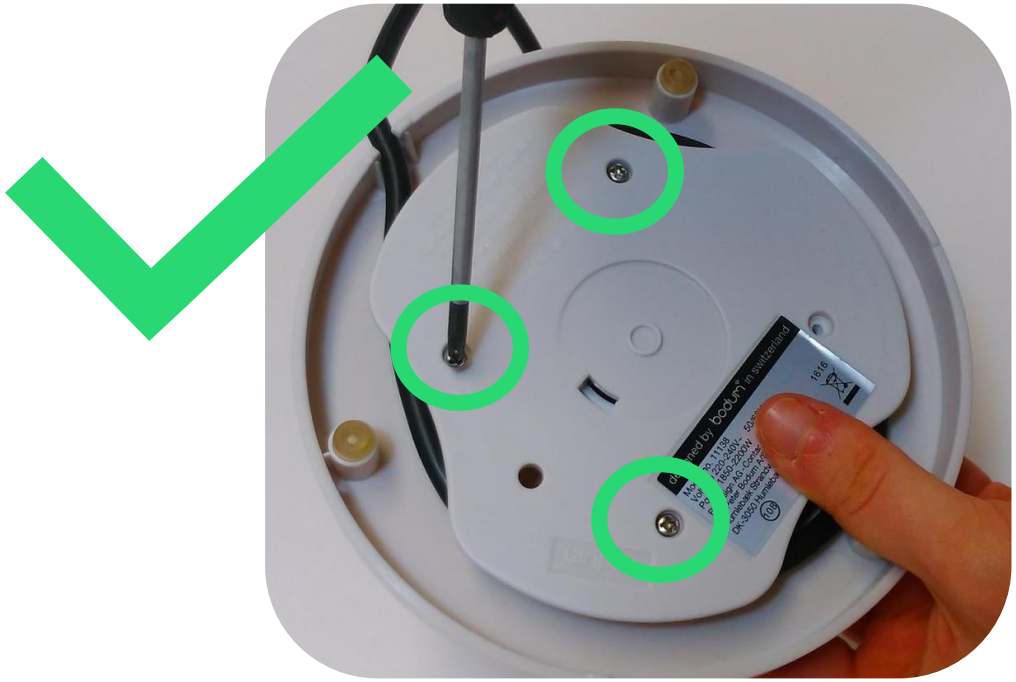


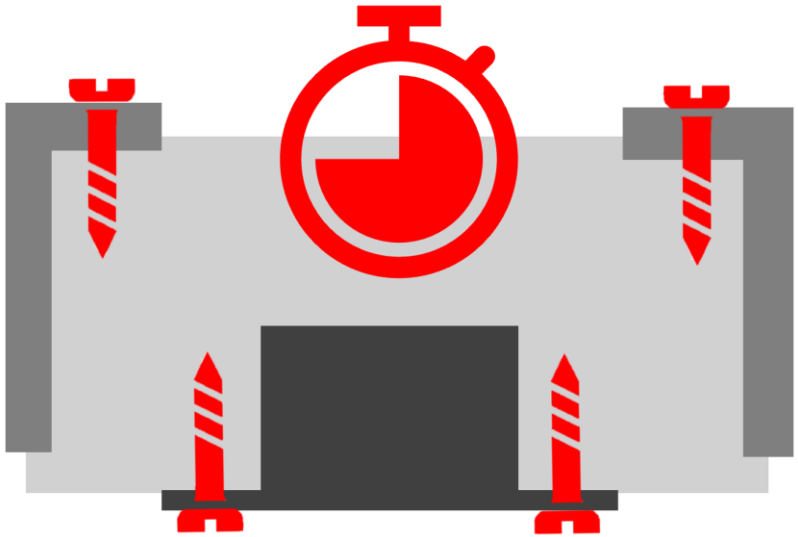
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Product Rotations Required

Multiple orientations of the connectors require turning and reclamping increasing the disassembly time

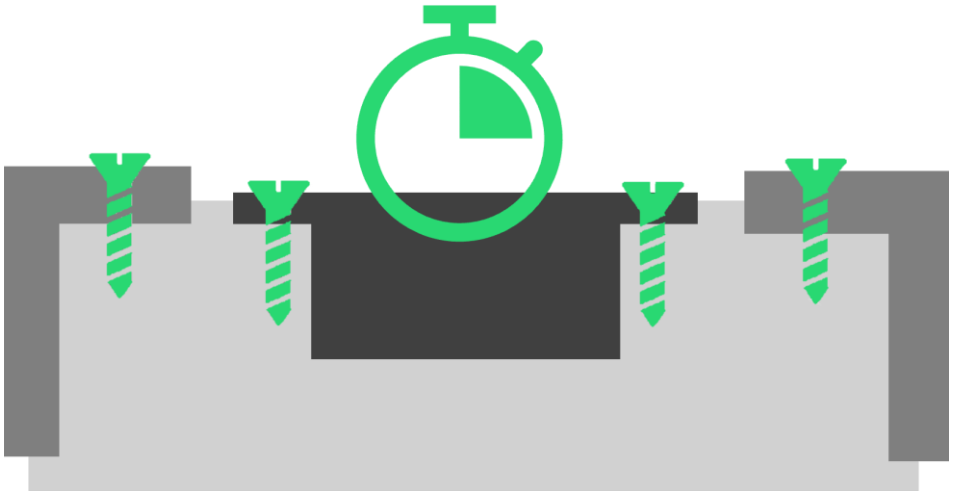


KU LEUVEN

FLANDERS MAKE

Unidirectional Disassembly

Ensure that all connectors are accessible in a single product position, enabling efficient disassembly



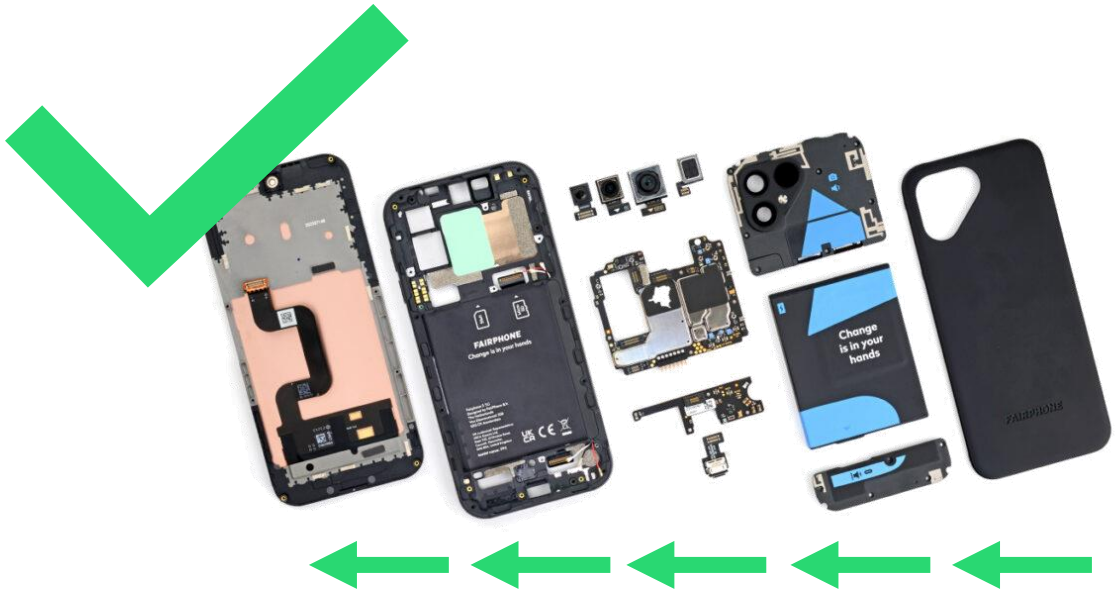


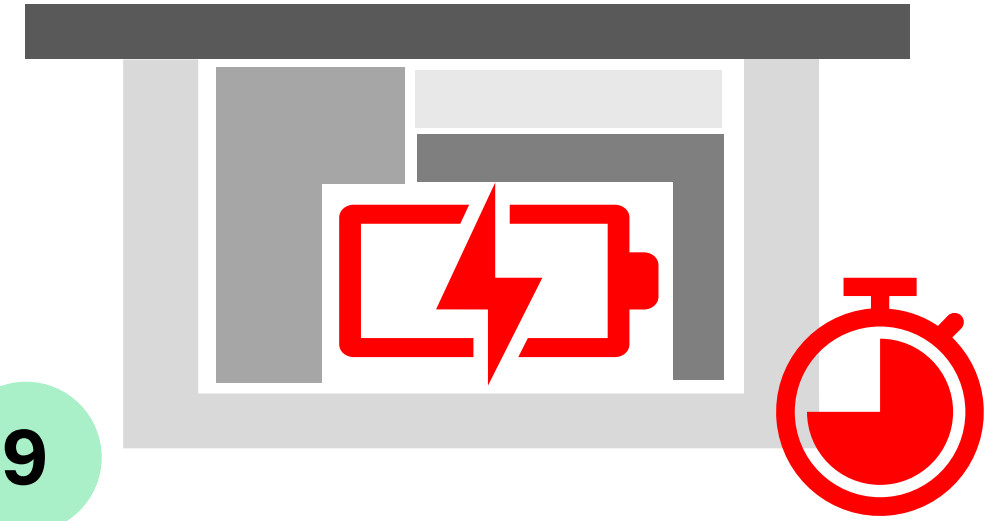
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Stacked Product Structure

Components are stacked on top of each other, resulting in restricted access to critical components



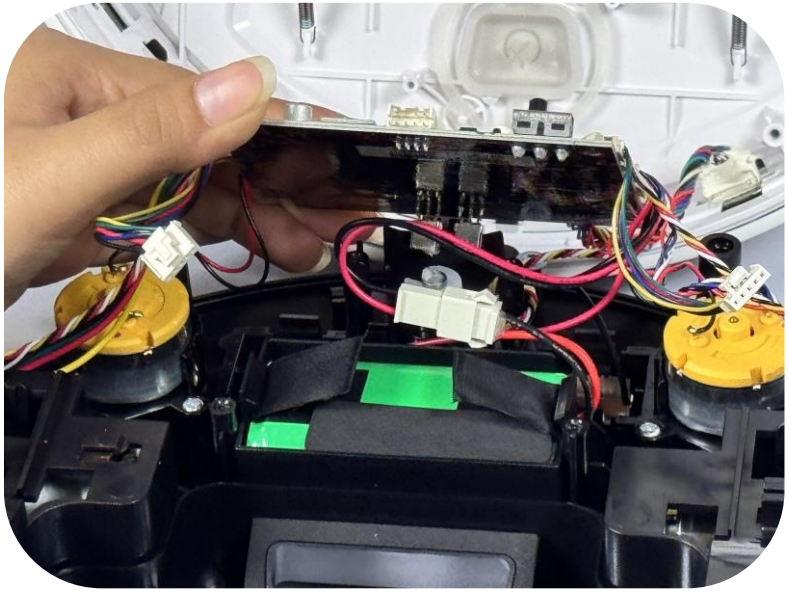


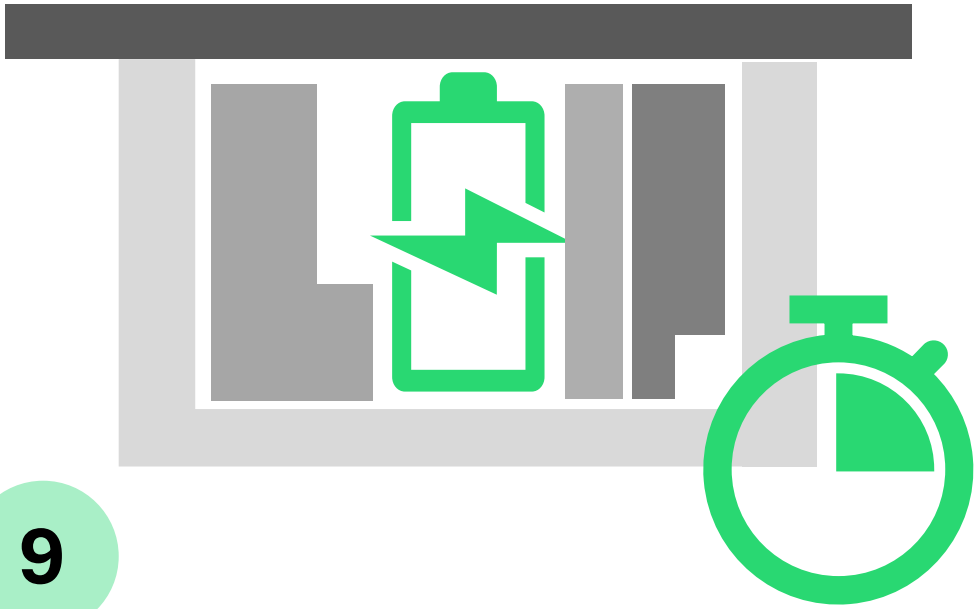
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

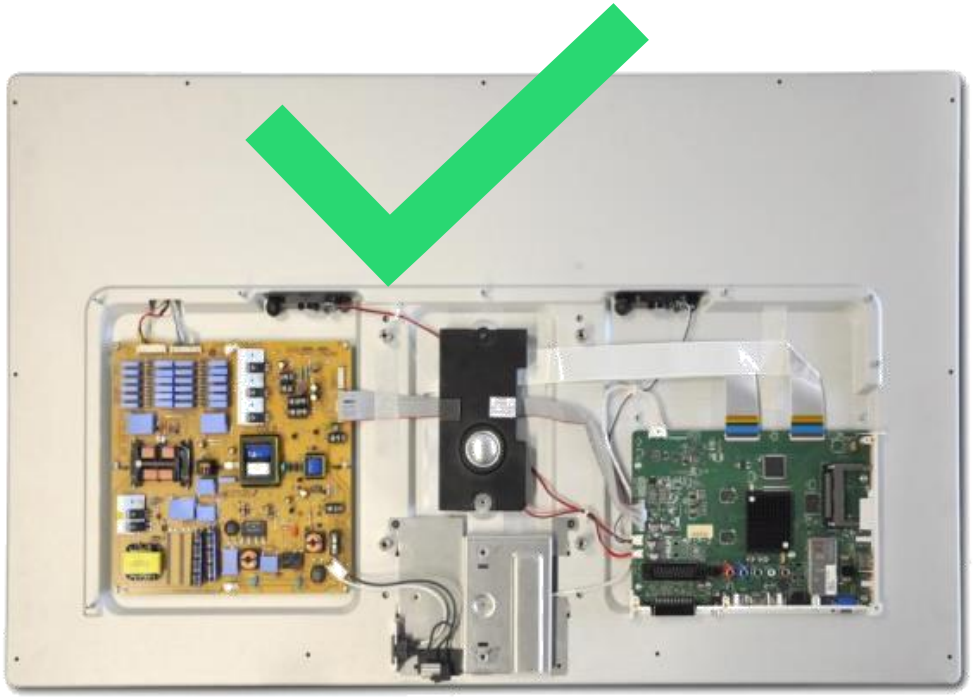
KU LEUVEN

FLANDERS MAKE

Hamburger Product Structure

The product housing retains all internal components, and when removed, direct access is provided to all critical components



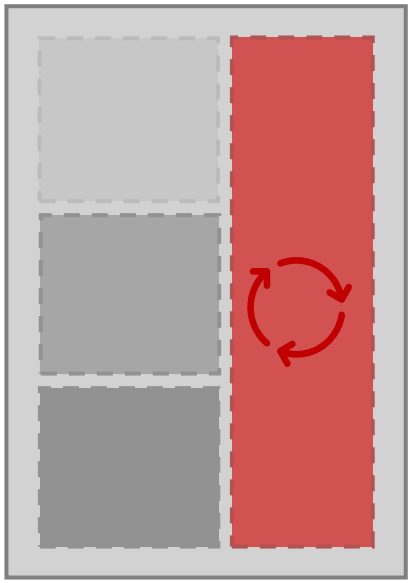


KU LEUVEN

FLANDERS MAKE

Monolithic Design

Hindering easy disassembly and separation of, e.g., reusable parts or parts prone to wear



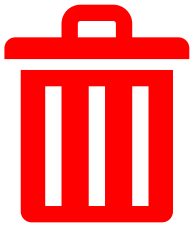


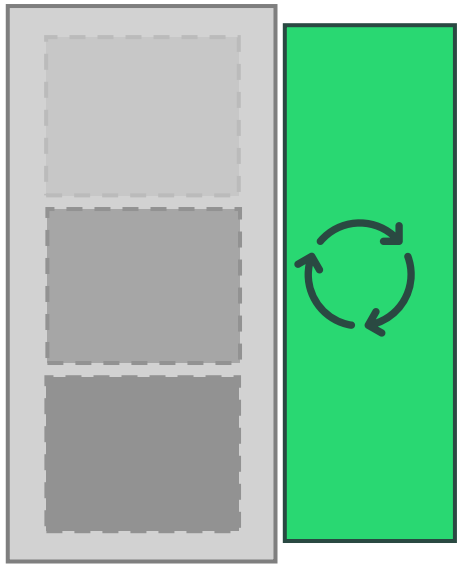
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Modular Design

Make the design modular by making components prone to wear or valuable for reuse easy to exchange



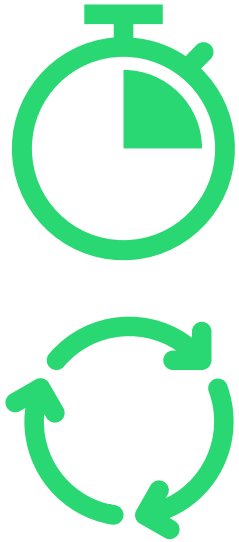


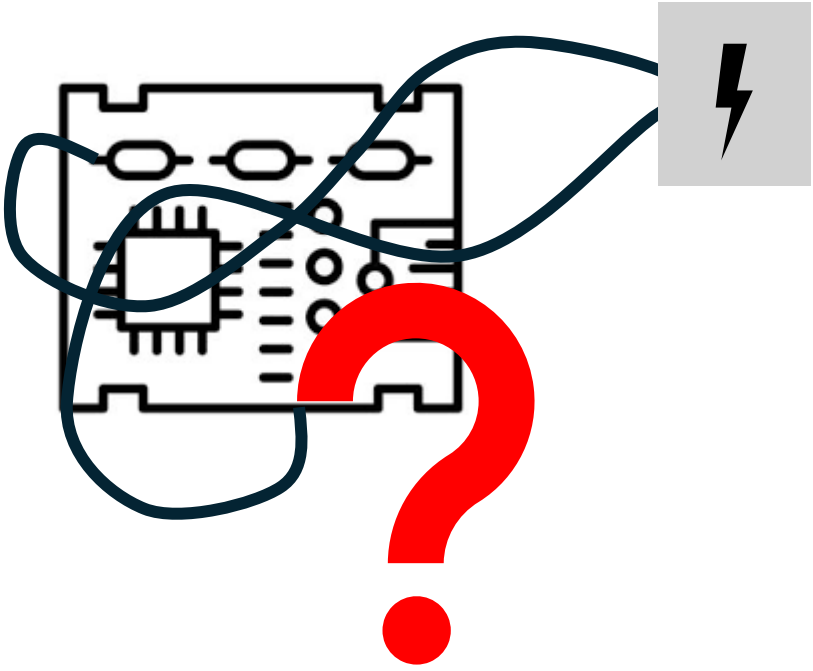
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

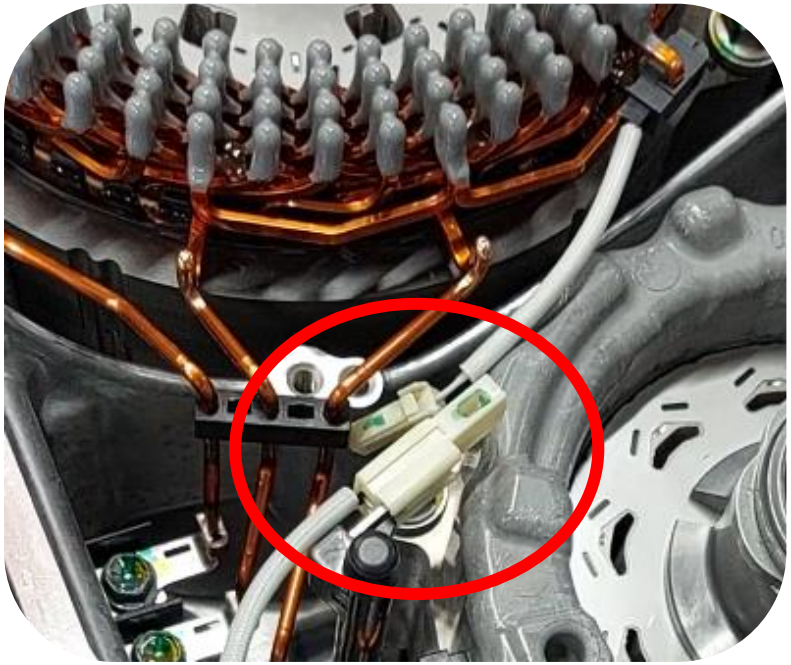
KU LEUVEN

FLANDERS MAKE

Undefined Position

Components whose location is not fixed in the product, such as cables, require additional localization steps prior to disassembly



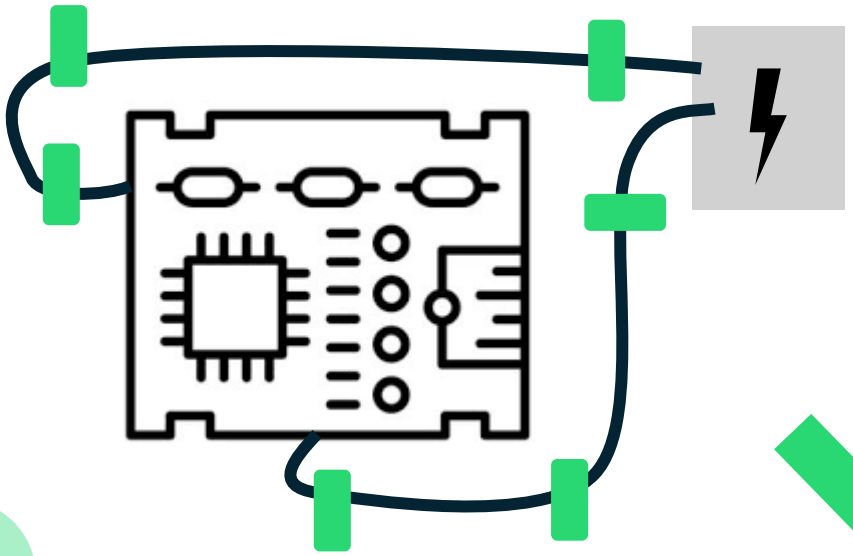


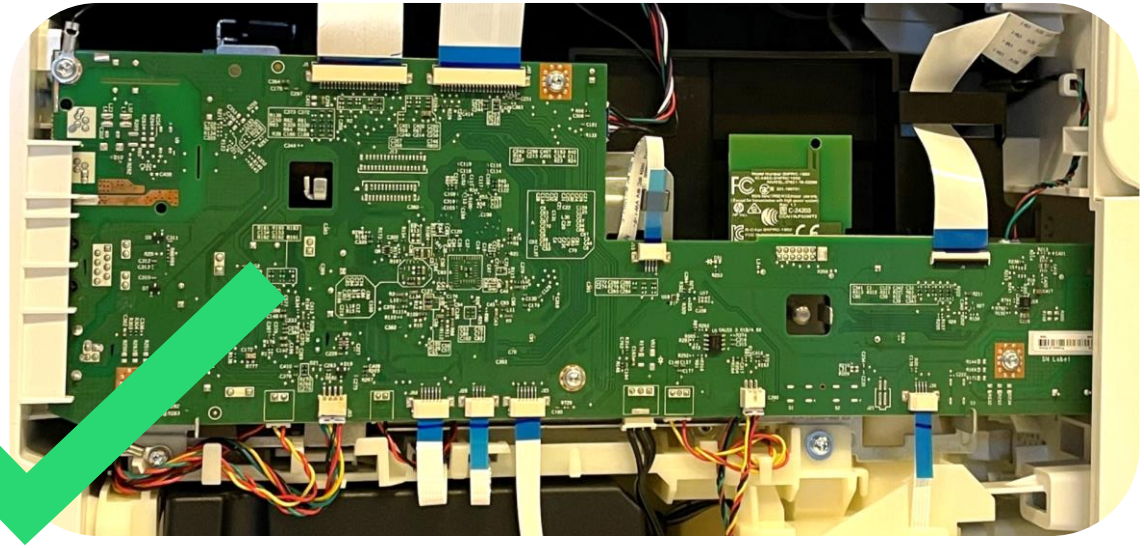
KU LEUVEN

FLANDERS MAKE

Predefined Position

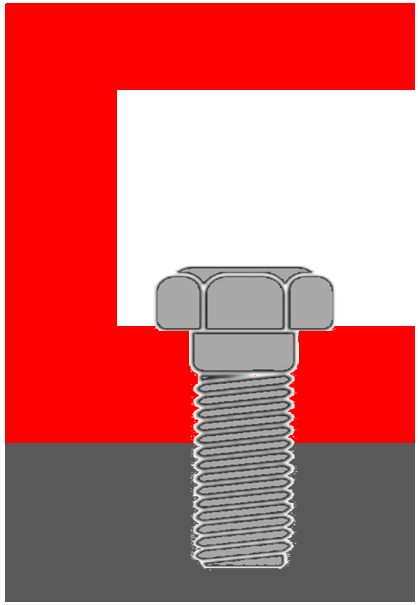
Assure all components retain a predefined position, e.g., by using on-board or fixed cable connectors and cable fixations





Limited Fastener Accessibility

Connectors cannot be accessed easily with robotic tools



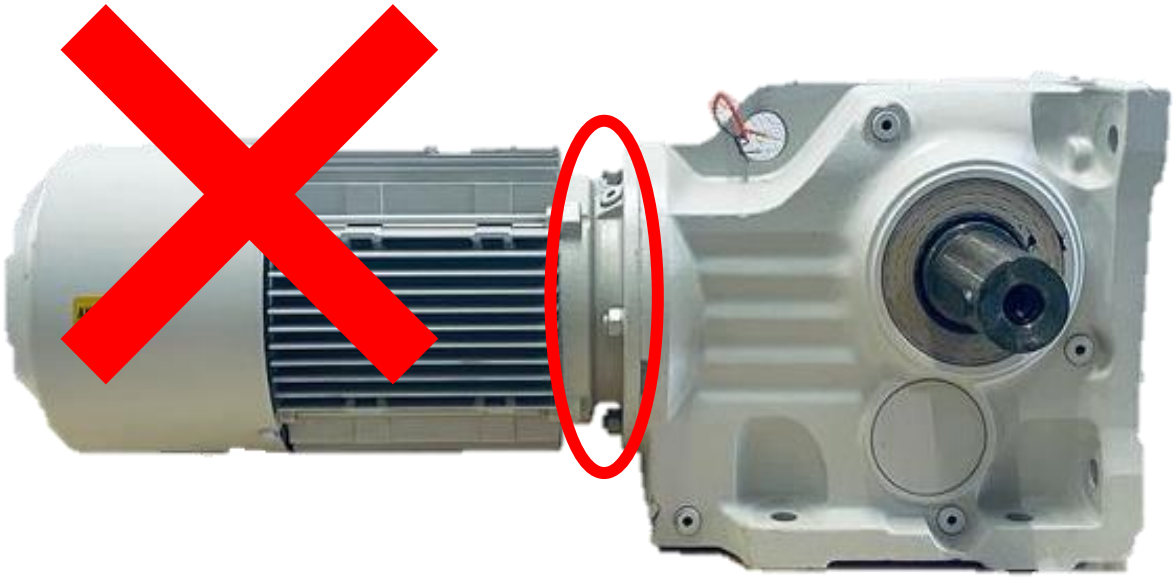


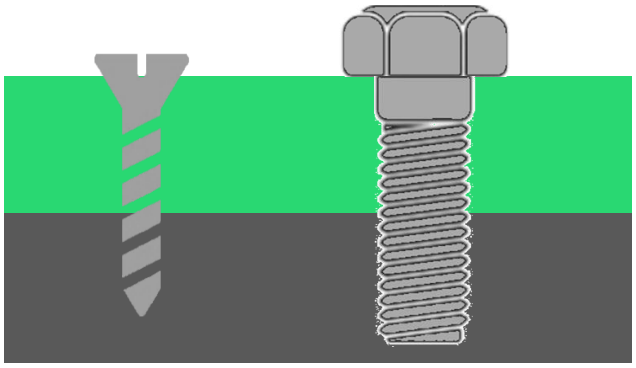
Image: Product photo of SEW-EURODRIVE K77DT100LS4/BMG/HR/AS (All rights reserved), from KLEMA Maschinenhandel, adapted for educational use

KU LEUVEN

FLANDERS MAKE

Easy Fastener Accessibility

Redesign parts or connectors to ensure easy access with robotic tools



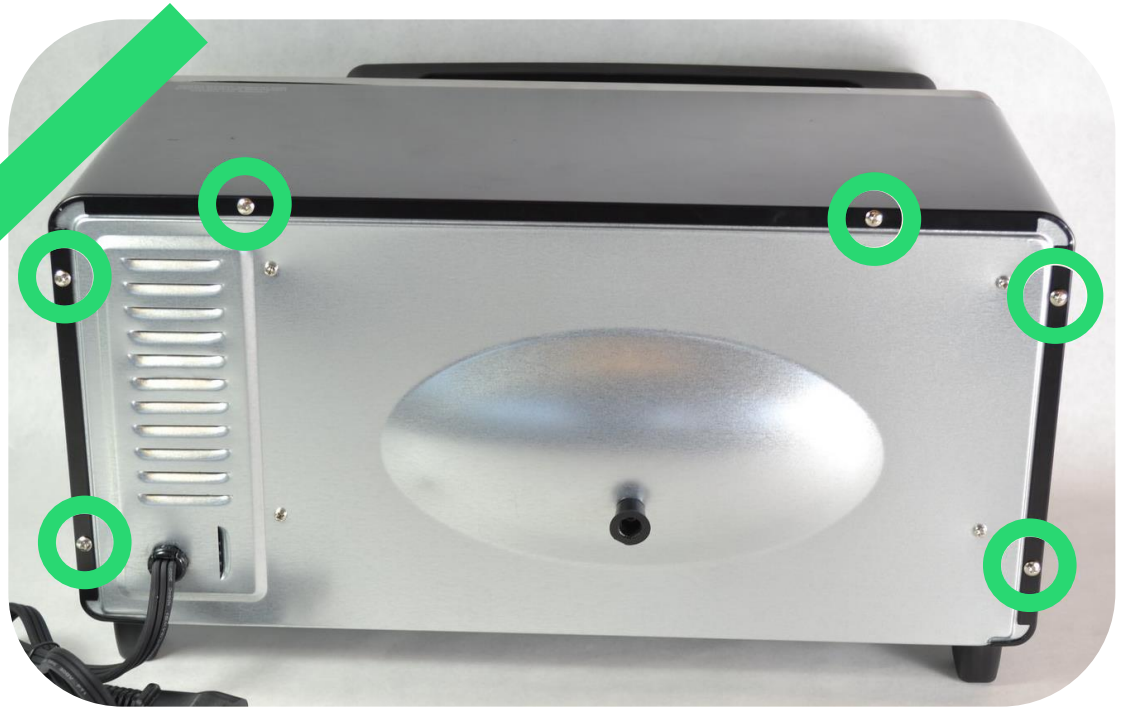


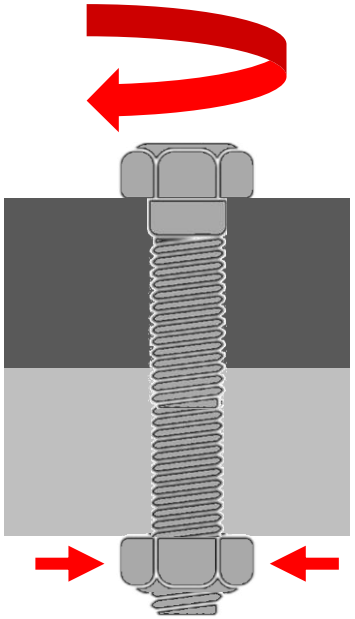
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Limited Robot Compatibility

Connectors or components that require multiple simultaneous disassembly actions are not compatible with single-arm robotic tools



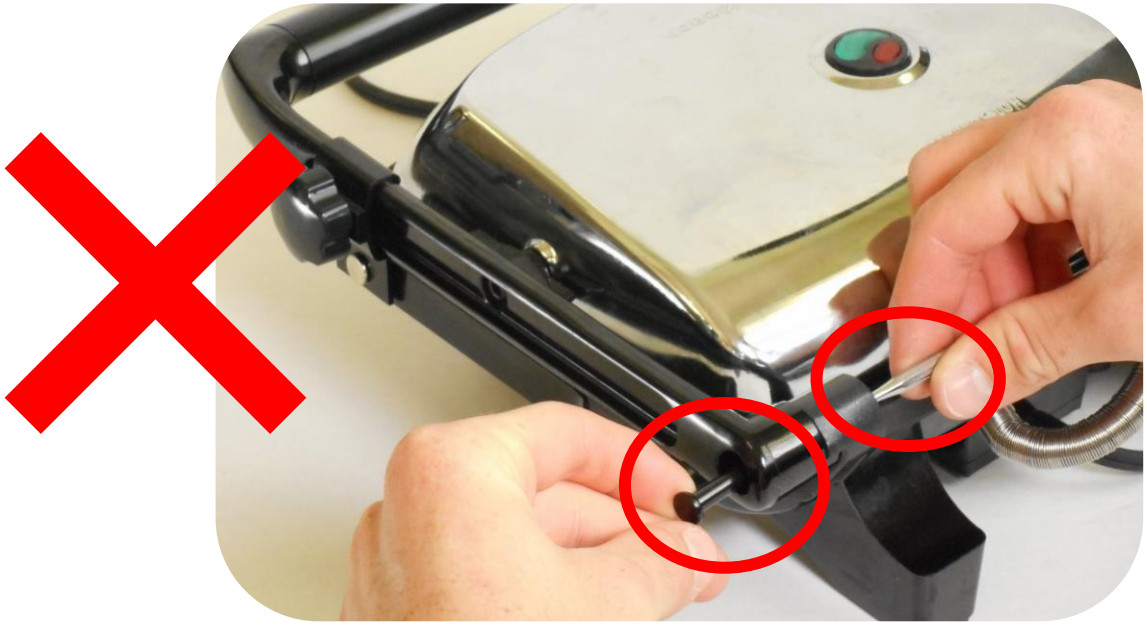


Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Robot Compatibility

Design components and connectors so they retain a fixed position and can be robotically disassembled

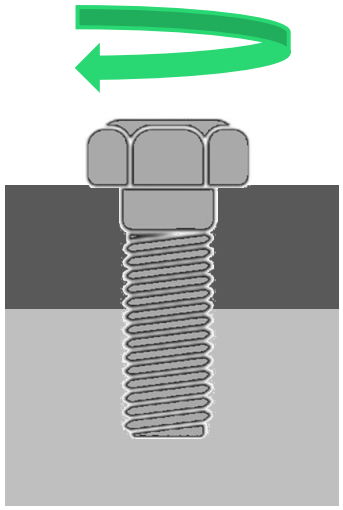
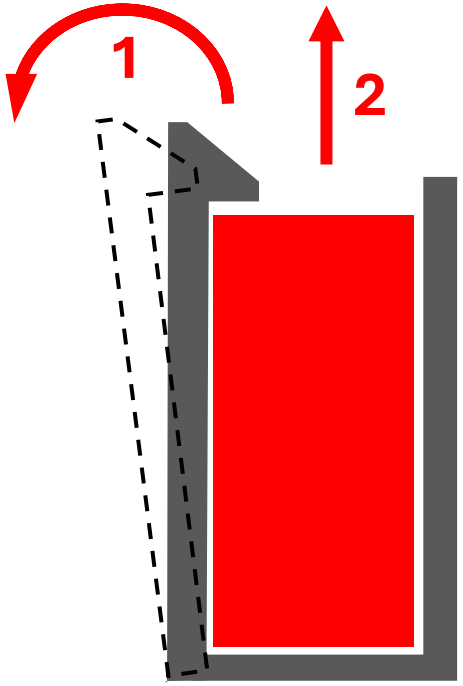
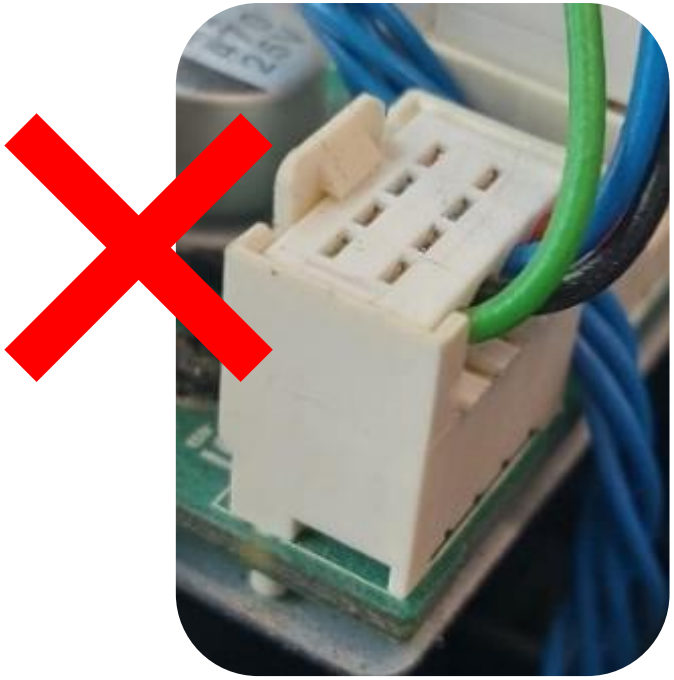


Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

Incompatible Snap-fits

Snap-fits that require simultaneous actions or multiple steps for removal with parallel finger grippers



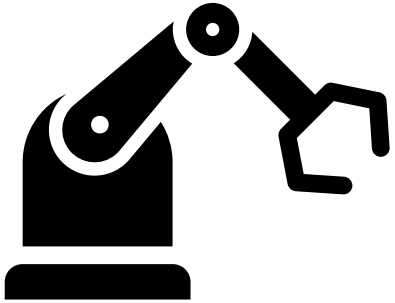


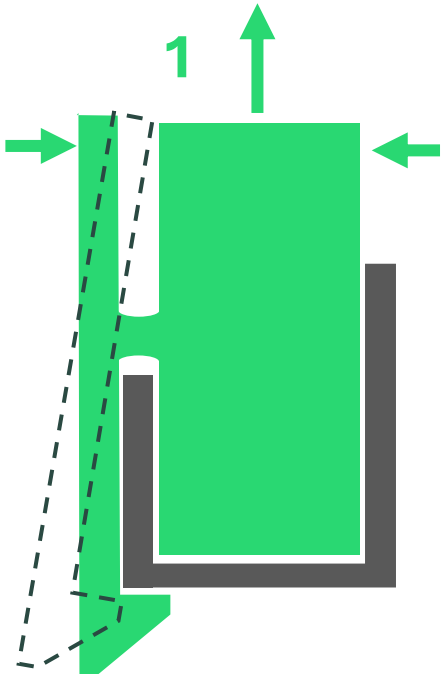
KU LEUVEN

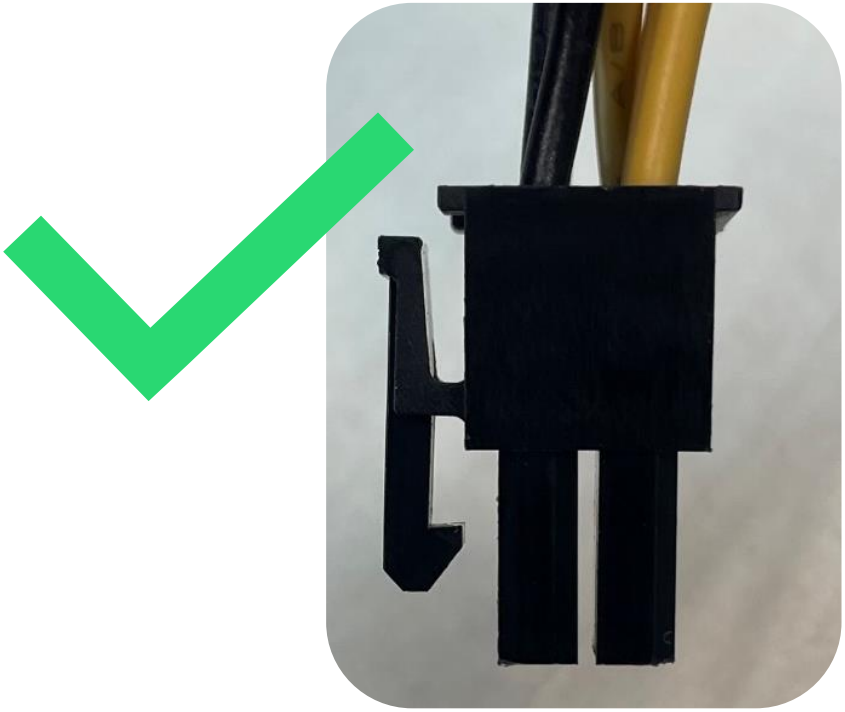
FLANDERS MAKE

Compatible Snap-fits

Modify snap-fit geometry to be opened in one action to ensure compatibility with robotic parallel finger grippers







KU LEUVEN

FLANDERS MAKE

Limited Detachability

Non-removable or adhesive connectors make non-destructive disassembly impossible

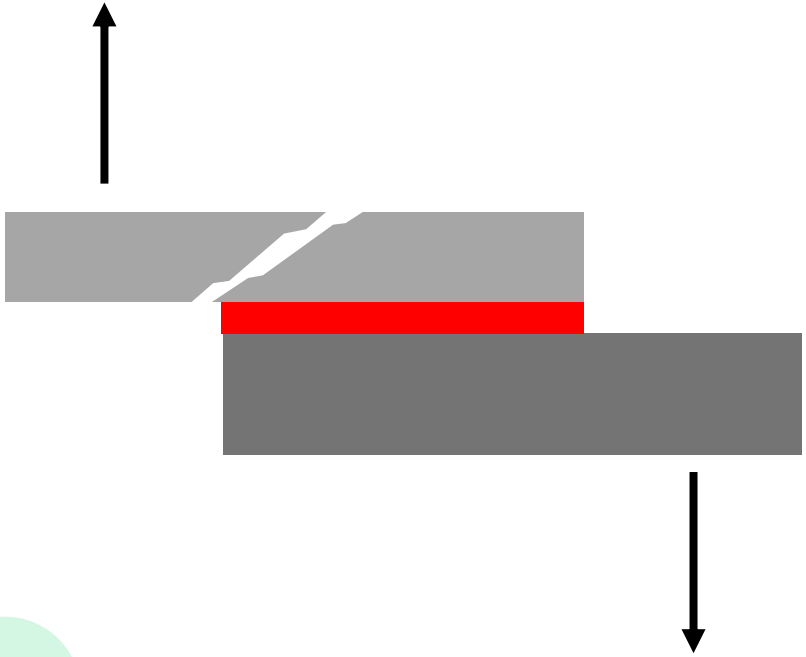


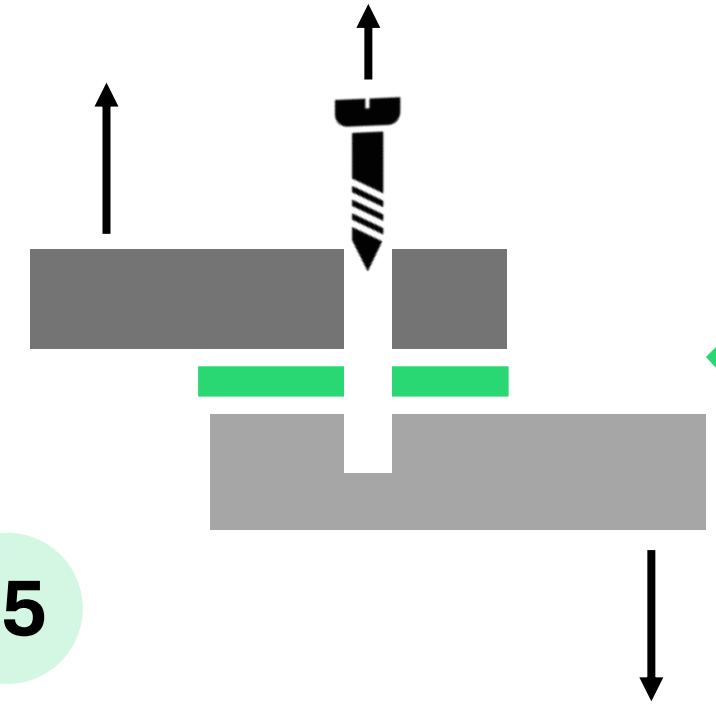
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

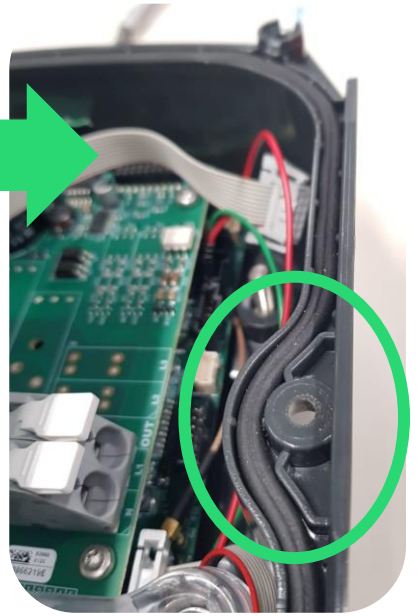
KU LEUVEN

FLANDERS MAKE

Full Detachability

Use removable non-destructive connectors (with rubber sealing if needed) to enable disassembly without damage





Detachability of Soldering

Large or strong welded/soldered joints do not allow for nondestructive disassembly

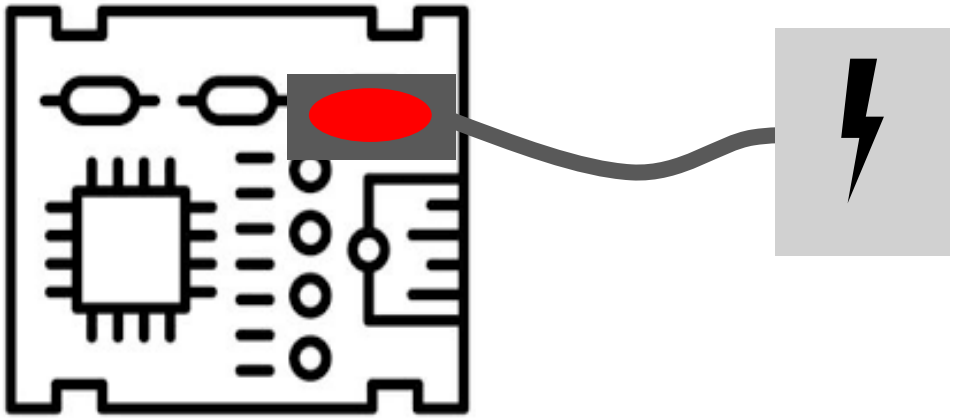


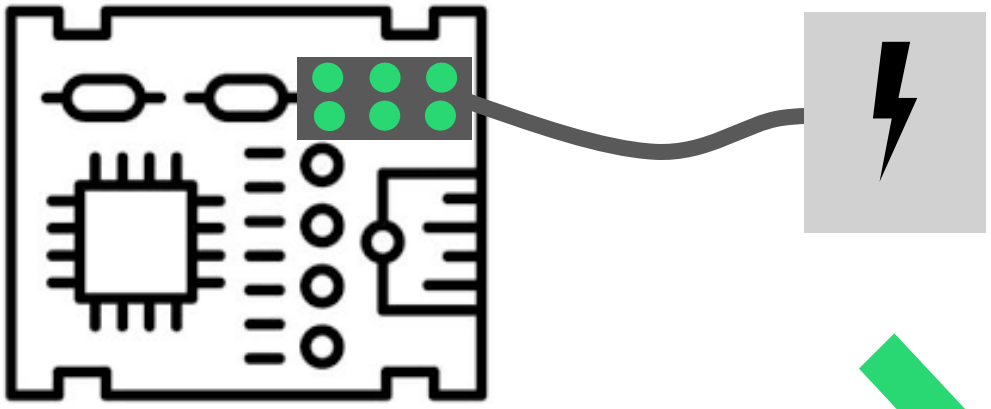
Image: Nuranu — “Can You Solder 18650 Batteries? The Pros, Cons, and Safety Tips” (All rights reserved), adapted for educational use

KU LEUVEN

FLANDERS MAKE

Allow Peeling of Small Spotwelds

Multiple small joints can assure the same conductivity, but can be separated without damaging the components



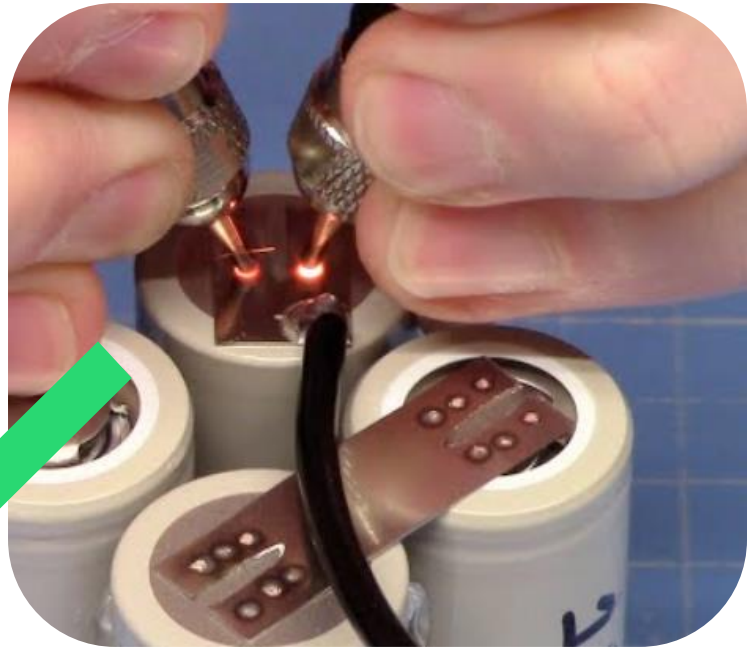


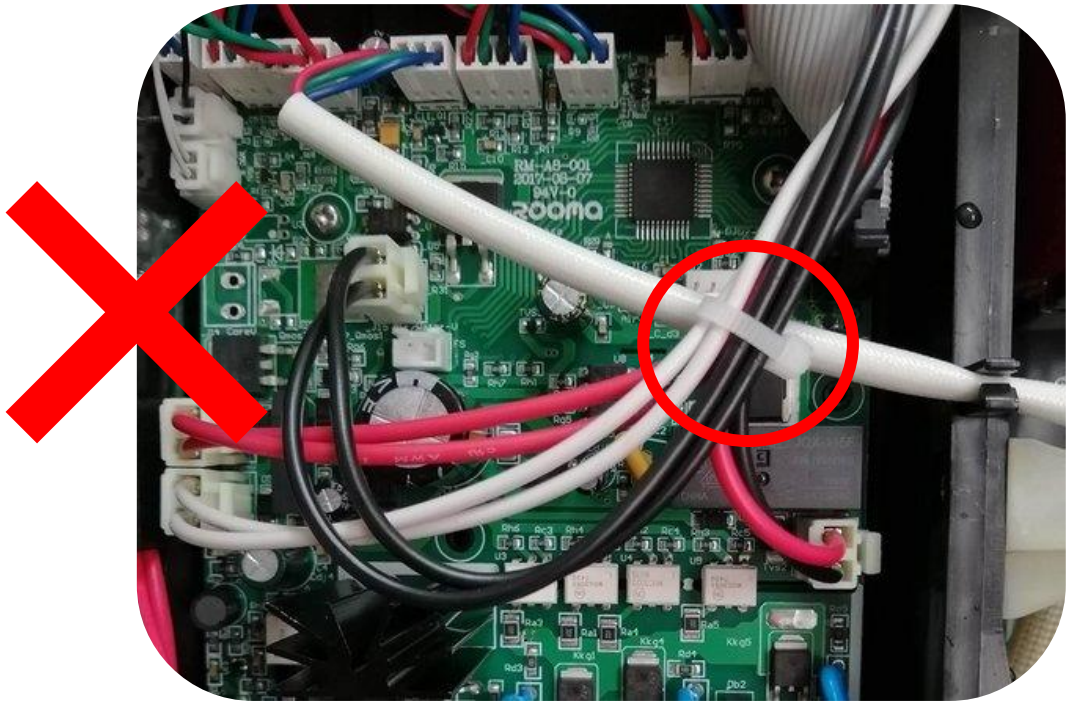
Image: YouTube video https://www.youtube.com/watch?v=P7ZOlzWEt8Y, used for educational purposes

KU LEUVEN

FLANDERS MAKE

Limited Detachability of Cables

Cables that are difficult to detach e.g., under closed hooks or fasteners, hinder robotic disassembly



KU LEUVEN

FLANDERS MAKE

Easy Detachability of Cables

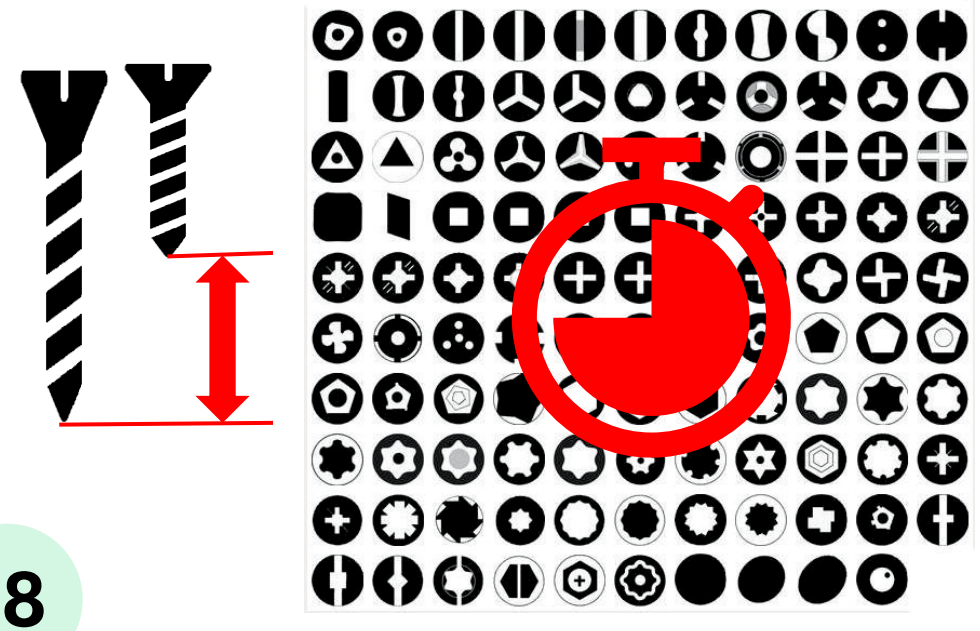
Use clamps or fastening systems for cables that allow fast cable detachment for robotic disassembly

KU LEUVEN

FLANDERS MAKE

Tool Change in Sequence

A high number and variety of connectors requires additional time for tool change and may result in errors during reassembly



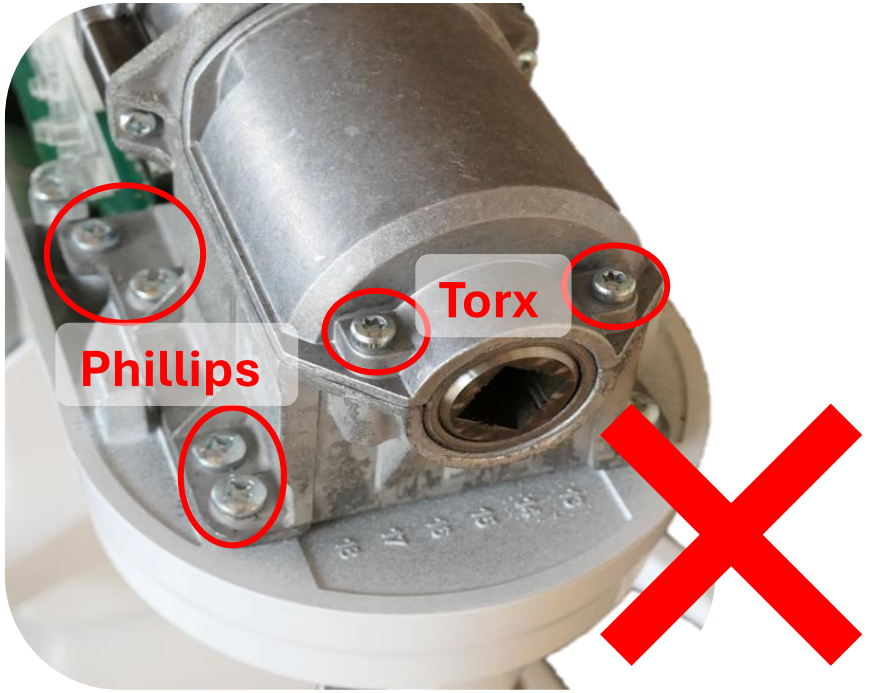


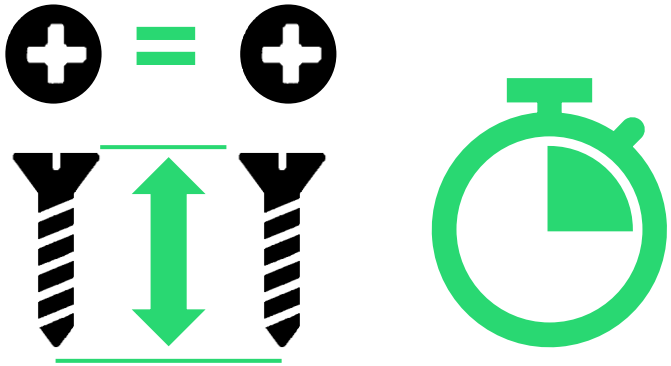
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

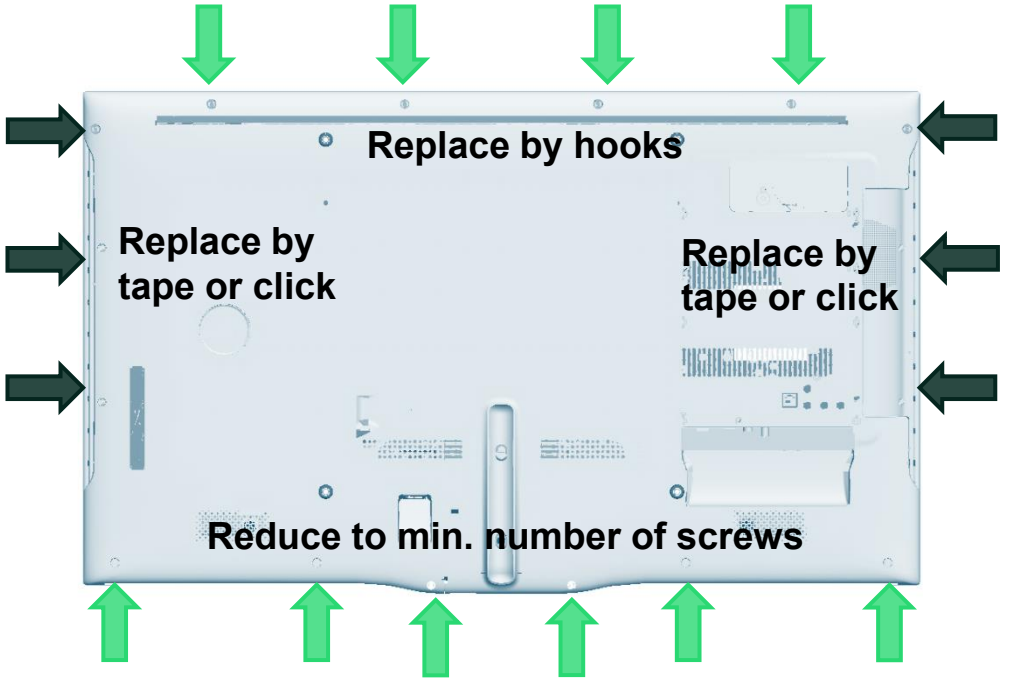
KU LEUVEN

FLANDERS MAKE

Uniformity in Fasteners

Minimize the number and types of connectors, e.g., by replacing part of the screws with a hinge or form fit



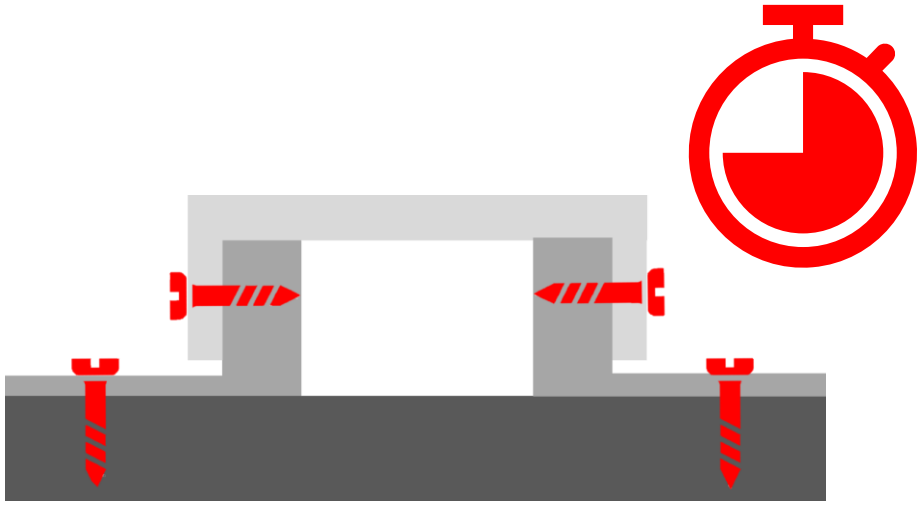


KU LEUVEN

FLANDERS MAKE

Multiple Fastener Orientations

Multiple fasteners placed in different orientations make disassembly inefficient



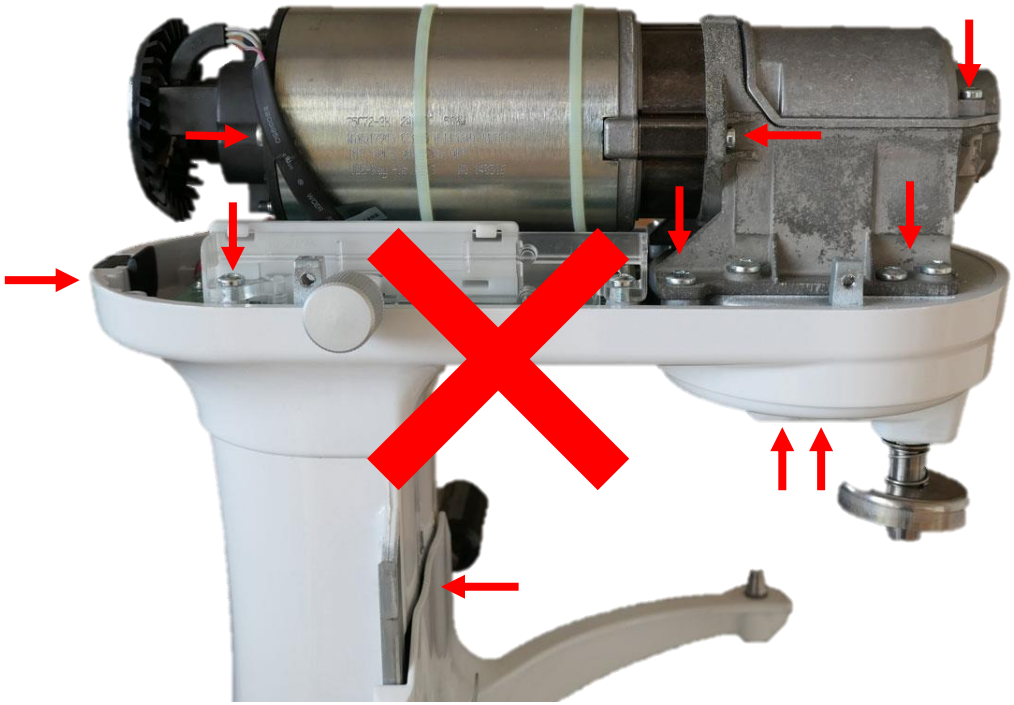


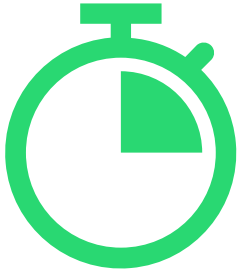
Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

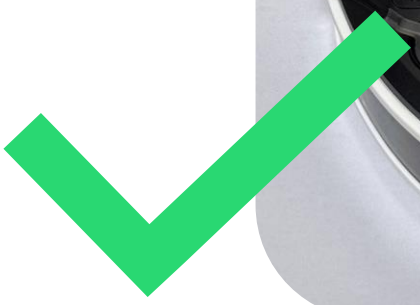
KU LEUVEN

FLANDERS MAKE

Single Fastener Orientation

Simplify fastener orientation e.g., by using stacked design to reduce number of fasteners, enabling efficient disassembly



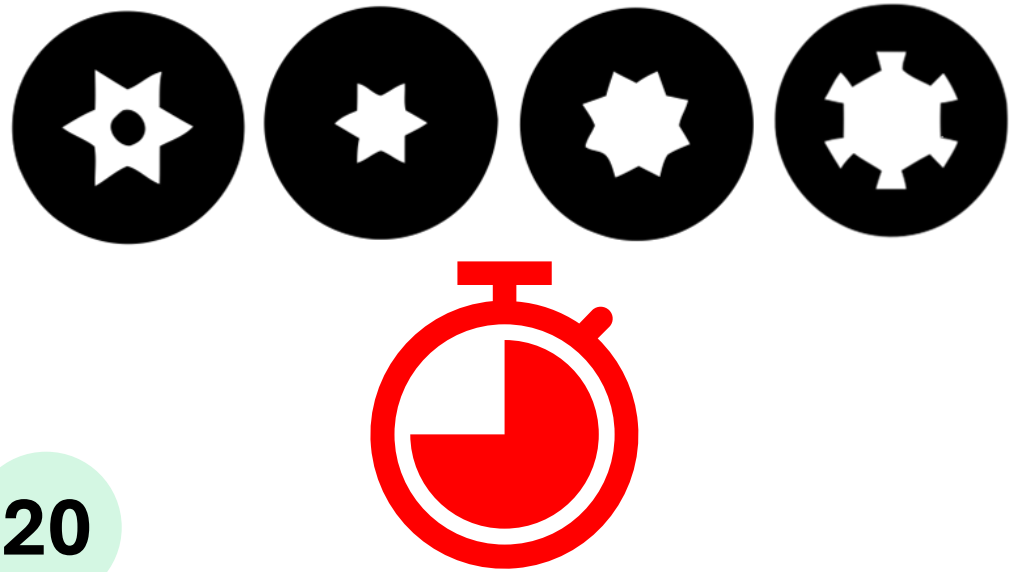


KU LEUVEN

FLANDERS MAKE

Inefficient Unscrewing

Screws requiring high positional precision ,
e.g., TORX, increase robotic disassembly time



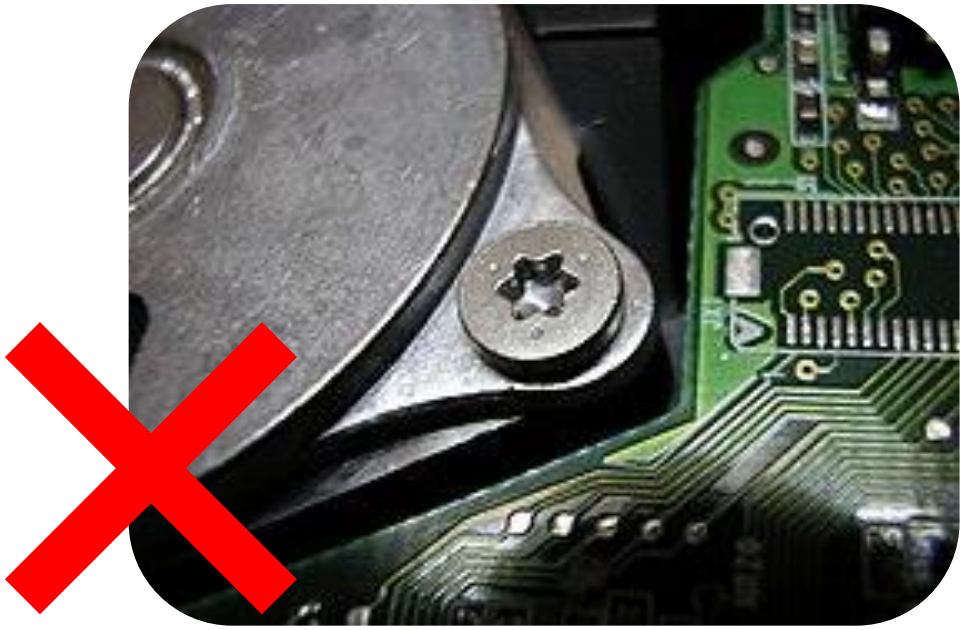


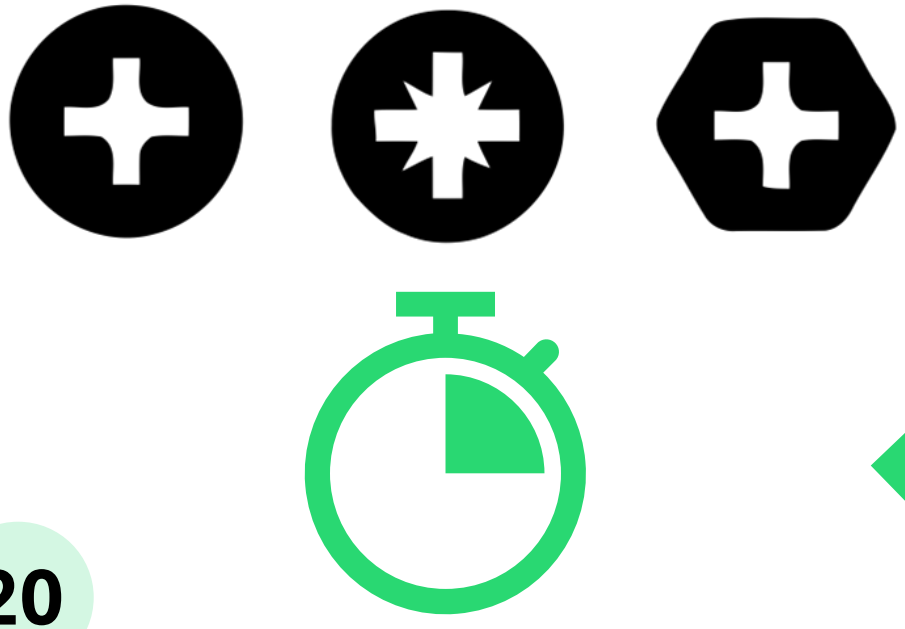
Image: VEM motors GmbH, Wikimedia Commons (CC BY-SA 4.0)

KU LEUVEN

FLANDERS MAKE

Efficient Unscrewing

Use self-aligning screws, e.g., Phillips, to reduce disassembly time



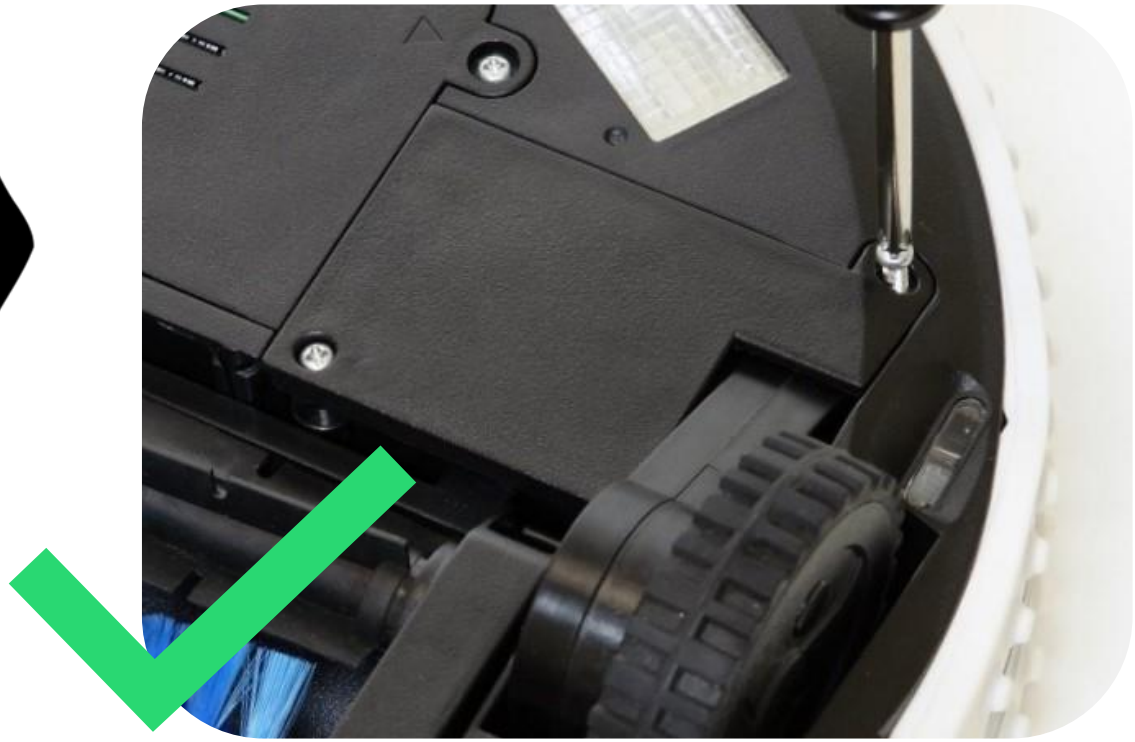


Image: iFixit (CC BY-NC-SA 3.0), adapted for educational use

Any Feedback?

Help us improve and
share your feedback at
https://PollEv.com/surveys/75upLjpRlZBpGQw8UjwtB/respond

Explore more!

Explore upcoming **Eco Design**
tools on our webpage at
https://sude.be/ecodesign