GUIDELINES FOR CRITICAL RAW MATERIAL EFFICIENCY

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This booklet is part of the master thesis titled: "**Towards guidelines for critical raw material efficiency in product design**."

It presents the key findings as practical design guidelines. For a more detailed explanation of the methods and research, refer to the full thesis.

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Introduction

Critical Raw Materials (CRMs) are essential for many modern technologies and can be found in components such as **motors, batteries, displays** and **printed circuit boards (PCBs)**. However, their supply is increasingly uncertain due to limited availability, geopolitical tensions, and challenges in recycling and recovery.

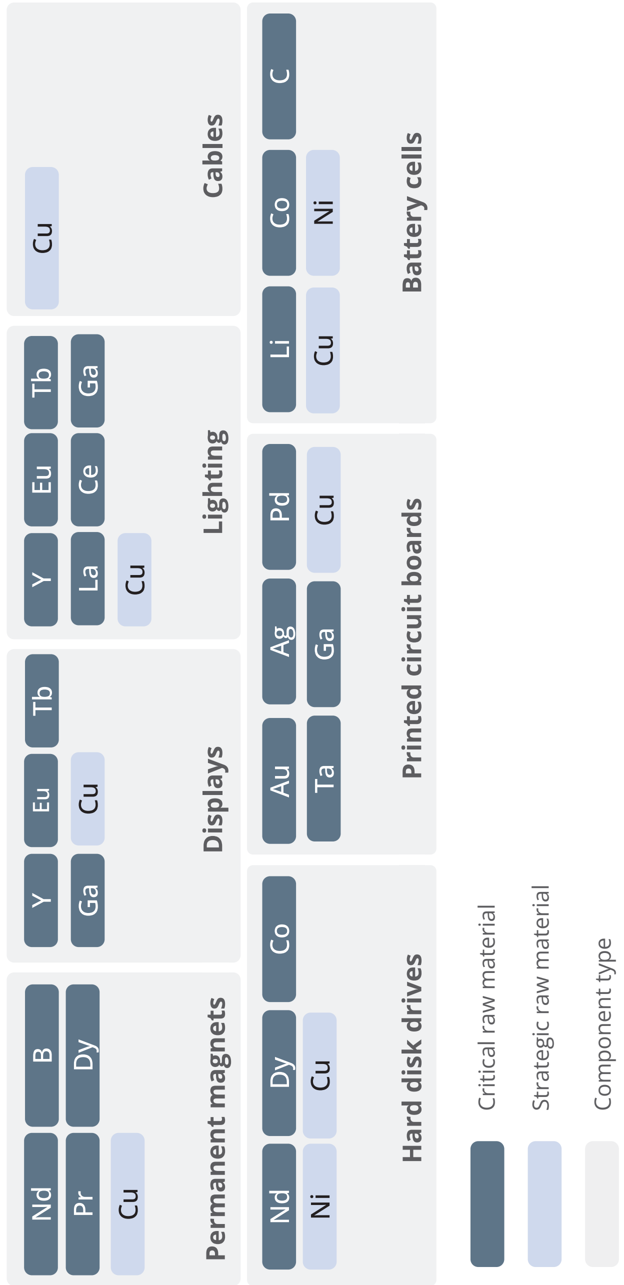
Product design plays a key role in addressing these challenges. Design decisions influence how CRMs are used in products, how long products remain in use, and how easily valuable components can be repaired, reused, or recovered. By considering these factors, designers can help reduce supply risks and contribute to a more resilient material future.

Who is this booklet for?

This booklet is intended for product designers and engineers who want to integrate CRM efficiency into their design process. It provides practical guidelines that illustrate how extending product lifetimes and improving the accessibility and recovery of CRM-containing components can be realised.

Examples from a cordless stick vacuum cleaner case study are used to illustrate how design choices influence CRM use and recovery. While product-specific, these guidelines should be seen as inspiration for applying CRM-efficient strategies across different design contexts.

Where to find Critical raw materials?



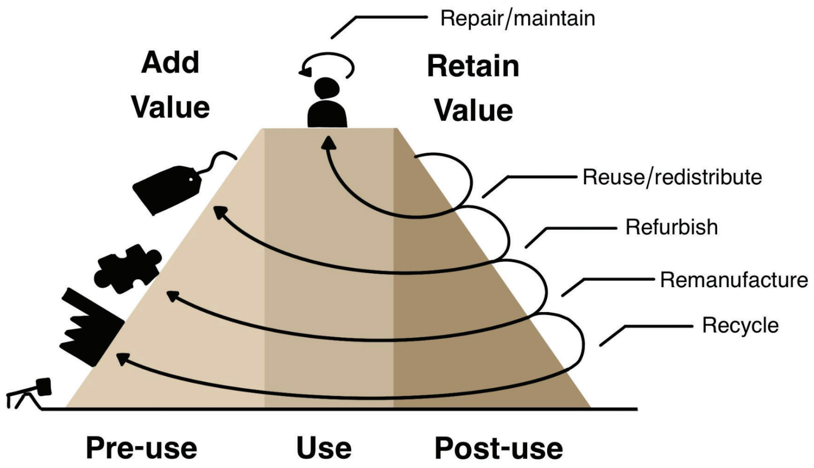
Iattoni et al. (2025)

CRM relevance

Demand for Critical Raw Materials (CRMs) is increasing due to the growth of technologies such as electrification, renewable energy, and digital products. At the same time, supply remains constrained and dependent on limited global production and geopolitical tensions.

These tensions increase supply risks and make reducing material demand more important. Improving CRM efficiency through longer product lifetimes, reduced material use and better recovery can help lower dependency on critical resources. This aligns with circular economy principles, which aim to keep materials in use for longer and recover value at the end of a product's life.

Design plays a key role, but improving CRM efficiency also depends on changes in policy, industry, and the market.



Achterberg, E., Hinfelaar, J., & Bocken, N. (2016)

Policy

The EU Critical Raw Materials Act (CRMA) and the Ecodesign for Sustainable Products Regulation (ESPR) promote longer product lifetimes, improved repairability, and CRM efficiency. However, they provide no product-specific guidance how to implement CRM efficiency. Product specific guidelines and policy regulations are needed to support designers in developing more CRM-efficient products.

Industry

Manufacturers need to treat CRM intensity as a key design parameter alongside cost, performance, and energy efficiency. This requires integrating strategies such as repairability, substitution, and lifetime extension into product development. Doing so can reduce dependency on critical materials and strengthen supply chain resilience.

Market

Market expectations need to shift towards improved repairability, standardisation, and longer product lifetimes to support CRM efficiency. This challenges business models based on rapid replacement and product differentiation, and instead favours reuse and long-term value.

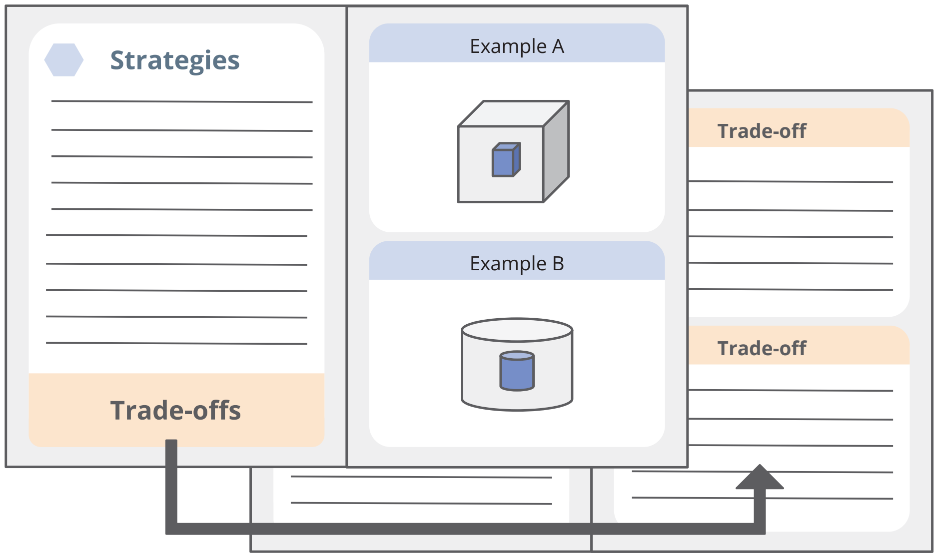
How to use this tool?

This booklet presents design strategies to improve CRM efficiency. The guidelines focus on how **component selection**, **product architecture**, and **connection methods** influence the use and recovery of Critical Raw Materials.

Guidelines
Each guideline includes a short explanation and visual examples from a cordless stick vacuum cleaner case study.

Trade-offs
Design strategies involve technical, economic, and systemic trade-offs. These trade-offs are indicated on each strategy page and explained in more detail in the trade-off section.

Additional tools
Methods such as Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) can support decision-making of CRM efficiency strategies by evaluating trade-offs and quantifying CRM efficiency. An indicator is added on the trade-off section to show when these tools are relevant.

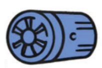


CRM hotspot mapping

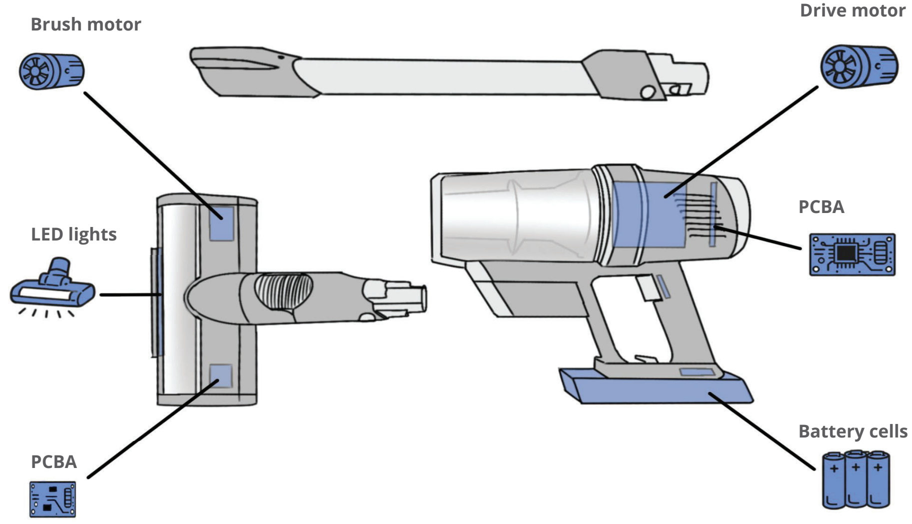
CRM hotspot mapping identifies and prioritises components that contain CRMs and offer the greatest potential for improving CRM efficiency. It focuses on components that are both high-risk and contain significant amounts of CRMs. The method combines **Economic Importance (EI)** and **Supply Risk (SR)** from the EU CRM assessment (European Commission, 2023) with an estimate of CRM quantity within components. This helps prioritise components where CRMs occur in substantial amounts rather than trace quantities. A more detailed description of the method can be found in the thesis report (Grupstra, 2026).

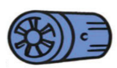
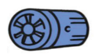
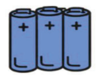
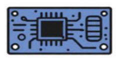
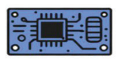
Identifying CRM hotspots for a specific component follows the following four steps:

Example component:

	Example component
1. Identify CRM containing component	 **Drive motor**
2. Assess material criticality How critical are the materials?	**EI > 6.0 SR > 3.5** = high criticality
3. Evaluate component relevance what is the % of CRM in component	**% CRM > 1% of mass** = High concentration
4. Determine CRM hotspot level (High / Medium / Low)	**High criticality + High concentration** = High hotspot

Cordless stick vacuum cleaner



Icon	Component	CRM content	CRM Hotspot
	**Drive motor**	Neodymium, (Dysprosium), (Praseodymium), Boron, Copper	**High**
	**Brush motor**	Neodymium, (Dysprosium), (Praseodymium), Boron, Copper	**High**
	**Battery cells**	Lithium, Cobalt, Natural graphite, Copper	**High**
	**Battery PCBA**	Palladium, (Tantalum), Nickel, Copper	**Low**
	**PCBA**	Palladium, (Tantalum), Nickel, Copper	**Low**
	**LED Lights**	Gallium, Indium, Copper	**Low**

1 Guidelines

1 Substitution

Replace CRM intensive components with alternatives that rely on more abundant or lower risk materials.

Substitution reduces dependency on Critical Raw Materials (CRMs) by selecting technologies or materials that require fewer or less critical resources. Many modern technologies depend on CRMs such as rare earth elements, cobalt, or lithium, which can be associated with supply risks and environmental impacts.

By choosing alternatives with lower CRM intensity, designers can improve the material resilience of a product. For example, brushless DC (BLDC) motors often rely on rare earth magnets, while alternatives such as DC motors with ferrite magnets or switched reluctance motors (SRM) require little or no rare earth materials. Battery technologies can also shift from lithium based chemistries toward emerging options such as sodium ion batteries, which rely on more abundant materials.

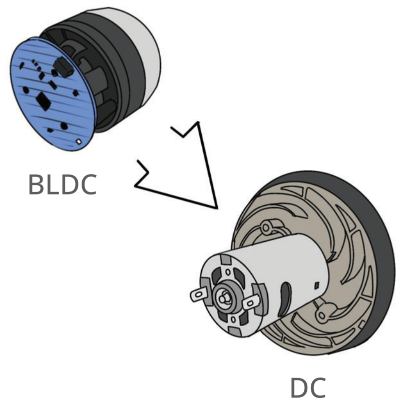
Considering substitution early in the design process helps reduce supply risks and supports more resource resilient product systems.

Trade-offs

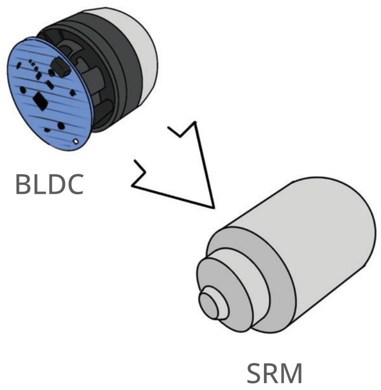
1. Standardisation and market flexibility
2. Product efficiency and CRM intensity

More info on p 35

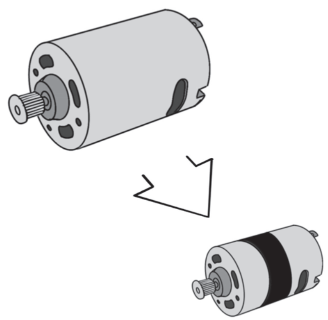
Substitute BLDC motors for DC motors



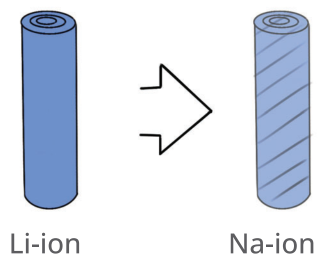
Substitute BLDC motors for SRM motors



Substitute the motors for less CRM intensive types



Substitute the battery cells for less CRM intensive types



2 Standardisation & Modularity

Set standards for component types and connection methods to reduce CRM use and enable reuse, repair, and recovery.

Standardising components such as motor types, connectors, or battery formats reduces the need for multiple CRM intensive variants and helps prevent overspecification of components. It also allows parts to be shared across different products, improving spare part availability and simplifying maintenance and replacement.

Modular design complements this approach by dividing products into interchangeable modules that can be easily removed, repaired, or upgraded. Using standard connectors, accessible fasteners, and visible attachment points enables non destructive disassembly and improves the recovery of valuable CRM containing components.

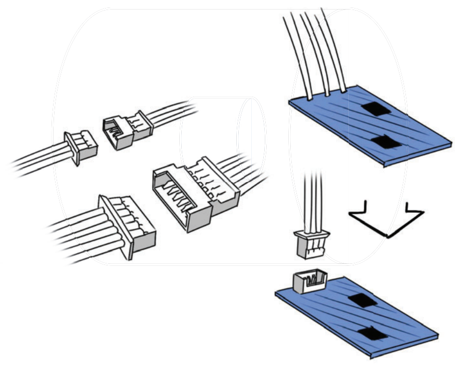
Together, standardisation and modularity extend product lifetimes, support component reuse across systems, and improve the recovery potential of CRMs, contributing to more resource efficient and resilient product design.

Trade-offs

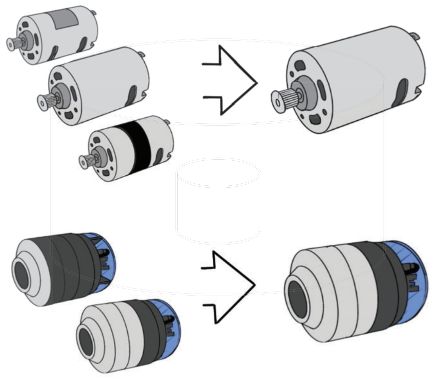
1. Standardisation and market flexibility
2. Product efficiency and CRM intensity

More info on p 35

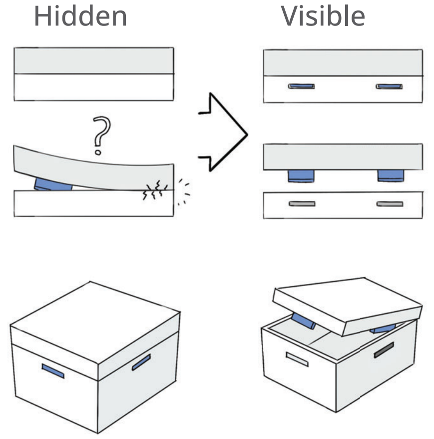
Use cable plugs to connect components



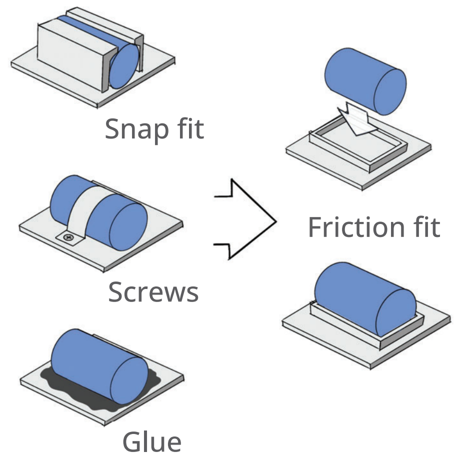
Set standards for components



Minimise hidden/irreversible snapfits



Use friction fit fasteners to secure CRM components



3 Pruning

Reduce components and features to the absolute functional necessity to minimize the use of Critical Raw Materials (CRMs) in the product.

Modern products often include additional features, sensors, and electronic components that increase complexity and introduce extra CRMs. While these additions may improve convenience or performance, they can significantly increase the overall CRM content of a product.

By critically evaluating which functions are truly required, designers can remove unnecessary components and simplify the product architecture. This reduces the number of CRM containing parts such as electronics, sensors, magnets, and batteries.

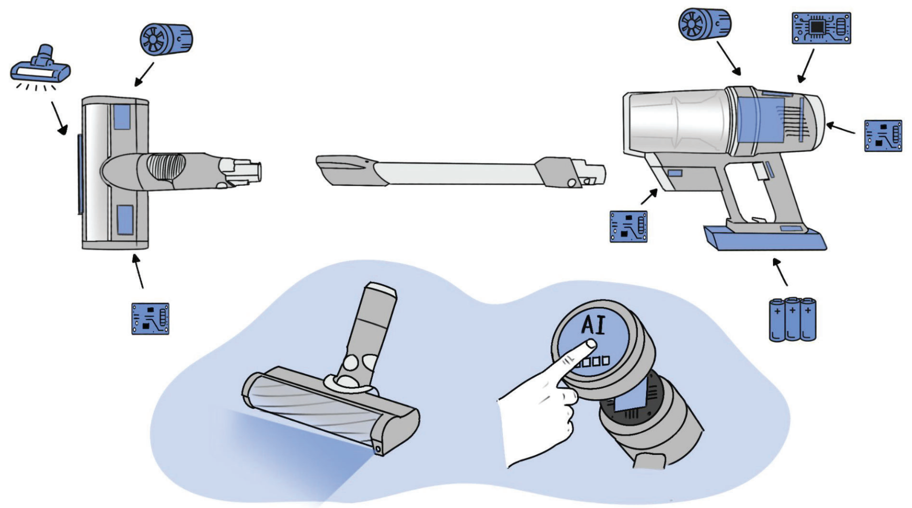
Prioritizing core functionality over feature expansion lowers material demand and can also improve reliability, reduce production complexity, and make products easier to repair and recycle.

Trade-offs

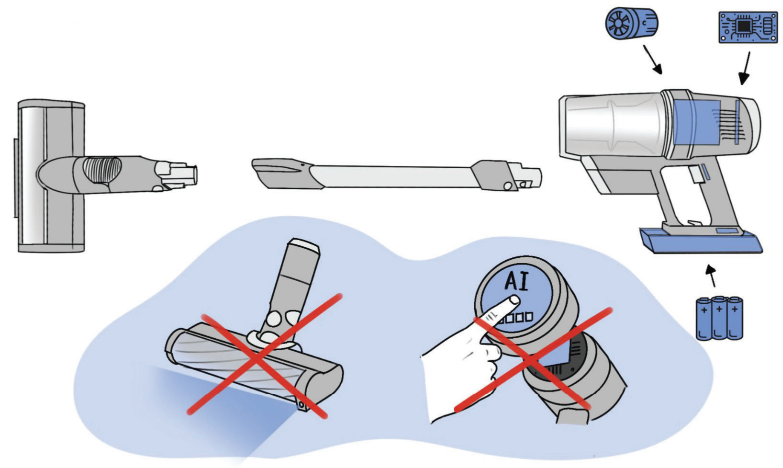
4 Pruning and feature driven marketing

More info on p 35

Features are added to the product



Reduce the components to the absolute functional necessity



4 Accessibility
- Surfacing

Surface CRM containing components within the product architecture to improve accessibility for disassembly, repair, and recovery.

Surfacing focuses on reducing the disassembly effort required to reach components that contain CRMs. In many products, CRM intensive parts are located deep within the product architecture, requiring the removal of multiple components and fasteners before they can be accessed.

By positioning these components closer to the product surface and minimizing the number of disassembly steps, designers can significantly reduce disassembly time and labour. This improves accessibility for repair and maintenance, helping extend the functional lifetime of products.

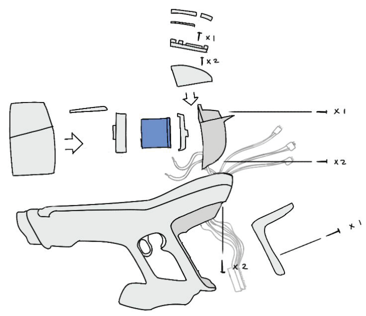
To illustrate the effect of surfacing, three examples of CRM containing components in cordless stick vacuum cleaners are shown, highlighting their disassembly depth and estimated disassembly time.

Trade-offs

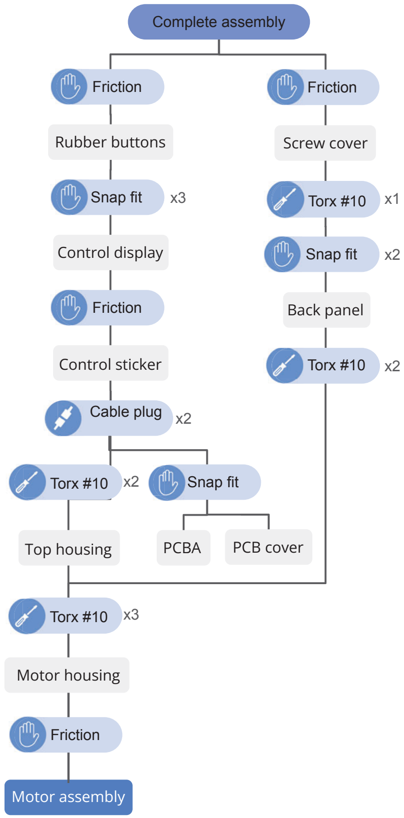
- 3 Design and manufacturing cost
- 5 Ease of disassembly versus disassembly depth
- 6 Design for repair and design for recycling

More info on p 35

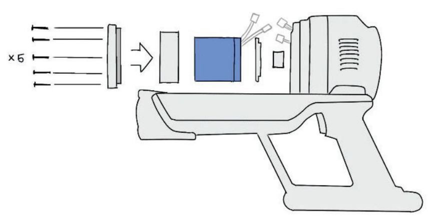
Motor example A



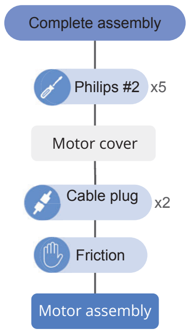
Disassemble time:
6,5 minutes



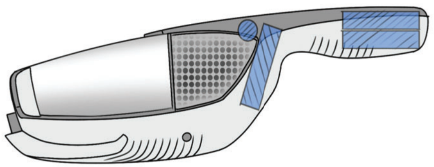
Motor example B



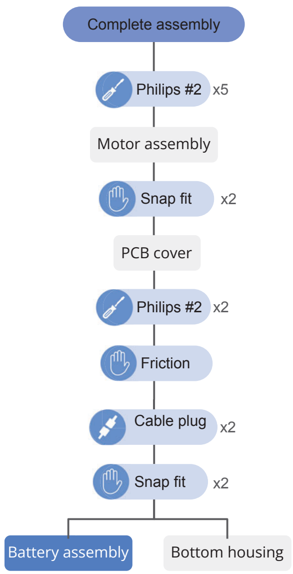
Disassemble time:
60 seconds



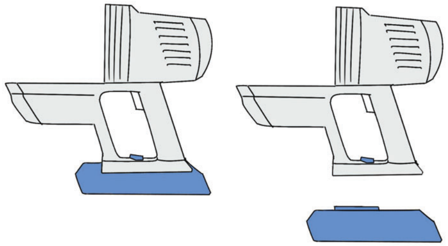
Battery example A



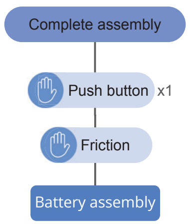
Disassemble time:
2 minutes



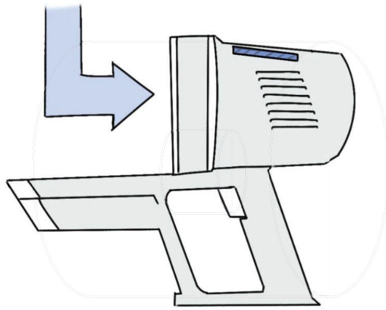
Battery example B



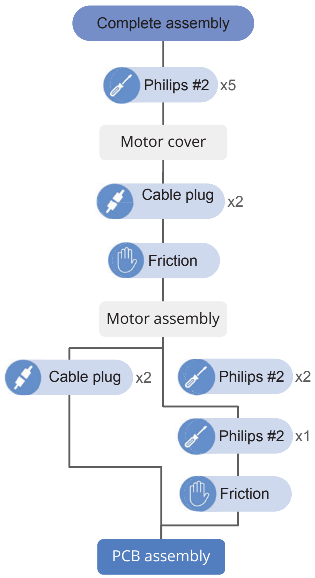
Disassemble time:
5 seconds



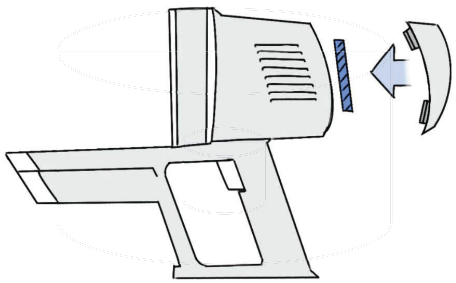
PCB example A



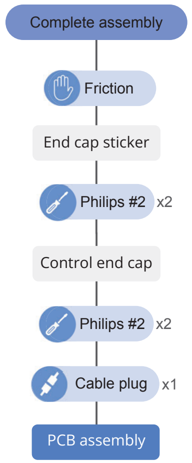
Disassemble time:
120 seconds



PCB example B



Disassemble time:
40 seconds



5 Accessibility
- Clumping

Group CRM containing components together within the product architecture to enable more efficient access and recovery during disassembly.

Clumping focuses on reducing the effort required to locate and access components that contain CRMs. In many products, CRM components are distributed across different areas of the product architecture, requiring multiple disassembly paths to reach them.

By grouping these components within the same module or location, designers can reduce the number of disassembly steps and tools needed to access them. This allows several CRM containing components to be removed together and thereby improves the efficiency of repair, maintenance, and end of life processing of CRM components.

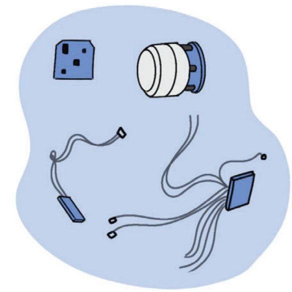
Two examples illustrate the effect of clumping. In Example A, CRM containing elements are distributed across four components throughout the product, whereas in Example B they are concentrated in only two components.

Trade-offs

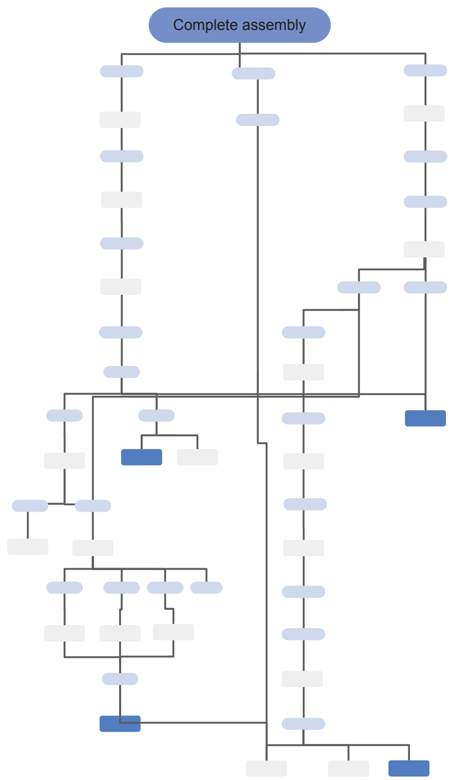
- 3 Design and manufacturing cost
- 5 Ease of disassembly versus disassembly depth
- 6 Design for repair and design for recycling

More info on p 35

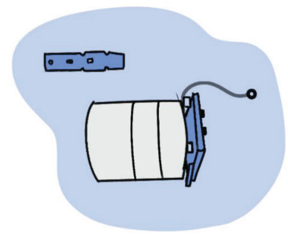
4 components



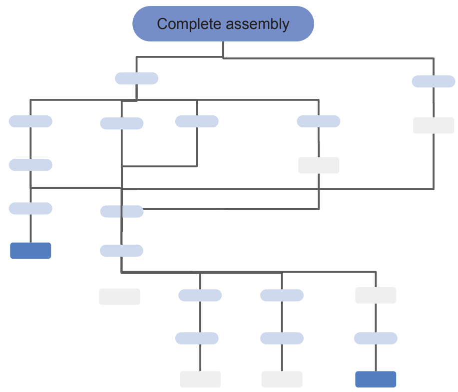
Disassemble time:
8 minutes



2 components



Disassemble time:
4,5 minutes



6 Accessibility
- Fasteners

Limit the number and variety of fastener types used to secure CRM containing components to improve accessibility during disassembly.

Fastener types such as screws, snap fits and friction fits are commonly used to secure components within a product. However, using many fasteners or multiple fastener types can increase the time and effort required to access Critical Raw Materials (CRMs) during disassembly.

By minimizing the number of fasteners and using consistent, easily removable types, designers can reduce the number of disassembly steps and tools required. This improves accessibility for repair and maintenance, helping extend the functional lifetime of products.

Two examples illustrate how additional connections can affect disassembly time. In Example A, extra screws are used to fasten the battery assembly, whereas in Example B these connections are removed.

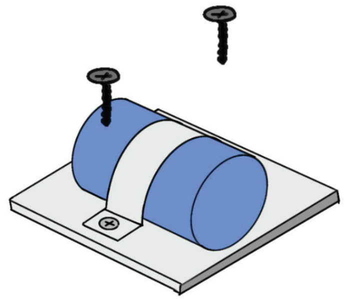
Trade-offs

- 3 Design and manufacturing cost
- 6 Design for repair and design for recycling

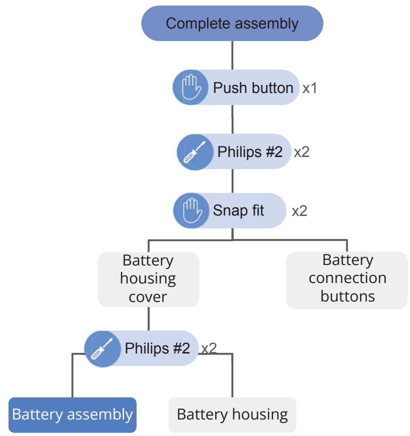
More info on p 35

25

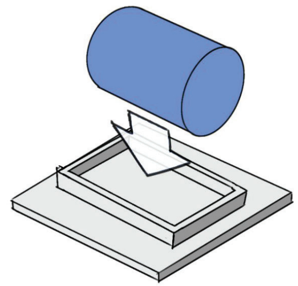
Screw connection



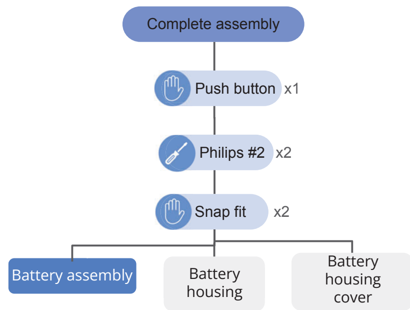
Disassemble time:
60 seconds



Friction fit



Disassemble time:
40 seconds



7 Accessibility
- Cable plugs

Use cable plugs instead of soldered connections to improve accessibility of CRM containing electronic components.

Electronic components such as PCBs are often connected to cable assemblies using soldered joints. While solder provides a strong electrical connection, it makes disassembly more difficult because wires must be cut or desoldered to remove the component.

By using cable plugs or connectors instead of soldered connections, components can be disconnected quickly and without damaging the surrounding parts. This significantly reduces the time and effort required to access and remove CRM components during repair, maintenance, or end of life processing.

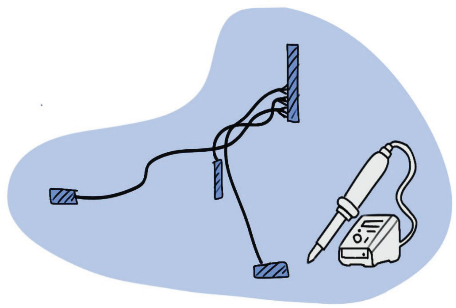
Two examples are shown of disassembly steps necessary to liberate a PCB module. Example A shows the steps when the component uses soldered connections wheresass example B uses cable plugs.

Trade-offs

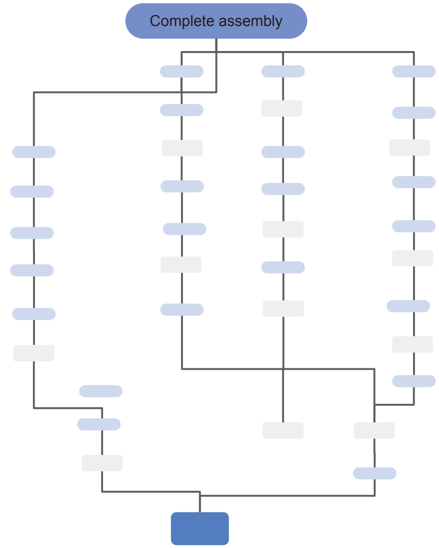
4 Design and manufacturing cost

More info on p 35

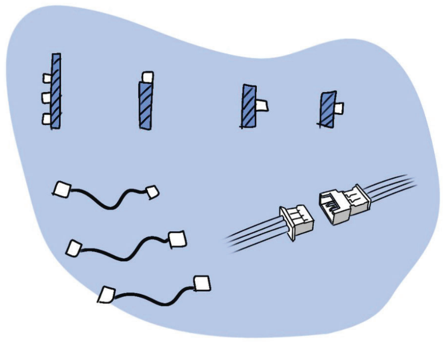
Soldering



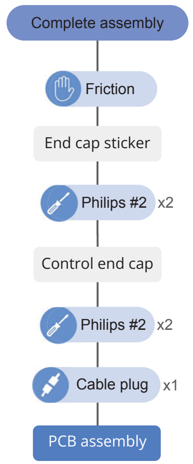
Disassemble time:
7 minutes



Cable plugs



Disassemble time:
40 seconds



8 Accessibility
- Embedded parts

Avoid embedding CRM components in non-removable subassemblies to ensure they remain accessible for repair and recovery.

In some products, components that contain CRMs are embedded within subassemblies that cannot be disassembled without damaging the surrounding parts. Examples include components that are overmolded, glued, or permanently enclosed within structural elements. When these components fail or reach the end of their life, they cannot be removed without destroying the entire subassembly.

By avoiding embedded designs and ensuring that CRM containing components can be removed through reversible disassembly steps, designers can improve accessibility of CRM components.

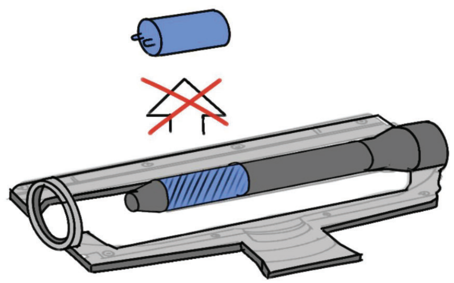
Two examples are shown to illustrate the difference: one vacuum brush motor is overmolded within a subassembly, while the other is secured with screws.

Trade-offs

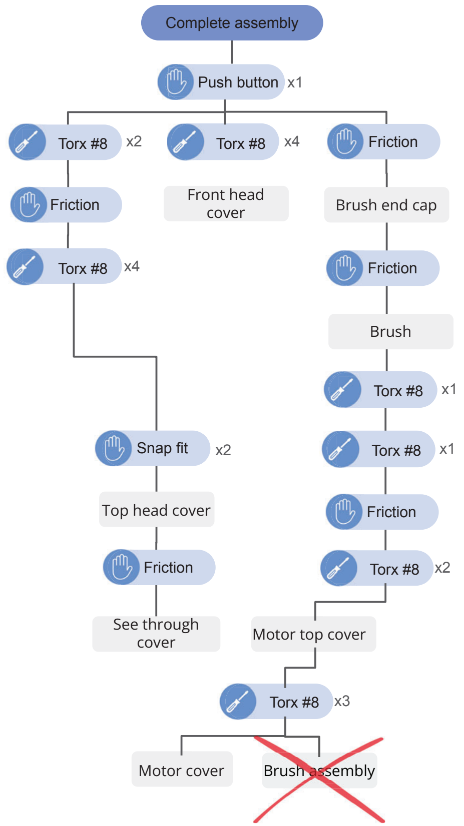
- 3 Design and manufacturing cost
- 5 Ease of disassembly versus disassembly depth

More info on p 35

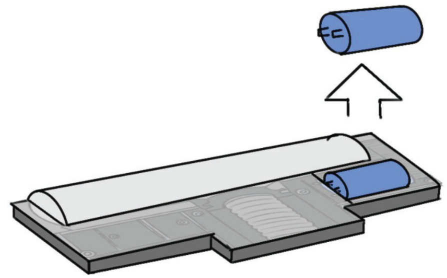
Example A



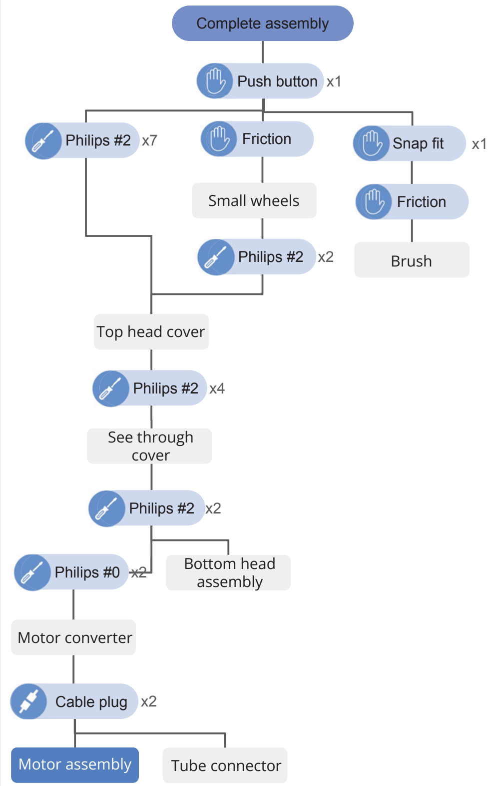
Disassemble time:
Failed



Example B



Disassemble time:
3,5 minutes



9 Improve documentation

Provide clear documentation on product composition and disassembly to support repair and recovery of CRM containing components.

Improved documentation helps identify where CRMs are located within a product and how they can be safely accessed. Without clear information, repair technicians and recyclers may struggle to locate CRM containing components or risk damaging them during disassembly.

Repair guides can provide step by step instructions that support safe and efficient disassembly while reducing the risk of components breaking. In addition, tools such as Digital Product Passports (DPPs) can provide detailed information on product composition, including the presence and location of CRMs.

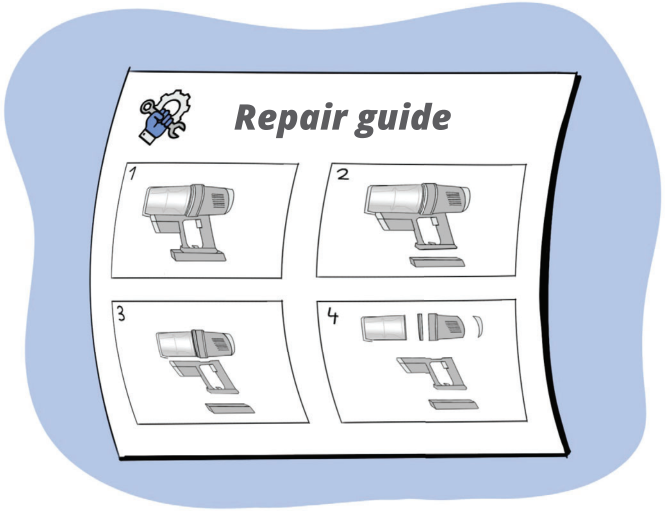
Providing accessible documentation improves transparency across the product lifecycle and helps ensure that CRM containing components can be repaired, reused, or recovered more effectively.

Trade-offs

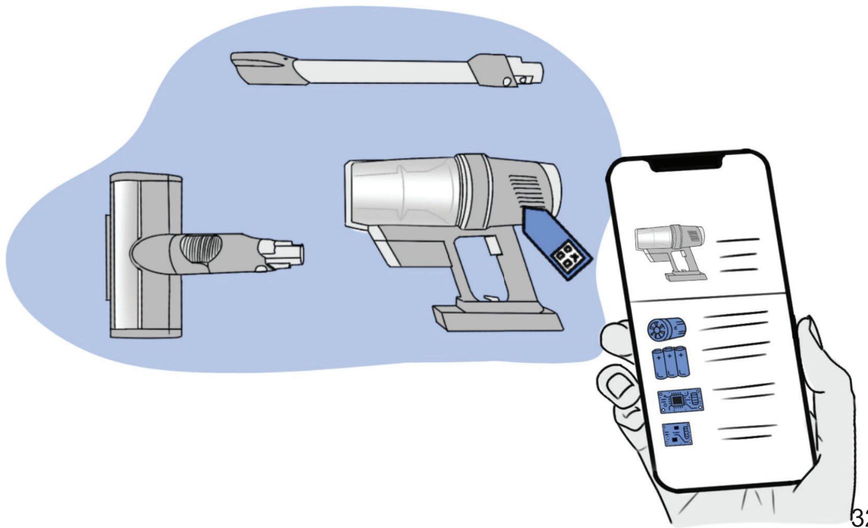
Design and manufacturing cost

More info on p 35

Create repair guides to guide the repair process



Show the CRM content through the DDP



2

Trade-offs

1 Standardisation and market flexibility

MFA

See page 39

Standardising components such as motors, batteries and fasteners can improve reuse, repairability and material recovery while reducing the overspecification of CRM intensive parts. However, strict standardisation may also limit product differentiation, design flexibility and potential innovation. Achieving CRM efficiency therefore requires carefully evaluation between standardisation and the development of alternative technologies.

2 Product efficiency and CRM intensity

MFA LCA

See page 39

High efficiency components such as BLDC motors with rare earth magnets improve energy performance but also increase CRM dependency. Alternatives with lower CRM content, such as brushed DC motors, typically reduce component efficiency and may shorten product lifetime due to mechanical wear. Choosing between product efficiency and CRM intensity depends on the products context and use case and should be taken into consideration when designing a product.

3 Design and manufacturing cost

Designing a products architecture to improve accessibility, modularity, and recovery can support CRM efficiency. However, adding access points, cable plug connectors or modular structures may increase manufacturing complexity, design and production costs. In cost sensitive product segments, these additional costs may reduce competitiveness if cheaper alternatives remain available. Adoption of CRM efficient design therefore depends on the product's business case and value proposition.

4 Pruning and feature driven marketing

Removing non essential product features containing CRMs can lower CRM demand. However, additional features may also improve functionality or performance. Designers should evaluate whether added features support the product's core functions and whether they increase the product's CRM intensity. If CRM components provide limited functional benefit, simplifying or removing them can improve CRM efficiency without limiting the product's primary functionality.

5 Ease of disassembly versus disassembly depth

A shallow disassembly depth for CRM components does not always guarantee improved CRM efficiency if access requires complex or destructive steps. Designers should therefore consider both component location and connection type when improving accessibility. Prioritising clearly visible, reversible connections such as screws or cable plugs can enable easier access than hidden snap fits or permanent, non-reversible connections.

6 Design for repair and design for recycling

MFA LCA

See page 39

Designers should consider whether CMR components are better suited for repair or recycling strategies. Design for repair favours modular structures and reversible connections that allow repeated opening and component replacement. Design for recycling prioritises assemblies that simplify material separation or shredding, but may limit non-destructive access. Selecting the most effective strategy depends on component's expected lifetime, reusability and material recoverability.

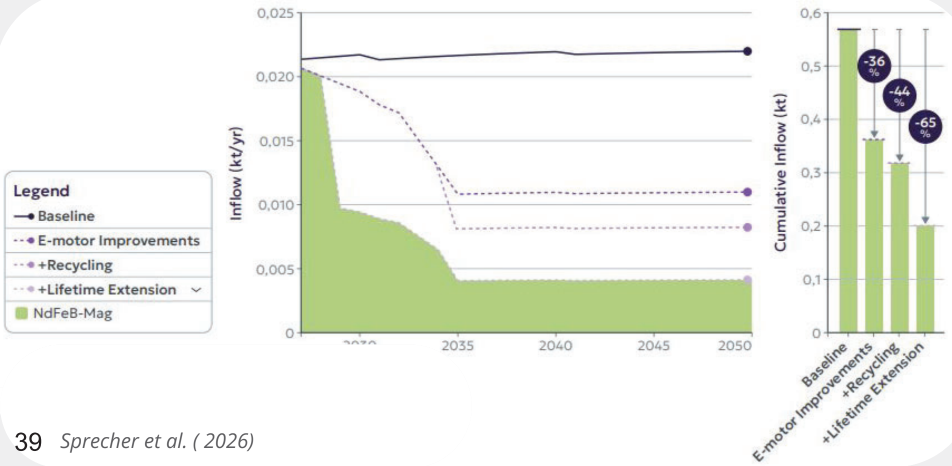
3 Additional tools

MFA Material flow analysis

Material Flow Analysis (MFA) helps designers quantify the potential impact of CRM efficiency strategies by estimating how much material can be saved.

MFA is particularly useful for evaluating how design strategies influence overall material demand. It can estimate how strategies such as extended product lifetimes or component substitution affect annual CRM consumption while maintaining the same level of product use.

To apply MFA, designers map the materials used in each component and estimate their quantities. Different material flow scenarios are then created to represent CRM efficiency strategies. Comparing these scenarios helps prioritise design interventions that can most effectively reduce CRM demand. An example of a dynamic MFA from Sprecher et al. (2026) is presented below.



Sprecher et al. (2026)

LCA Life cycle assessment

Life Cycle Assessment (LCA) helps designers quantify the environmental impacts of a product across its entire lifecycle, including material extraction, manufacturing, use and end-of-life processing. It can reveal environmental effects that are not immediately visible from a design perspective alone.

LCA is particularly useful for evaluating trade-offs, such as product efficiency versus CRM intensity, where a design change may reduce CRM use but increase energy consumption or introduce other environmental impacts.

Designers use LCA by modelling the product system and comparing alternative design scenarios. These scenarios may include extending product lifetime or substituting CRM-intensive materials. By comparing the results, designers can identify solutions that reduce overall environmental impact while improving the efficient use and recovery of critical raw materials.

Together, MFA and LCA provide a more complete understanding of CRM efficiency strategies. MFA quantifies the reduction of critical raw materials achieved through different design strategies, while LCA evaluates their broader environmental impacts across the product lifecycle. Using both tools can help designers make more informed decisions and develop more resource-efficient products.

Curious to learn more?

This booklet is part of the graduation project "Towards guidelines for critical raw material efficiency in product design."

The full thesis provides additional background, explains the methods used, and offers more detailed insights into the development of the guidelines.

If you are interested in learning more about the project or have questions about CRM efficiency in product design, feel free to get in touch.

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