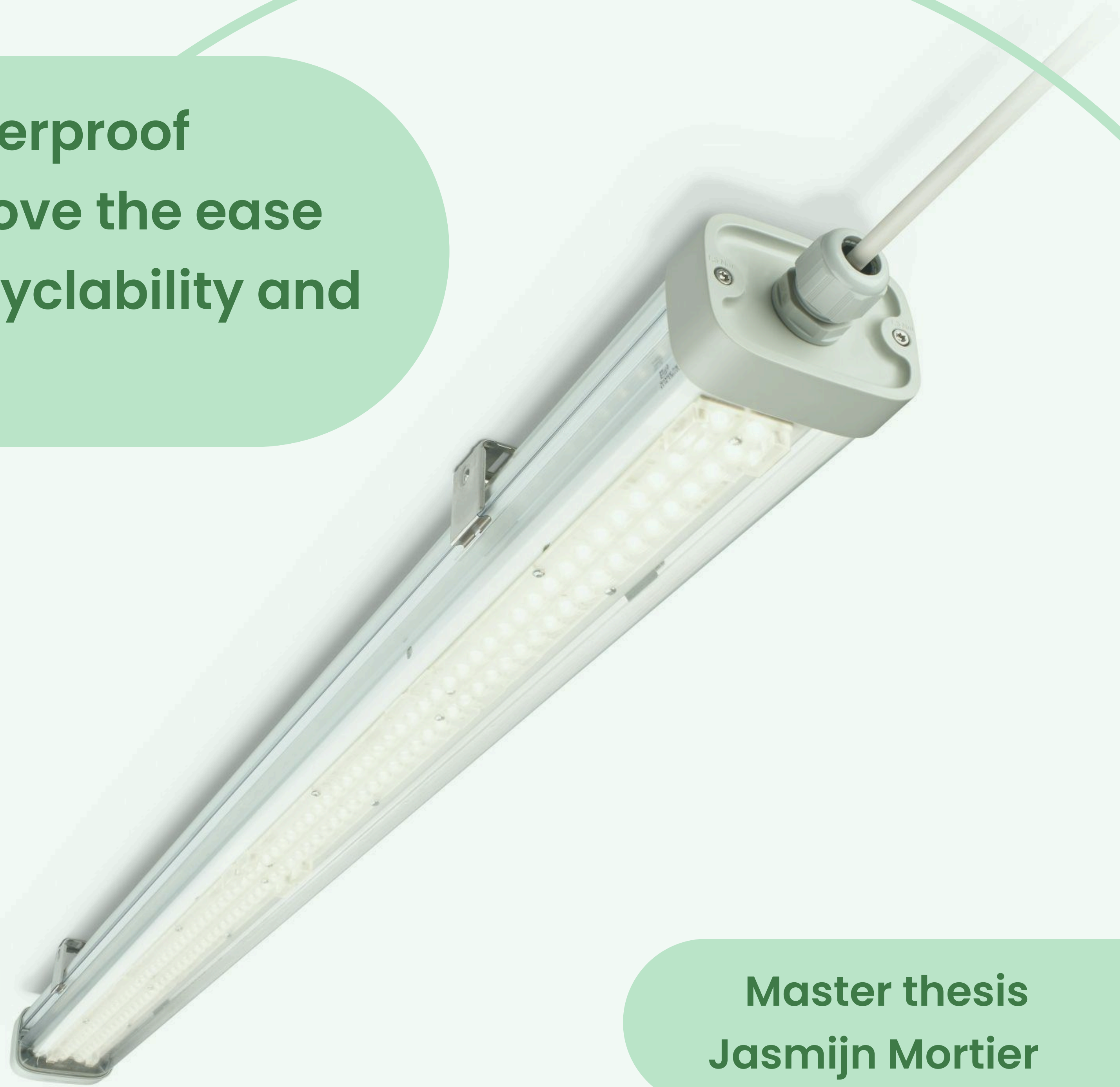
# Redesign of a waterproof luminaire to improve the ease of installation, recyclability and repairability



Master thesis

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# Abstract

This report aimed to take a look at the relation between repair and recycling, while considering the user aspects and application. This has been done by analysing two waterproof linear shaped luminaires on their ease of installation, repairability, and recyclability by doing interviews with installers and recyclers, using the Disassembly and Recyclabity map, and conducting a shredding experiment.

Insights from analyses which were interesting in the scope of this project included: repair of the luminaire on site is hardly done due to high labour costs and low failure rates of the components and installers are willing to disassemble at the end of life to improve liberation in recycling. Shredding experiments showed complications in the recyclability of the seal, metal folding around other parts and materials not being recycled in the WEEE line, like PC.

As a result of the analyses, redesign directions have been identified and ideas have been generated. From those ideas, one concept has been chosen with the help of experts to maximise the benefits in the installation, repairability and recyclability, as well as the feasibility and costs.

In the redesign focus lay on making the parts in need of maintenance (the battery and driver) and the electrical connector quickly and easily accessible for the installer on site, while improving the recyclability of the luminaire and considering the application requirements of waterproofness. The redesign shows both the driver and batteries are accessible on site in 10 seconds with a complete battery replacement taking 31 seconds in total (compared to 148 in the old design). Next to that, uni-material assemblies have been strived for to increase the recyclability.

The thesis finalises with an advice to designers on how to design for recycling, repair, and for all domains simultaneously and shows the relevance of keeping in touch with the intended user throughout the project.

# Abbreviations

## Abbreviations

B2B = Business to business
B2C = Business-to-consumer
e-waste = Electronic waste
GF = Glass fibre
IK = Impact protection (= resistance against mechanical impacts)
IP = Ingress protection (= resistance against dust and water)
LED = Light Emitting Diodes
PC = Polycarbonate
PCB = Printed Circuit Board
WEEE = Waste Electrical and Electronic Equipment

## Definitions

Lamp = Light source (bulb)
Ledboard = A PCB with LEDs
Luminaire = Complete lighting product (with housing)

# Confidentiality disclaimer

Due to confidentiallity in this project, some pictures and Appendices are not included in this report, and are only accessible by the committee and the company.

Some confidential references are refered to by "c.ref" and are not listed in the references list.

As the company wishes to remain anonymous, they will be called "the company" hereafter.

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# 1. Introduction

## 1.1 Research context

Nowadays, we use many electronic products, such as phones, computers, vacuum cleaners, washing machines and luminaires. Eventually, they break down and are thrown away as e-waste. Every year, around 62 tonnes of e-waste is generated globally (UNITAR, 2024). As most of these materials are currently lost in the process, it is important to close the material loop and move towards a circular economy. This model proposes different strategies to extend the product lifetime and eliminate waste. Two of these strategies include the repair and recycling of products. Both are being promoted by different European directives.

The Right to Repair directive obliges companies to repair goods and supply spare parts for a few years (European Union, 2024a). The ESPR directive states that a product should be high-quality recyclable (European Union, 2024b). However, when redesigning the product to be more repairable by, for example, using screws, you limit the possibility to recycle the product through shredding. Unfortunately, little knowledge is currently available on these tensions between repairability and recyclability and how to design for those. This report will therefore investigate these tensions by analysing and redesigning a luminaire.

## 1.2 Company

This graduation project is done in collaboration with a lighting company in Eindhoven. This company is the world market leader in lighting solutions for different segments for professionals and consumers, in, for example, homes, industries, offices, retail and outside. Besides luminaires, they sell lighting controls and connected lighting systems. They also provide special lighting solutions to, for example, horticulture, and UV-C disinfection. (c.ref 3).

They want to accelerate the transition to a circular economy by developing products which can be recycled, reused, repaired and refurbished, all to prevent sending waste to landfills and preserve value. This is part of their Brighter Lives, Better World 2025 sustainability program. (c.ref 8) (c.ref 9)

## 1.3 Products

Two luminaires (see Figure 1 and 2) will be analysed and one will be redesigned in this graduation project. Due to confidentiality they are hereafter called the “Sandwich” and the “Tubular”: These are so-called linear-shaped waterproof lighting solutions. They fall into the same product line, where the Tubular is in the higher segment and thus more expensive than the Sandwich. Target markets are industries, parking garages, warehouses etc, and to some extent, they can be used in harsher industries, as they have an IP66 (degree of protection against water and dust) and IK08 rating (degree of protection against external mechanical impact).

Due to the placement of these luminaires in warehouses, harsher environments, etc, repair and installation should be as quick as possible, as installers want to limit the time on site due to accessibility and environmental conditions. To facilitate this, the company aims for further optimalisation of the product architecture, while simultaneously improving the recyclability and carbon footprint of the luminaire. As most of these luminaires are installed in parking garages and a Ledification wave is upcoming here, the focus will lie on this context.

*Figure 1: Sandwich (c.ref 1)*

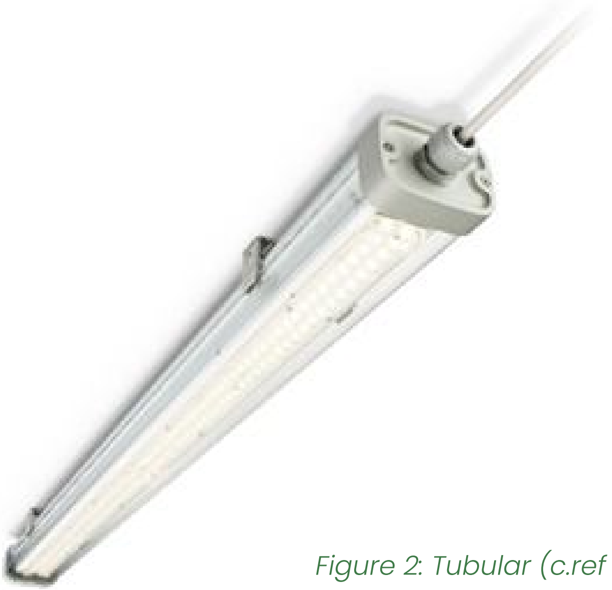


*Figure 2: Tubular (c.ref 2)*

## 1.4 Design assignment and research questions

Based on the problem scope, defined in the previous section, and the research context, the following design assignment is derived:

*"Redesign a linear-shaped waterproof luminaire for use in parking garages, designed for ease of installation, repair and recycling demonstrated through a product prototype and deriving design criteria"*

To support the design assignment, the following research questions were drawn up (see Table 1). Here the methods and preferred outcomes are also mentioned. The research questions help in defining redesign focuses and criteria for the redesign to comply with.

*Table 1: Research questions*

| | Research question | Methods | Desired outcome |
|---|---|---|---|
| **RQ1** | **What product features determine the luminaires' ease of installation, maintenance and de-instalment on site?** | Observe and interview installers in the field and analyse these results | List of redesign directions to improve the luminaire on and a list of installation criteria for the redesign to comply with |
| **RQ2** | **Which product features determine the repairability of the luminaire when disassembling it manually?** | • Manually disassembling the luminaire,<br>• Disassembly mapping,<br>• Hotspot mapping,<br>• Interviews with installers | List of redesign directions on the repairability of these luminaires and a list of repairability criteria for the redesign to comply with |
| **RQ3** | **Which product features determine the recyclability of the luminaire when shredding it?** | • Design for recycling guidelines<br>• Recyclability map<br>• Shredding luminaires and analysing fragments<br>• Literature research<br>• Contact recyclers and experts<br>• Interview installers end-of-life | List of redesign directions (material combinations and connections) in the recyclability of this luminaire and a list of recyclability criteria for the redesign to comply with |
| **RQ4** | **Which product features hinder each other when evaluating recyclability, repairability, ease of installation, and the luminaire's technical performance?** | Analyse the problems by laying them all next to each other and see which conflict with each other or with the requirements of the luminaire | List of tension points to consider for the redesign and a list of criteria on tensions and application for the redesign to comply with |

## 1.5 Report structure

This report will first present important background knowledge on e-waste and the circular economy (Ch. 2). Next, the luminaires will be analysed on their ease-of-installation, repairability, recyclability and tension points (with application and within the 3 domains) respectively (Ch. 3, 4, 5 and 6). After each chapter, a list of problems and criteria will be made for further implementation in Chapter 7, where the redesign focus will be determined and the most important criteria for the redesign are selected. In Chapter 8, the ideation phase, different solutions will be given for those problems, and the most promising ones will be selected. From those concept ideas, a final redesign (Ch. 9) will be made by making a product demonstrator. The report will end with a discussion & recommendations for further research (Ch 10) and a conclusion (Ch 11).

# 2. Background

*In this chapter, current background knowledge within the scope of the project will be summarized, to understand the space we are operating in and what is done up until now already within this field. Here, the e-waste problem, repair and recycling will be discussed. The chapter ends with an explanation of the analysed products.*

## 2.1 E-waste problem

### 2.1.1 E-waste

E-waste includes all devices in their end-of-life which have a cable, battery or plug. Amongst them are IT and ICT hardware, luminaires, electronic tools, medical devices, household appliances and sports equipment (E-Waste Nederland, 2024). The E-waste stream is one of the fastest-growing waste streams currently in the world. In 2022, 62 million tonnes of e-waste was generated. This will, according to the Global E-waste Monitor by the UN, increase to 82 million tonnes annually in 2030. Globally, only 22.3% of this waste is properly collected and recycled. In Europe, only 42.8% is properly recycled (Figure 3). Looking at lamps (the light source), only 5% get properly recycled globally (Figure 4) (UNITAR, 2024). The other almost 80% of WEEE is either disposed of in lower-income countries and recycled outside formal systems there or landfilled in other countries (The Growing Environmental Risks of E-Waste, 2024).

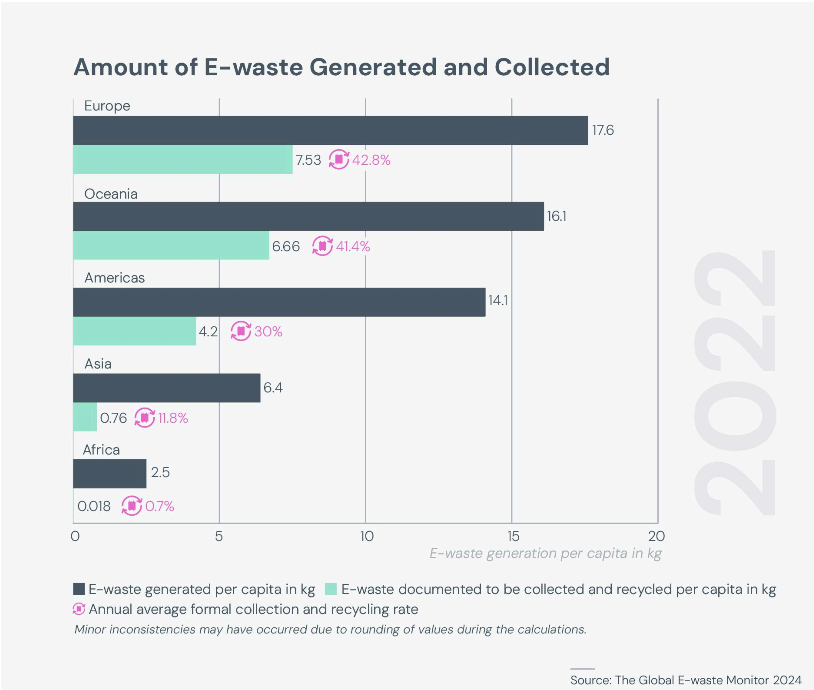



*Figure 3: The amount of E-waste generated and collected in the world per continent, from The Global E-waste Monitor (UNITAR, 2024)*

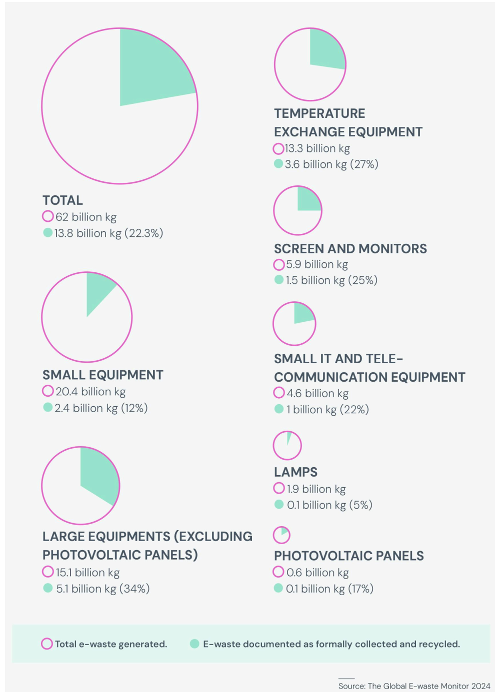



*Figure 4: The amount of E-waste generated per product category in the world, from The Global E-waste Monitor (UNITAR, 2024)*

Material recovery is economically important, as these materials can be reused, and no materials will be lost. Next to that, there will be less $CO_2$ emissions due to the extraction and production of new virgin materials, as they are not needed anymore. But also, for humans, wildlife and nature is material recovery important, as e-waste is not biodegradable and often contains toxic materials like mercury, cadmium, and lead. These can accumulate in nature, water, and air when landfilled or improperly disposed of. (Turrentine, 2024) (The Growing Environmental Risks of E-Waste, 2024)

## 2.1.2 Circular economy

To battle this e-waste problem, a shift towards a circular economy is proposed. The aim of this model (Figure 5) is to extend the lifecycle of products and to eliminate waste. This can be done by reusing, recycling, refurbishing, repairing and sharing products. Fewer new raw materials will then have to be used, and less waste will be created. This results in fewer emissions and keeping environments and biodiversity's intact. Also, we reduce our dependence on other countries for raw materials (European Parliament, 2023).

## 2.1.3 Legislation

There are a few laws applicable to aid society towards a circular economy. The EU aims, amongst others, to move into a circular economy with the Circular Economy Action Plan (2020). This plan promotes sustainable product design, a decline in waste and aims to empower users through for example the Right to Repair directive (European Parliament, 2023). This directive will be explained more in-depth in section 2.2.1. Next to that, there is the updated eco-design directive, named the Ecodesign for Sustainable Products Regulation (ESPR) directive, that requires - amongst others - a product to be high-quality recyclable (European Union, 2024b).


*Figure 5: Model of the circular economy (European Parliament, 2023)*

## 2.2 Repair

### 2.2.1 Directives

In April 2024, the European Parliament introduced the Right to Repair directive. The manufacturer is here obliged to repair a product for free when it falls within its legal warranty and when repair is less expensive than or equally expensive as replacing the product. When a product needs to be repaired, but falls outside its legal warranty, the company is obliged to repair it up until 7-10 years after its purchase. Also, they need to provide the customer with tools and information to repair the products on their own, which include information, spare parts, repair platforms, affordable repair services, etc. With this directive, the EU hopes to prolong the life of products and create less waste (European Parliament, 2024). For the lighting industry, this would mean that the driver and the LED boards need to be replaceable with basic tools and enough information should be available to the repairer to do so (Product architect company, personal communication, October 8, 2024). Also, it means that spare parts need to be available for 8 years after the last luminaire placement in the market (European Union, 2023).

### 2.2.2 Design for Repair

There is already considerable knowledge on how to improve the product's repairability. Various product architecture assessment methods for repair exist, including the disassembly map by De Fazio et al. (2021), which maps the product architecture and its connections, and the hotspot map by Flipsen (2020), which indicates what disassembly steps require significant time or effort and identifies high-value economic or environmental parts that should be prioritised. Next to that, the repairability from a broader point of view (looking at spare parts, availability of tools and repair manuals) can be assessed by, for example, the French Repairability Index (hereafter called FRI). However, the FRI score is more targeted to Business-to-Consumer (B2C) products, instead of Business-to-Business (B2B) products, which these luminaires apply to. Also, redesigning a product by using the FRI is hard since it does not give direct feedback on which parts or connections are problematic, but is mostly used to tell how repairable the product is from a broader point of view. (Ministères Aménagement du territoire Transition écologique, 2024). Therefore, the disassembly map and the hotspot map are the only methods used in this project.

Besides these assessment methods, there are different strategies on how to improve the repairability of a product. One is to use solely reusable connectors. Others include the use of surfacing (moving critical parts up in the disassembly tree), clumping (grouping parts and forming a subassembly) or trimming (bringing down the number of activities to reach critical parts). (De Fazio et al., 2021) Other strategies can be to design for simplicity, modularity and robustness and allow fasteners to be visible (Dangal et. al., 2022).

To target the design more to user behaviour, a designer can think of using triggers to indicate product maintenance or faults. Also, product upgradability and stimulation of product attachment can increase the lifetime of a product as users are less likely to throw those away. Finally, making repair an attractive option by (for example) including a repair manual, or access to repair support is a strategy to improve the repairability of the product. (Van den Berge et al., 2020) (Van den Berge et al., 2023)

## 2.3 Recycling

At the end of its end-of-life, if the product cannot be refurbished or repaired, it should be recycled to retrieve its materials. This way, these materials can be used in new products and thus can contribute to the circular economy. As said before, only 42,8% of E-waste in Europe is properly collected and recycled (UNITAR, 2024). Products are getting more complex, and it is hard to recycle multi-material products (Stichting OPEN, 2023). Therefore, it is important for designers to design for recycling. To gain a better understanding, the recycling process and current design for recycling guidelines will be described in this chapter.

### 2.3.1 Recycling process

All WEEE-recyclers use slightly different processes and processing sequences to recycle WEEE. In this project, the recycling process of a Dutch WEEE recycler is taken as a reference (as visualised in Figure 6) (Dutch recycler process controller, personal communication, December 18, 2024). This process was compared with another recycler (Marketing Director plastic recycler, December 16, 2024) and processes described in literature (Fakhredin, 2018) (Menad, 2016) and was broadly the same. Below the process will be explained.

In the Netherlands, old e-products are handed in at an electronics store, second-hand shop or recycling centre. From here, they are sorted in 7 sorting centres in the Netherlands (WEEE Nederland, 2022). Hazardous parts like batteries, ink toners, mercury and liquids, must be manually removed in the **depollution phase**, so the next recycling step is optimised. After that, the products will go to the **liberation phase**. Here, the products will be shredded into smaller fragments to allow part- and material seperation.

From there, the aim is to get pure and homogenous fragments in the **separation phase**. This will be done through different separation techniques. Magnet separation will be used to retrieve the ferrous fraction and eddy current separation for the aluminium fraction. In the ferrous fraction, the iron fragments will be separated from the present copper ones (from ferrous fragments on PCB's) by a variable magnet. In the aluminium fraction, colour separation will be used to separate print plate fragments from the aluminium fragments. In the fraction where ferrous and aluminium materials are removed, different optical, manual and machine separation techniques are used to retrieve other materials like copper and stainless steel. After that, similar techniques are used to separate plastics from the waste materials. The resulting waste materials are burned. For the plastic fraction, a 1.1 kg/l density bath is used to separate the floating plastics (PP, PE, ABS and PS) from sinking plastics (all others including PC and PMMA). The sinking plastics might contain flame retardants, which may not be

## Recyling process

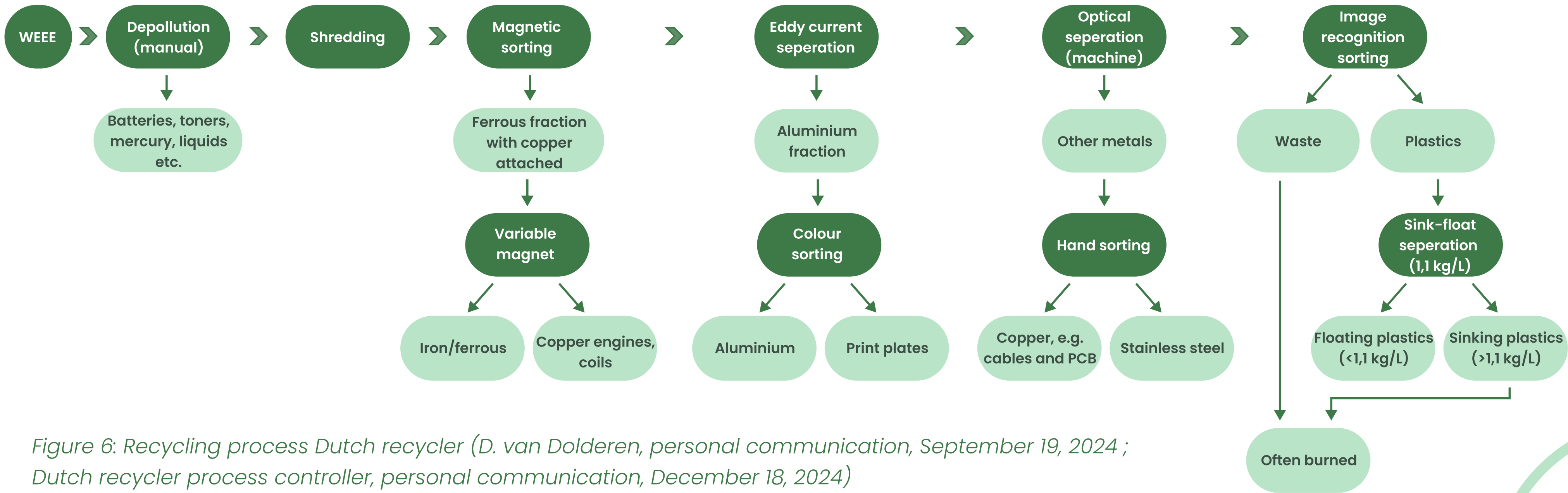



*Figure 6: Recycling process Dutch recycler (D. van Dolderen, personal communication, September 19, 2024 ; Dutch recycler process controller, personal communication, December 18, 2024)*

used in new products anymore by law. These sinking plastics are therefore all burned. The floating plastics are further separated with density baths into separate PP, PE, ABS and PS fractions. Those can be further processed into granulates.

The separated floating plastics, steel, stainless steel, copper, aluminium and print plates will be sent to material processing companies to process further into new base materials in the final phase of recycling, **the reprocessing phase.** For the reprocessing phase, more steps are taken. As we will focus on liberation and separation mainly, this process will suffice for the scope of the project.

### 2.3.2 Design for recycling

A common problem during recycling is that non-recyclable materials are used and that materials sometimes do not end up in the right material group, this will pollute waste streams, and the resulting materials will not be homogenous and pure. This is often due to hard-to-separate connections (Fakhredin, 2018). There are different ways to assess the recyclability of a product.

The first one is the **theoretical material recyclability,** which tells if the material can in theory be recycled. These can be assessed by analysing the materials, via literature research and using design guidelines. There are already multiple guidelines on design for recycling found in literature, however, they are not well-augmented with examples in practice (Van Dolderen et al., 2024). Van Dolderen made a list of these different design guidelines and checked those on their reliability. These include guidelines about which material, connections and product architecture to avoid or use. They will be used later on in this project to assess the luminaires.

The second one is the **practical material recyclability,** which allows us to tell if the material is recycled in practice at the WEEE recyclers. Sometimes a material can in theory be recycled but not recycled in practise. For this, it would be important to talk to recyclers in this project.

The final one is to assess the **technical product recyclability** of a product, which tells how well materials and connections will liberate into homogenous fragments. This can be determined by shredding the product and analysing the connections left (the mixed materials).

Assessing the technical product recyclability can be done in combination with the recyclability map made by Versloot (2024), which gives a visual overview of the liberation problems in the product architecture. This can be compared to the disassembly map later to see where tensions arise between the recyclability and repairability of the luminaire. These methods (the shredder experiment and the recyclability map) are selected as the main methods for this project, as these will give the in-depth insights needed to redesign the product.

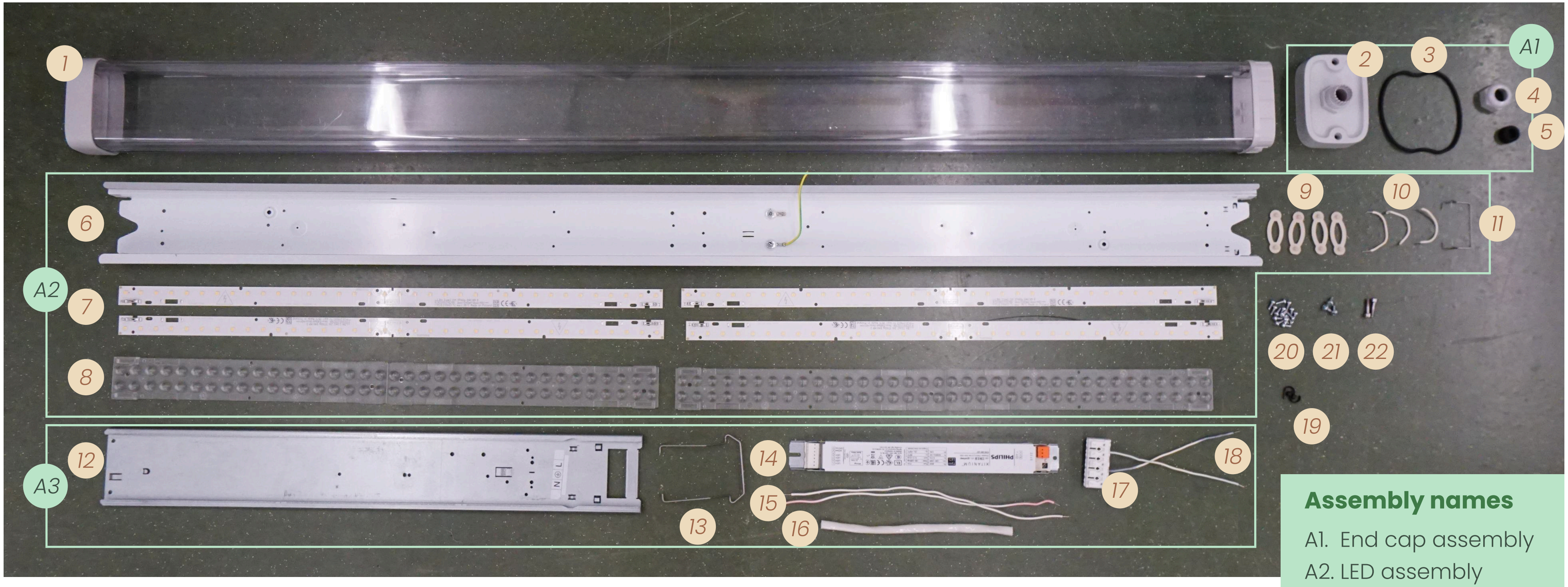
## 2.4 Product architecture

In the upcoming chapters, the two luminaires mentioned in chapter 1.3 are analysed on their ease of installation, repairability and recyclability. The lighting company sells multiple versions of these luminaires with different part compositions (e.g. different lengths, emergency batteries different connectors, drivers, or motion sensors). For the repair analysis, the two luminaires received are analysed as they are.

For the recycling part, only the basic components (that every luminaire has) have been analysed. The Sandwich is a 1.5m luminaire with a motion sensor and a push-in connector. The Tubular is a 1.2m luminaire with a push-in connector. Their knolled pictures are shown in Figure 7 and Figure 8 with the names of all components. Note here that the brackets shown in Figure 9 and the cable plugs are not included.

*Figure 9: Brackets of the Tubular (left) and the Sandwich (right)*

## Knolled picture Tubular




**Assembly names**

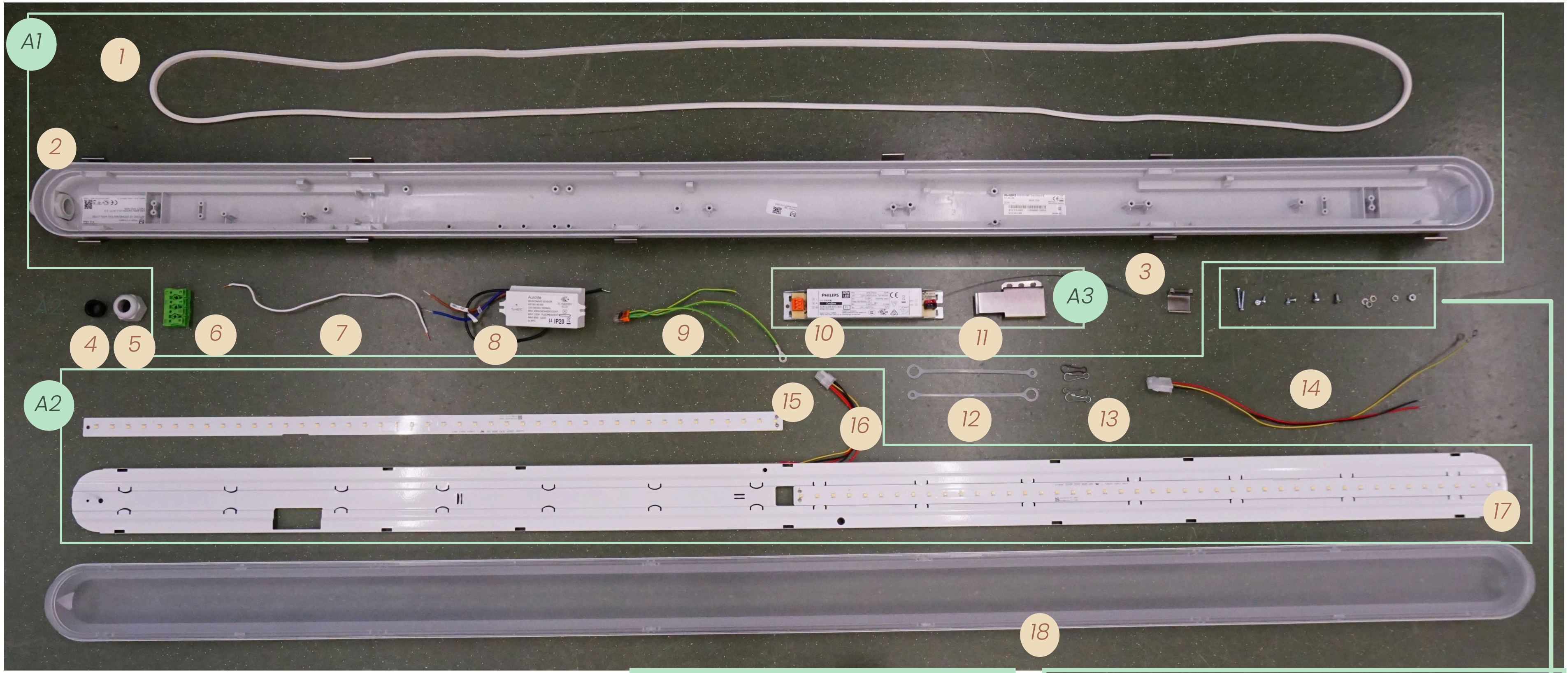
A1. End cap assembly
A2. LED assembly
A3. Gear tray assembly

### Component names

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1. Housing Tube with glued end cap parts | 1x | 7. Ledboard | 4x | 14. Driver | 1x | 20. T10H screws D3 L10 | 16x |
| 2. End cap | 1x | 8. Lensplates/optics | 4x | 15. Cables long (driver - ledboard) | 2x | 21. T20H screws D4 L10 | 3x |
| 3. End cap gasket | 1x | 9. PCB Grommets | 4x | 16. Wire enclosure | 1x | 22. T20H screws D4 L20 | 2x |
| 4. Cable gland | 1x | 10. Small ledboard cables | 3x | 17. 5 pole push-in connector | 1x | 23. Cable plug | 1x |
| 5. Cable gland gasket ring | 1x | 11. Driver bracket closing spring | 1x | 18. Cables medium (connector - driver) | 3x | 24. Brackets | 2x |
| 6. Reflector, wire, ground cable | 1x | 12. Gear tray | 1x | 19. Tie wraps | 2x | | |
| | | 13. Gear tray closing spring | 1x | | | | |

*Figure 7: Knolled picture Tubular*

## Knolled picture Sandwich




**Assembly names**

A1. Gear tray assembly
A2. Ledassembly
A3. Driver assembly


**Component names**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1. Housing gasket | 1x | 7. Wire | 1x | 13. Small clips | 4x | 18. Optical Cover | 1x | 24. External tooth lock | |
| 2. Housing | 1x | 8. Movement sensor | 1x | 14. Connection wire | | 19. T10 screws d3 l22 | 2x | washer D4 | 3x |
| 3. Hooks/clips | 12x | 9. Wires with connection | 1x | driverside | 1x | 20. T10 screws d3 l8 | 2x | 25. Washer D4 | 1x |
| 4. Cable gland gasket | 1x | piece (ground) | 1x | 15. Ledboard (L2) | 2x | 21. PH1 screws d3 l7 | 2x | 26. Nut D3 | 1x |
| 5. Cable gland | 1x | 10. Driver | 1x | 16. Connection wire | | 22. PH1 screw d4 l11 | 1x | 27. Cable plug | 1x |
| 6. 4 pole push-in | 1x | 11. Driver bracket | 1x | Ledboardside | 1x | 23. T20 screw d2 l11 | 1x | 28. Brackets | 2x |
| connector | | 12. Retention cords | 2x | 17. Reflector | 1x | | | | |

*Figure 8: Knolled picture Sandwich*

# 3. Installation

## 3.1 Introduction installation

A luminaire needs to be installed before it can be used. In environments like warehouses, parking garages, industries and similar, the time on site needs to be as short as possible. This is because processes in, for example, industries need to be stopped, the conditions on site are not that pleasant to work in and the accessibility is not great. To see how the installation efficiency can be improved, it is important to know what installers think about the ease of installation of these luminaires. The research question (RQ) that will be answered in this chapter is:

*RQ1: "What product features determine the luminaires' ease of installation, maintenance and de-instalment on site?"*

To answer this question, an installation was simulated, qualitative research was done by doing a workshop with installers and interviews with installers, who have experience on these luminaires, have been conducted. After discussing the results, a selection of the most important aspects will be given to use further in the project and the research question will be answered.

## 3.2 Methods to assess the ease of installation

To get an understanding of the installation of the luminaires, a few methods have been conducted. First, the installation was experienced hands-on by the researcher, to get an understanding of the steps taken and to see what works well and what does not. From here, a flowchart with the steps taken was made to compare the luminaires and see where can be optimised. Also, some parking garages with older versions of the Tubular and the Sandwich with TL light have been visited to see how it is installed (see Figure 10 for the Sandwich and Figure 11 for the Tubular).

*Figure 10: Sandwich in Parking garage*

*Figure 11: Tubular in bicycle parking*

Next to that, two different user studies have been conducted. One was a workshop where in 20 minutes, multiple questions were asked to 20-25 installers (clients of the company) about the installation, repair and recycling of waterproof luminaires, like the Tubular and the Sandwich. This was done by using Menti. The answers they gave were shown on the screen and were used as a base for further questions to and discussions with the installers (for an example see Figure 12). The aim here was to know the pains and gains in installing and repairing an industrial luminaire. The installers present all had previous experience with these luminaires. The questions and results can be found in Appendix B.

The other user test consisted conducting interviews with installers. In an approximately one-hour session, with the installer, multiple in-depth questions were asked on the instalment and repairability of the luminaires. The aim of these interviews was to experience their workflow and get to know their preferences and feedback on the design of the Sandwich and the Tubular. One sample of both the Sandwich and the Tubular were taken to this interview so they could experience and point things out during the interview. For the complete interview guide see Appendix C. In total four installers in the Benelux (with mostly experience on the Sandwich) and two colleagues from the company from Scandinavia working together with installers (mostly experience on the Tubular) have been interviewed for this project.


*Figure 12: Example Menti answers on screen*

## 3.3 Insights ease of installation

From these research steps, insights can be drawn. From all interviews a combined summary of the workflow of the installers and a list of feedback points can be found in Appendix D. Here, the most impactful and most often mentioned insights for the project will be shared.

### 3.3.1 Installer actions and general preferences

First, it is important to gain an understanding of the workflow of the installers, which is shown in Figure 13.

An observation drawn here is that fewer steps are needed to install the Sandwich (six) in comparison to the Tubular (nine). For maintenance, certainly in parking garages, installers need to check the batteries of the luminaires (which are part of the emergency lighting and are present in 1 per 5 luminaires). This should be done once every 4 years, often together with their replacement as well. For the replacement of the batteries, it also becomes clear that more steps are needed for the Tubular than for the Sandwich.

An important insight drawn from the workshop and interviews was that repair of other parts of the luminaire is hardly done, as the labour costs for diagnosing the problem and repairing it, exceed the product costs. Therefore, complete luminaire replacement is often chosen over repair, and the broken one is thrown away. Here, installers also tend to separate some materials from the luminaire to throw away separately (e.g. batteries, steel and sometimes plastics). They would also be willing to remove for example drivers and LED boards to improve the recycling process. However, it should be quick and easy to remove those.

The Sandwich and the Tubular can be installed in many applications like warehouses, parking garages, storage rooms, cellars etc. Dutch installers mentioned in general a preference for the sandwich architecture of the Sandwich over the slide-in architecture of the Tubular, due to it being the most cost-effective and easy to install solution. The Tubular is mostly used in industrial settings, food production or cleaning facilities due to its better resistance against water, steam, and smoke, or if the customer specifically requests it.

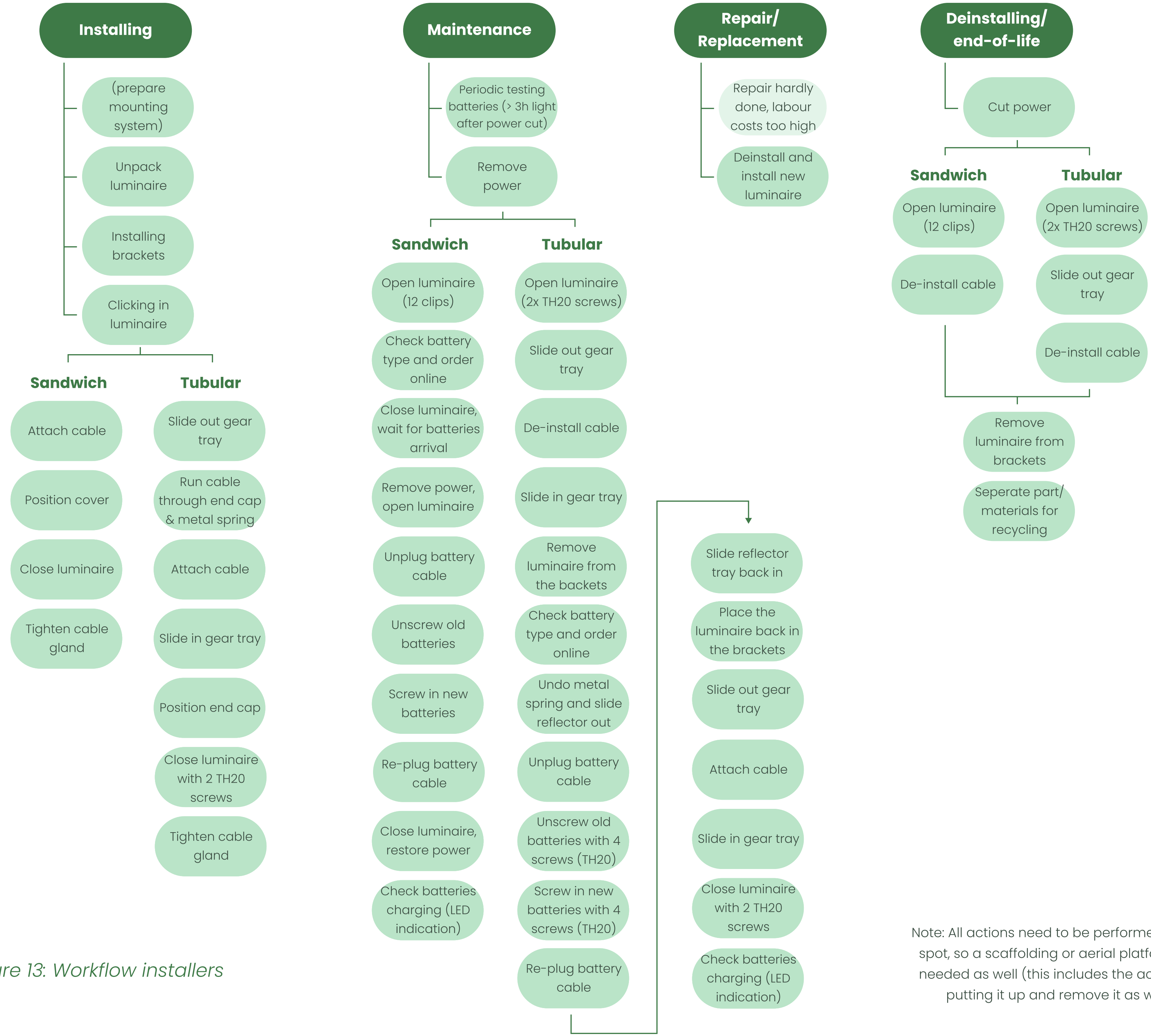



*Figure 13: Workflow installers*

Note: All actions need to be performed on the spot, so a scaffolding or aerial platform are needed as well (this includes the actions of putting it up and remove it as well)

### 3.3.2 Installer feedback on the luminaires

To ensure an efficient installation process, installers mentioned that they found it preferable in these products that:

- The luminaire (smaller than 1.8 meter) can be handled by one person,
- There is an easy access to the electrical connectors (mentioned by the cSandwich),
- There is enough flexibility in the mounting system,
- The luminaire is robust against handling during installation and maintenance, while reliable in delivering light output during the products' lifetime.

To ensure that these positive aspects of the Sandwich and the Tubular luminaires are maintained during the redesign process, they have been taken along in the set of requirements.

Installers explained their workflow as described in Figure 13 and gave details on different actions they conducted. From these interviews, the following redesign directions were identified to improve their workflow. More preferences and improvements for the luminaires on their ease-of-installation and maintenance, which are not mentioned here, can be found in Appendix E.

- **Usage of less packaging material.** The use of extra parts, plastics and (paper) installation manuals should be minimised to improve efficiency and create less waste.

- **Easier accessibility of parts in need of maintenance.** For example, the emergency batteries can be difficult to reach either due to cluttering of wires, feed-through of the cable and other parts in the Sandwich (Figure 14) or due to them being positioned deep inside the Tubular (Figure 15). In case of the latter, the entire luminaire needs to be removed before replacement of the emergency batteries can be done.

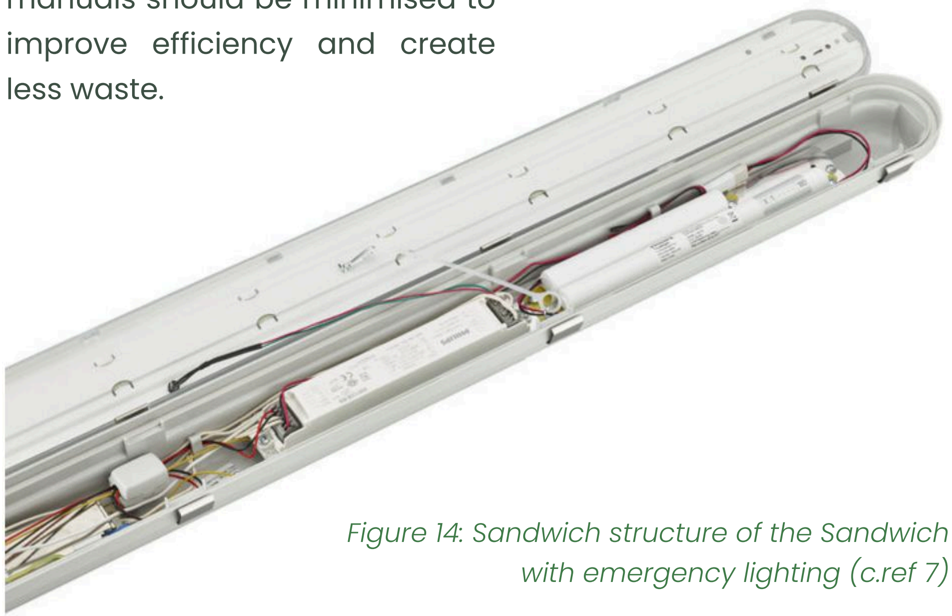


*Figure 14: Sandwich structure of the Sandwich with emergency lighting (c.ref 7)*

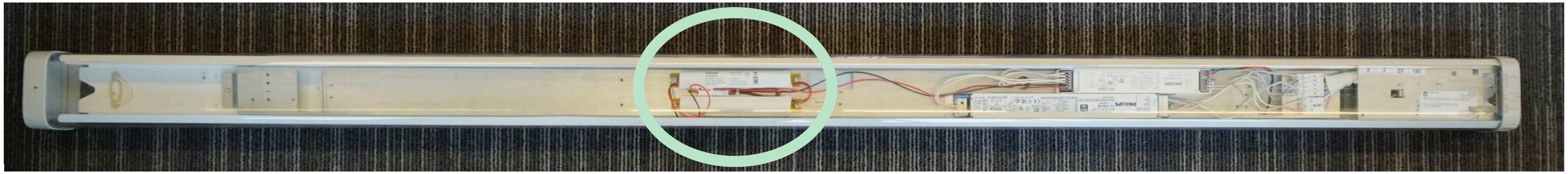


*Figure 15: Positioning emergency batteries in the Tubular, top view*

- **Standardisation of the parts in need of maintenance** is desired. This makes the replacement and ordering process more efficient. A pain point that was mentioned is, for instance, the variety of battery types used in emergency lighting.

- A design that allows **quick and low effort entry into the luminaire**, while preventing parts to be clamped when closing the luminaire, is desired (Figure 17). For instance, the housing clips of the Sandwich take time and effort to open (Figure 16).

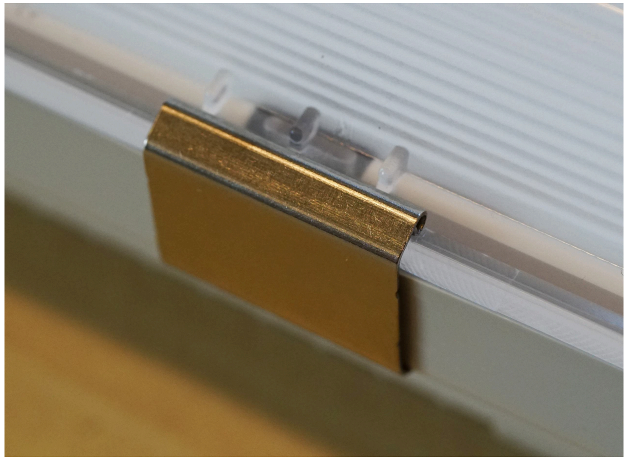


*Figure 16: Housing clips Sandwich*

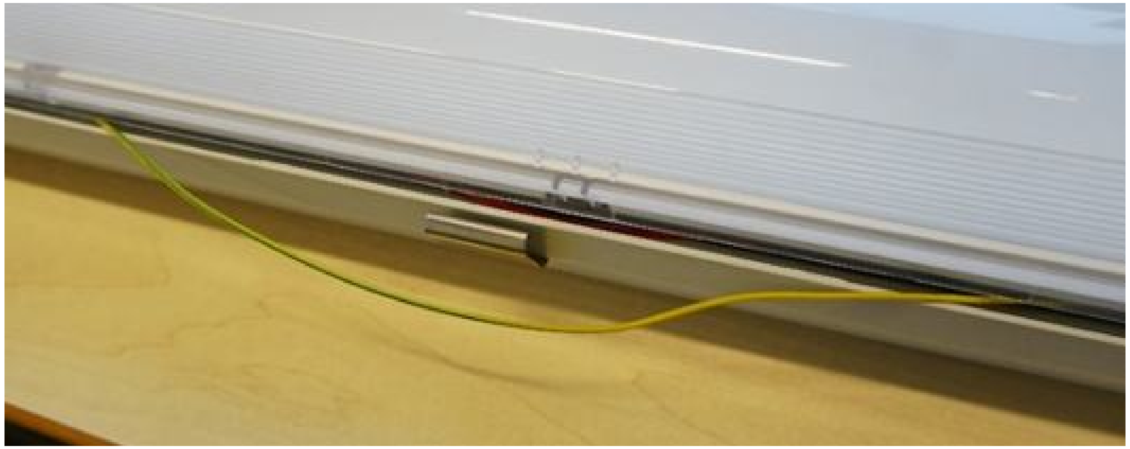


*Figure 17: Wire in between the cover and housing Sandwich*

- **The access to the connector should be as easy as possible for installation on-site (with existing cables) and off-site (during pre-installation).** The sandwich structure of the Sandwich (see Figure 14) allows easy access to all components, including the connector in both situations. The slide-out mechanism of the Tubular (where a connector is placed on a slidable gear tray) (see Figure 18) works well during pre-installation. However, by sliding the gear tray out, the length of the luminaire is extended. The accessibility of the connector then conflicts with limited cable lengths on site (certainly during luminaire replacement projects). Next to that, loosening the metal spring to release the gear tray is more difficult to see and undo above the head. Moreover, untrained installers may forget to put the cable through the metal spring at first instance, preventing the luminaire from closing.

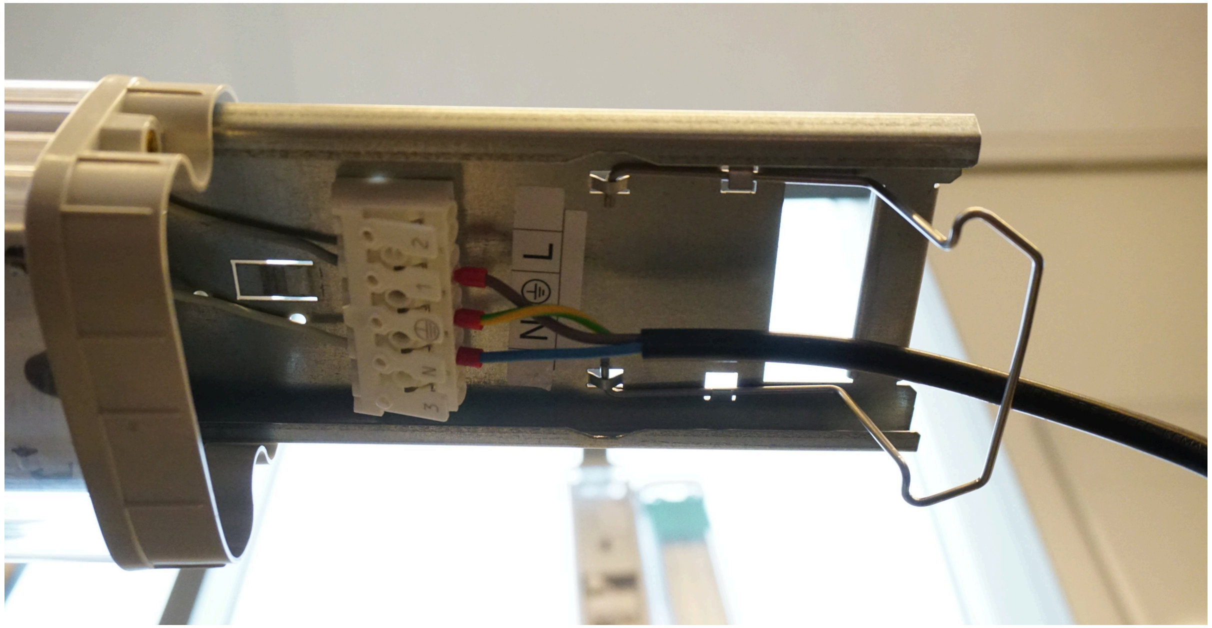


*Figure 18: Slide out system Tubular*

## 3.4 Conclusion ease of installation

By experiencing the installation, doing a workshop and conducting a few interviews, insights have been gained on the installers' point of view on the Sandwich and the Tubular. From this, we can answer our research question:

*RQ1: "What product features determine the luminaires' ease of installation, maintenance and de-instalment on site?"*

This question can be answered by generating a few **criteria** which should be used to improve the ease of installation, maintenance, and deinstallation:

- The installation time is as short as possible and requires only a few steps
- The connector is easily accessible when working above your head
- There is enough flexibility in the mounting system attachment
- The product can both be pre-installed elsewhere before bringing it on site and installed with existing cables on-site
- Parts are prevented from getting in between the closure of the luminaire (e.g. wires)
- Parts in need of maintenance are within a few steps accessible on the spot
- Spare parts are standardised
- The luminaire can be quickly deinstalled and removed
- Installation can be done by one person for luminaires <1.8m

For the complete list of criteria derived from this analysis, see Appendix N, the list of requirements and wishes for the redesign.

To finalise this chapter, a summarised overview of the redesign opportunities for instalment, maintenance, and de-instalment has been created from these analyses to consider further in the project (Table 2).

*Table 2: Redesign directions selected on installation*

| Sandwich | Tubular | Both luminaires |
|---|---|---|
| Reduce cluttering inside the luminaire because of feed-though and emergency batteries | Improve the accessibility of the connector resulting from the slide-out system and metal spring mechanism | Facilitate disassembly for recycling |
| Avoid clamped parts during luminaire closure | Improve the accessibility and positioning of the emergency batteries | Standardise spare parts |
| Improve low-effort entry into the luminaire | | Reduce packaging |

# 4. Repair

## 4.1 Introduction repair

In a product's lifetime, it often occurs a product part breaks down and needs repair. Therefore, it is important to investigate the repairability of these luminaires. This will be done by answering the following question:

*RQ 2: Which product features determine the repairability of the luminaire when disassembling it manually?*

For this, the luminaires were manually disassembled, hotspot maps and repairability maps were made, and user tests with installers were conducted. From these analyses, the problems to consider will be determined, and the research question will be answered.

## 4.2 Methods to assess the repairability

To assess the repairability of the luminaires a few methods have been used. First, the luminaires were manually disassembled. This was done in two ways: when placed on the table and when it was hung on a simulated "ceiling". For the second, we made sure to dismantle it while staying in one place (like you stand on a ladder). Besides disassembly, these luminaires were afterwards also reassembled to see if more issues would come to light. A full disassembly guide can be found in Appendix F.

### 4.2.1 Hotspot map

Secondly, to assess the disassembly steps on their connection types, time and effort needed, a disassembly map and hotspot map have been created for these luminaires.

For the hotspot map, so-called hotspots can be found by filling in the steps you need to take to disassemble the product in an Excel sheet template. The criteria in Table 3 were needed for this analysis, more explanation on these can be found in Appendix G1. With this information, the hotspot mapping tool will indicate the hotspots in the following categories:

- Time (= Long time needed to take a certain step)
- Activity (= Difficult or critical step)
- Priority part (= Part with high functionality and/or high maintenance or failure rate)
- Environmental impact of the component (= Part is made of a material(group) with a high environmental burden)
- Economic value of the product (= Part is made of materials with a high economic value)

The hotspot maps for both luminaires can be found in Appendix G.

*Table 3: Criteria needed for the Hotspot map*

| Name criteria | Explanation |
|---|---|
| Type of activity | The required activity to remove the connector |
| Required tool | The tools needed to remove the connector |
| Tool size (if applicable) | The tool size needed to remove the connector |
| Task frequency | The number of connectors which need ot be removed |
| Total time to disconnect | The time it takes to remove all connectors of this kind |
| Force | Force required from the user to remove the connector |
| Accessibility | The degree of accessibility of the connector |
| Positioning | The level of tool placement |
| Failure likelihood | The likeliness of the product part to fail during the products' lifetime |
| Functional relevance | The degree of importance for the functioning of the product |
| Material group | Material group of the removed part |
| Weight (g) | Weight of the removed part in grams |

### 4.2.2 Disassembly map

For the disassembly map method, the disassembly steps are visually shown with connection blocks. These show information about the connection and action taken (see Figure 19). Issues are indicated through penalties if a connector is difficult to see/access, the product needs to be turned around to access all connectors of that step or if a connector is non-reusable (Figure 20). Also, the hotspots (priority parts, economic and environmental) from the hotspot map are indicated (see Figure 21).

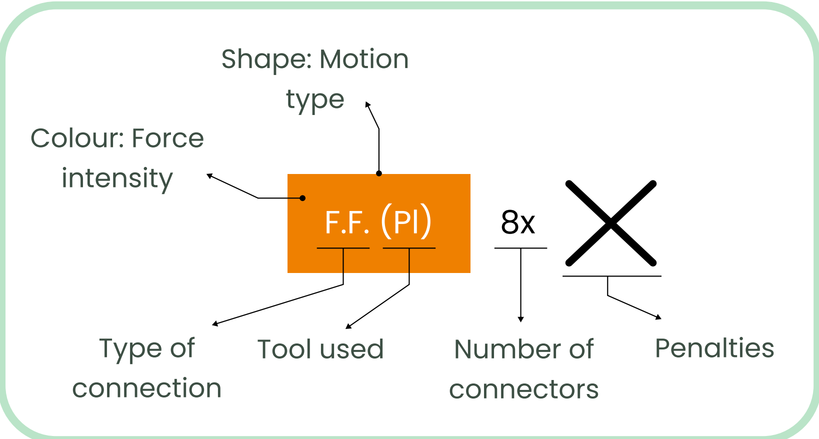



*Figure 19: Layout connection box*

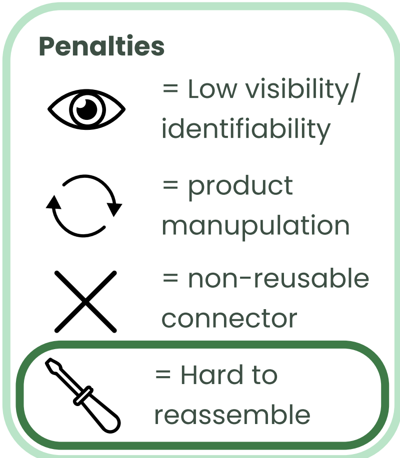



*Figure 20: Penalties disassembly map*

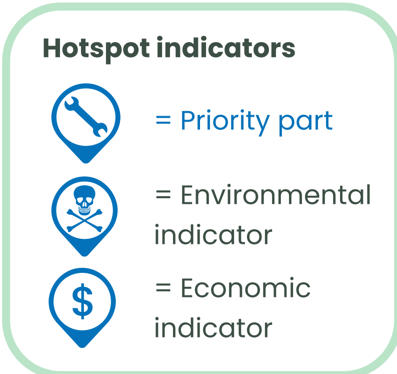
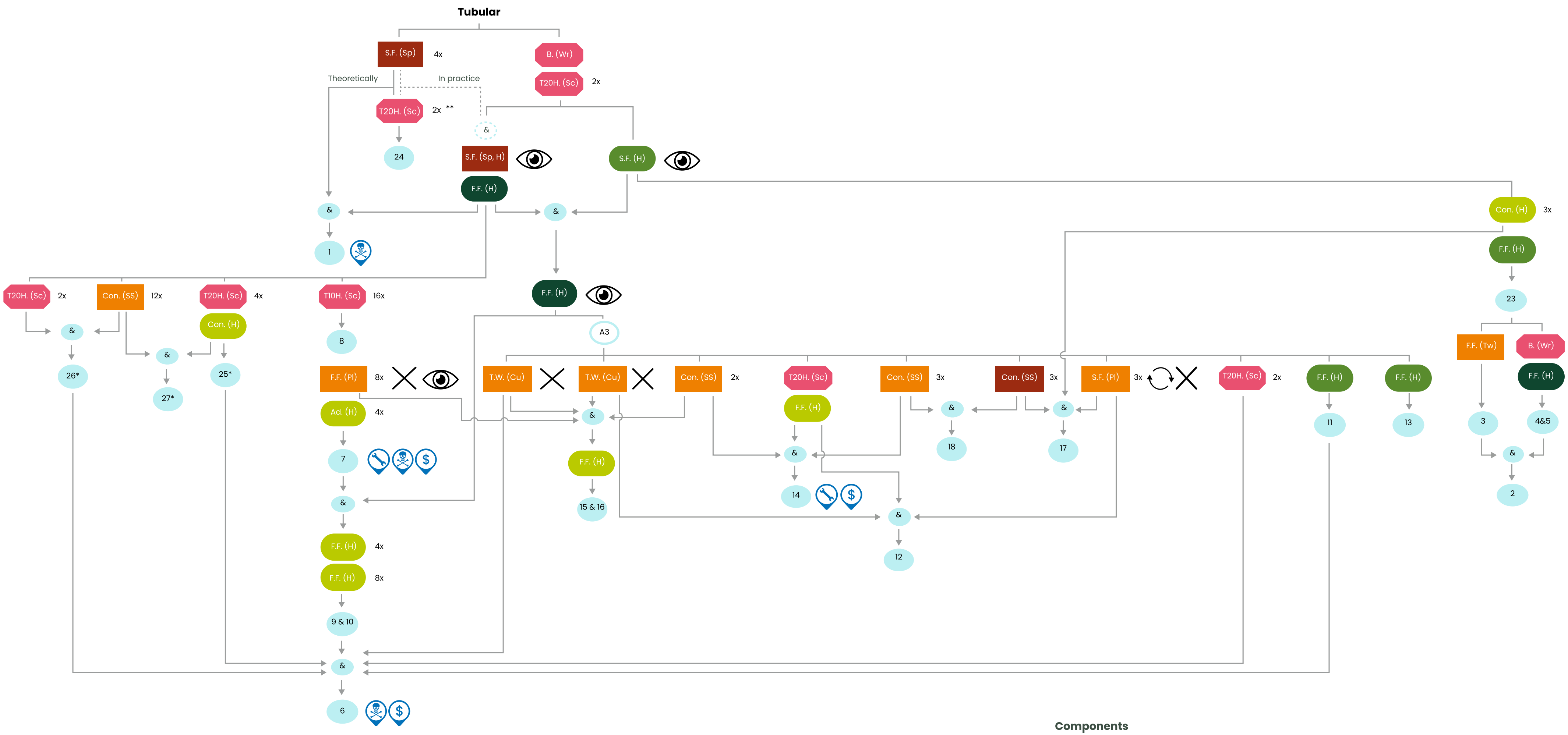



*Figure 21: Hotspot indicators*

In this project a new penalty has been introduced, the "hard to reassemble" connector (see Figure 20). This icon is given when: the connector can be reassembled but it is unclear how to exactly, reassembling costs way more effort than its disassembly, or it compromises the functioning of the product. Examples are when the orientation of the part can be in multiple ways, more parts are assembled with that one connector (ex. multiple O-rings) or a part is hard to insert, potentially resulting in incorrect reassembly, thus compromising the functional or mechanical properties of the product. This icon has been introduced since the disassembly map says little about the reassembly process. However, reassembly is always an important aspect of repair as well. Sometimes it is easier to disassemble the product than to reassemble it, so an icon representing difficulties in this process should give new and useful insights.

The disassembly maps for the Tubular and Sandwich are shown in Figure 22 and Figure 23 respectively. Here, disassembly on the table is assumed, as this is done most often in practise (compared to disassembly on the spot). In the map is indicated, however, if a connection is specifically hard to undo on the ladder. To assess the repairability of the luminaires through the disassembly map, it is important to pay attention to the following aspects:

- The dark-coloured connection blocks, which indicate an action requires quite some force
- The penalties, which indicate if a connection is hard to undo due to accessibility, tool placement or product manipulation, or indicate the connector is non-reusable or hard to reassemble.
- Parts with hotspots (priority parts, environmental or economical value) that are low in the diagram, which indicate a lot of steps are needed to disassemble that connector. Also, it is important to assess the steps coming to those parts, if they have a penalty or require high force to undo.




**Type of tool**
(Sp) = Spudger
(Sc) = Screwdriver
(SS) = Small pushing screwdriver?
(H) = Hand
(Tw) = Tweezers
(Pl) = Pliers
(Cu) = Cutters

**Connectors**
F.F. = Friction Fit
S.F. = Snap Fit
Con. = Connector
B. = Bolt
T.W. = Tiewrap
T10H = Torx 10 screw
T20H = Torx 20 screw
Ad = Adhesive

**Hotspot indicators**
= Priority part
= Environmental indicator
= Economic indicator

**Penalties**
= Low visibility/ identifiability
= product manupulation
= non-reusable connector
= Hard to reassemble

**Force intensity**

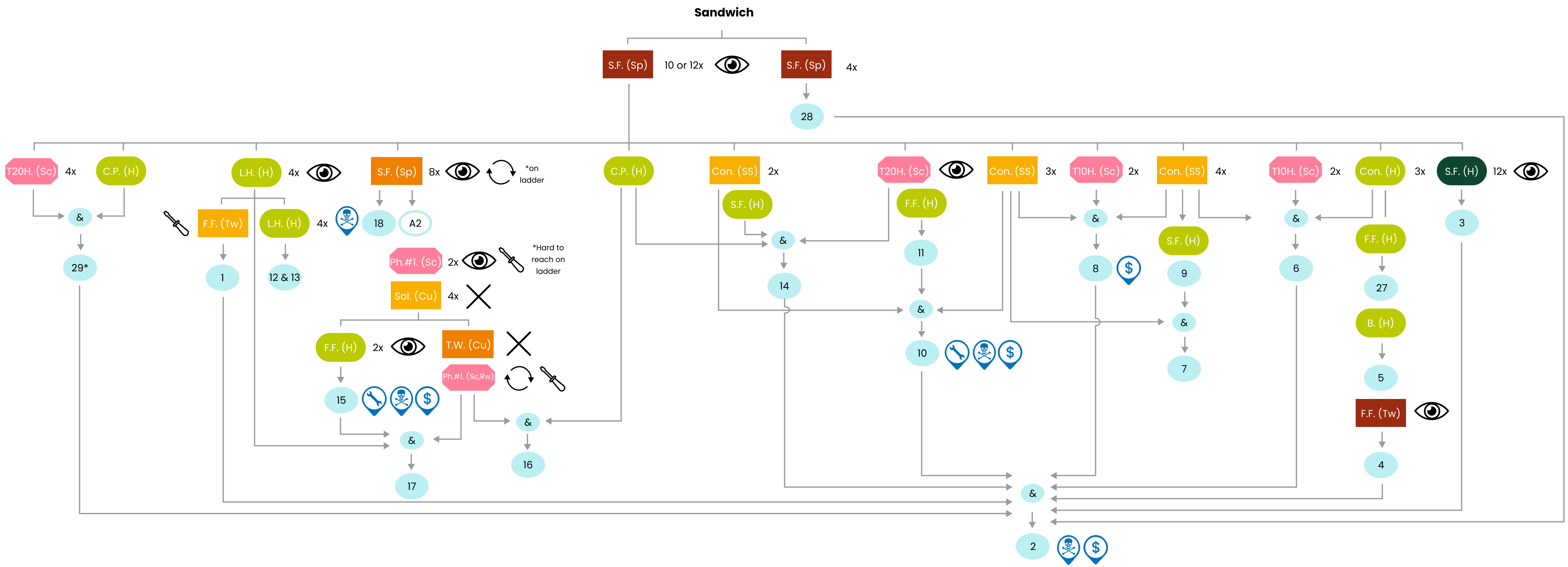
| Motion type: | Low | Medium | High |
|---|---|---|---|
| Hand motion | | | |
| Single motion tool | | | |
| Multiple motion tool | | | |

**Components**

1. Housing Tube with glued end cap parts
2. End cap
3. End cap gasket
4. Cable gland
5. Cable gland gasket ring
6. Reflector + wire + ground cable
7. Ledboard
8. Lensplates/optics
9. PCB Grommets
10. Small ledboard cables
11. Driver bracket closing spring
12. Gear tray
13. Gear tray closing spring
14. Driver
15. Cables long (driver - ledboard)
16. Wire enclosure
17. 5 pole push-in connector
18. Cables medium (terminal block - driver)
19. Tie wraps
20. T10H screws D3 L10
21. T20H screws D4 L10
22. T20H screws D4 L20
23. Cable plug
24. Brackets
25. Emergency batteries
26. Emergency batteries driver
27. Battery wire

* Note: this luminaire had no emergency batteries or - drivers, but were added here to showcase their position in the disassembly tree, as the batteries are in need of disassembly during the luminaire's lifetime

*Figure 22: Disassembly map Tubular*




**Connectors**
F.F. = Friction Fit
S.F. = Snap Fit
Con = Connector
B. = Bolt
LH. = Loop Hole
C.P. = Cable Plug
T.W. = Tiewrap
Sol = Soldered cable
Ph. #1 = Phillips 1 screw
T10H = Torx 10 screw
T20H = Torx 20 screw

**Type of tool**
(Sp) = Spudger
(Sc) = Screwdriver
(H) = Hand
(Tw) = Tweezers
(Cu) = Cutter
(SS) = Small pushing screwdriver?
(Rw) = Ring Wrench

**Hotspot indicators**
= Priority part
= Environmental indicator
= Economic indicator

**Penalties**
= Low visibility/ identifiability
= product manupulation
= non-reusable connector
= Hard to reassemble

**Force intensity**

| Motion type: | Low | Medium | High |
|---|---|---|---|
| Hand motion | | | |
| Single motion tool | | | |
| Multiple motion tool | | | |

**Components**
1. Housing gasket
2. Housing
3. Hooks/clips
4. Cable gland gasket
5. Cable gland
6. 4 pole push-in connector
7. Wire
8. Movement sensor
9. Wires with connection piece (ground)
10. Driver
11. Driver bracket
12. Retention cords
13. Small clips
14. Connection wire driverside
15. Ledboard (L2)
16. Connection wire Ledboardside
17. Reflector
18. Optical Cover
19. T10 screws d3 l22
20. T10 screws d3 l8
21. PH1 screws d3 l7
22. PH1 screw d4 l11
23. T20 screw d2 l11
24. External tooth lock washer D4
25. Washer D4
26. Nut D3
27. Cable plug
28. Brackets
29. Emergency batteries

* Note: this luminaire had no emergency batteries, but were added here to showcase their position in the disassembly tree, as they are in need of disassembly during the luminaire's lifetime

*Figure 23: Disassembly map Sandwich*

## 4.3 Insights repair

The methods used in the previous section provided multiple insights. First, the user insights on repair in general are explained as they are important for understanding repair in the context of this project. After that, the insights for the Sandwich and Tubular will be described.

### 4.3.1 Insights from interviews

From the interviews done with installers, the following insights were gained:

- Repair on the spot is hardly done, as the labour costs for diagnosing and repairing the problem are higher than replacing the luminaire. When these luminaires are repaired, they are replaced with a spare one on-site and repaired elsewhere.
- Most of the time, maintenance is performed on these luminaires, sometimes they are upgraded and repair is hardly done
- To comply with the Right to Repair directive, the driver and the LED boards should be repairable in these products.
- In practise, when a luminaire fails to deliver light, it is more than 90% of the time related to a driver failure. Next to that, the plastic covers used in the linear-shaped luminaires degrade over time and will then be in need of repair. The LED boards hardly fail and are almost never repaired (verified during installer workshop and with the company's experts).

### 4.3.2 Disassembly insights from disassembly map and hotspot map

From the disassembly map, hotspot map, manual dis- and re-assembly, and consulted repair manuals (c.ref 4), installation manuals (c.ref 5) (c.ref 6) and YouTube videos, multiple redesign opportunities were identified. For the complete list, consult Appendix H. Below a summary of these aspects is given to be further considered in this report. These redesign opportunities were mostly selected when an action obstructed easy access to the priority parts and when non-reusable connectors were used.

Both luminaires require **high intensity actions at the start** of the disassembly tree. These actions need to be performed before any part can be reached. For the Tubular, it means undoing two metal springs (see Figure 24).

*Figure 24: Metal springs (Tubular)*

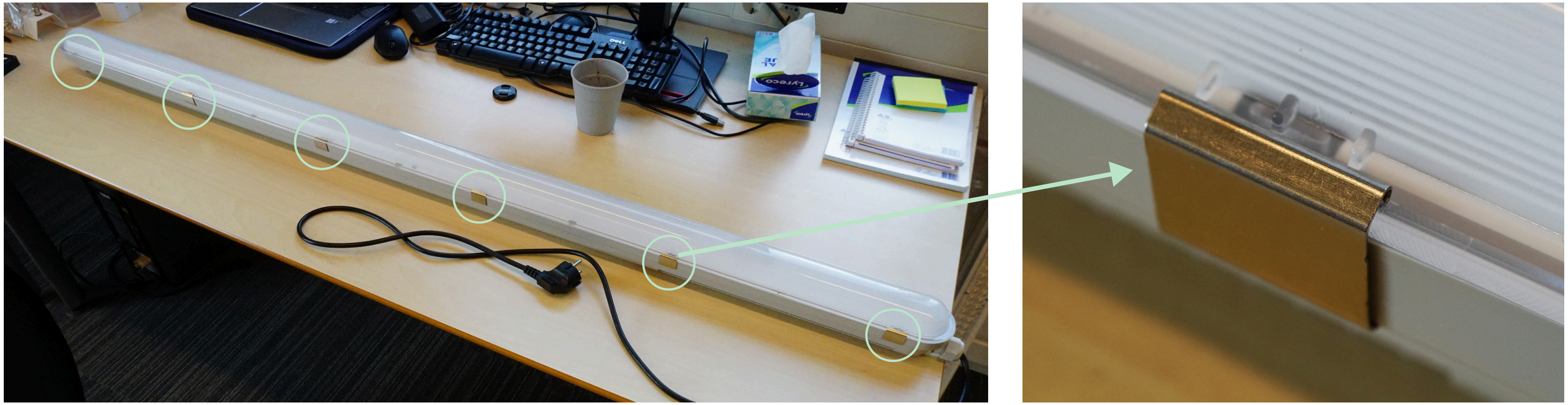


*Figure 25: Opening twelve metal clips (Sandwich)*

Releasing them in the field is not (yet) perceived as intuitive by installers.

For the Sandwich, this means undoing 12 metal clips (see Figure 25) with a flathead screwdriver or spudger, requiring high force and tool placement precision. Especially when the luminaire is positioned above the head. The restricted accessibility, low visibility from below and heavy force needed hamper the ease-of-repair. Both are therefore high activity hotspots.

The access to all components should be as quick, easy and intuitive as possible. Therefore, multiple redesign opportunities are considered here for both luminaires.

**Maintenance and full disassembly on the spot is not possible for the Tubular.** To access the components, the reflector tray needs to slide out (see Figure 26).

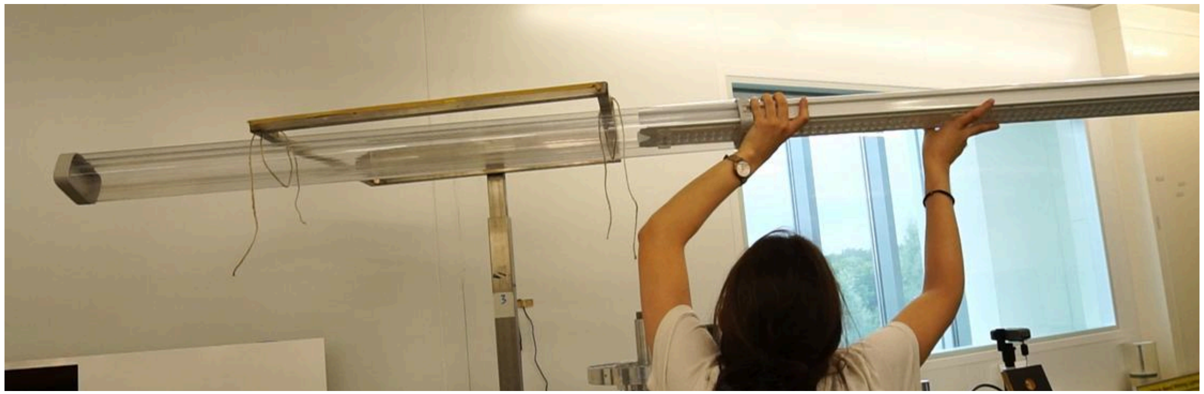


*Figure 26: Sliding out components (Tubular)*

If another luminaire or other object is within 1 meter of it, the tray cannot fully slide out and the components cannot be reached. If the installer manages to get the reflector out, it would be hard to repair parts on the ladder, as there is little working space, and components can easily fall. In practice, these luminaires are taken off the brackets and replaced with a spare luminaire. The broken one is brought to a workplace and repaired there. An interesting redesign opportunity would then be to allow disassembly on the spot for the Tubular, to save time and effort. Looking at the Sandwich, all components are easily replaceable once the luminaire is opened, as the installer immediately has access to all electronic parts because of the sandwich architecture (see Figure 26). To remove, for example, the driver after the luminaire has been opened, only the screw and the wires need to be undone. Then, the driver can be quickly removed and replaced by a new one on the spot.

**The accessibility of the driver for the Tubular can be improved.** The driver can only be reached after the reflector has been removed from the tube by at least half its length, for which the luminaire most likely needs to be removed from the ceiling. Then the metal spring needs to be undone, and the gear tray should be pulled out of the reflector (see Figure 28). There are little use cues in the product indicating this pull-out motion is possible and it is not indicated in the repair manual.

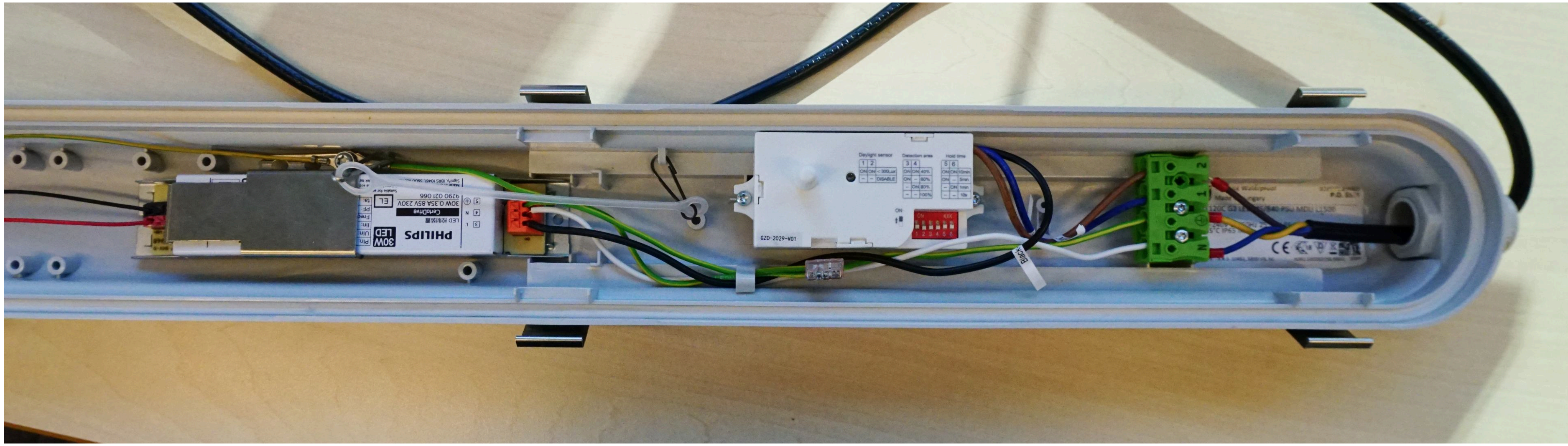



*Figure 26: Opening twelve metal clips (Sandwich)*

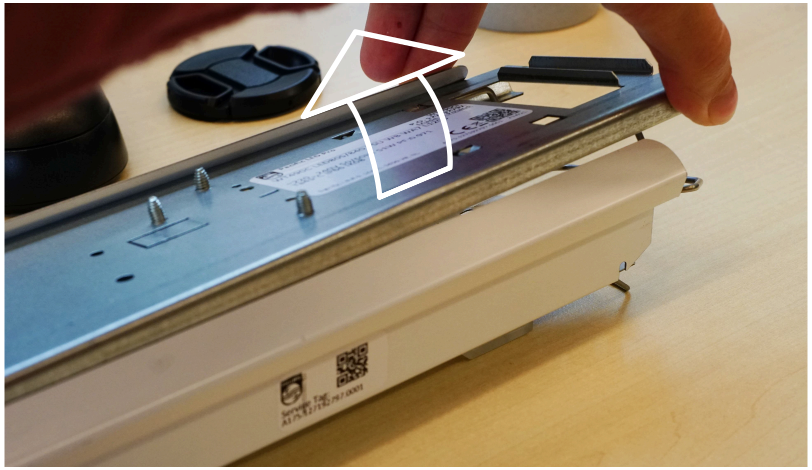


*Figure 28: Pulling the gear tray out (Tubular)*

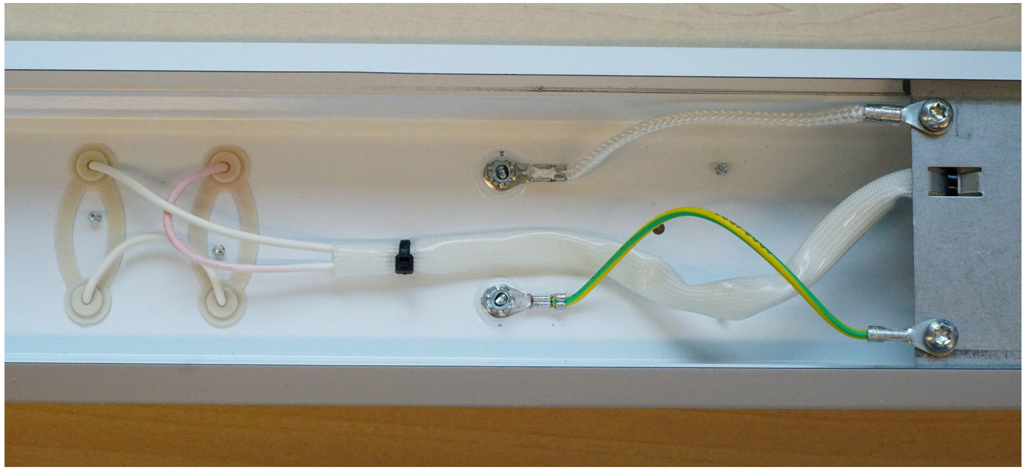


*Figure 29: Wires restricting the gear tray from sliding out (Tubular)*

The slide-out function (how the connector is accessed) can be seen as the dominant moving feature in this gear tray design. However, accessing the driver by sliding it out, is not possible as the wires to the reflector and LED board would prevent that (see Figure 29). These wires should then be cut or removed, requiring the LED board connections to be undone. Accessing these take also quite some steps, as described in the next point, so that is not the preferred way to go. When the driver is reached, the driver can easy be removed by undoing one screw and a few wires, something that should remain in a redesign. Allowing quick and intuitive access to the driver is desired in these luminaires, certainly as the driver is a priority part and is after the batteries in need of replacement most often on site.

As said before, the LED boards do often not require repair as they seldom break down. However, to comply with the Right to Repair directive, the company is obliged to allow repair of the LED boards. **In both luminaires, the LED boards take a considerable amount of time to be removed due to their placement low in the disassembly tree (hence quite some steps are needed), as well as their use of non-reusable connectors.**

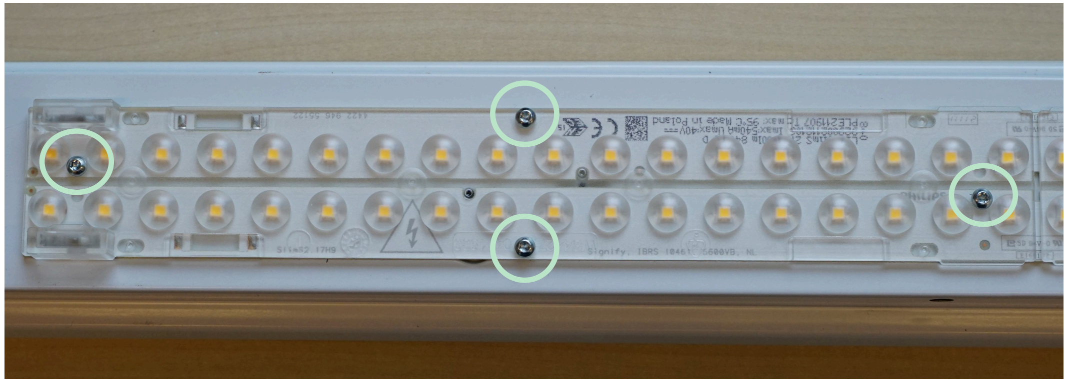


*Figure 30: Four of sixteen screws to undo the optics (Tubular)*

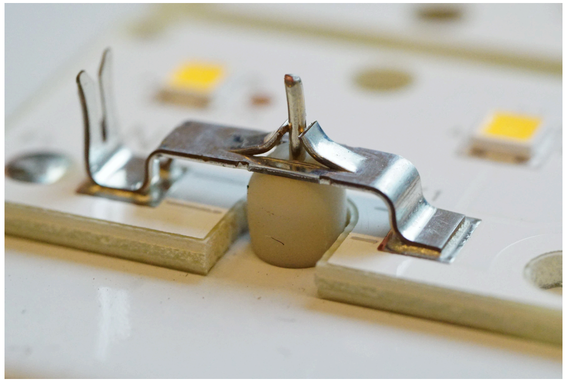


*Figure 31: Metal connections to the LED boards (Tubular)*

For the Tubular, sixteen screws (Figure 30) and eight metal connections to the LED-boards (Figure 31) need to be undone, both, therefore, being time hotspots. Apart from that, it was unclear how to undo the metal connections (as there are no use cues and no indication in the repair manual). They cannot be reused as the electrical connection would be too weak after bending (hence the penalties given in the disassembly map). For the Sandwich, eight snap fits need to be undone for the cover (Figure 33) and due to different protrusions holding the reflector in place, it is not clear which to undo. Apart from that, the wires to the LED boards need to be desoldered or cut (Figure 32), categorising them as non-reusable connectors. An interesting redesign opportunity for both luminaires here, is to improve the disassembly of the LED boards by allowing quicker access and using solely reusable connectors.

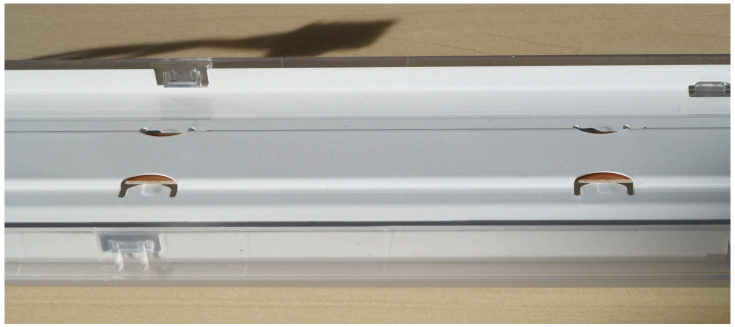


*Figure 33: Different protrusions (Sandwich)*

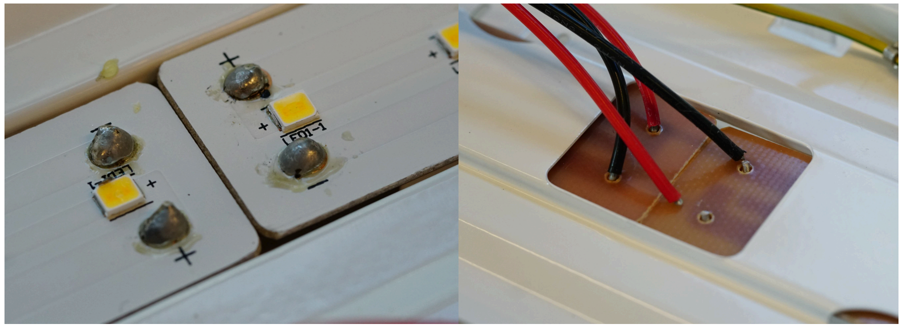


*Figure 32: Soldered cables (Sandwich)*

**When dis- and reassembling the Sandwich on the spot, connections consisting of nuts, bolts and O-rings in the Sandwich are difficult to undo and redo** (see Figure 34 and Figure 35). To loosen or tighten a nut-and-bolt combination, two tools are needed simultaneously. Apart from that, during re-assembly all O-rings, the nut, and the bolt need to be held into place and prevented from falling. The cable shoes, which are tightened with these connections, should also be prevented from touching the housing or reflector. This results in these steps being quite complex to conduct, making them activity hotspots. In the Tubular, a pleasant feature is the usage of screws that stayed in the end cap, reducing the risk of losing them. Minimizing the use of small parts and mitigating the risk of losing them is desired in these luminaires, since they are often placed on the ceiling at high heights.

*Figure 34: Use of O-rings, a nut, bolt and cable shoe on the reflector Sandwich*

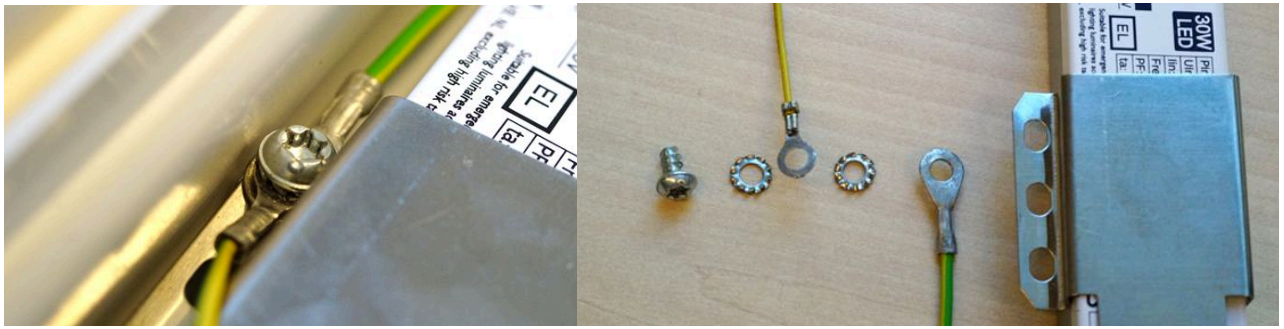



*Figure 35: Use of O-rings, cable shoe and screw to hold the driver in place Sandwich*

## 4.4 Conclusion repair

In this chapter, manual disassembly, the hotspot map, the disassembly map, and installers' feedback have been used to gain insights on the repairability of the luminaires. These will be used to answer the research question and make a summarised list of problems to consider further in the project. As described in the previous section, repair is hardly done by installers because of labour costs. Therefore, these luminaires often get thrown away. However, to comply with the upcoming directives, the repairability of the driver and LED boards should be improved. To make repair for these luminaires possible, diagnosing and part replacement needs to be either very easy, straightforward, and quick or parts of the business case need to be adapted to make repair a more attractive option. If repairs in practice are unlikely to be done, the redesign should focus on improving the ease of luminaire replacement. This can be done by making the luminaires retrofit and allowing quick and easy removal and reinstallation. It is also valuable to focus on design for disassembly to increase the purity and value of waste streams, so the recyclability of the product can be improved. Installers mentioned willingness to disassemble luminaires for recycling, if it can be done quick and easy.

To ease the disassembly for installers, for both repair and end-of-life, it is important to focus on the following redesign directions per luminaire as seen in Table 4. These opportunities have been selected based on access to priority parts (PCB and LED board) and non-reusable connectors, as seen in the insight generation section.

*Table 4: Redesign directions selected on the repairability of the luminaires*

| Sandwich | Tubular |
|---|---|
| Allow easy entry into the luminaire through low force metal enclosure clips | Allow easy entry into the luminaire, through minimizing high intensity actions of undoing the metal springs |
| Allow quick and intuitive access to the LED board | Improve accessibility of the internal components on the ladder |
| Improve the disassembly of the LED boards by using reusable connections only | Allow intuitive access to the driver |
| Prevent the use of many fasteners and small parts in one fastening connection (O-rings, nuts and bolts) | Allow quick accessibility to the LED boards, by avoiding too many screws |
| | Improve the disassembly of the LED boards by using reusable and intuitive LED board connections |

From these analyses, the research question can be answered by writing down a few requirements facilitating the repairability of the luminaires:

*RQ 2: Which product features determine the repairability of the luminaire when disassembling it manually?*

The most important resulting **criteria** are:

- Allow quick diagnosis of the problem on-site, after which repair can immediately take place.
- The battery, driver and LED board should be quickly, easily and intuitively accessible and replaceable on the spot
- The luminaire allows easy and low-effort entry to all internal components
- The connectors are visible from the position of the installer (below the luminaire)
- The connectors that need to be undone to reach a repairable (priority) part are all reusable
- The parts can be reassembled the same way, which makes the process straightforward

For the complete list of criteria derived from the repairability analysis, see Appendix N (the list of requirements and wishes for the redesign).

# 5. Recycling

## 5.1 Introduction recycling

Every product eventually reaches its end-of-life, including these waterproof luminaires. They end up as e-waste (also confirmed with installers). As we have noticed in the previous chapter, these luminaires often get thrown away when broken, as labour costs are too high compared to replacing the luminaire. It is therefore important to analyse if these luminaires are recyclable and how the recyclability can be improved. This will be done by answering the following research question:

*RQ 3: Which product features determine the recyclability of the luminaire when shredding it?*

To answer this, a shredding test has been conducted, and a resulting recyclability map has been made to assess the technical recyclability. Next to that, the design for recycling guidelines have been used to assess the theoretical recyclability and two recyclers have been visited and talked to, which helped in assessing the practical recyclability of the luminaries.

## 5.2 Methods to assess the repairability

### 5.2.1 Design for recycling guidelines

In literature, a lot of design for recycling guidelines are already present. As mentioned in Chapter 2, Dorien van Dolderen, a PhD student at the TU Delft, has analysed these guidelines and combined them in a list. From that list, the most reliable and relevant prescriptive design guidelines for these luminaires were selected and considered in talks with recyclers and when conducting the shredding experiment. The criteria selected originate mostly from the work of Feenstra et al. (2021), (Berwald et al., 2021), Hultgren et al. (2012), Leal et al. (2020) and Castro et al. (2004). This way of analysing (looking at existing guidelines) has been done to see where problems might arise in the choice of material (combination), connection choice.

### 5.2.2 Recyclers visit and recycling process.

To assess the practical material recyclability of these luminaires, two WEEE recyclers have been visited and contacted in this project. One of them focused on the recycling of plastics. The process of the Dutch WEEE recycler contacted was used as a reference for this project and was already described in Chapter 2.3.1. A sink/float test was conducted with 10 grams of salt in 100 ml water (see Figure 36) to determine which

*Figure 36: Sink-float test 1.1 kg/l*

plastics in the luminaires would sink and which would float in the recycling process (to separate recyclable and non-recyclable plastics). This test was done to the practical recyclability of the luminaires; to see whether the materials of the luminaire would be recycled in practise. For the complete test see Appendix I.

### 5.2.3 Shredding experiment method

To assess the technical product recyclability and thus know which connections and material combinations are causing difficulties in the recycling process, a shredding experiment was conducted with a Dutch recycling company. For this, three new Sandwiches and five new Tubulars have been shredded (see Figure 37). All differ a little bit in their

*Figure 37: Five Tubulars and three Sandwiches before shredding*

component composition, which can be found in Appendix J. Often it was related to the length (1.2, 1,5 or 1.8 meters), type of driver, presence of a motion sensor, presence of a cable (in reality they are sometimes removed, and sometimes not) and type of connector (Wargo or push-in).

### Weighing

Before they got shredded, all parts were weighted and all connections in the luminaire were analysed and counted. As some connections are not reusable, some weights were assumed by looking at the disassembled luminaire for repair (which was already weighted per part) or by weighing the assembly and subtracting parts of which the weight was known. There is a high interest in the behaviour of the connections of the luminaire when shredded. The behaviour of the connections is more important than having a slight difference in material weight, as weight losses are inevitable when shredding. Overall, the difference in luminaire weight and the sum of all the parts is <0,5%. So, it is safe to say the data is reliable enough for further analysis. All weights can be found per part in Appendix K.

### Shredding

The shredding experiment was done on a different shredder than used in the recycling process (Figure 38). Therefore, the shredded fragments were smaller than usual (max 35 mm compared to 70 mm). Knowing this, problems that occur, will most likely also occur in the overall recycling process as well but some problems might not come to light. Shredding was done in 5 batches of 1 or 2 luminaires simultaneously. After each batch was shredded, the shredding machine was kept running a bit longer and ran backwards as well to retrieve the most fragments possible. Overall, 90% of the fragments had been recovered and could be analysed.

*Figure 38: Shredder experiment*

### Sorting

The sorting experiment was done based on the material and part compositions of Table 7. These different sorted materials were weighted and compared to the amount of material that entered the shredder. After that, the mixed fragments were analysed to gain insights on which connections and material combinations remained and will thus be an issue for the recyclability of the luminaires. In this analysis, a WEEE recycler has been asked to look at the mixed fragments to determine the recyclability of the mixed fragments and its placement in the process. To visually show the liberation of the connections, a recyclability map has been created.

*Table 7: Fragments sorting*

| Name criteria | Other |
|---|---|
| Ferrous fraction | Mixed fragments |
| Non-ferrous metal fraction | Too small to sort |
| PC (mixed) | Unknown |
| Silicone | |
| Rubber | |
| Other plastics (PA, plastic driver etc) | |
| LED boards | |
| PCB | |
| Copper (cables & wires) | |

## 5.3 Insights recyclability

From the shredding experiment and the interviews with recyclers, insights have been gained on where problems arise in these products. First, we look at the technical product recyclability by looking at the material losses during shredding and the liberation rate of the connections. Secondly, we look at the practical and theoretical material recyclability looking at the material use in the product and using insights gained from recyclers.

### 5.3.1 Shredding results

From the shredding experiments, it became clear which materials were lost and which mixed fragments remained for the Tubular and Sandwich. 71% of the Sandwich's and 75% of the Tubular's fragments were liberated homogeneously (see Figure 39 and Figure 40). The biggest overall losses are in the PC and ferrous fractions for both

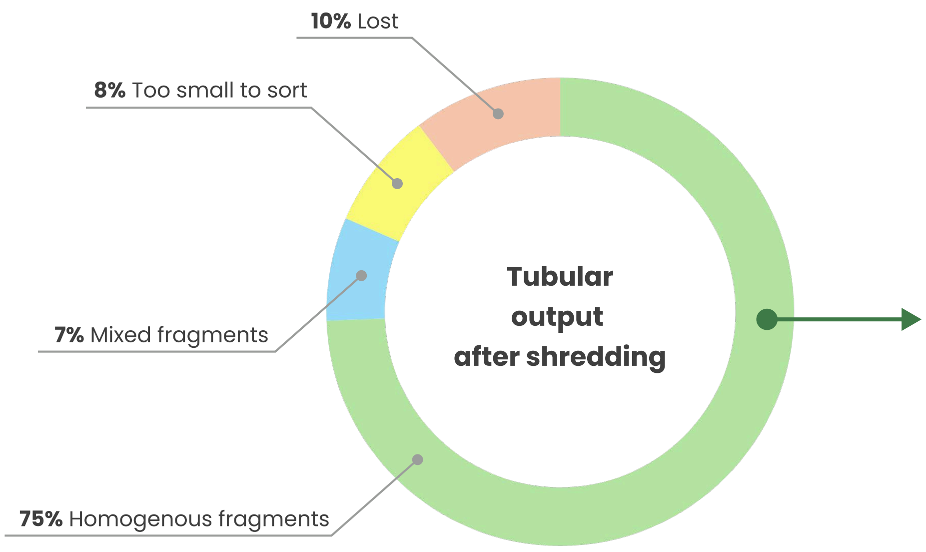



Figure 39: Results after shredding Tubular

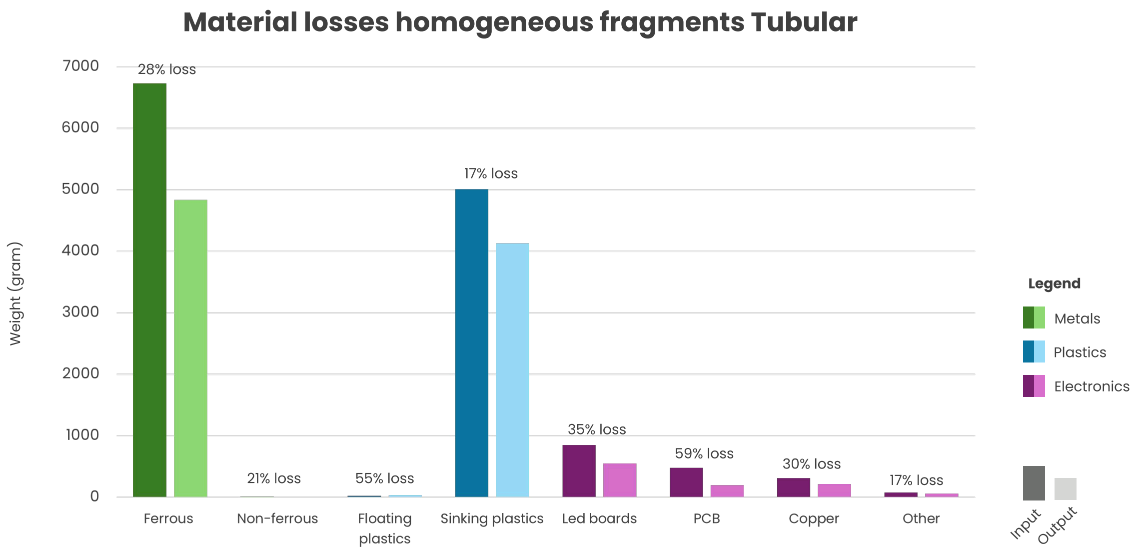



Figure 41: Results after shredding Tubular

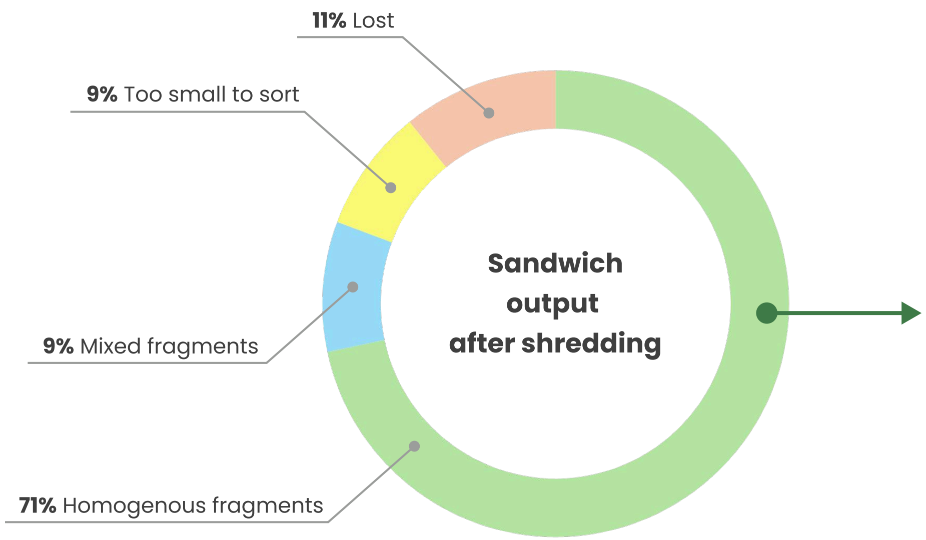



Figure 40: Results after shredding Sandwich

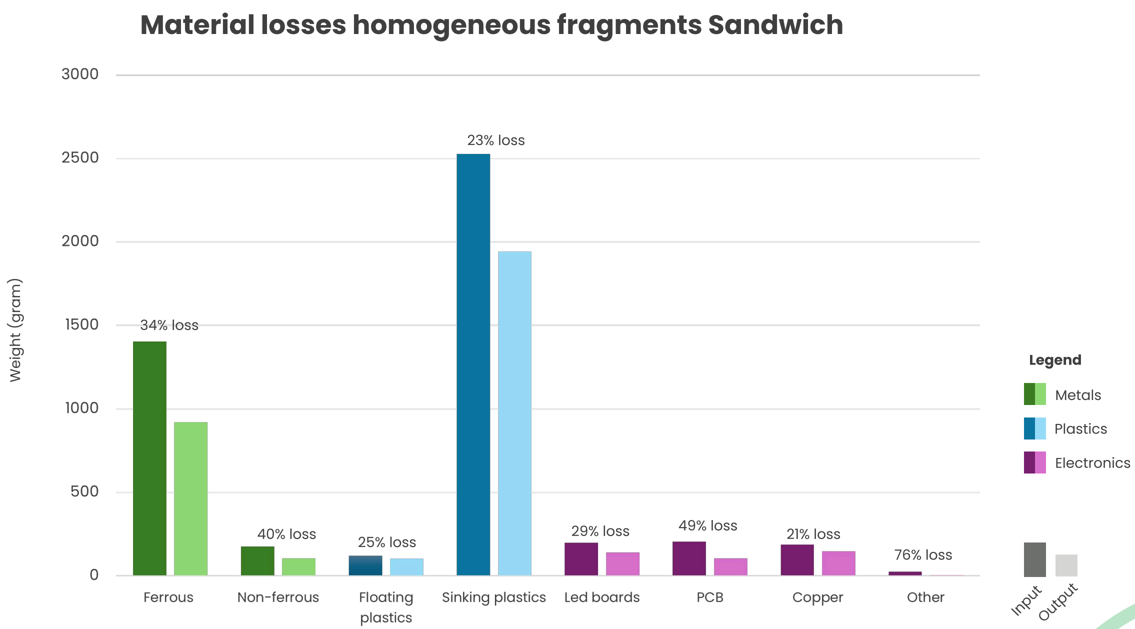



Figure 42: Results after shredding Sandwich

luminaires. Looking at the luminaires individually (Figure 41 and Figure 42), great losses are in the PCB fraction (49%) and the other electronics fraction (connectors etc) with 76% for the Sandwich. For the Tubular, the biggest losses were in the wire enclosure (80%), rubber (83%) other plastics (65%) and PCB (59%) fraction. The reason for this can be found by looking at the mixed fragments (7% of the total weight for the Tubular and 9% for the Sandwich). Interestingly, there seemed to emerge a material that was not seen in the analyses beforehand: flimsy PC (see Figure 43). This floats - in contrast with bigger PC parts - and pollutes the plastic stream.

## 5.3.2 Technical recyclability

### 5.3.2.1 Liberation rate connections

There were different mixed fragments found in the fraction after the shredding experiment.

*Figure 43: Flimsy PC, less than 0.5 mm thick*

These all have been analysed and the connections left have been compared to the connections previously in the luminaire. An in-depth analysis of the mixed fragments and connections liberation can be found in Appendix L. In Table 6, the liberation rate of the connection groups can be found. It becomes clear that the use of glue, metal inserts, and nut-and-bolt connections are problematic, as they all remain intact. Also, the use of silicone gaskets, soldering and screws was not ideal. Snap fits, tie wraps, screws for the LED boards, and friction fits liberated quite well.

Comparing the luminaires, it is clear that the overall liberation rate of the connections is quite similar (79% vs 80%). Looking at the connection groups, a difference can be found in the liberation rate of the screws. These are higher for the Tubular than for the Sandwich (20% difference). This has to do with the high percentage of LED board screws in the Tubular compared to other screws, which liberated quite well.

### 5.3.2.2 Recyclability maps

Through the mixed fragments analysis, a recyclability map can be made for the Sandwich and the Tubular, a method developed by Versloot (2024). This is done to visualise which connections and materials in the product architecture are recyclable and where problems arise. It can be compared with the repairability map to see where tensions in the product architecture arise.

In this disassembly map, the connection blocks give information about the type, material and liberation degree of the connector (see Figure 44). The part blocks, also indicate the part material. Finally, valuable and hazardous materials are indicated by the symbols in Figure 45.

The recyclability maps for the Sandwich and Tubular can be found in Figure 46 and Figure 47 respectively. Here is it important to pay attention to red, orange and yellow connection blocks. These do not liberate well. Next to that, it is important to look at the placement of valuable materials.

*Table 6: Comparison liberation rate Sandwich and Tubular*

| | Sandwich | | | Tubular | | |
|---|---|---|---|---|---|---|
| **Connection types** | **Total Connections** | **Total remained** | **Liberation rate** | **Total Connections** | **Total remained** | **Liberation rate** |
| Screws | **50** | **20** | **60%** | **128** | **26** | **80%** |
| Nuts and bolts | **4** | **4** | **0%** | **0** | **0** | **-** |
| Rivets | **0** | **0** | **-** | **10** | **2** | **80%** |
| Metal inserts | **0** | **0** | **-** | **10** | **9** | **10%** |
| Soldering | **11** | **6** | **45%** | **0** | **0** | **-** |
| Snap fits | **139** | **3** | **98%** | **56** | **0** | **100%** |
| Friction fits | **13** | **4** | **69%** | **108** | **27** | **75%** |
| Tie wraps | **3** | **0** | **100%** | **10** | **1** | **90%** |
| Glue | **0** | **0** | **-** | **10** | **10** | **0%** |
| Connector-wire | **36** | **17** | **53%** | **49** | **3** | **94%** |
| **Total** | **256** | **54** | **79%** | **381** | **78** | **80%** |

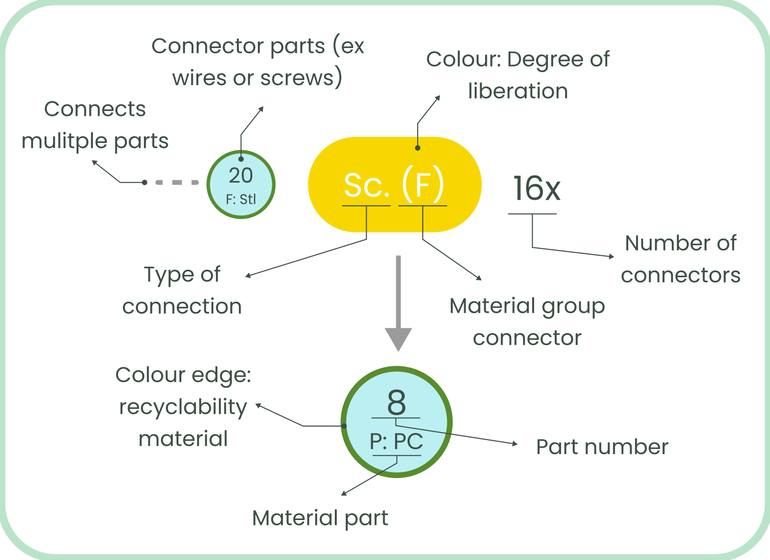



*Figure 44: Connection blocks recyclability map*

**Special material indication**

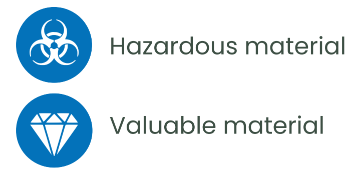
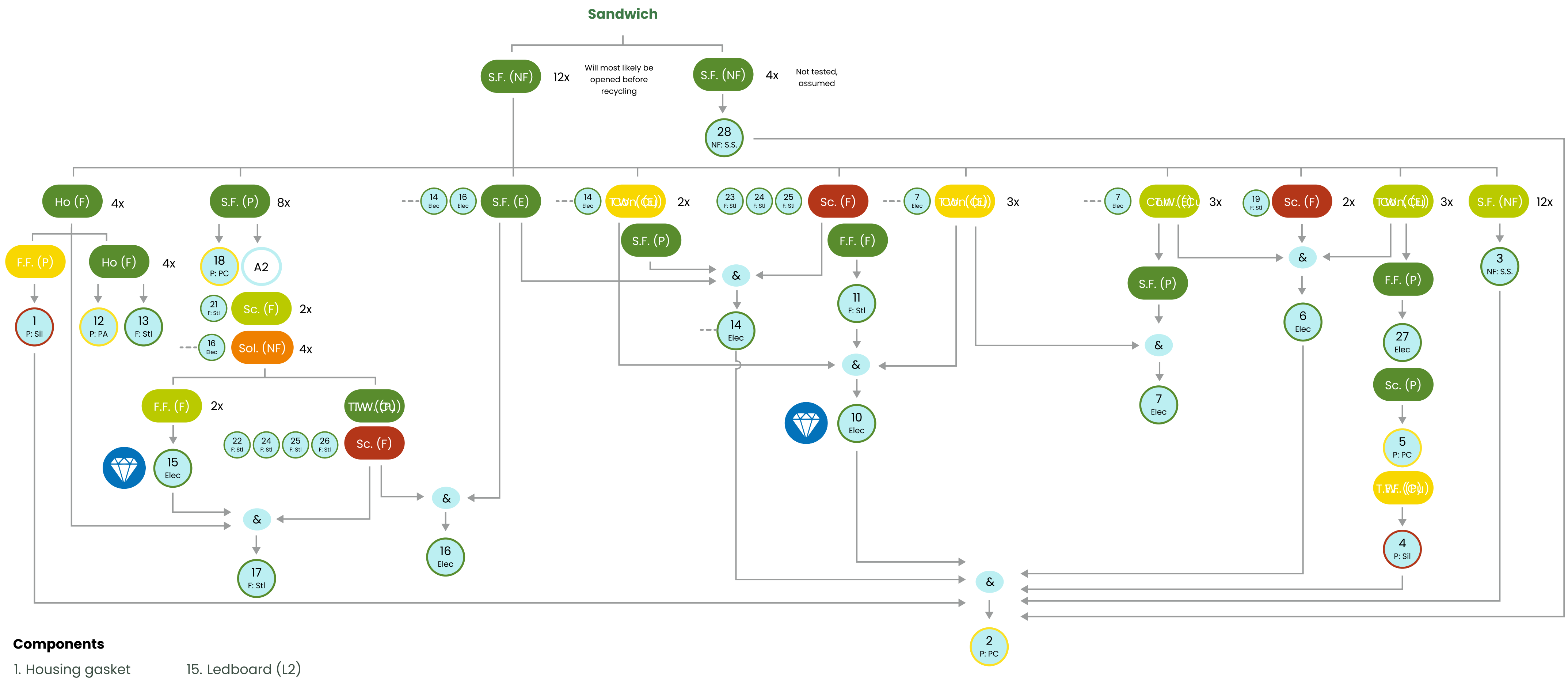



*Figure 45: Icons hazardous and valuable materials*

If poor liberated connections need to be undone before this part can be retrieved, a solution should be found for that.




**Components**

1. Housing gasket
2. Housing
3. Hooks/clips
4. Cable gland gasket
5. Cable gland
6. 4 pole push-in connector
7. Wires
8. -
9. -
10. Driver
11. Driver bracket
12. Retention cords
13. Small clips
14. Connection wire driverside
15. Ledboard (L2)
16. Connection wire Ledboardside
17. Reflector
18. Optical Cover
19. T10 screws d3 l22
20. -
21. PH1 screws d3 l7
22. PH1 screw d4 l11
23. T20 screw d2 l11
24. External tooth lock washer D4
25. Washer D4
26. Nut D3
27. Cable plug
28. Brackets

**Liberation scale**

- Good (>95%)
- Often (75-95%)
- Somtimes (40-75%)
- Occasionally (5-40%)
- Never (5-40%)

**Connections on liberation scale**

- S.F. — Snap fit
- Ho — Hook
- T.W. — Tie wrap
- Con. — Connector - wire
- Sc. — Screw
- F.F. — Friction fit
- Sol. — Soldered cable

**Material type group connector**

F - Ferrous
NF - Non-ferrous
P - Polymer
E - Electronics
O - Other

**Special material indication**

- Hazardous material
- Valuable material

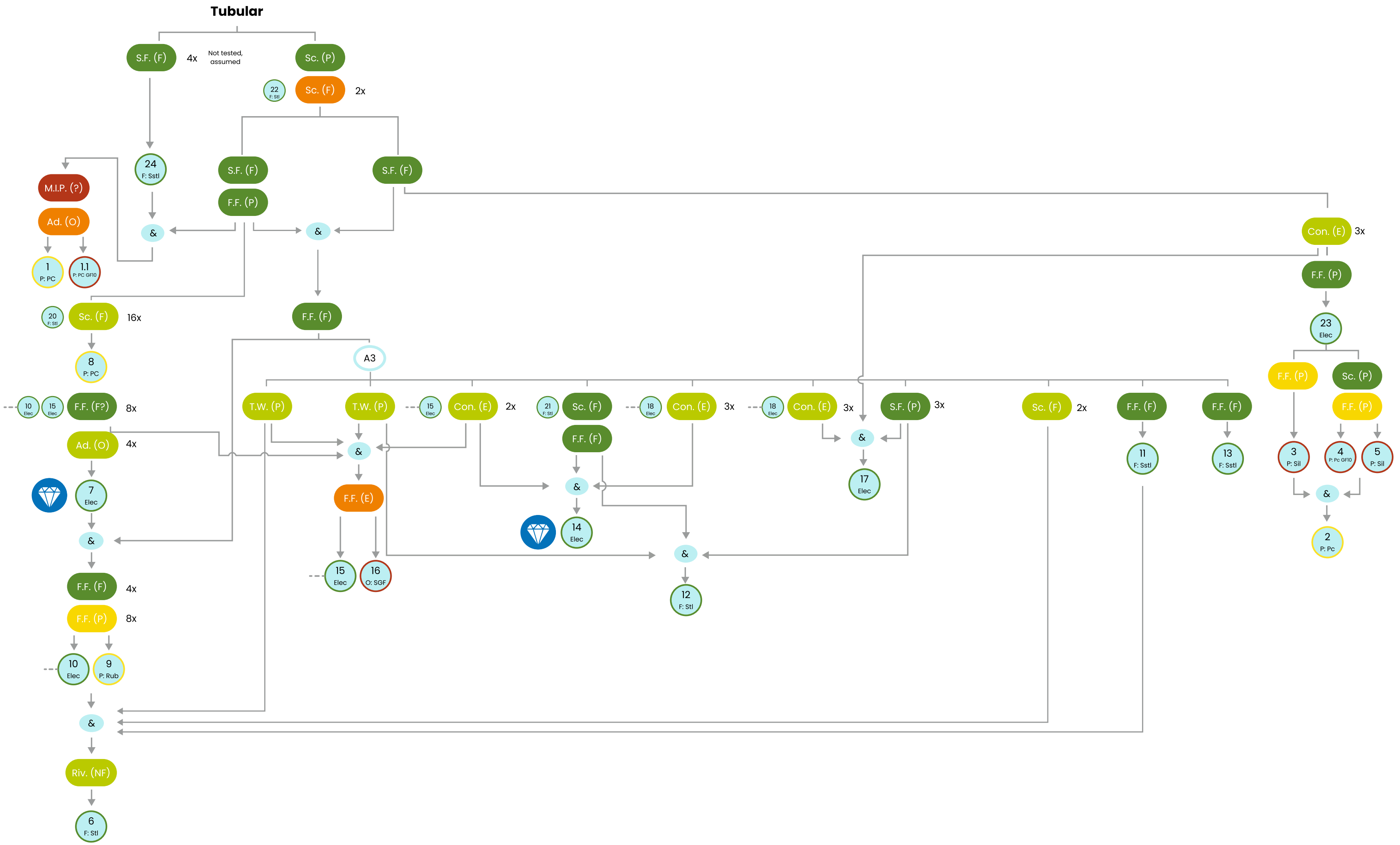
**Material part**

F: Stl = Ferrous Steel
NF: Sstl = Non-Ferrous Stainless steel
P: PC = Polymer Polycarbonaat
P: PA = Polymer Polyamide
P: Sil = Polymer Silicone
Unk. = Unknown
Elec. = Electronics

**Recyclability part**

- X — Material of part is recyclabe in current e-waste process
- X — Material of part is recyclable, but is currently not recycled in the e-waste process
- X — Material of part is not recyclable in current e-waste process

*Figure 46: Recyclability map Sandwich*




**Components**

1. Housing Tube with glued end cap parts (1.1)
2. End cap
3. End cap gasket
4. Cable gland
5. Cable gland gasket ring
6. Reflector + wire + ground cable
7. Ledboard
8. Lensplates/optics
9. PCB Grommets
10. Small ledboard cables
11. Driver bracket closing spring
12. Gear tray closing spring
14. Driver
15. Cables long (driver - ledboard)
16. Wire enclosure
17. 5 pole push-in connector
18. Cables medium (terminal block - driver)
19. Tie wraps
20. T10H screws D3 L10
21. T20H screws D4 L10
22. T20H screws D4 L20
23. Cable plug
24. Brackets

**Liberation scale**

- Good (>95%)
- Often (75-95%)
- Somtimes (40-75%)
- Occasionally (5-40%)
- Never (<5%)

**Connections on liberation scale**

- S.F. Snap fit
- T.W. Tie wrap
- Con. Connector - wire
- Riv. Rivet
- F.F. Friction fit
- Sc. Screw
- Ad. Adhesive
- M.I.P. Metal insert in plastic

**Material type group connector**

F - Ferrous
NF - Non-ferrous
P - Polymer
E - Electronics
O - Other

**Special material indication**

- Hazardous material
- Valuable material

**Material part**

- F: Stl = Ferrous Steel
- F: Sstl= Ferrous Stainless Steel
- NF: Sstl = Non-Ferrous Stainless steel
- P: PC = Polymer Polycarbonaat
- P: PA = Polymer Polyamide
- P: PES = Polymer Polyethersulfone
- P: Rub = Polymer rubber
- P: Sil = Polymer Silicone
- Elec. = Electronics
- O: SGF = Silicone-coated fiberglass fabric

**Recyclability part**

- X Material of part is recyclabe in current e-waste process
- X Material of part is recyclable, but is currently not recycled in the e-waste process
- X Material of part is not recyclable in current e-waste process

*Figure 47: Recyclability map Tubular*

It becomes visually clear which connections are problematic from the recyclability map. For the Sandwich, those are the screws, connectors, soldered wires and gaskets. For the Tubular, the metal insert, adhesive, end cap screws, gaskets and cables to grommets, and wire enclosure are the most problematic ones. They will be explained more in-depth in the next section.

### 5.3.2.3 Redesign directions resulting from mixed fragments

From the recyclability map and the mixed fragments analysis, a list of poorly liberated connections and problematic mixed fragments can be made. They are selected on which either occurred most often in the fraction, liberated the worst according to the disassembly map or were problematic in the WEEE recycling process according to the recyclers spoken to. Some problems occurred for both luminaires. These will be mentioned first, after which Sandwich- and Tubular-specific problems will be mentioned. The most problematic mixed fragments which should be investigated further in this project are indicated with a exclamation mark.

**Overarching problems**

! Both Luminaires have **silicone gaskets** in the PC housing (Sandwich, Figure 48) or end cap (Tubular, Figure 49). For both, problems arose. For the Sandwich, the casing was dented in because of the shredder, and the push-in gasket silicone was trapped as a result. For the Tubular, the silicone was mostly glued to the PC, due to the injection moulded seal. Only 22% of the mixed silicone fragments of the Tubular was also clamped, therefore, the glued seal is the biggest problem here. For both luminaires, a sink-float test was conducted, and all fragments floated because of the silicone.

*Figure 48: Clamped silicone in PC housing (Sandwich)*

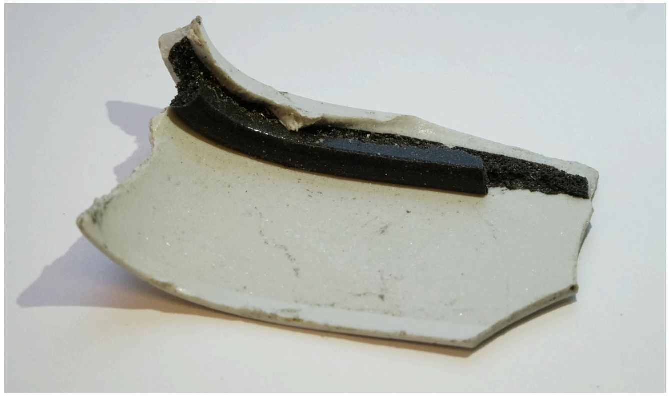


*Figure 49: Glued silicone in PC end cap (Tubular)*

Recyclers mentioned this as a problem, certainly when the silicone remained on the PC because of glue. These PC and silicone fragments will then pollute the floating plastic stream.

For the Sandwich, it is less of a problem as the fragments will be shredded into smaller pieces and the silicone falls out, however, this is not certain. Most mixed fragments of the Sandwich can be categorised in this problem and for the Tubular it was the 3rd biggest problem. Therefore, it is good to investigate this problem further.

**Metal parts** fold around other materials, including precious materials like PCBs (Figure 50) and LED boards. All materials, apart from the ferrous metals will then be lost, as they end up in the metal fraction and being burned. The metal casing of the driver gave the most problems as it folded around the PCB. For both luminaires, it was a common problem and worth investigating further.

There were also problems with the **connectors** (see Figure 51). It is not certain where the connectors

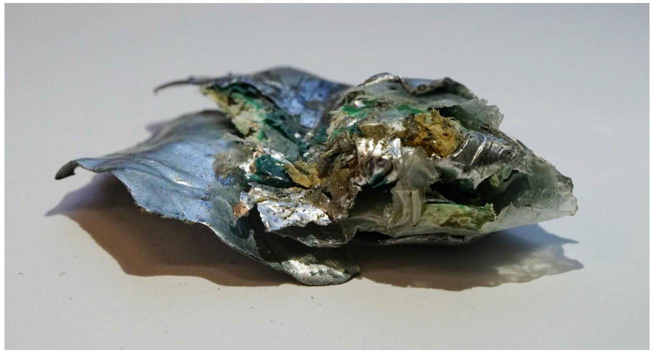


*Figure 50: PCB in metal folded fragment*

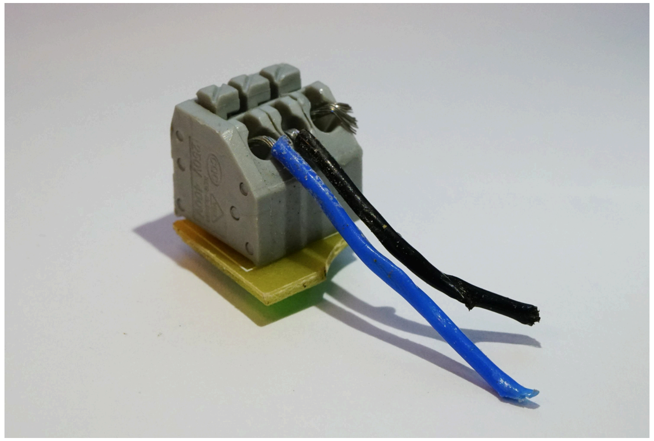


*Figure 51: Connector with wires on PCB*

*Figure 52: Nut-bolt connection (Sandwich)*

themselves end up. Depending on the orientation on the conveyor belt it either ends up in the copper fraction (where the plastic will be burned) or in the sinking plastics fraction (where everything will be burned and lost). Next to that, some will have connectors with wires in them, which do not come loose. Smaller connectors will also remain on the PCB as they are soldered, which might lead to losing PCB materials, which are precious.

**Sandwich**

The **nut-and-bolt connection** did not liberate in 4 out of 4 times (Figure 52). Therefore, the aluminium cable shoe (connected to the reflector by the nut and bolt) will be lost and will slightly pollute the ferrous fraction. The amount is, however, limited and small impurities in the ferrous fraction are allowed (2% impurities of the total fraction).

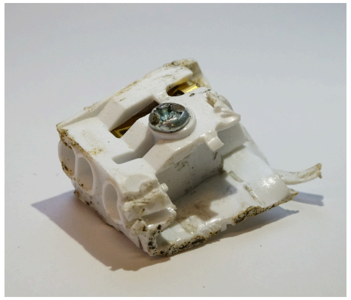


*Figure 53: Screw in connector (Sandwich)*

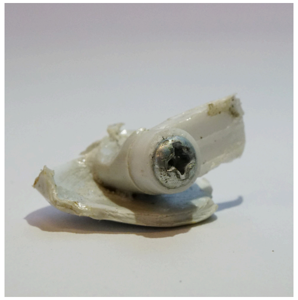


*Figure 54: Screw in pull safe and PC (Sandwich)*

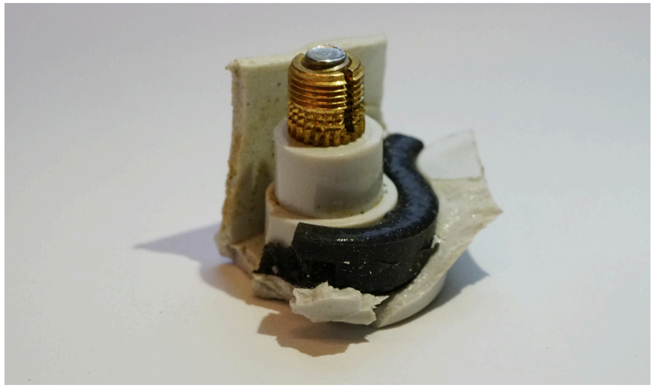


*Figure 55: Metal inserts in PC (Tubular)*

*Figure 56: Glued PC parts (Tubular)*

All **screws** apart from most of the LED board screws remained. These non-liberated include screws staying in PC, the connectors (Figure 53), and a pull safe (Figure 54) which is all problematic for recycling. In total 17 of these fragments were present, so it is interesting to investigate this further.

**Tubular**

In the tube, **metal inserts** are present and the end cap is screwed to the tube. Of the 10 screws present in the batch only one liberated (Figure 55). As these screws are not magnetic, all materials will likely be lost in the sinking plastics fraction. It is good to consider this problem further in the project.

End cap parts are **glued** to the transparent tube (see Figure 56). One problem here is the use of glass fibre in the end cap (see next section), which is not desired in recycling. Attaching this to clear PC without fillers contaminates the fraction. Next to that, the glue can pollute the plastic fraction if it does not dissolve in the process. It is the 3rd biggest problem and is therefore good to investigate further.

**Cables** remain in the **rubber grommets** (Figure 57) and in the **wire enclosure** (Figure 58). Ideally,

*Figure 57: Wire remains in rubber grommet (Tubular)*

*Figure 58: Wires remain in wire enclosure (Tubular)*

these fragments would end up in the copper fraction, where the rubber and wire enclosure will be used as fuel for the burning process. However, they might end up as waste or in the sinking plastics fraction, where all materials will be burned.

Also here, other **screws** are used which did not liberate. Some of them were used to attach metal brackets to the metal trays, these are not problematic as they all end up in the correct ferrous fraction. However, some remained in the lens plates (Figure 59), these will increase the density of the fragments and allow them to sink and get burned. It happened with 9 out of 96 screws, so it is a low-scale problem.

### 5.3.3 Material recyclability

To assess the **practical material recyclability** of the luminaires, the recycling process has been

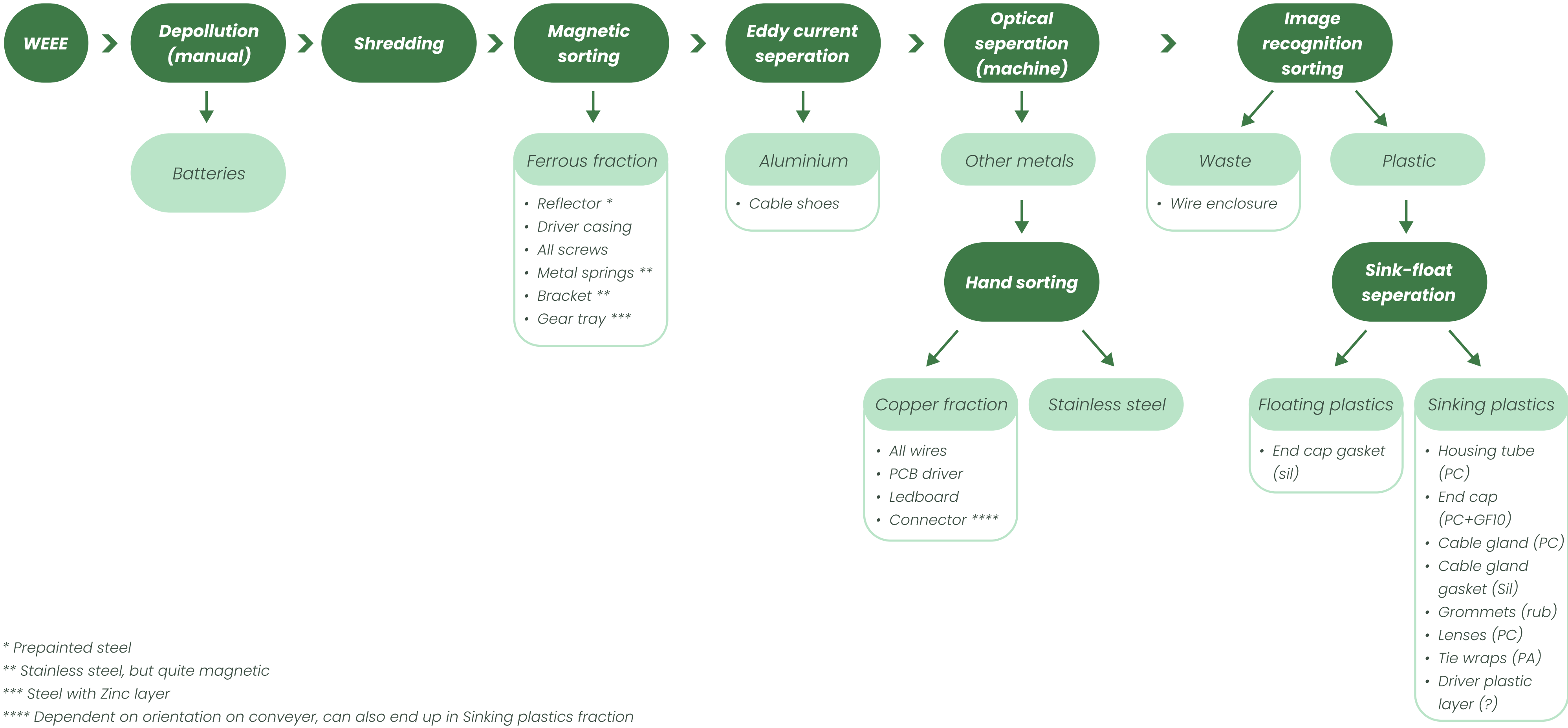
*Figure 59: Screws remain in PC lens plates (Sandwich)*

determined for both the Tubular (Figure 60, next page) and the Sandwich (Figure 61, second next page) and interviews with recyclers have been held. For the recycling processes, please note that the process is slightly simplified, such as the number of parts of the luminaire (only the parts present in every luminaire are considered). Next to that, PA (with a density of 1.13 kg/l) would end up in the float fraction according to the homemade sink float test, but recyclers said that PA would end up in the sink fraction. The latter has been assumed.

During talks with recyclers, the use of the recycling processes and looking into design guidelines, the following aspects are problematic in the design of the luminaires:

- Multiple parts and materials are not recycled, because they are seen as waste or will be burned (which can be seen in Figure 60 and Figure 61). These include silicone, which floats and contaminates the recycled plastic fraction. All other plastics in the luminaires are heavier than 1.1 kg/l and will end up in the sinking plastics fraction, where they will be burned and thus be lost. For the Tubular specifically, the silicone-coated fibreglass fabric enclosure rope (seen as waste), the rope and rubber (will be burned) will also not be recycled in the WEEE recycling process.
- PC is currently not recycled at the two recyclers spoken within this project.

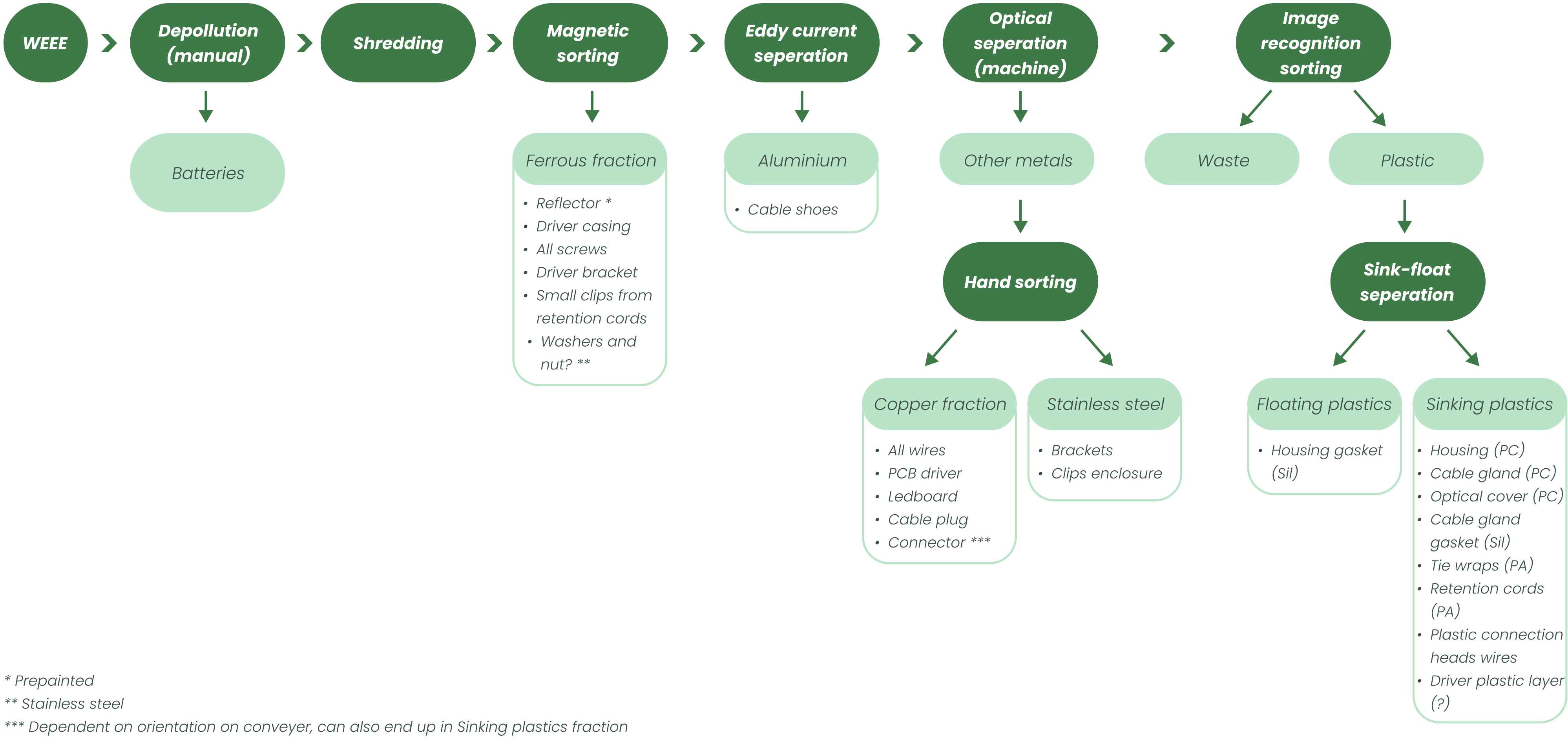
## Recyling process for the Tubular




*Prepainted steel*
** *Stainless steel, but quite magnetic*
*** *Steel with Zinc layer*
**** *Dependent on orientation on conveyer, can also end up in Sinking plastics fraction*

*Figure 60: Flow charts parts Tubular in the recycling process*

## Recyling process for the Sandwich




* Prepainted
** Stainless steel
*** Dependent on orientation on conveyer, can also end up in Sinking plastics fraction

*Figure 61: Flow charts parts Sandwich in the recycling process*

It ends up in the sinking fraction and will then be burned. This happens because there is a ban on the use of flame retardants in new products. These are eliminated when plastics with a density higher than 1.1 kg/l are removed. However, tests are ongoing on how flame retardants can be removed from the sinking fraction and how PC can be retrieved from the sinking fraction. A possibility is to retrieve all PC components from the installation site and deliver them to a PC recycler to recycle them there or recycle them in-house.

- Glass fibre is a problem for plastics recycling (Feenstra et al. 2021, Berwald et al., 2021 & Hultgren, 2012). After these plastics containing glass fibres have been shredded, they will contaminate the recycled plastic stream as glass-containing fragments will increase the density of the fraction. This causes plastics to sink and incinerated. Therefore, it is best to avoid using glass fibres in plastic if possible. This has been used in the end cap of the Tubular.
- Colour coatings on plastics are not ideal to use (Feenstra et al. 2021, Berwald et al., 2021 & Hultgren, 2012), as they contaminate the plastic fraction. However, if it is mass-coloured, it is not a problem, as recycled plastic will be coloured itself. (Marketing Director plastic recycler, 16 December 2024)
- Using a secondary finish on metals, like the white powder coating for the reflector or a zinc layer for the gear tray, is not ideal as it will lead to impurities in the ferrous fraction (its practical effect depends on the nature of the coating) (Castro et. al). However, the resulting metal fraction can never be 100% pure. According to the WEEE recycler, 2% impurities are within the limits in the complete batch, this can include colour and material coatings. (Dutch recycler process controller, personal communication, 18 December 2024)
- For recyclers PCBs, aluminium and copper are the most valuable materials.

## 5.4 Conclusions recycling

In this chapter, a shredding test has been conducted for both luminaires, recyclability maps have been made, and recyclers have been visited. This way, insights were gained on the recyclability of the Sandwich and the Tubular, which can be used to answer the research question:

*RQ3: "Which product features determine the recyclability of the luminaire when shredding it?"*

The recyclability of a product is determined by the liberation rate of the connections and the materials used. A few **criteria** can be made for the luminaire to comply with:

- The liberation rate of valuable and non-recyclable materials should be as high as possible
  - The PCB and LED boards should be liberated completely to avoid valuable material losses
  - The silicone seals should be liberated completely to avoid pollution
- Metal inserts and screws should liberate completely from plastics
- For plastics with a density >1.1 kg/l, an end-of-life process plan should be set up to recycle these materials further
- Materials (apart from PP, PS, ABS and PE) ending up in the plastic fraction with a density smaller than 1.1 kg/l are minimized to avoid pollution
- There are no non-recyclable materials used, or if used they should liberate completely

For the complete list of criteria derived from this analysis, see Appendix N, the list of requirements and wishes for the redesign.

From the analyses on recyclability, a summary of the selected redesign opportunities can be made in Table 7. These were selected based on how problematic it is for the recyclability of the luminaire and will be investigated further later on in the project.

*Table 7: Selection of redesign directions recycling*

| Sandwich | Tubular | Both luminaires |
|---|---|---|
| Improve the liberation rate of steel screws from plastic parts | Improve the liberation rate of metal inserts and screws from the plastic end caps and the tube | Minimise pollution of the floating plastics fraction as a result of the silicone seal |
| | Minimize pollution of the plastic stream because of glue and glass fibres in the end cap | Improve the recovery rate of precious materials like PCBs and LED boards, by minimizing steel folding |
| | Improve the practical material recyclability of the wire enclosure and liberation rate of the wires held together with this enclosure | Improve the practical material recyclability of Polycarbonate |

# 6. Tensions between installation, repair, recycling & application

## 6.1 Introduction

Different domains have been considered for the Sandwich and the Tubular. However, tensions will arise between these three and the technical properties of the luminaires considering the application (including waterproofness). This chapter will investigate these tensions. This will be done by listing the problems and application requirements and identifying what contradicts them. Also, the disassembly and recyclability maps will be used to compare these domains for tensions related to the selected problems. With this information, the following research question can be answered.

*RQ4: Which product features hinder each other when evaluating the recyclability, repairability, ease of installation and the luminaire's technical performance?*

These insights will help in redesigning the luminaire later on and give new criteria to look into in the redesign.

## 6.2 Tensions in repair and recycling

To see where tensions and synergies in repair and recycling occur, it is interesting to compare the connection blocks from the disassembly maps (top ones) and recyclability maps (bottom ones) (Figure 62 and Figure 63 for the Sandwich and the Tubular respectively). From here implications in the designs become clear.

To compare the maps, notice here for the disassembly map, the penalties and dark coloured connection blocks, which indicate difficult actions. Light coloured blocks are easy actions. For the recyclability map, notice yellow, orange and red blocks, indicating poor liberation and green coloured blocks for proper liberation.

# Sandwich

## Tensions

| | Opening enclosure clips | Opening Cover snap fits | Screws (almost all) | Tie wrap |
|---|---|---|---|---|
| **Disassembly** | S.F. (Sp) 10 or 12x | S.F. (Sp) 8x *on ladder | T20H. (Sc) | T.W. (Cu) |
| **Recyclability** | S.F. (NF) 12x most likely opened during recycling | S.F. (P) 8x | Sc. (F) | T.W. (P) |
| **Explaination** | Are hard to dissassemble, lot of force is required and it is hard to see all clips on the ladder. However in recycling they all come loose, as they will be shredded with undone clips. | Requires more force to disassemble and is hard to access for the installer. Also here, will the snap fits easily liberate in the shredder. | All screws except for the LED board screws did not liberate easily in the shredder. However, for repair they are quite easy, requiring low force (except for the ones with extra washers, which are hard to reassemble). | Tie wraps are not reusable looking at the repairability, however, they liberated properly in the shredder. |

## Synergies

| | Removing cable gland gasket | Soldering wires | Friction fit (driver & ledboard) | Hook snap fit for cables |
|---|---|---|---|---|
| **Disassembly** | F.F. (Tw) | Sol. (Cu) 4x | F.F. (H) | S.F. (H) |
| **Recyclability** | F.F. (P) | Sol. (NF) 4x | F.F. (F) | S.F. (P) |
| **Explaination** | The cable gland gasket was hard to remove (due to precise placement of the tool and low visibility) and did not liberate well during shredding. | The soldered wires connection to the LED boards is not reusable, and thus not preferred in terms of repairability. I did also not liberate well in the shredder. Therefore, it would be ideal to avoid soldering connections. | Using friction fit to attach the LED board to the reflector and the driver bracket to the driver worked well for both. For recycling some LED boards and PCB's however got folded in metal, because this got bent by the shredder, so it was not related to the friction fit connection. | Cables are held in the housing with plastic hook like snap fits. The cables are here easy to remove and liberate well in the shredder. |

*Figure 62: Tensions and similarities repair and recycling Sandwich*

# Tubular

## Tensions

| | Undo metal springs | Slide out internal components | Disconnecting wires from LED board | Wires in wire enclosure |
|---|---|---|---|---|
| **Disassembly** | S.F. (Sp, H) | F.F. (H) | F.F. (Pl) 8x | F.F. (H) |
| **Recyclability** | S.F. (F) | F.F. (P) | 10 Elec, 15 Elec, F.F. (F?) 8x | F.F. (E) |
| **Explaination** | Hard to dissassemble, lot of force required and hard to see on the ladder. However in recycling it liberates well | Sliding the internal components out requires a lot of force, and is difficult with walls or products next to it. It does liberate well in recycling | Disconnecting the wires from the LED board is done by bending the metal parts sidewards, this is hard to understand and not reusable. It does however liberate well in recycling | The wires are easy to remove from the wire enclosure. In recycling, these parts stay often together, which is not desired |

## Synergies

| | Driver screw | Driver friction fit | Glued endcap part with metal inserts to tube | Gasket removal end cap and cable gland |
|---|---|---|---|---|
| **Disassembly** | T20H. (Sc) | F.F. (H) | Cannot be done | F.F. (Tw), F.F. (H) |
| **Recyclability** | 21 F: Stl, Sc. (F) | F.F. (F) | M.I.P. (?), Ad. (O) → 1 P: PC, 1.1 P: PC GF10 | F.F. (P) → 3 P: Sil, F.F. (P) → 5 P: Sil |
| **Explaination** | The driver screw is easy to undo and accessible and liberates properly in the shredding process | After the screw has been unscrewed the driver can easily slide out the gear tray. This connection can also be easy undone in the shredder | Grey GF PC is glued to the transparent tube and metal inserts are present in the GF parts. This cannot be removed for repair and do not liberate properly in the shredder | The gaskets in the end cap and cable gland are hard to remove for repair and do not liberate well in the shredder too |

*Figure 63: Tensions and similarities between repair and recycling Tubular*

## 6.3 Tensions with application requirements

As we talk about linear waterproof luminaires, application and technical requirements come into play. These luminaires have an IP66 and IK08 rating. For the IP rating, seals are important. If the seals are to be redesigned due to their bad recyclability, it is important to design a solution where the waterproof levels stay the same or ideally improve. This also counts for the use of the metal inserts in the tube of the Tubular. These make sure the end cap and seal close properly and no water or dust can enter at this point. Mainly glue is used to waterproof the other side of the tube, which is bad for both repairability and recyclability.

To gain the best water- and dustproof properties, the openings in the luminaire should be very limited. The Tubular has a smaller opening than the Sandwich, which gives it better waterproof properties. However, the smaller opening and the additional slide out system compromise the ease of installation as well as limit the repairability. The latter is affected because all components need to slide out before any repair or maintenance can be performed. The Sandwich is perceived better in both the installation and repairability, but its waterproofness is limited. Its waterproofness is partially determined by the enclosure clips as they must be tight enough for the seal to work well. However, installers mentioned these clips are sometimes too tight to undo and close, which limits its installation and repairability.

Looking at the materials used, it was not ideal for the recyclability to use PC, as it is currently not recycled in the WEEE-recycling process. However, the thermal and strength properties of PC are needed, allowing the luminaires to be used in heavier industries and comply with the IP and IK ratings. Next to that, the use of white powder-coated steel is also not ideal for recycling, as it pollutes the ferrous stream. It is, however, used for its reflection properties (leading to a significant difference in lumen efficiency of the luminaire). Another recyclability issue found, was the steel folding around, for example, the LED board, PCB, cables and more. However, steel is used there for its thermal properties (since LEDs can get very warm), mechanical strength, protected earth connection and electromagnetic interference (EMC) support.

As for the LED boards in the Tubular, 16 screws were used to avoid bending of the lens plates and LED boards due to heat. However, this takes a long time to unscrew, limiting the repairability of the lens plates and LED boards.

## 6.4 Conclusion

In this chapter, the tensions between the recyclability, repairability, ease of installation and application requirements have been investigated. This has been done by comparing the disassembly map with the recyclability map and by comparing the found problems with the application requirements of the luminaire. With this information, the fourth research question can be answered:

*RQ4: Which product features hinder each other when evaluating the recyclability, repairability, ease of installation and the luminaire's technical performance?*

In short, the more waterproof you want the luminaire to be, the harder it will be to install, repair, and to some extent recycle. This has to do with the use of little open spaces, glue and closing mechanisms. Next to that, some of the material choices suitable for thermal and strength properties, like white-coated steel and PC, are not great for the recyclability. Looking at connections, conflicts arise when using screws (bad for recycling, good for repair), snap fits (bad for repair, good for recycling), tie wraps (bad for reusing, good for recycling) and some friction fits (hard to undo, good for recycling).

The **requirements** from the application and the technical specifications of the luminaire to consider here are:

- The luminaire complies with the IP66 and IK88 rating
- The thermal properties of the luminaire remain the same, to avoid failure of electronic components
- The optical properties should remain the same, thus thermal expansion and displacement of the lenses should be avoided
- The mechanical strength properties should remain the same

# 7. Redesign focus & list of requirements

Based on all analyses conducted, a list of problems to address for the Sandwich, Tubular, and both combined (see Appendix M) as well as a list of criteria (Appendix N for the full list) have been generated. From those, the focus for a redesign will be identified and a list of requirements and wishes is created which will be considered in the redesign process.

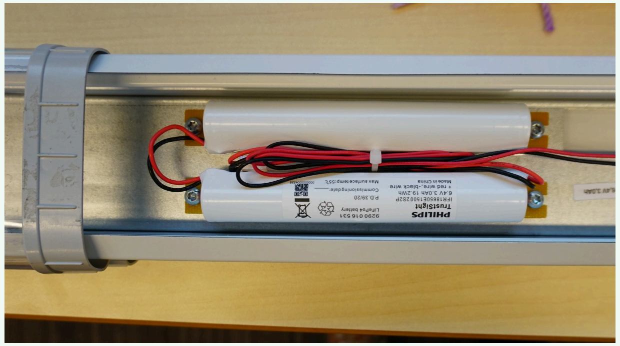
After the analyses were done and talking with the product manager of both luminaires, it was decided to continue to redesign the Tubular. The insights from the Sandwich were either already taken into consideration in the factory (for example the LED boards), relatively easy and quickly solvable problems (like the wiring problem) or were also present in the Tubular (like the seals and the metal folding). Next to that, the Sandwich is for installers already a desirable product, for which only small adaptations would already create more satisfaction. There are more complex and interesting problems to investigate for the Tubular, which can improve the market position of linear-shaped luminaires in harsher environments.

From the analyses on installation, repair and recycling and their tensions, four focus directions were selected based on the severity of the problem, the domains it influences, its complexity, and innovativeness (Table 8). This has been done in consultation with the company. For the full selection process, see Appendix O. The selected problems the redesign will focus on as well as their importance are highlighted in Figure 64.

*Table 8: Selection redesign focus*

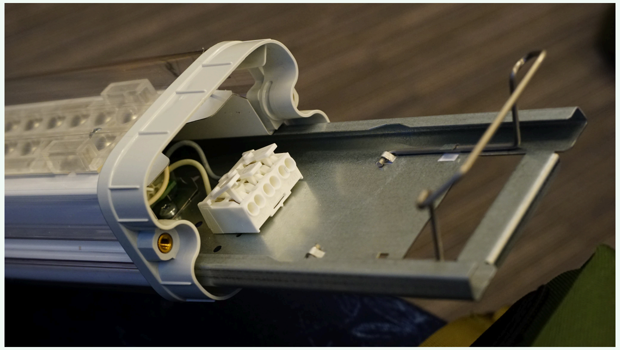
| Installation | Score |
|---|---|
| Slide out system | 24 |
| Emergency batteries | 24 |
| Disassembly for recycling | 17 |
| Packaging | 10 |
| **Repair** | **Score** |
| Undo metal springs | 18 |
| Internal component access | 21 |
| Access LED board | 15 |
| Metal LED board connections | 16 |
| Access driver | 11 |
| **Recycling** | **Score** |
| Silicone seal | 22 |
| Steel folding | 21 |
| Use of PC | 19 |
| Metal inserts | 19 |
| Glue in PC | 16 |
| Cables in enclosure & rubber | 10 |

## 1. Improve the accessibility of the battery



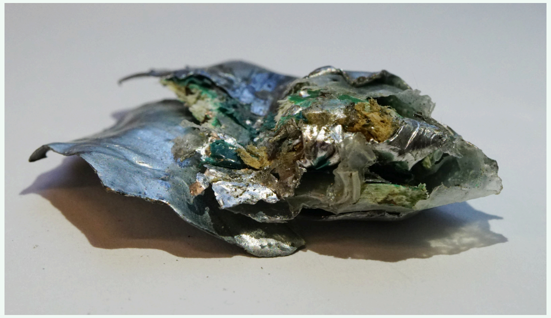
This should be done every four years and is currently done by replacing the whole luminaire and repairing the battery elsewhere on a table. Facilitating this on the spot would save time and money and ideally allow better overall repairability on the spot, as drivers and LED boards cannot be repaired on the spot as well.

## 2. Improve the accessibility of the connector



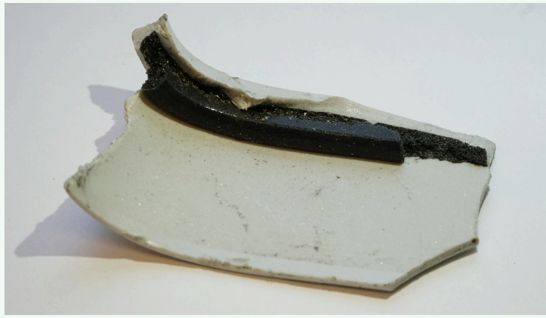
Currently installers find it hard to install the luminaire to existing cables on site due to space limitations and the accessibility of the slide-out system. Increasing installation time and thus money is important here.

## 3. Prevent metal folding



Metal from the driver and reflector fold around PCB's, LED boards, and more. Therefore, valuable materials are lost. Again, this was a problem for both the Sandwich and the Tubular

## 4. Improve the recyclability of the seal



Currently the seal sticks to the end cap and uses a lightweight non-recyclable silicone, polluting the floating plastics stream. This problem was present for both the Sandwich and the Tubular

*Figure 64: Four redesign directions*

While solving the above-mentioned problems, an important requirement is to design for waterproofness, as mentioned in the previous chapter. Therefore, the goal of this redesign is to:

*"Redesign the Tubular, to be quick and easy to install and be serviceable on the spot while keeping waterproofness and improving part liberation in recycling "*

From the analyses, different criteria on installation, repairability, recyclability and application could be derived that the redesign should meet. Together with some criteria from the company, a list of requirements and wishes has been created (for this full list, see Appendix N). The most important ones to consider and use for the redesign are highlighted in Table 9 and Table 10.

*Table 9: Program of requirements for the redesign*

| Requirement | Explanation | Source |
|---|---|---|
| The luminaire should comply with the IP66 and IK08 ratings | Application requirements, to withstand water, dust, chemicals and mechanical hits in the environment | Ch6, Product manager |
| The luminaire can be installed with existing cables on the spot | Allow retrofit installation, where cables are present on site | Ch3, installers |
| The luminaire can be pre-installed with a cable on a table before bringing it on site | To allow installation in more extreme applications (to limit time on site) and where cables on site are not present | Ch3 |
| The batteries are accessible and replaceable every four years on site, on the spot | Easy maintenance is allowed and less time is needed for repairs. Less waste will be created | Ch3 & 4 |
| Installation can be done by one person for luminaires smaller than 1.8m | To limit installation time and labour costs and make installation easy | Ch3 |

*Table 9: Program of wishes for the redesign*

| Wishes | Compliance | Source |
|---|---|---|
| The installation time is as short as possible and requires only a few steps | To improve the ease of installation and limit installation time | Ch3, installers |
| The connector is easily accessible when working above your head | To improve the ease of installation of the cable on site | Ch3, installers |
| The battery and driver should be quickly, easily and intuitively accessible and replaceable on the spot | These parts should be replaceable by directive and in need of replacement most often. Allow proper access makes repair costs profitable over replacing the complete luminaire | Ch3, Ch4 |
| The opening and closing of the luminaire can be done quick and easy and requires little effort and tools | Improves installation, maintenance and repairability time | Ch3, Ch4, installers |
| Homogenous liberation of valuable, non-recyclable and incompatible materials should be higher than 80% | Improve material recovery and limit pollution of fractions. Currently 62% of these materials were retrieved. | Ch5 |
| The redesign fits (with only small changes) within the current luminaire dimensions and shapes | This way implementation can be done easily and quickly | Product manager, product architect |
| The costs should be as low as possible. If extra costs are needed, they should weigh up against the advantages for the clients | Create enough value for the price for clients and create a profitable product | Product architect |
| The design language of the tube stays as intact as possible | Keeping the unique selling point of the Tubular intact | Product manager |
| The redesign shows inspiring solutions | To use this research within the team and use it in further research | The company |

# 8. Concept generation and selection

This chapter will present the ideation process of creating a concept. This was done through iteration, brainstorming, competitor analyses, a morphological chart and a Pugh matrix ranking by experts. The chapter concludes with an explanation and justification for the chosen concept.

## 8.1 Idea generation

The process of the concept generation and selection process is schematically shown in Figure 65.

The first step was to generate different ideas to solve the problems mentioned in the previous chapter. These were generated using the directions/prompts shown in Table 11. Some ideas were generated by looking at the Tubular's competitors like Etap, Glamox and Sammode (for a short analysis of these products, see Appendix P). Ideas for the three most important and complex prompts (accessibility of the connector, accessibility of the

*Table 11: Ideation directions*

| **Prompts idea generation** |
|---|
| Accessibility connector* |
| Accessibility batteries* |
| Connection batteries |
| Connection gear tray |
| Connection reflector tray |
| Recyclability seal* |
| Prevent metal folding |
| Closing end cap |

* used in brainstorm sessions

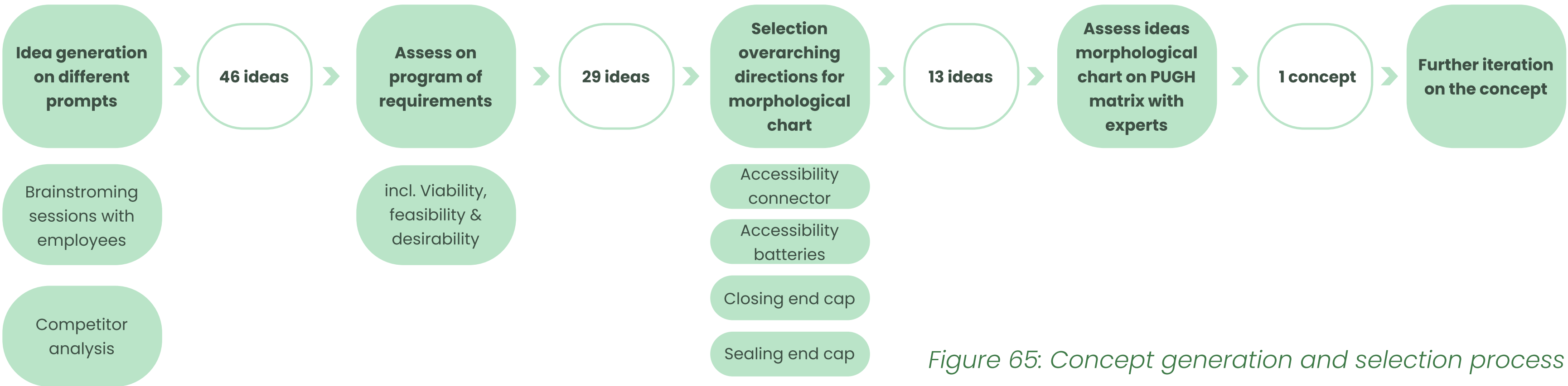



*Figure 65: Concept generation and selection process*

battery and recyclability of the seal) were generated with the help of the company's employees during short brainstorm sessions. In these sessions, the issues of the current luminaire were first explained, and then questions were asked to generate ideas on:

1. How can we make the electrical connection easier, while maintaining waterproofness?
2. How can we access the battery on the spot, while maintaining its waterproofness?
3. What kind of seals can we come up with that avoid the use of silicone? Or can we come up with designs to avoid using a gasket?

Initially the plan was to do this in a group setting, so they could first draw ideas and then compare and discuss these ideas in the group. However, due to circumstances, these sessions were with only two or three employees simultaneously and became more of a sparring session. Eventually, 46 ideas were generated. These were assessed on their feasibility (can it be made), desirability (by installers and product management), and the requirements. From those 46 ideas, 29 ideas ticked all the boxes. The complete set of these ideas and their assessments can be found in Appendix Q.

## 8.2 Concept selection

### 8.2.1 Pugh matrix & selection

To create a preliminary concept for further development, a morphological chart was made to explore possible solutions. Some ideas are dependent on the choice of other idea directions (for example the connection of the battery to the the luminaire is dependent on the generated idea on how the battery should be accessed). Therefore, four overarching directions were put in this morphological chart: the accessibility of the connector, the accessibility of the battery, the opening the end cap and the recyclability of the seal. All 13 ideas left were rated using the Pugh matrix on a -3 to 3-point scale with the current Tubular used as a baseline, scoring 0 on all criteria. The ideas were rated by the product architect, product manager and an installer on the criteria derived from the program of wishes. These criteria used to rate the ideas are shown in Table 12, together with their weights assigned in consultation with the company.

*Table 12: Criteria for the PUGH matrices*

| Criteria PUGH | Weights |
|---|---|
| Ease of installation | 5 |
| Recyclability | 5 |
| Repairability/disassembly | 4 |
| Feasibility | 4 |
| Costs | 3 |
| Innovation | 2 |
| Look and feel | 2 |

The complete Pugh matrices with reasonings behind their scores can be found in Appendix R. The ideas from the morphological chart together with their final scores are shown in Figure 66 and the highest scoring concept is shown in Figure 67. This concept has been selected to continue with. It includes placing the battery at the other end, placing the connector on the end cap, access the luminaire through a sliding mechanism and using another sealing material. The next sections will explain for each sub-concept how it improves the redesign and why it stands out compared to the other ideas in the morphological chart.

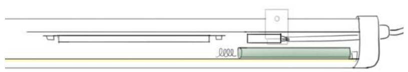
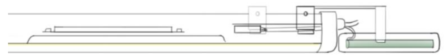
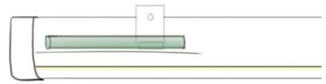
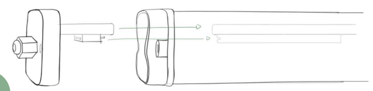
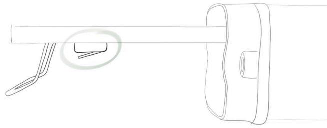
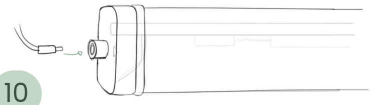
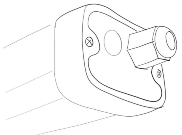
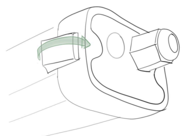
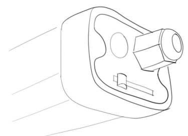
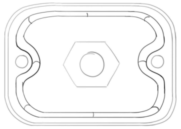
| | | | | |
|---|---|---|---|---|
| Accessibility battery | Battery on connected gear tray<br>**Confidential (see Appendix Q)**<br>4 | Battery pack camera<br><br>2 | External battery pack<br><br>-11 | Battery at other end<br><br>19 |
| Accessibility connector | Connector on end cap<br><br>18 | Connector close to edge & different metal spring design<br><br>16 | External connector<br><br>10 | |
| Closing end cap | Screws<br><br>0 | Big closing clips<br><br>5 | Sliding mechanism<br><br>18 | |
| Recyclability seal | Push in gasket<br><br>5 | Other material<br><br>12 | Silicone on tube<br><br>-22 | |

*Figure 66: Morphological charts with scores resulting from the PUGH matrix*

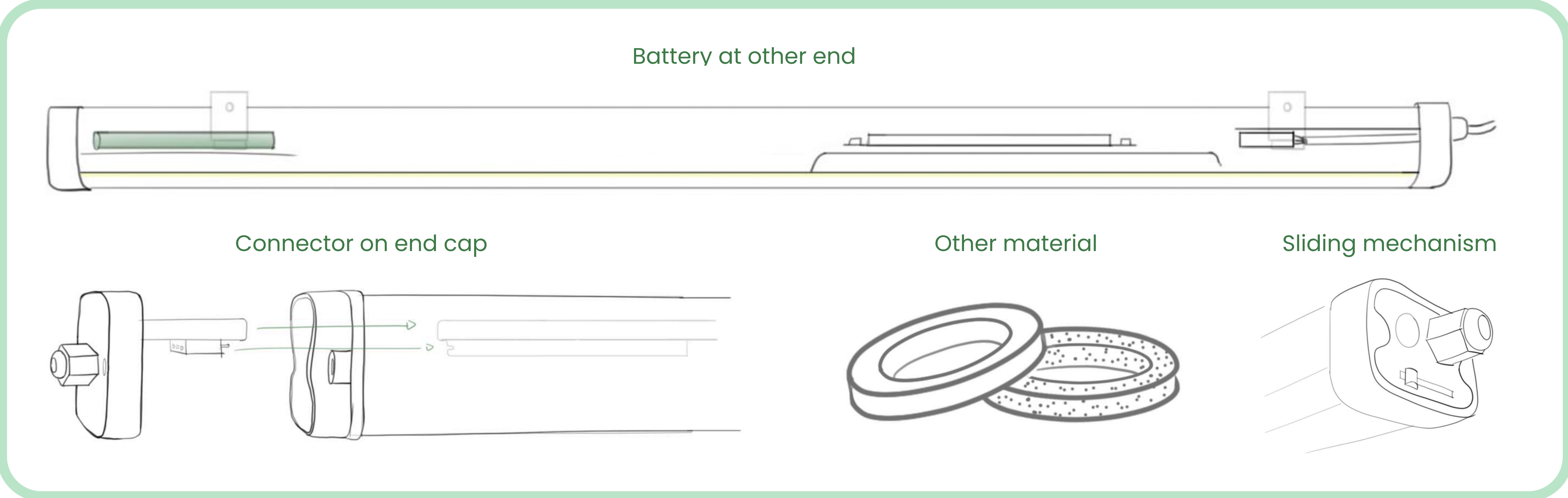



*Figure 67: Selected concept*

### 8.2.2. Accessibility of the battery: at the other end

The chosen idea, placing the batteries at the end, would allow the installer to loosen the end cap at that side, replace the batteries and reattach the end cap (see Figure 68). It is an easy way of replacing the battery and can make use of the existing building blocks, requiring little extra cost. Things to consider for the next iteration would

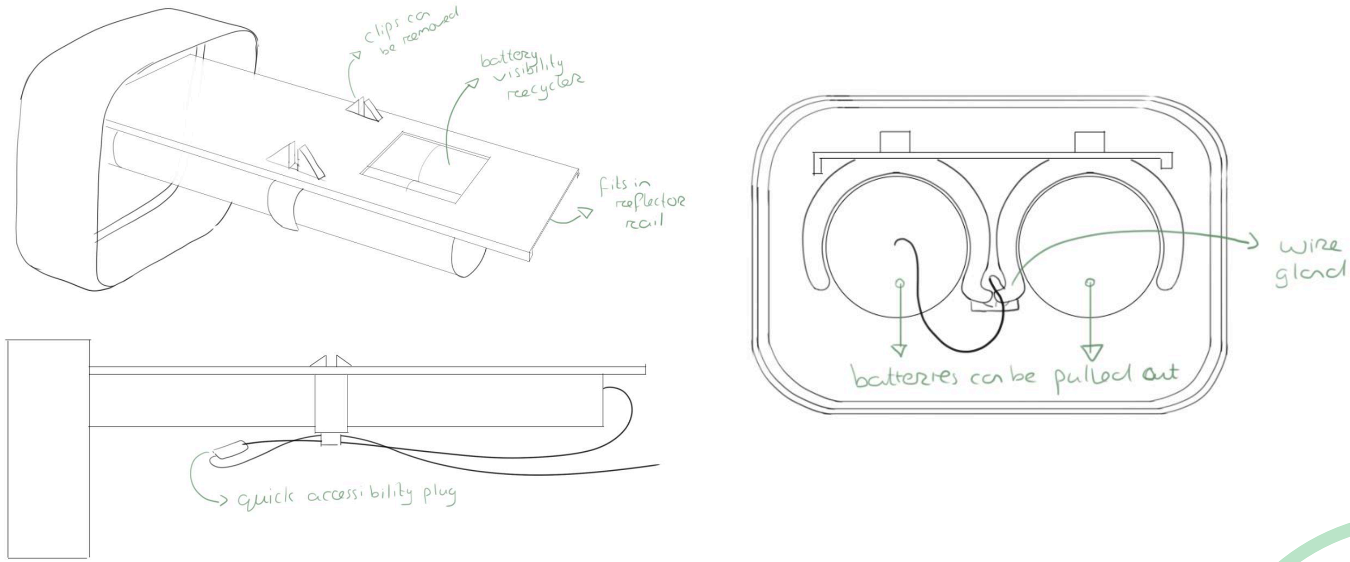



*Figure 68: Placement battery at the end idea iteration*

be the extended wiring needed inside the luminaire, the visibility of the batteries for the recycler and installer and the attachment of the batteries to the end cap.

Other ideas in the morphological chart on the accessibility of the battery would have brought along thermal problems. Batteries cannot withstand a lot of heat. Placing them close to the driver or other heat emitting components poses a risk of overheating. Other ideas generated would require a more structural change in design, making it more expensive or more difficult to install, like the external battery.

### 8.2.3 Accessibility of the connector: on the end cap

The best rated concept to access the connector was placing the connector on the end cap (see Figure 69), which was seen in the previous generation as well (see Figure 70). Installers mentioned that this previous Tubular generation was perceived better in terms of installation in retrofit situations, as connecting and disconnecting was quicker and easier. This concept disappeared in the current Tubular. The idea of bringing this concept back was rated slightly better than the runner-up, bringing the connector closer to the edge and designing a more intuitive slide-out system (see Figure 66). A limitation in placing the connector on the end cap is space, as the design of the current tube is smaller than the previous generation (it might not fit). The runner-up will then be a good backup as it will solve most problems for installers as well. However, the number of installation steps would remain the same in this case, meaning the overall improvement would be smaller.

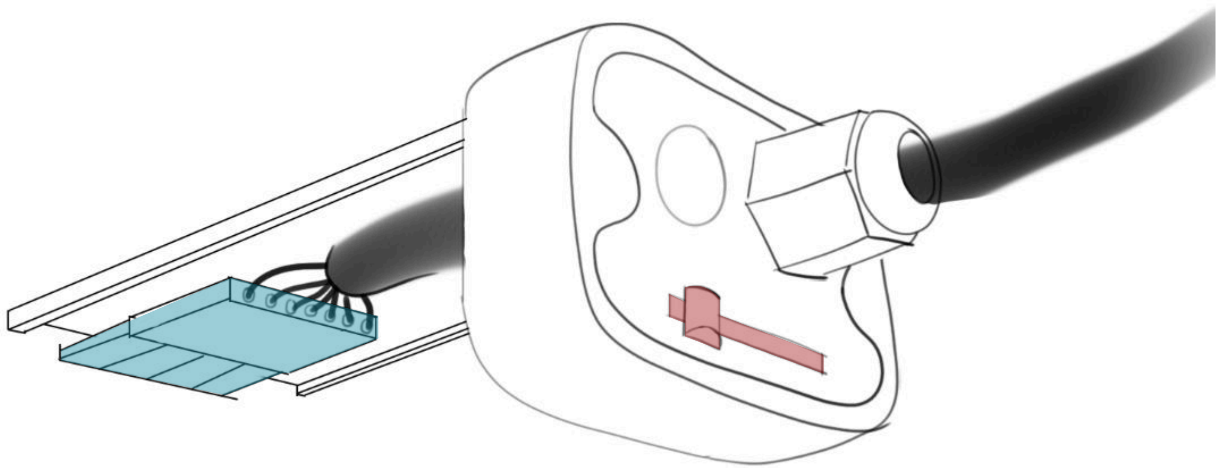


*Figure 69: Concept connector (blue) with sliding mechanism (red) on the end cap*

*Figure 70: End cap previous generation Tubular*

Other ideas that were generated before the morphological chart for the end cap would have given problems in terms of waterproofing. The external connector (present in the morphological chart) would have been too costly and/or impactful to the design to implement.

### 8.2.4 Closing the end cap: sliding mechanism

A sliding mechanism to open and close the end cap was rated best, looking at the closing mechanisms (see Figure 69). This would require no extra tools and is quick and easy to undo and close. The turning knob from the previous generation was also better perceived, so bringing this function back would be appreciated by the installer. A limitation of the sliding mechanism is again the space and the waterproofing of the mechanism as it needs to comply with the IP66 rating. Currently, screws are used. However, they take more time to undo, can corrode over time and do not liberate well from the end cap during shredding. Other ideas, like the big closing clips, would not be strong enough if made from plastic, corrode if made from metal, change the design appearance, and be dust accumulators.

### 8.2.5 Recyclability of the seal: use other material

Improving the recyclability of the seal of the Tubular can be done best by changing the material. Silicone is often used for sealing waterproof luminaires, including the Tubular, as it is thermally resistant, can withstand a lot of chemicals and is very cheap. However, silicone is currently not/poorly recyclable, so replacing it with a recyclable material with similar sealing properties would solve the most problems here. After researching literature and talking with experts, it became clear there is no material currently available with similar chemical and thermal properties as silicone and better practical material recyclability. Materials PTFE (RAM Gaskets, 2020) and Viton (The Chemours Company FC, 2021) would be equally chemically and thermally resistant as silicone but are only recyclable at specific recyclers (and not by the WEEE recyclers) (WasteTrade, 2023). TPU and TPE are also theoretically recyclable, but again not recycled in the WEEE line. Apart from that, both are less thermally resistant than silicone. (Yang, 2025) (Sharma, 2024) EPDM is better thermally resistant than TPU and TPE but has bad recyclability and thus is also not an option.

As there is no material to be found with equal properties and better recyclability, a part of the problem would be solved by using a gasket instead of an injection moulded seal; which was rated second best in the morphological chart. The product architect of the Tubular mentioned that these gaskets are already used in the current design. As seen in Ch5 and Appendix L7, the injection moulded seal (Figure 71) was responsible for 78% of the mixed silicone fragments. Only 22% was clamped in and would still raise problems if a gasket was to be used. The current design of the end cap does thus already facilitate better silicone liberation than the Sandwich housing due to one sturdy edge (see Figure 72). Note here, that these products were shredded into fragments of 35 mm but in practice they are shredded into fragments of 70 mm, resulting in possible less liberation of silicone. However, during processing, these parts are shredded into smaller pieces and might eventually liberate. If the gasket would then also made of a heavier silicone (>1.1 kg/l), all components (PC + silicone) would end up in the sinking fraction,

*Figure 71: Glued silicone, note here it is not clamped in like the Sandwich. Most mixed fragments, namely 78% were like this*

*Figure 72: End cap Tubular, with one thin edge and the end cap body enclosing the silicone seal*

so pollution of the floating plastic fraction is prevented. The final recommendation here for the company, is thus to continue using the end cap design with a gasket made of heavier silicone (> 1.1kg/l) to prevent pollution of the floating plastics.

### 8.2.6 Metal folding: recommendations

The prevention of metal folding was not taken into consideration in the morphological chart. Different ideas were generated but most of them would not work due to mechanical and thermal properties or would increase the price too much (ex. creating the metal parts from plastic compromises thermal flow and using thicker material increases the material amount and costs). The only suitable solutions generated here were the use of fracture lines and pre-disassembly of the PCB in the driver and LED board by the installer. However, both would not solve the complete problem as metal would still fold around (other) parts, just in a smaller amount. Additionally, further research into both options is recommended to test whether they would actually help prevent metal folding. The right number of fraction lines should be added and placed in such a way that bending of the metal parts can be prevented, the parts can be cut into desired fragments and the parts themselves retain enough mechanical strength. For the pre-disassembly, the PCB of the driver and LED board should be easily accessible and removable in a few seconds. This would require a completely new fastening system for the LED boards and optics, and a redesign of the driver casing, as it is currently very hard to open. Since other directions are prioritised, metal folding prevention is kept as a recommendation to the company for further research.

## 8.3 Concept conclusion

In this chapter, a concept has been chosen (as seen in Figure 73) by using brainstorming techniques, competitor analyses, a morphological chart and the use of a PUGH matrix. It has been explained why this concept was rated highest and why some directions have been left as a recommendation (the recyclability of the seal and the prevention of metal folding). This concept scores highest as it is the most feasible, requires little extra costs, has the potential to improve the accessibility to the connector, battery and the internals the most.

In the next chapter, the concept is taken as a starting point and the challenges mentioned before are taken into consideration in a final redesign proposal.

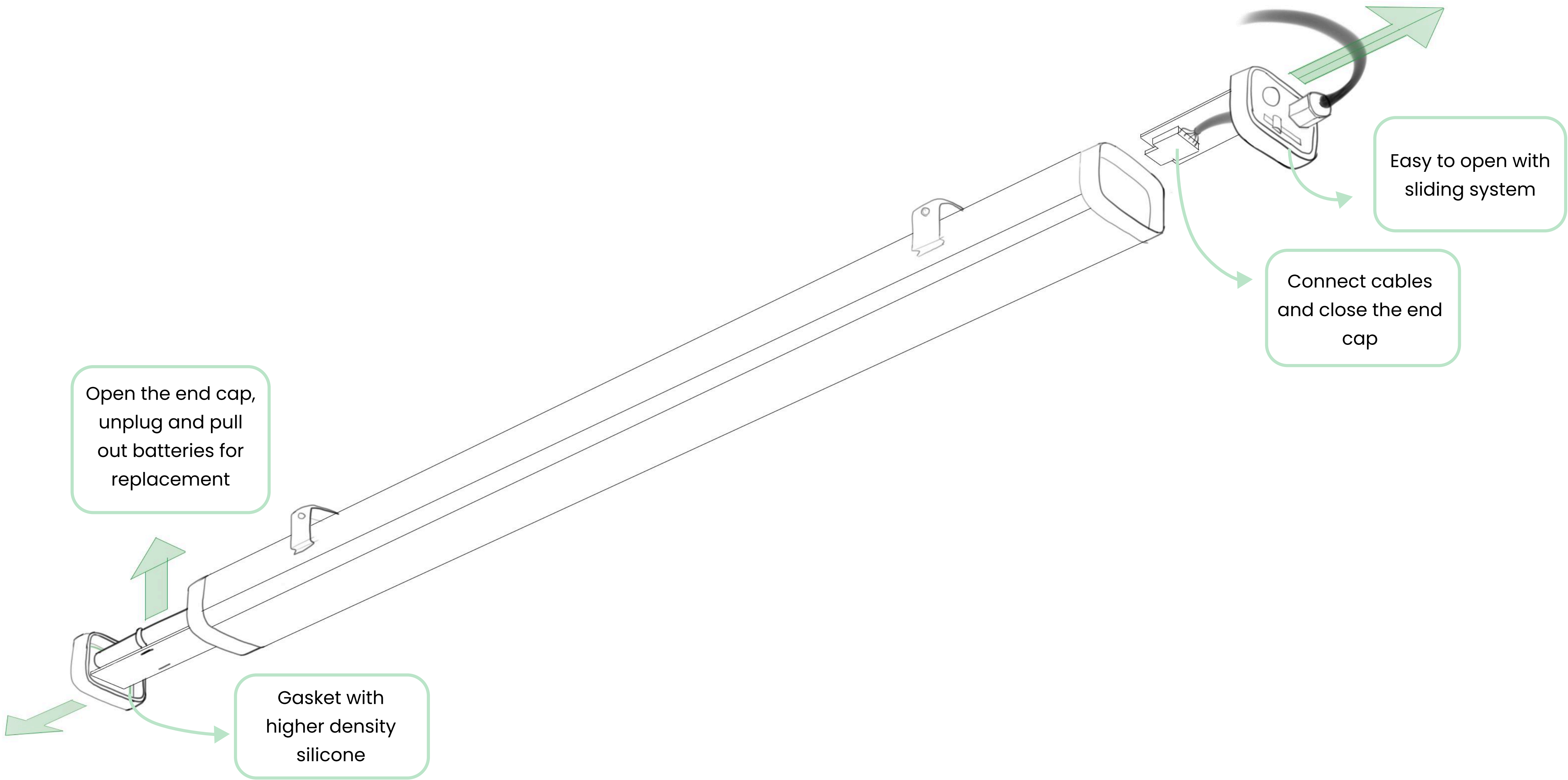



*Figure 73: Selected concept*

# 9. Final redesign

*This chapter will describe the final redesign proposal through a product demonstrator. This demo was developed through multiple iterations, 3D CAD modelling and 3D printing. The design will be evaluated to see whether the ease of installation, disassembly and recyclability have been improved. This chapter will conclude with some limitations and recommendations on the redesign.*

## 9.1 Overview redesign

In Figure 74, the proposed redesigned demonstrator is showcased. This chapter will discuss the 3 redesigned subassemblies (Figure 75): the end cap (Figure 76), the battery tray (Figure 77) and the driver tray (Figure 78). The demonstrator is made to test all assemblies in practice and to find out where issues are raised and improvements are needed. In Appendix S, an exploded view with an overview of the changes and the Bill of Materials (BOM) can be found.

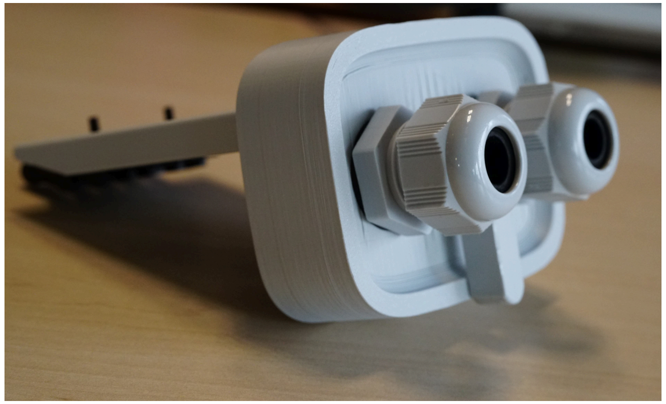


*Figure 76: End cap assembly external view*

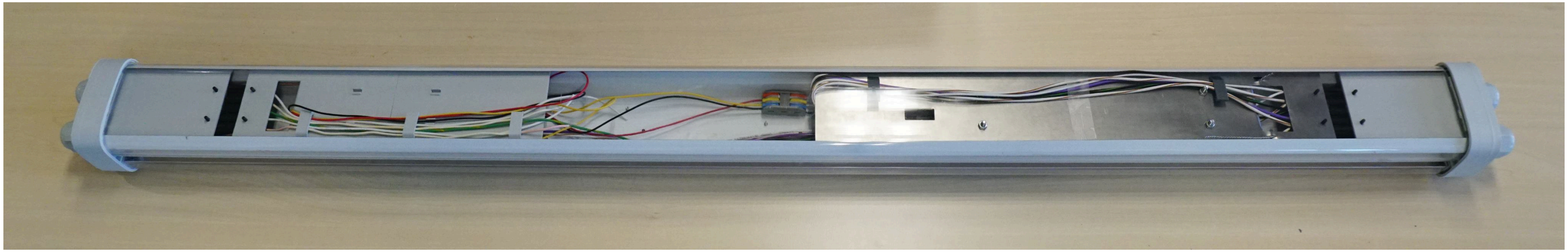


*Figure 74: Product demonstrator*

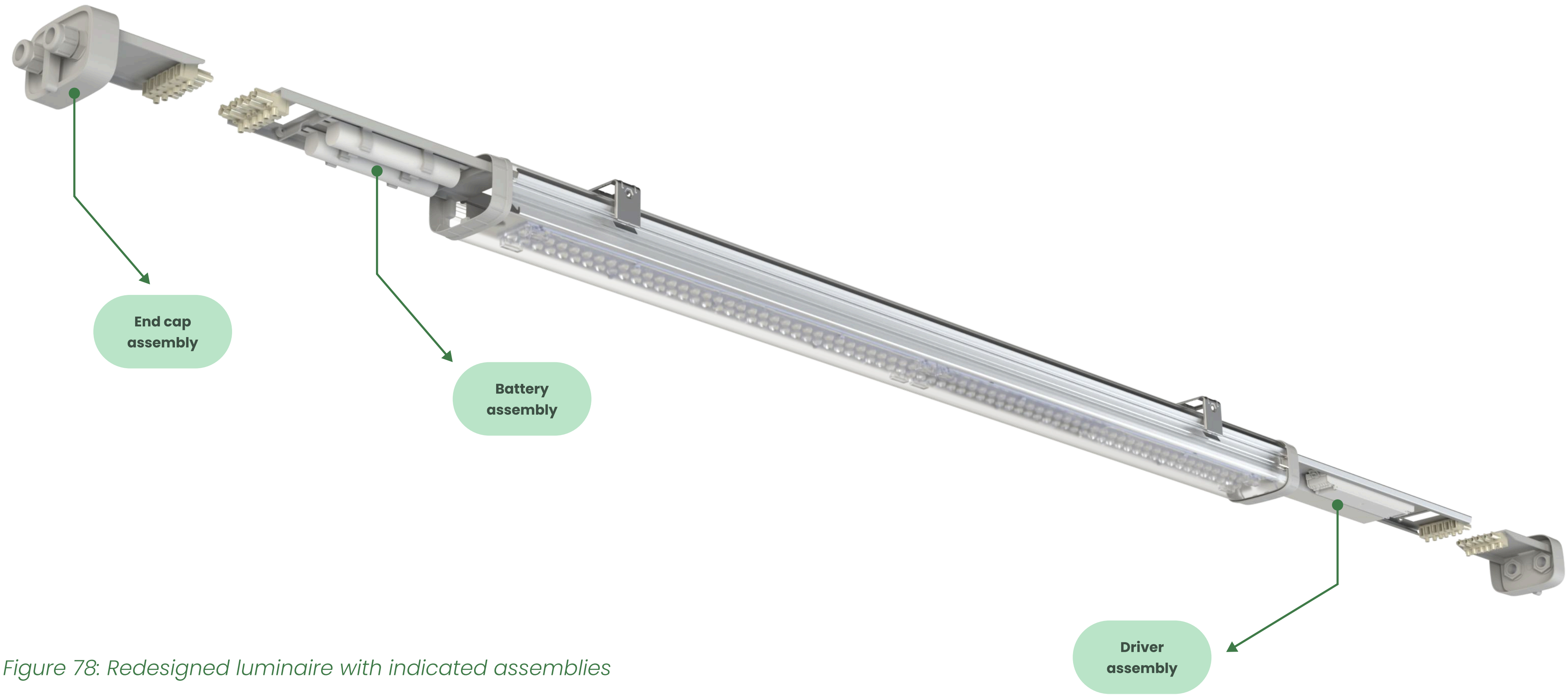



*Figure 78: Redesigned luminaire with indicated assemblies*

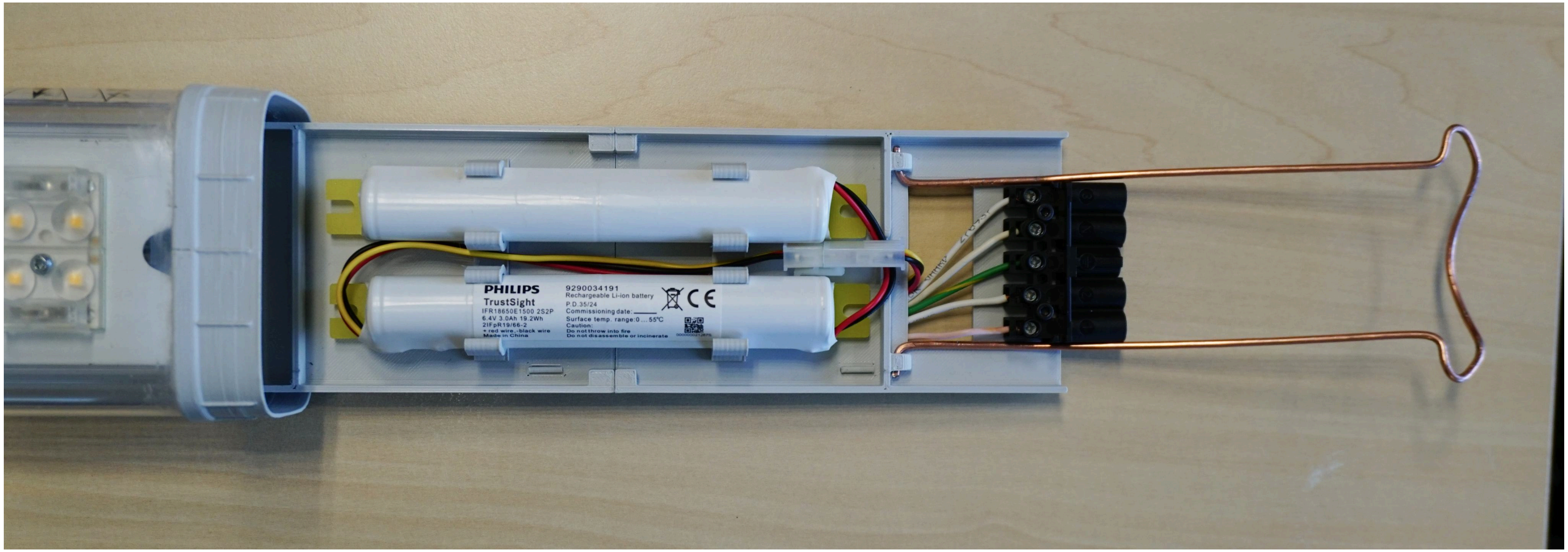



*Figure 77: Battery tray assembly demonstrator*

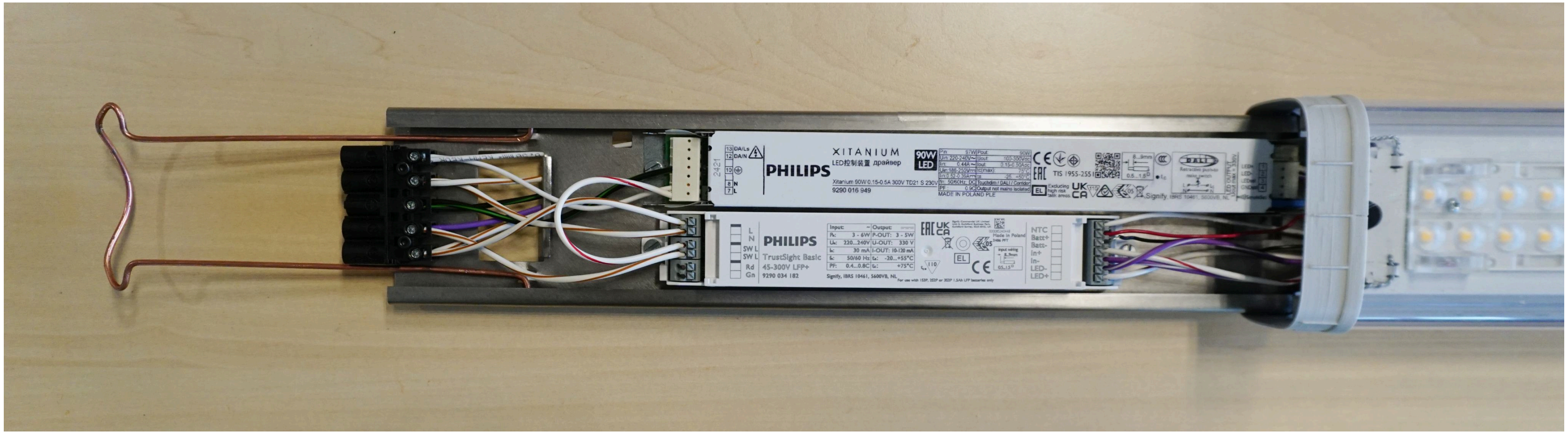



*Figure 78: Driver tray assembly demonstrator*

## 9.2 End cap design with turning mechanism

### 9.2.1 Connector on the end cap

The connector is placed on the extended end cap (see Figure 79) instead of on the gear tray to facilitate easier access to the connector on site, while keeping pre-installation possible. For this, an end cap extension has been added. This feature is slightly slanted at the end to facilitate easy entry into the luminaire (see Figure 80). The whole part is made of PC without glass fibre, to keep uniformity in the materials and allow better recyclability (as the density of PC is not changing because of the GF). This improves the recyclability. The spacing between the connector and the end cap sides is similar to the Sandwich (7,5 cm), for which no problems were mentioned in terms of spacing, and the least problems will occur with cable lengths on site this way. Looking at the type of connector, a connector with a push-in or lever design side and a male/female side would be ideal to use (see Figure 81). This is for several reasons:

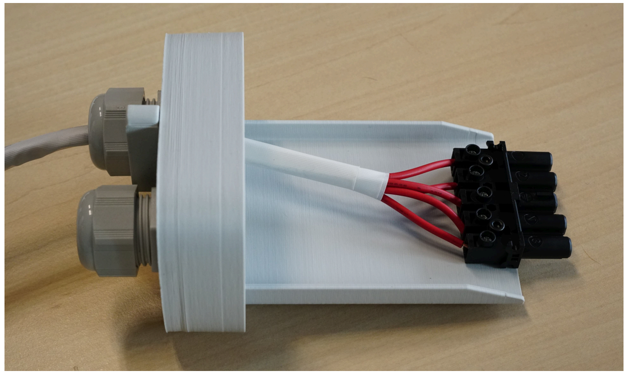


*Figure 79: Connector on the end cap*

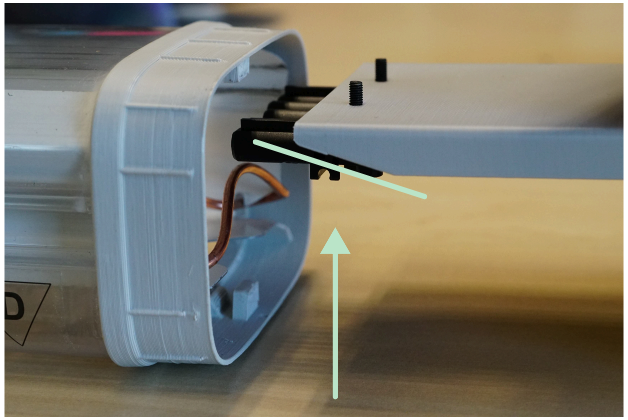


*Figure 80: Slightly slanted entry edge end cap*

- Installing the cable to the connector can be done quickly, easily, and without any tools. The push-in connector was also preferred among installers
- The connectors can click into each other in the luminaire to make an electrical connection when closing the end cap, which allows quick installation
- The wires can be removed without cutting (good for repairability), by pressing the levers

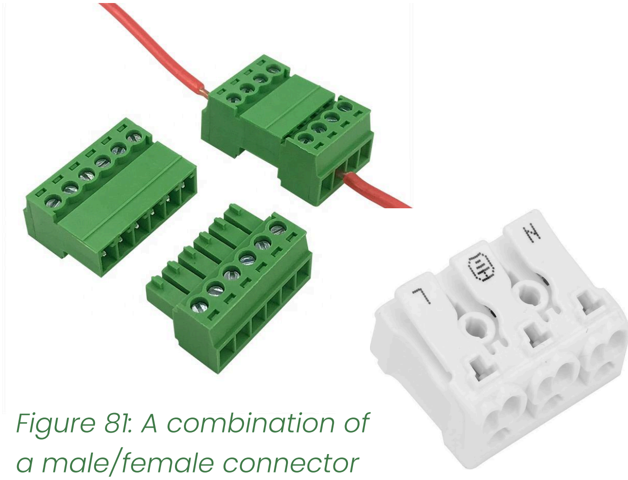


*Figure 81: A combination of a male/female connector (top left) and a push-in connector (bottom right) is recommended*

In the timeframe of the project this type of connector was not available. Therefore, the demo makes use of a Wieland connector where the cables need to be screwed in. This allows the male/female connection to be tested, as it is already known that a push-in connector is preferable and quick. Finding or manufacturing the ideal connector would be recommended to lower the installation time.

For the demo, the connector is screwed on the end cap. To facilitate better liberation during shredding, the connector should be snap-fitted to the end cap. This might, however, decrease its ease of disassembly but these connectors are hardly disassembled in practice. As the connectors are made of a different plastic than the end cap and consist of different metals, striving for complete liberation is then preferred, hence the choice to use snap fits.

### 9.2.2 Turning mechanism

The previous chapter ended with using a sliding mechanism as the highest-scoring closing system of the end caps. However, after exploration and iterations, it became apparent that a sliding mechanism would leave a big gap in the end cap, which is hard to properly seal for an IP66 rating. As waterproofing is the most important requirement in these luminaires, a turning mechanism (similar to the previous generation) has been proposed in the redesign (see Figure 82 & Figure 83 (in Appendix T) for the exploded view of the end cap). For this turning mechanism, different options were explored as well, where eventually the best-fitting and most sturdy one was selected. For all options explored, see Appendix U.

The mechanism makes use of a locking handle with a snap fit which holds the handle, end cap and a

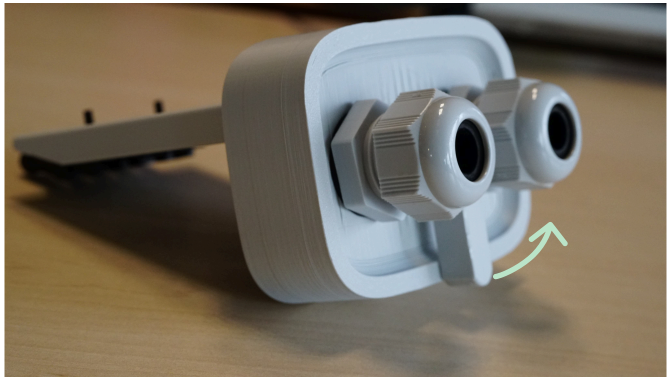


*Figure 82: Turning mechanism exterior*

locking plate together (see Appendix T, Figure 84). The locking plate locks behind protrusions on the PC injection moulded part of the tube. The luminaire can be sealed between the locking handle and the end cap with a gasket ring and in the end cap with a gasket (as already present in the current design). The turning motion of this mechanism is limited by a gap in the end cap sheet for the connector (see Appendix T, Figure 85).

The mechanism locks at the long ends of the end cap (see Figure 86). Also here, different options were explored for the locking placement. Locking at the short ends would conflict with the cable glands, cables and end cap sheet. Locking at the corners is possible (see Figure 86 and Appendix T, Figure 87 for a worked out example) but would require a more complex mechanism with more parts and hinges. This would decrease the sturdiness of the design and increase the costs. The proposed mechanism might be less waterproof than locking at the short edges or in the corners but is the most viable and sturdy, and facilitates internal and looped feed-through for 5 pole cables. However, the closing force should be tested further to ensure waterproofness.

This redesign was proposed to limit the opening and closing time of the luminaire, as it improves installation and disassembly time. Next to that, almost all components (except for the connector) are made of PC and no screws and metal inserts are present in this end cap. This all improves the recyclability of the end cap assembly.

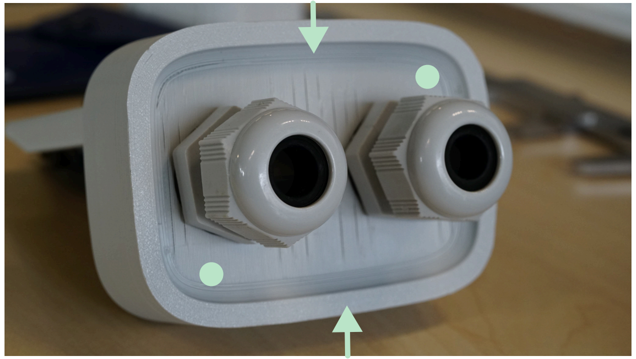


*Figure 86: Locking places mechanism (arrows) and possible locking places (circles)*

## 9.3 Battery tray

Another important proposal in this redesign is the placement of the batteries on a separate gear tray at the end of the luminaire. At first, the idea was to slide it out with the end cap simultaneously. However, when cable lengths are limited on-site and a feed-trough is used, the luminaire cannot extend by a great amount. Therefore, the choice has been made to make use of the end cap designed in the previous section and make a separate slideable battery tray (see Figure 88).

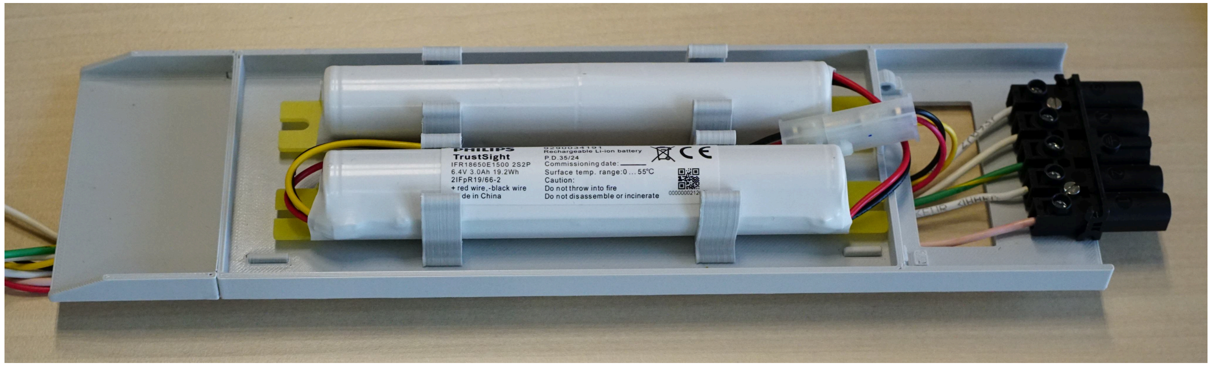


*Figure 88: Battery tray*

The batteries can be accessed by opening and removing the end cap. After that, the metal spring should be undone and the battery tray can be pulled out. The visibility and accessibility of this spring have been optimised by adding a curvature (see Figure 89). The battery tray has 2 battery clips holding the batteries in place. After unplugging the cable, the batteries can then be pulled out of these clips (see Figure 90), facilitating a tool-free replacement of the batteries. The clips themselves are separately clicked on the tray, to facilitate repair once one of the clips gets broken and to facilitate better manufacturability (all in one part requires a more complex mould for injection moulding due to negative draft angles). The batteries are limited in sliding around by the addition of ribs on the tray (see Figure 91), which also contribute to the mechanical strength of the tray. A gap in the battery tray is made to guide the wires along the top of the tray instead of along the batteries. Guiding clips keep them close to the part, so they do not get stuck (see Figure 92). This way replacement of the batteries is optimised as the wires will not get in the way, something that was annoying when it happened, as mentioned by the installers.

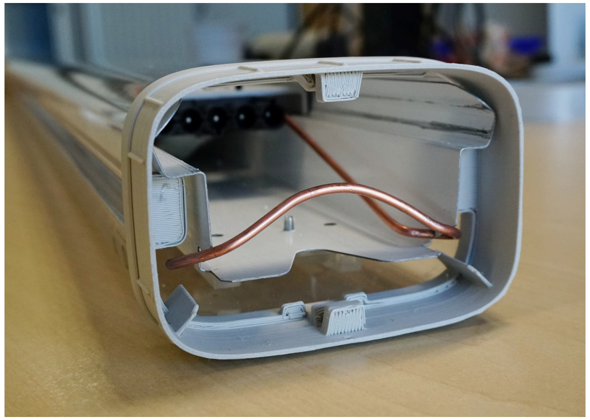


*Figure 89: Curvature in metal spring*

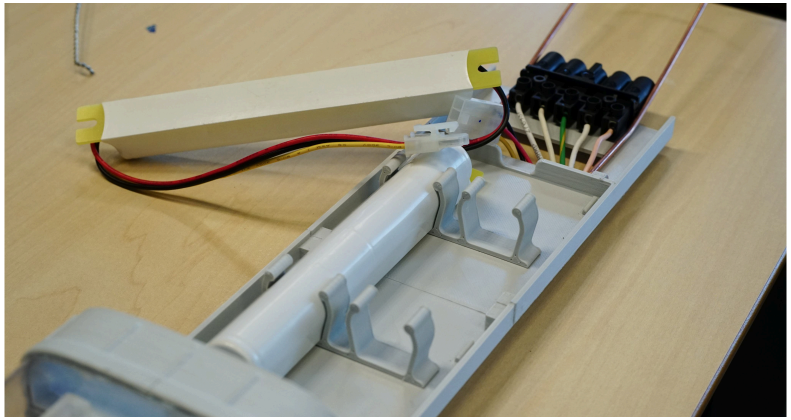


*Figure 90: Disassembling batteries from two battery clips*

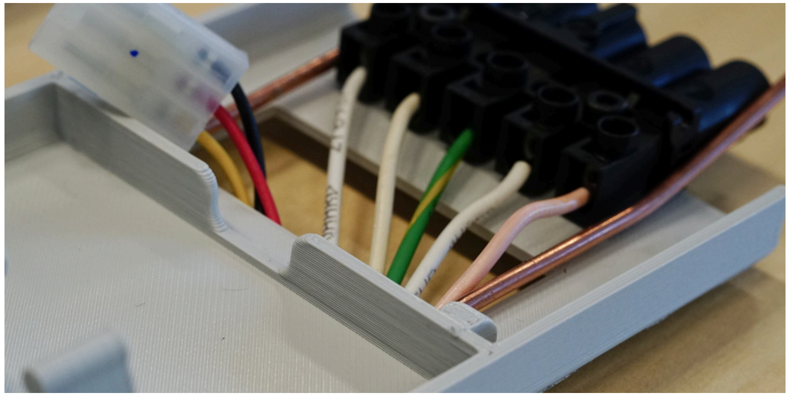


*Figure 91: Ribs to prevent battery movement & increase mechanical strength battery tray*

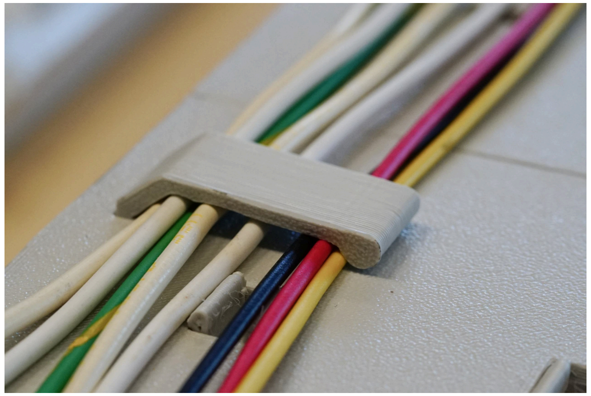


*Figure 92: Wire guiding clips on battery tray*

Before it was decided to make the battery tray of PC, a steel version was also explored in order to keep uniformity in the design with the gear tray (see Figure 93). However, some issues came to light while prototyping this which are listed below:

- As plastic battery clips were used in metal, 2 different materials were used in this assembly. Even though liberation due to the snap fits would not be a problem, it would be ideal to strive for a single material in the assembly.
- The wire guiding parts damaged the wires (see Figure 94). To solve this plastic protection parts should have been added to the metal tray, thus more mixed materials.
- The more steel is used, the more metal folding over other parts during shredding will occur. As this was an issue highlighted in Ch5, making the battery tray of plastic would minimize that.
- When pulling the batteries out, the fingers should be placed slightly below the batteries. Here the edges of the metal are sharp and thus a safety concern for the installer. There are different ways to solve this problem with metal but these would require a more complex and more expensive part than making it out of plastic.

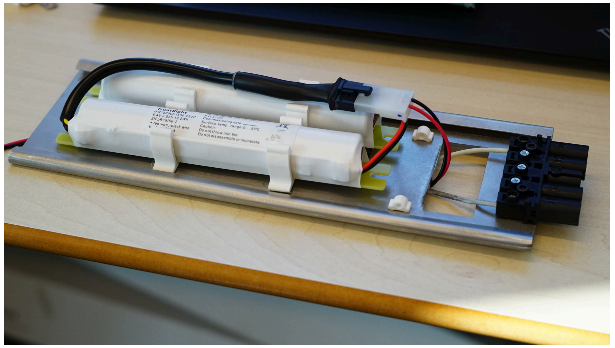


*Figure 93: Battery tray of metal*

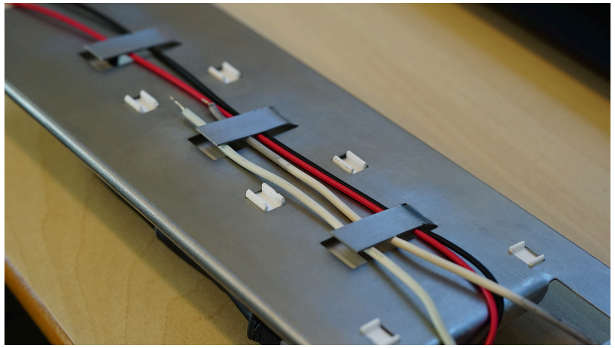


*Figure 94: Sharp edges metal damage the wires*

## 9.4 Driver tray

As the design of the end cap has been changed, the gear tray design (hereafter called driver tray) needs to change as well. Next to that, the aim was to facilitate better replacement and disassembly of the driver on the spot. This driver tray needs to be made of metal because of the protected earth connection and electromagnetic interference (EMC) support. Next to that, using metal will give more mechanical strength during slide out, as this tray is longer than the battery tray (because of longer drivers). The driver tray (see Figure 95) can be slid out, by again undoing and pulling the metal spring. After that, both drivers can be disassembled by undoing the screws and wires of both drivers. A disadvantage when repairing on-site is the space limitation. If another product, wall or similar is close to the luminaire, it might be possible that the driver tray cannot be slid out completely. To make it more feasible, the luminaire driver (the longest of the two) is fastened with only one screw (just as in the current design). After undoing this, the driver can be pulled out of the driver tray and the wires at that side can be undone (as there is enough wire length available). A bend is made to correctly guide the driver back into the right spot during reassembly, after the wires are attached (see Figure 96). The wires for the feed-trough are again guided over the top of the driver tray and held together by plastic snap-fitted guiding parts (plastic is used to avoid damaging the wires) so they are not hindering the driver's dis- and reassembly (see Figure 97). For the demo, the driver tray has been water jet cut and bent in the workshop at the company.

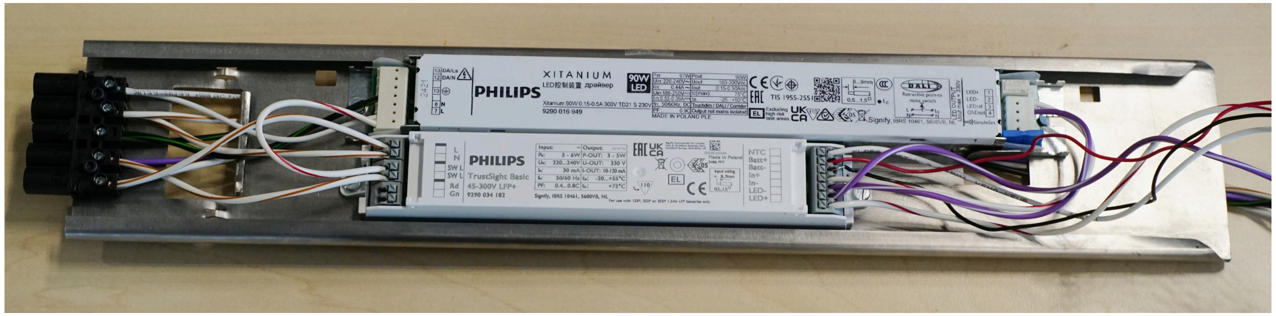


*Figure 95: Driver tray*

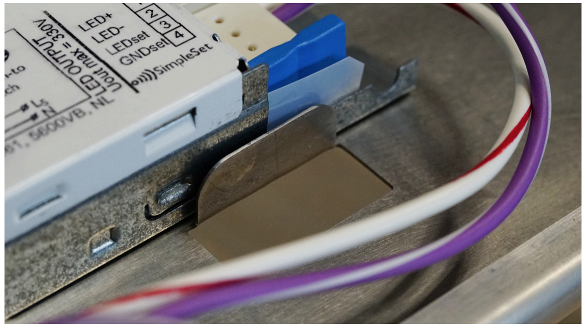


*Figure 96: Bend edge to guide driver in place*


*Figure 97: Guiding parts wires driver tray*

## 9.5 Evaluation redesign

### 9.5.1 Evaluating the ease of installation

Installers had mentioned issues with the limited cable length on site for the current Tubular. This redesign aimed to solve this issue by placing the connector on the end cap and closer to the cable gland. When the desired connector (with a push-in input) is used, the installation and de-installation can be done without any tools. De-installation can also be quickly done by pulling the end caps out and removing the luminaire from the brackets. The cable can be removed by pushing the levers in and pulling the cables out. In Figure 98, improvements in the installation and de-installation flow can be found, also compared with the Sandwich. The number and types of steps are similar to the Sandwich, which is positive, as this luminaire was perceived as easy to install.

## 9.5.2 Disassembly map and replacement test

As improvements in the disassembly have been made, it is worth looking at the disassembly map to compare it to the current design (see Figure 99). From here it is noticeable, that the redesign disassembly map is now bigger, as more components have been added (Battery tray, an extra end cap, more wiring). However, the luminaire now consists of more framed subassemblies, which gives a more structured way of disassembly.

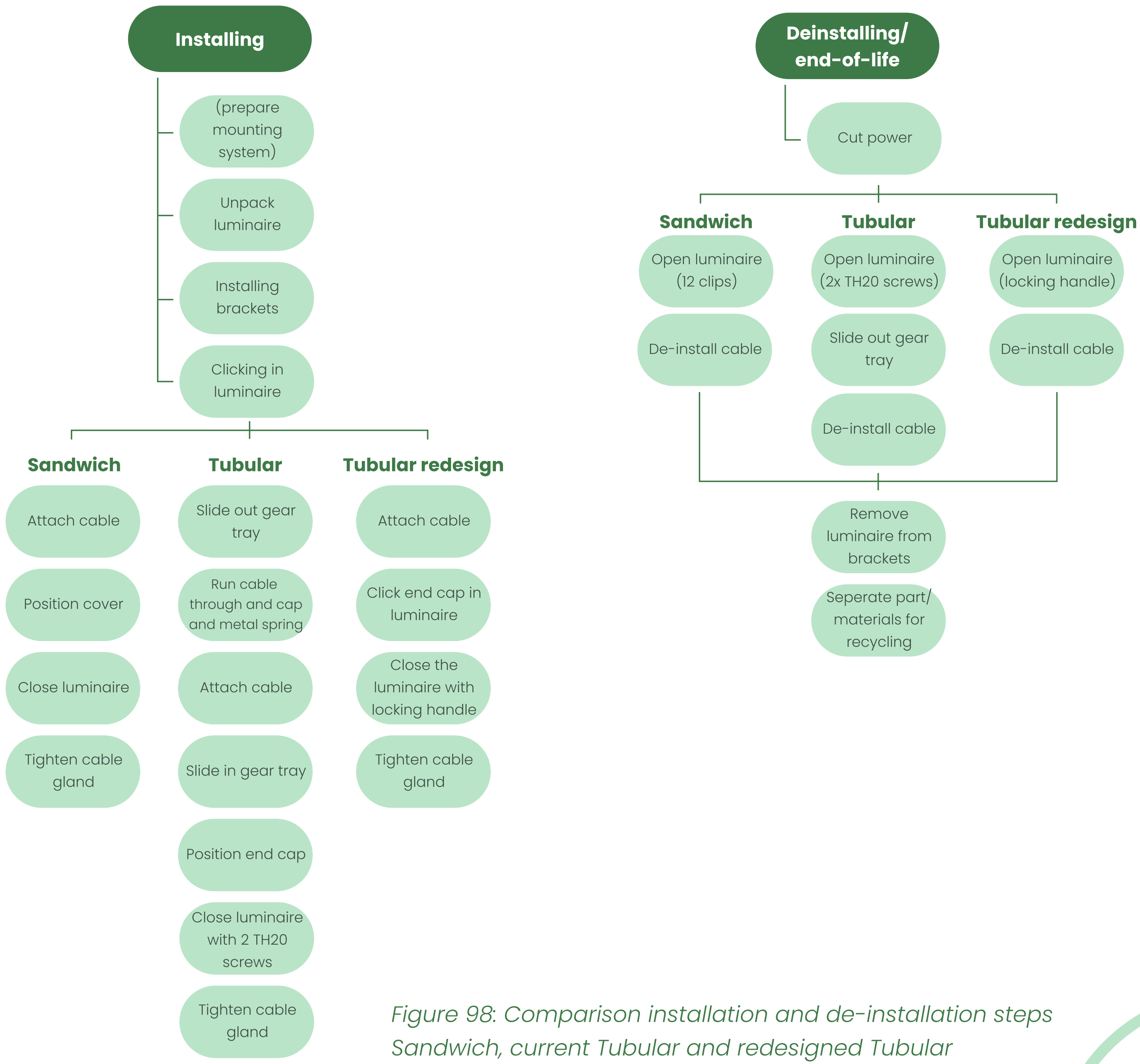
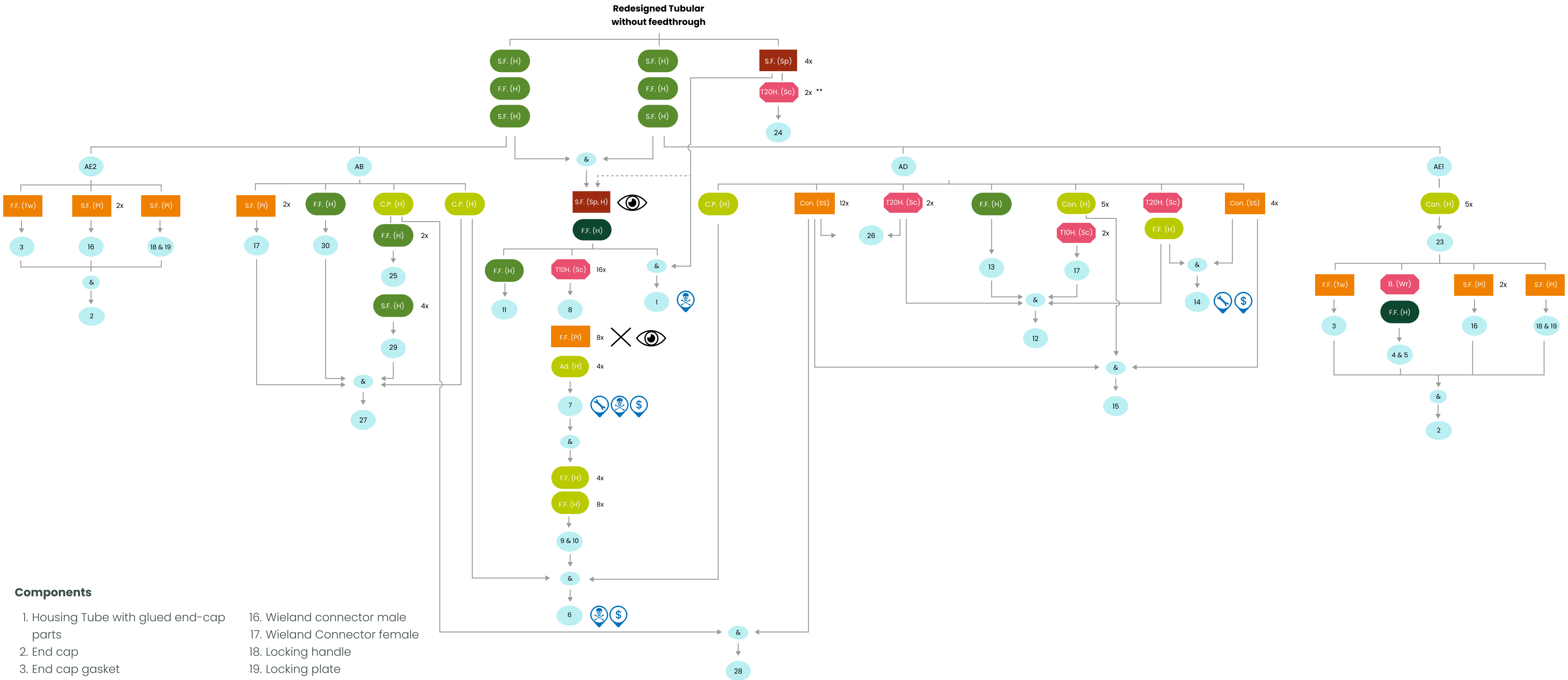



*Figure 98: Comparison installation and de-installation steps Sandwich, current Tubular and redesigned Tubular*




**Components**

1. Housing Tube with glued end-cap parts
2. End cap
3. End cap gasket
4. Cable gland
5. Cable gland gasket ring
6. Reflector + wire + ground cable
7. Ledboard
8. Lensplates/optics
9. PCB Grommets
10. Small ledboard cables
11. Driver bracket closing spring
12. Gear/Driver tray
13. Gear/Driver tray closing spring
14. Driver
15. Wires
16. Wieland connector male
17. Wieland Connector female
18. Locking handle
19. Locking plate
20. T10H screws D3 L10
21. T20H screws D4 L10
22. ~~T20H screws D4 L20~~
23. Cable plug
24. Brackets
25. Emergency batteries
26. Emergency batteries driver
27. Battery tray
28. Battery wire
29. Battery clips
30. Battery tray closing spring

**Type of tool**
(Sp) = Spudger
(Sc) = Screwdriver
(SS) = Small pushing screwdriver?
(H) = Hand
(Tw) = Tweezers
(Pl) = Pliers
(Cu) = Cutters

**Connectors**
F.F. = Friction Fit
S.F. = Snap Fit
Con. = Connector
B. = Bolt
T.W. = Tiewrap
T10H = Torx 10 screw
T20H = Torx 20 screw
Ad = Adhesive

**Hotspot indicators**
= Priority part
= Environmental indicator
= Economic indicator

**Penalties**
= Low visibility/ identifiability
= product manupulation
= non-reusable connector
= Hard to reassemble

**Force intensity**

| Motion type: | Low | Medium | High |
|---|---|---|---|
| Hand motion | | | |
| Single motion tool | | | |
| Multiple motion tool | | | |

**choice of screw is determined by installer

*Figure 99: Disassembly map redesigned Tubular*

To disassemble the batteries in the current design, seven steps, including 3 heavy intensity force ones, were required. This included taking down the complete luminaire to bring it to a workplace, requiring a lot of time and effort. Next to that, three different tools were needed to disassemble the batteries (a wrench, a screwdriver (TH20) and a flathead screwdriver). In the redesign only five moderate-intensity force steps must be conducted. They do not require any tools, and they can be disassembled on the spot. Therefore, replacement can be done quicker and on the spot. This comparison is visualised in Figure 100.

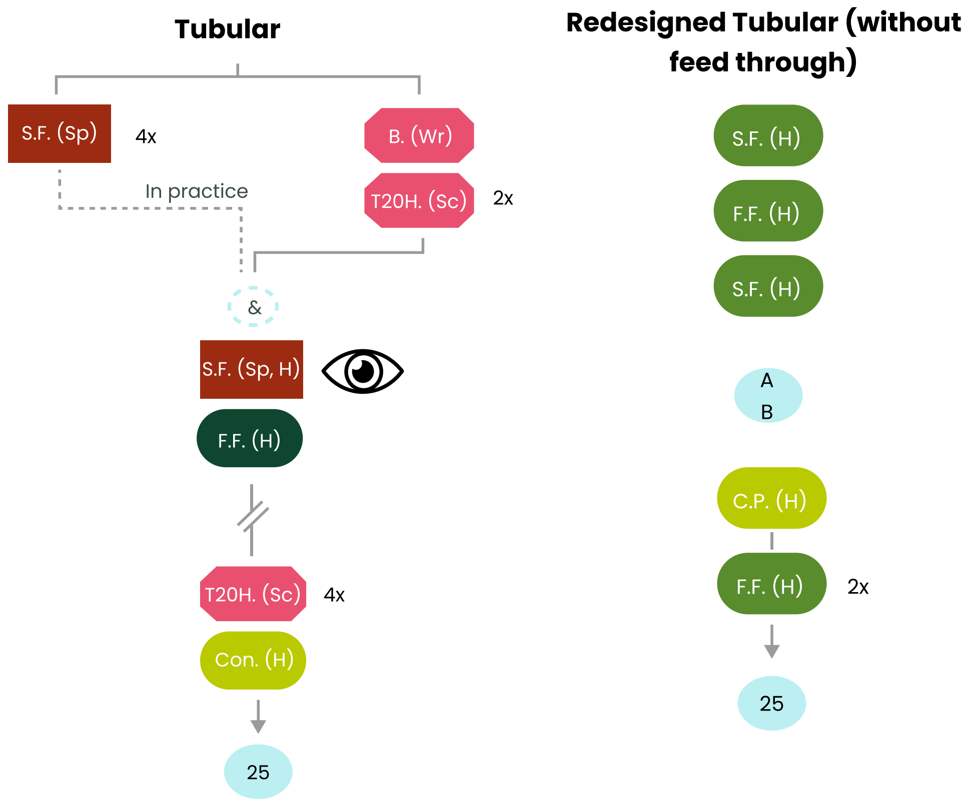



*Figure 100: Comparison disassembly steps removal battery*

To disassemble the other priority part, the driver, 10 steps needed to be conducted in the current design. This included four high-intensity force steps, three accessibility penalties and required four different tools to disassemble. To disassemble the driver, the luminaire should also be taken down to do the repair elsewhere. In the proposed redesign, six low to medium-force intensity steps are needed, requiring only two tools. Also here, the driver can be disassembled on the spot. This comparison is visualised in Figure 101.

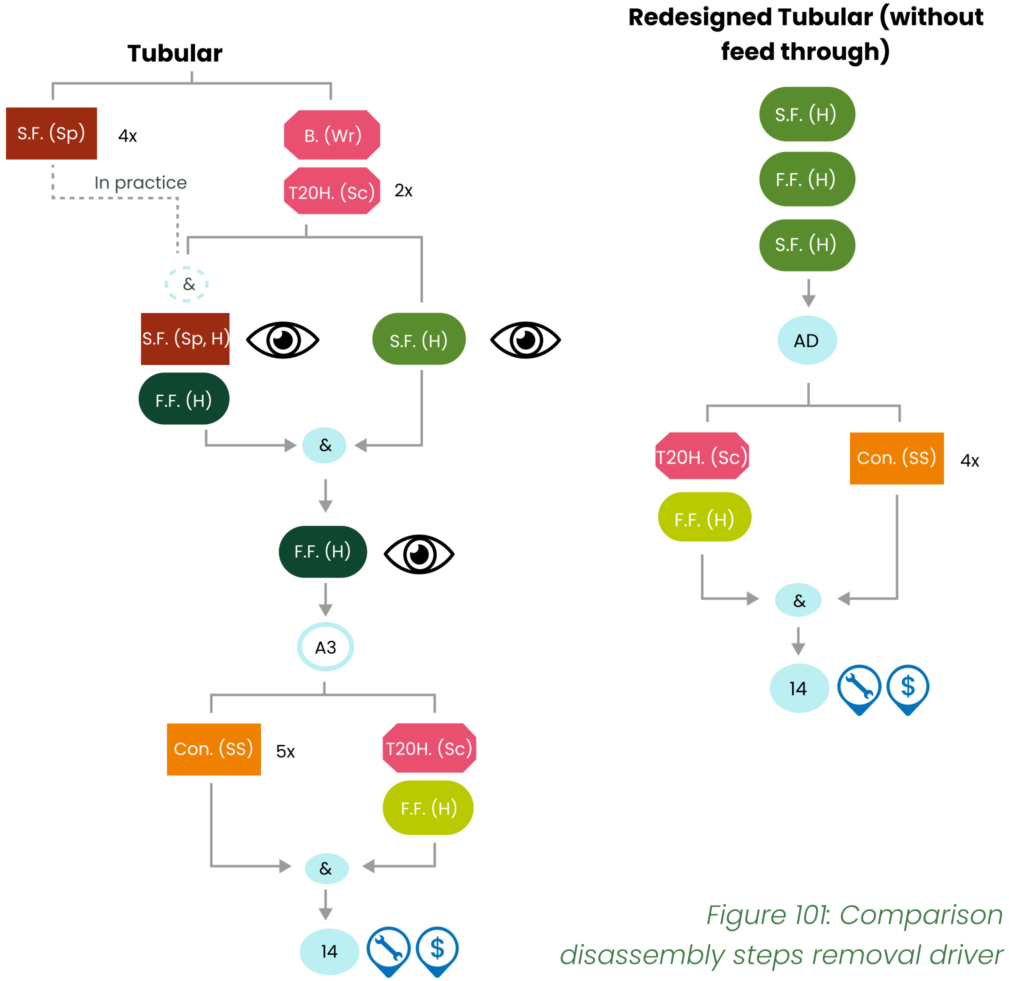



*Figure 101: Comparison disassembly steps removal driver*

In terms of replacement time, an improvement is visible (see Table 13). The replacement process of the battery is more than 4,5x quicker compared to the current design. The replacement of the driver will also be quicker, as the entry to the driver and the closing of the luminaire after driver repair is 3-4 times quicker compared to the current design.

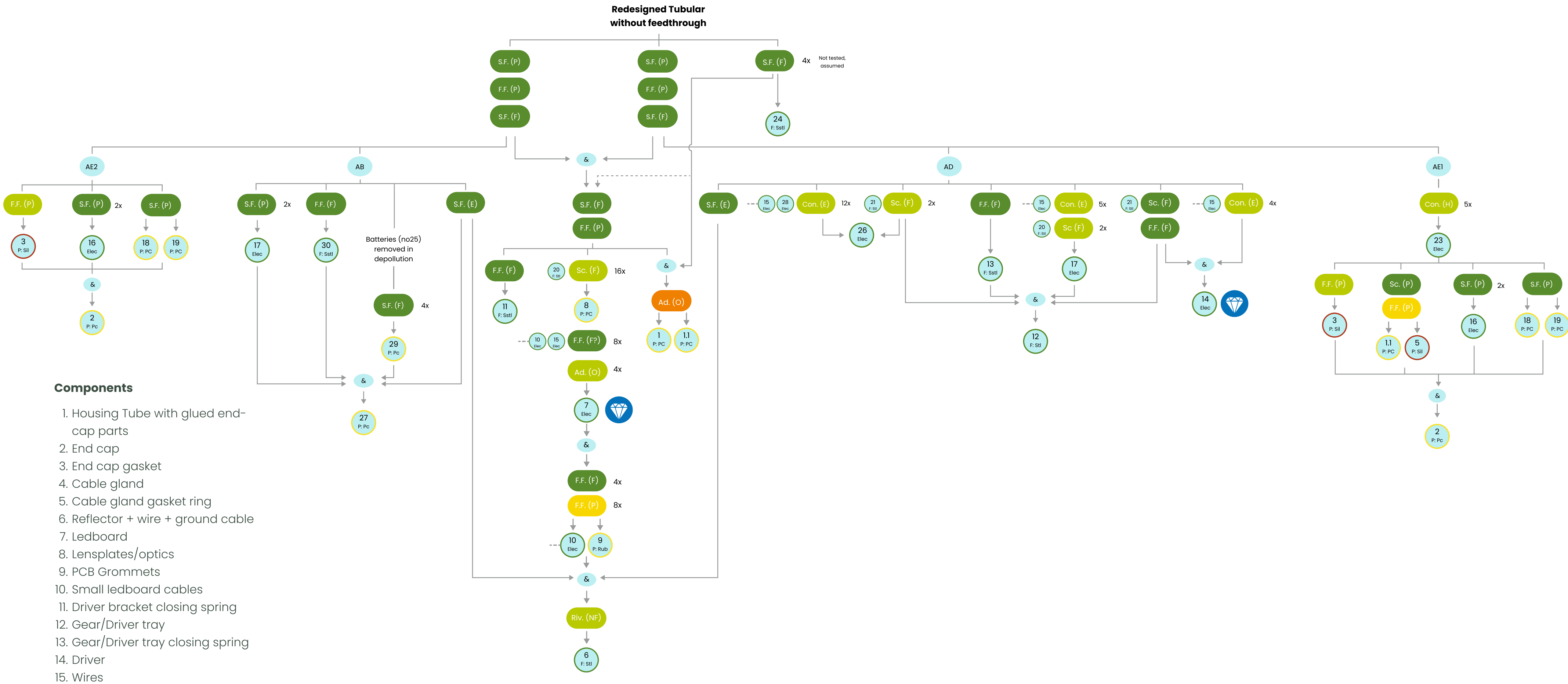
*Table 13: Time comparison current Tubular with redesigned Tubular*

| | Replacement batteries (sec) | Battery replacement on the spot? | Access to driver (sec) | Closing after driver replacement (sec) | Driver replacement on the spot? |
|---|---|---|---|---|---|
| Current design | 148* | No | 42* | 30* | No |
| Redesign | 31 | Yes | 10 | 9 | Yes |

** Note: time to remove luminaire from brackets and bringing it elsewhere, is not included in the time*

### 9.5.3 Recyclability map

When the recyclability maps of the Current design and redesign (Figure 102) are compared, now only three connections are sometimes or occasionally liberated (the glued end caps part, the cable gland sealing and the wire/rubber connection of the LED board assembly). Four connections which were never, occasionally, or sometimes liberated have been removed or improved. The metal inserts and metal screws for the end cap are removed and replaced by the PC turning mechanism. Therefore, all materials in the end cap are the same, improving the recyclability. The end cap sealing is a gasket instead of an injection moulded seal and will be made of a heavier silicone to prevent pollution of the floating plastics fraction (see Ch8). Finally, the wire enclosure rope has been removed, as this part was not recyclable. An alternative to protect the wires from heat on the reflector needs, however, be found. Next to that, a proposal has been made to remove the glass fibre in the PC end caps to improve the products' material recyclability. Finally, by making the battery better accessible at the end, the depollution phase has also been optimised, as entry into the luminaire and removal of the batteries is quicker and requires fewer steps.




**Components**

1. Housing Tube with glued end-cap parts
2. End cap
3. End cap gasket
4. Cable gland
5. Cable gland gasket ring
6. Reflector + wire + ground cable
7. Ledboard
8. Lensplates/optics
9. PCB Grommets
10. Small ledboard cables
11. Driver bracket closing spring
12. Gear/Driver tray
13. Gear/Driver tray closing spring
14. Driver
15. Wires
16. Wieland connector male
17. Wieland Connector female
18. Locking handle
19. Locking plate
20. T10H screws D3 L10
21. T20H screws D4 L10
22. ~~T20H screws D4 L20~~
23. Cable plug
24. Brackets
25. Emergency batteries
26. Emergency batteries driver
27. Battery tray
28. Battery wire
29. Battery clips
30. Battery tray closing spring

**Liberation scale**

- Good (>95%)
- Often (75-95%)
- Somtimes (40-75%)
- Occasionally (5-40%)
- Never (<5%)

**Connections on liberation scale**

- S.F. – Snap fit
- F.F. – Friction fit
- T.W. – Tie wrap
- Sc. – Screw
- Con. – Connector - wire
- Ad. – Adhesive
- Riv. – Rivet
- M.I.P. – Metal insert in plastic

**Material type group connector**

F - Ferrous
NF - Non-ferrous
P - Polymer
E - Electronics
O - Other

**Special material indication**

- Hazardous material
- Valuable material

**Material part**

- F: Stl = Ferrous Steel
- F: Sstl= Ferrous Stainless Steel
- NF: Sstl = Non-Ferrous Stainless steel
- P: PC = Polymer Polycarbonaat
- P: PA = Polymer Polyamide
- P: PES = Polymer Polyethersulfone
- P: Rub = Polymer rubber
- P: Sil = Polymer Silicone
- Elec. = Electronics
- O: SGF = Silicone-coated fiberglass fabric

**Recyclability part**

- X – Material of part is recyclabe in current e-waste process
- X – Material of part is recyclable, but is currently not recycled in the e-waste process
- X – Material of part is not recyclable in current e-waste process

*Figure 102: Recyclability map redesigned Tubular*

### 9.5.4 Assessment program of requirements and wishes

To see if the redesign complies with the criteria set in in chapter 7, it has been checked with the program of requirements and wishes in Table 14 and Table 15:

The tables show the redesign complies with most criteria set in the program of requirements and wishes. A couple of criteria are in theory improved, but should be tested to validate if that is indeed the case in practise, like the improved recyclability, the waterproofness and the costs vs product balance.

*Table 14: Assessment redesign on program of requirements*

| Requirement | Compliance | Explanation |
|---|---|---|
| The luminaire should comply with the IP66 and IK08 ratings | 🟡 | Should be tested, issues might be encountered with the turning mechanism only |
| The luminaire can be installed with existing cables on the spot | 🟢 | By placing the connector on the end cap, it can be facilitated |
| The luminaire can be pre-installed with a cable on a table before bringing it on site | 🟢 | The end cap will facilitate cable installation also off-site |
| The batteries are accessible and replaceable every four years on site, on the spot | 🟢 | By the implementation of the battery tray, the batteries are easier accessible and replaceable on the spot |
| Installation can be done by one person for luminaires smaller than 1.8m | 🟢 | Could be done with the current design and can still be done with the redesign |

*Table 15: Assessment redesign on program of wishes*

| Wishes | Compliance | Explanation |
|---|---|---|
| The installation time is as short as possible and requires only a few steps | | Should be tested, issues might be encountered with the turning mechanism only |
| The connector is easily accessible when working above your head | | By placing the connector on the end cap, it can be facilitated |
| The battery, driver and LED board should be quickly, easily and intuitively accessible and replaceable on the spot | | The end cap will facilitate cable installation also off-site |
| The opening and closing of the luminaire can be done quick and easy and requires little effort and tools | | By the implementation of the battery tray, the batteries are easier accessible and replaceable on the spot |
| Homogenous liberation of valuable, non-recyclable and incompatible materials should be higher than 80% | | Could be done with the current design and can still be done with the redesign |
| The redesign fits (with only small changes) within the current luminaire dimensions and shapes | | The demonstrator showcases that this is possible, no changes have been made in the tube dimensions |
| The costs should be as low as possible. If extra costs are needed, they should weigh up against the advantages for the clients | | There are extra costs due to the added components, but the entry into the product and the accessibility of the battery and driver have been improved. Therefore, it can weigh up against the costs. It should validated with product management |
| The design language of the tube stays as intact as possible | | By the implementation of the battery tray, the batteries are easier accessible and replaceable on the spot |

## 9.6 Design limitations and recommended iterations

This redesign also comes with a few drawbacks. They will be mentioned and explained in this chapter.

### 9.6.1 Cable management

The long wires in a through-wiring configuration are limiting the slide in of both trays. As the trays are extended by a great amount, the wires for feed-trough should facilitate that. But when sliding in, these wires are then too long and buckle and turn inside of the luminaire, therefore getting in the way of the sliding motion of the trays (see Figure 103). It is recommended to solve this problem, as a feed-trough is often sold, certainly in parking garages (Account manager company, personal communication, 18 February 2025). A solution can be to place two terminal blocks at the ends of the tray and two in the luminaire. When the trays are slid back in, a connection is made between the trays and the luminaire. Between the two placed in the luminaire, a wire can run for the feedthrough. This requires more connectors, but less wiring. Another option is to avoid using internal feed-through but run it outside the luminaire only. All in all, it is recommended to look further into this cable management issue.

### 9.6.2 BOM and manufacturability

More components are used compared to the current design, making the manufacturing a bit more complex, which probably results in increased manufacturing costs. However, it can weigh up against the advantages of easier installation and disassembly and improved recyclability, making the proposed features worth implementing.

Next to that, the manufacturability of the parts should be further investigated. The metal driver tray is, for example, manufacturable, as the design was quite similar to the gear tray of the current design. Next

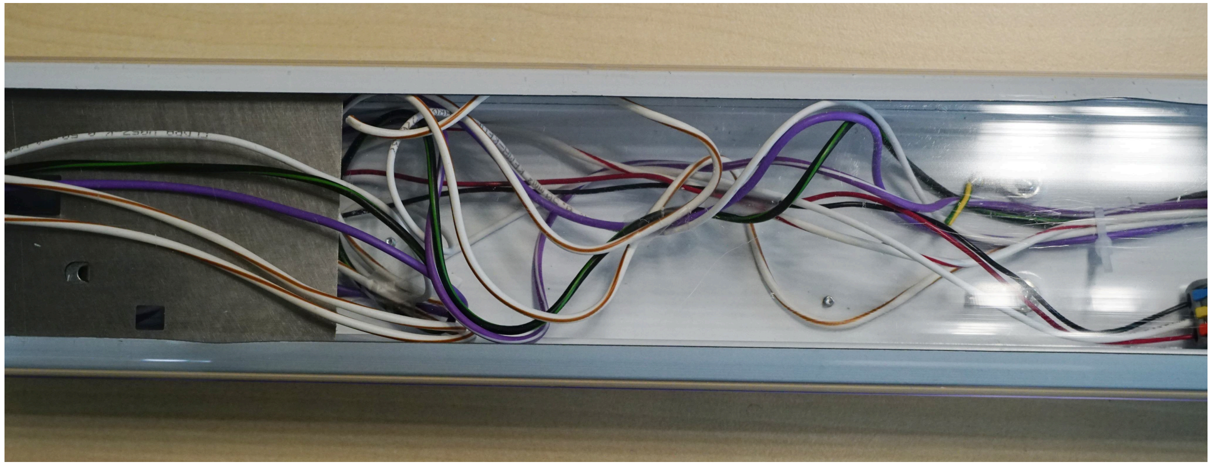


*Figure 103: Cluttered wires in the redesigned Tubular*

to that, it was validated and made by the employees of the workshop at the company. The battery tray is with some small changes also manufacturable. Here it is recommended to look at the drafting angles of the sides and at the guiding clips at the top of the battery tray, as these give negative drafting angles. For the end cap, most features can be injection moulded, but the gap in the connector sheet raises difficulties. A more complex mould needs to be used to make this part. Another option is to make a separate part from this connector sheet and click it with the snap fit from the turning mechanism to the end cap.

### 9.6.3 End cap design

There are a few aspects of the end cap design that should be tested or improved. The first and most important point is to test the end cap and the turning mechanism on waterproofness, and mechanical forces for the IP and IK ratings. As this luminaire is quite easy to open, it might be less hufterproof. For this project, this has not been considered and it should be further investigated if needed. Also, further investigation is needed for the fit of a single 7-pole cable (with cable gland) in combination with the turning mechanism. This option is less sold than the 5-pole cable, so was therefore not considered in this project to narrow down the scope.

To further improve the end cap design, it is recommended to look further into the user-friendliness and installers' desirability of the turning mechanism by testing the mechanism with installers. Use cues should be added as well for opening and closing of the luminaire. As said in the previous section, it is important to investigate the manufacturability of this end cap. This also includes making proper snap fits to fasten the connector to the end cap.

### 9.6.4. Testing

It is very important to test the redesign further with the installers, certainly on its ease of installation in a retrofit situation and pre-installation and on maintenance and replacement of the batteries and drivers on site. Next to that, the improved recyclability of the redesign should be confirmed by talking to the recycler as well as shredding the luminaire and analyse these fragments. In this report, assumptions based on previous results have been used to assess the recyclability of the redesign. Therefore, it is important to gain insights into the recyclability of the redesign in practice as well.

### 9.6.5 Driver connections

A final redesign recommendation is to investigate the connection between the wires and the driver. Now all wires need to be loosened individually, and the installer needs to remember or figure out how to how to reassemble them. A simple plug system or using pins might be an option to optimize the disassembly even further and decrease replacement time.

## 9.7 Conclusion

In this chapter, a redesign has been proposed for the Tubular. This has been done by:

1. Improve the accessibility to the internal components, through an easy and quick to open end cap due to the turning mechanism. Whether installation, maintenance or de-installation is done, little time is needed to enter the product decreasing time on site.
2. Improve the accessibility of the connector for retrofit situations by placing the connector on the end cap.
3. Improve the accessibility to the battery and drivers on site by placing them on separate and fully slidable gear trays at the start and end of the luminaire, thus improving the replacement time and effort of these batteries and drivers on site.
4. Improve the recyclability by striving for as few different materials as possible per subassembly, removing metal inserts and screws in the end cap and making the batteries easier to access in the depollution phase.

This chapter also mentioned multiple limitations and recommendations to look out for when implementing this redesign, the important ones including cable management, testing with installers, the waterproofness and mechanical resistance.

This proposed redesign increases the ease of handling and efficiency in terms of installation and maintenance for the installer, which is something they desired. By keeping the design solutions close to the original design, they are relatively easy to implement, and the design language stays similar. By allowing easier and quicker access to the driver and the batteries, the Tubular will also be a step closer in complying with the Right to Repair directive. Next to that, disassembly for recycling will be allowed. These aspects will allow the Tubular to be ready for future developments while still being desirable by installers.

# 10. Discussion

In this chapter, the project and its outcomes will be discussed, its limitations will be explained and recommendations for further implementation and further research will be given.

## 10.1 Designing for installation, repair, recycling and application

This report aimed to redesign a luminaire on the ease of installation, recyclability, and repairability while maintaining the application requirements (see Ch1). Designing for multiple domains simultaneously is not easy as many contradictions between them can be encountered. As a designer, it is therefore important to ask what should be prioritised for each specific part or subassembly.

Looking at the Tubular, the biggest priority for e.g. the end cap was the waterproofness, followed by the ease of handling and then the recyclability. For the battery tray, the ease of handling was prioritised but for fastening the connector, priority was laid on the quality and the recyclability. Asking these questions on what to prioritise, is important to optimise as many domains as possible, where possible.

This report highlighted that even though repair and recycling are promoted through different directives, for these luminaires, the focus lies more on the quality and ease of installation. A product cannot be viable, if its price-quality ratio is bad and if it is difficult to work with for the users (here installers). Therefore, it was very valuable during this project to talk to the users: the installers. Not only for the selection of the redesign direction and redesigning itself but also to learn how things are done in practice and what to prioritise in a product. For these luminaires, it became clear that hardly any repairs were done due to high labour costs and low failure rates, and that installers would not mind disassembling the luminaire for recycling. They prioritised the ease of installation and quality above, for example, repair of the complete luminaire. Only the batteries and sometimes the driver needed to be replaced. For those it was important to improve the ease of disassembly for repair.

For the other parts, it is interesting to question, whether it is even necessary to focus on repairability when the product or part lasts for more than 10 years due to its quality. It might then be more valuable to extend the product lifetime and focus on better quality than to facilitate repairability. A relevant question to ask here is:

What is more sustainable, keeping (for example) thousands of LED boards in stock, made from valuable materials but rarely used, to allow for potential repairs? Or extending the lifetime of the LED boards but without the option for replacement or repair, meaning the entire luminaire needs to be replaced in the rare occasion a LED board fails? It seems more valuable to strive for ease of disassembly for repair for the parts in actual need of replacement and to focus more on the ease of disassembly for recycling for the other parts. Certainly, in this application and when part disassembly should be done quickly, the liberation rate can be improved by pre-disassembly for recycling. This way of disassembling is, however, different than for repair, as connections do not have to be reused anymore but should liberate very quickly and easily. A recommendation on how to focus on repair and recycling to designers would be to:

*"Strive for optimal quality of the product and user experience first. If after that, parts are in need of replacement during its product lifetime, allow for this by easing the disassembly for repair. For other parts, allow for proper liberation, by striving for the uniform use of materials, proper part liberation and facilitate the ease of disassembly for valuable, hazardous and non-recyclable materials."*

Besides that, a recommendation while designing for multiple domains simultaneously is to keep talking to the intended users, to create a desirable product and keep questioning yourself "What to prioritise and what to optimise?" in every decision there is to make, as sometimes one aspect needs to be prioritised in part A and another aspect in part B.

## 10.2 Disassembly map

For the repairability, the hotspot map and disassembly map were used. These methods are extensive and quite time-consuming but they give a well-argumented overview on where problems arise. However, as said before in chapter 4, it tells little on the reassembly of the parts and connectors, which is another aspect of repair. This report introduced a new penalty: the "hard-to-reassemble" penalty. It is valuable to see if actions leading to, for example, a priority part are hard to reassemble, as this should also be as quick as possible as well in repair. Sometimes reassembling can be harder than disassembly, hindering the repairability of the product, also mentioned by Dangal et. al. (2022). Unfortunately, in this project, the focus lay (within the repairability context) on the repair of the batteries and driver for the Tubular only. Here no "hard to reassemble penalties" were given to these actions to get to the battery and driver. Therefore, the use of the penalty has not been tested properly in this report. Further use of the penalty should be conducted to see if it is a beneficial addition to the disassembly map.

In conversations with different employees from the company, it became clear that it was difficult to communicate where exactly problems arise using the disassembly map. If you are not familiar with this method, it is hard to understand what is happening and which connection is which. As the disassembly map is valuable for insight generation, finding a way to make it more accessible for others who are not experienced with this map would be a benefit. This way more fresh insights from different points of view can be gathered during discussion meetings and brainstorm sessions. This also counts for the recyclability map.

## 10.3 Design for recycling

To assess the recyclability, a few luminaires have been shredded, recyclers have been consulted, and some design guidelines have been used. During the interviews with recyclers, it became clear that recycling is a moving process. Every recycler uses a slightly different process and recycles different materials. This makes it difficult to design for recycling.

It is also difficult to predict how a product behaves during shredding. An example is the use of screws or connector and wire connections, as some come loose while others do not. Or when and why steel will fold around other components and which type of glues will dissolve in the recycling process? Guidelines currently existing in literature are quite general, as it, for example, tells to not use screws. However, the shredding test conducted in this report mentioned 80% of the screws of the Tubular liberated. Therefore, not all screws should be avoided, but a product should be designed in such a way that liberation of screws through shredding can be facilitated. More research should be conducted on these specific topics to allow designers to better design for recycling.

Another implication which can be encountered during design for recycling is the fact that there are many materials which can be recycled in theory but are not in practice. This can have to do with too complex separation processes or too little material collection, making it not viable for recyclers to recycle these materials. Both luminaires analysed in the project, contained PC, which is necessary for the locations where the luminaires are used. PC is recyclable in theory but not (yet) in practice. It is not yet clear how to manage this; do you use another material to facilitate recycling on the WEEE-line or do you keep using it, but recycle it as a company yourself? More research on how to design for, manage this and how to facilitate recycling for these materials would be relevant.

## 10.4 Analysis and redesigning

This project placed considerable focus on the analysis. From the analyses, different design criteria were derived, from which the important ones were selected. Those were used to select the concept and test the redesign. This way of working gave a clear window to operate in to redesign a desirable and more sustainable luminaire and was a pleasant method to use. It did however limit the scope, leaving little room for out-of-the-box ideas, as those would not fit in the picture.

## 10.5 Limitations

In the project, there were certain limitations encountered. They will be described below:

- During the interviews, there was, unfortunately, no opportunity to see the installers work in the field on the luminaires. This would have brought some more valuable insights for both the installation and repair analysis, as aspects not mentioned in interviews can be observed.
- Both the Sandwich and the Tubular are sold in many countries, where all installers have different ways of working and have other preferences. In this project, insights were gathered from only two regions, the Benelux and Scandinavia. In the Benelux, the Sandwich is installed most often, therefore most insights had been gained on this luminaire, and less for the Tubular. During the project it became clear that it is hard to design for all these countries at once. Therefore, this redesign should be tested and validated with more regions to see whether the redesign works in those contexts as well, or not.
- Next to that, recycling processes might differ in all these different countries. In this project, the recycling process of the Benelux was considered and used. To optimise the recyclability of this luminaire, it is valuable to take recycling processes from other countries the luminaire is sold to into account as well.
- In the shredding process, the luminaires were shredded into smaller fragments (35 mm) than would be in the usual WEEE recycling process (70 mm). Therefore, some problems might not have come to light in this project, which would happen when shredded on the WEEE line. Shredding the luminaires on the WEEE line and analysing these results can provide additional insights.

- For repair and recycling, the basic luminaires have been analysed. The luminaires might consist of more parts, e.g. motion sensors, feed-through and emergency batteries. As these were not available and to keep the project manageable, these were left out in the initial analysis of the project
- Due to time constraints, not all issues were considered in the redesign. To finalise the iteration on the Tubular, more aspects need to be investigated. They will be explained in the next section, recommendations.
- In the demonstrator, 3D printing has been used to create most of the parts. Limitations here are the strength and changes in geometry of these 3D printed parts compared to an injection moulded part (for example the battery tray needed to be cut in half, which decreased the strength of the part but would not have fit on the build plate otherwise). Therefore, not all tests could be conducted in the timeframe of this project (waterproofness, closing forces etc) and some parts are only manufacturable after another iteration on these parts has been conducted (as the focus for the redesign lay a bit more on demo making and testing the principle, than direct manufacturability).
- Finally, due to time and confidentiality constraints, the redesign could not be tested with installers and recyclers to assess it further. This is recommended to do as soon as possible when continuing with this product further.

## 10.6 Recommendations

This chapter can be finalised with several recommendations for further development of the redesign and further research. In Chapter 9, several recommendations have been given on the redesign level already. The most important ones are summarised here:

- Strive for better cable management in the luminaire to improve the slide-in and slide-out functions of the trays
- Test the desirability of the redesign, the ease of installation, and the ease of maintenance/disassembly with the installers through user tests
- Test the waterproofness and mechanical resistance of the redesign to see whether it complies with the IP and IK rating. This should mainly be tested on the turning mechanism.
- Confirm whether the recyclability has indeed been improved by talking to recyclers or through shredding and analysing.
- Improve the manufacturability of the end cap and the battery tray, certainly when injection moulding these, as negative draft angles are present.

If the company wants to further improve the Tubular in terms of ease of installation, recyclability and repairability it would be valuable to solve some of the problems mentioned in Appendix O. The advice would be to:

- Look into opportunities to allow disassembly for recyclability. This redesign already aided into the right direction, as the batteries, and driver are easier to disassemble on the spot than before. This should also be done for the other parts. This way part liberation can be increased and also the metal folding problem can be tackled (which was the biggest recyclability issue).
- Look into the disassembly of the LED boards. In the disassembly map of the redesigned Tubular, this priority part is quite low in the disassembly tree and non-reusable connectors need to be undone to remove the LED boards. Improving the disassembly would allow the company to comply with the Right to Repair directive.
- Investigate on how PC can be practically recycled. This could be done by finding a recycler who recycles PC or even recycle it in-house. A more radical solution would be to use another material, which is recyclable in practice.
- Look into how spare parts can be standardised. Installers mentioned this as an issue in replacement, as they would first need to check at the ceiling which part to order, before ordering and replacing can be done. This requires a lot of time and effort and can thus be streamlined.
- In terms of recyclability, it is valuable to solve the metal folding problem. In this report two ideas have been given to solve this issue; disassembly for recycling and the use of fracture lines. Both should be explored further, combined with other ideas to solve this problem.
- Next to the previous point, the recyclability of the seal can be improved. No material was found in this project which would match with the properties of silicone and be practically recyclable. Therefore, further research is needed.

Further research in general is needed in terms of recyclability, to allow designers to use guidelines which work in most cases (e.g. which type of screws liberate better than others and what to do with materials which are theoretically recyclable, but not in practice?). Also, it is interesting to look further at disassembly for recycling. If a consumer, installer or company can already liberate valuable or non-recyclable materials quickly before the product gets thrown away, the retrieval of materials from the recycling process would be more efficient.

# 11. Conclusion

In this project a redesign for a linear luminaire, the Tubular, was proposed to showcase how the ease of installation, repairability and recyclability can be improved, while the application requirements were kept the same. This has been done by analysing the Tubular and the Sandwich on those three domains. From there, the most impactful redesign directions have been selected to create a redesign from. Also, a list of criteria has been established which showcases what to look out for in designing for the different domains simultaneously, while - in this case - designing linear-shaped luminaire products for parking garages and industries (see chapter 7 and Appendix N).

The redesign showcased an improved accessibility of the electrical connector. This has been achieved by placing the connector on the end cap and making use of the turning mechanism as a closing system. Currently, installation on site with cables present on-site is a challenge. With this redesign, the installation time and steps are similar to the easy to install Sandwich, requiring only four steps (which were seven in the original Tubular design) and can be installed on- and off-site.

Next to that, an improvement in accessibility for the battery has been proposed. These batteries should be replaced every four years in emergency luminaires. In the current design, the batteries were difficult to access on the spot due to their placement in the middle of the luminaire. Therefore, complete luminaire replacement needed to be done. The proposed redesign places them at the end of the luminaire, which has been made easy to access on the spot by opening the end cap with the turning mechanism and pulling the battery tray out. After that, the batteries can easily be replaced by clicking them out. The total replacement time is decreased by 79%, as it now takes 31 seconds to replace the battery. The battery and drivers can also be easily dismantled in the depollution phase of the recycling process.

Finally, this report investigated other materials for the silicone sealing, as silicone is not recyclable. However, this turned out to be unsuccessful, as there was no recyclable material with similar thermal and chemical properties found. Therefore, a recommendation for the sealing is to use a gasket with a higher density silicone over an injection moulded seal with a low-density silicone. This way the material recovery can be improved, and the material pollution of the floating plastics can be minimised.

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# Confidential references (c.ref.)

Due to confidentiality, this part of the reference list is not available in this publication

# Appendices

# Appendix A: Project brief

**Personal Project Brief – IDE Master Graduation Project**

**Name student** Jasmijn Mortier **Student number** 5,062,055

## PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

**Project title** Redesign for improving the on-site repairability, maintenance and recyclability of an industrial luminaire and develop design guidelines

*Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.*

### Introduction

*Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)*

Every year, a lot of E-waste is generated in the world. It is therefore important to move towards a circular economy, so the products' lifetime can be extended and waste will be reduced. Repair and recycling are then two important strategies to look into. Companies are also obliged to do that, according to the right-to-repair directive and the ESPR directive. For the first, the company is a.o. obliged to repair goods and supply spare parts for a few years. (1) When redesigning the product to be more repairable by, for example, using screws, you limit the possibility to recycle the product through shredding. A product should be high-quality recyclable according to the ESPR directive (2). So design complications arise to comply with both directives. Unfortunately, little knowledge is present yet on these tensions between repairability and recyclability and how to design for those.

The main stakeholder in this project is , the market leader in lighting solutions for professionals and consumers. They want to improve their linear luminaire portfolio, e.g. the (see Figure 1). This lamp is widely used in industrial settings, like warehouses, food production, heavy and chemical industries, parking garages etc. Therefore, it is robust and needs to withstand a.o. water, dust and chemicals. They want to improve this luminaire on its repairability so it takes less time to repair and install while taking the application requirements into account. As lamps do not have an infinite lifespan and these lamps are exposed to chemicals, it is also useful to look at its recyclability and what this process would look like. Other stakeholders are the installer and the user, who - respectively - want to be able to repair the lamp easily and effectively and work under proper lighting conditions. Looking at recyclability, the recycling company also comes into play. They want to be able to recycle the luminaires as properly and efficiently as possible.

(1)
https://www.europarl.europa.eu/news/en/press-room/20240419IPR20590/right-to-repair-making-repair-easier-and-more-appealing-to-consumers

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*introduction (continued): space for images*

image / figure 1

image / figure 2

DESIGN FOR our future

TU Delft

# Personal Project Brief – IDE Master Graduation Project

## Problem Definition

*What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.*
*(max 200 words)*

Materials and parts can be retrieved through repair or recycling. However, the current design architecture of products does not always enable products to be easily repaired. The ease of repair and ease of maintenance are extremely important for luminaire due to the high-risk areas where the luminaire needs to be installed (e.g. high temperatures, corrosive atmospheres). has little knowledge of the viewpoints of installers and maintenance staff on the repairability of their luminaire and how to reduce the repair and installation time on site while still keeping the product properties the same. Next to that, when designing a luminaire for repairability, it often limits the recyclability. There is little knowledge of these bottlenecks in product architecture, which prevents designers from properly designing products for repair, maintenance, and recycling. In addition, since these luminaires are exposed to chemicals the question arises in which waste stream they will end up (e.g. e-waste, chemical waste,…).

## Assignment

*This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)*
*As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:*

Redesign a linear luminaire, e.g. the luminaire - used in industrial conditions - to improve its on-site repairability and ease of installation, while considering the effects on recyclability. Based on the results, the design for repair guidelines will be expanded.

*Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)*

- First, research will be done on repair, installation, luminaire architectures, recyclability and useful methods
- After that, we analyse the luminaire's current repairability and ease of installation by disassembling it. To evaluate the repairability of the luminaire, the PROMPT method (which includes a.o. the disassembly map) and the FRI (French repairability score) will be used. Next to that, we ask different installers in the field of this lamp, for feedback on the product's repairability, maintenance and ease of installation to get user insights through an observation study and interview. For this, an interview guide will be made before these sessions.
- To evaluate the recyclability, we will conduct a shredding test at a recycling centre, analyse these fragments and connections and make a recyclability map. This will allow us to see which product features work well.
- With all these insights, we select the areas to focus on with the biggest focus on repair and ease of installation.
- Through iterative design using a.o. a list of requirements, guidelines from existing literature, prototyping, concept sketching, possibly the morphological chart and a Harris profile, and CAD design, solutions for these problems can be found.
- The final deliverable will be a redesigned embodied product demonstrator, with improvements in its repairability, ease of installation and recyclability and a final set of design guidelines for the designers to use in future luminaires

## Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

*Make sure to attach the full plan to this project brief.*
*The four key moment dates must be filled in below*

| | |
|---|---|
| **Kick off meeting** | 27 September 2024 |
| **Mid-term evaluation** | 28 Nov 2024 |
| **Green light meeting** | 13 Feb 2025 |
| **Graduation ceremony** | 12 Mar 2025 |

*In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project*

| | |
|---|---|
| Part of project scheduled part-time | |
| For how many project weeks | |
| Number of project days per week | |

Comments:

## Motivation and personal ambitions

*Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).*

*Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.*
*(200 words max)*

This project has quite some sustainability aspects in it and includes lighting design. Both are fields I am interested in and followed courses in. That was the reason I wanted to do this project. Next to that, I have the following learning goals:
(1) I would like to get a deeper and more real-world understanding of recycling and repair. I have little knowledge of recycling specifically, and I aim to create and redesign sustainable circular products later on. Gaining knowledge on this topic seems therefore crucial to me.
(2) I would like to learn more about the product's architecture and connections through prototyping and cad-modelling. To design functional products it is important to gain this knowledge, and I felt throughout my university years I gained too little knowledge about it to say I can design a product completely on my own.
(3) I would like to be better at planning and managing a project. I tend to be perfectionistic and therefore limits me to stick to a schedule properly. I hope this project is helping me to learn to manage a project well and be satisfied with the result.
(4) Hand in hand with ambition (2) I would like to learn more about prototyping techniques. I love a hands-on approach and I feel prototyping is a great way to communicate an idea to your clients.
(5) Lastly, I would like to be able to communicate better with companies and clients. I want to get better at it as it is important for information, personal connections and client satisfaction.

# Appendix B: Questions and answers installer workshop

**What makes a luminaire nice to install?** *(open question)*

- Wieland connector (7 times)
- No or little packaging (5 times)
- Quick/speed (5 times)
- Properly, easy and clear to mount with good mounting material (5 times)
- Easy(/clear) to install (3 times)
- Fits in old/previous dimensions (2)
- Sturdy parts (2 times)
- Easy material (2 times)
- Lightweight (1 time)
- Wire through (1 time)

During discussion: how is it easy to install????

**What problems do you encounter during installment?** *(open question)*

- Lot of packaging waste (8 times)
- Product damage (due to transport) (5 times)
- Loose parts (5 times)
- No or unclear installation manual (2 times)
- Delivery time (2 times)
- No QR code but installation manual (1 time)
- Bad packaging material (1 time)
- Unboxing (1 time)
- Planning (1 time)
- Small connection part (1 time)
- Different montage techniques and other look product (1 time)
- Retaining clips come loose (1 time)
- None (2 times)

During discussion: They prefer a QR code on the luminiare over a paper manual, or QR code on the packaging.
Some luminaires look different if they re-order.

**Which design is easier to install?**

- Sandwich (13 times)
- Tubular (9 times)

People preffering the Tubulay, is because they do not have to open the metal enclosure clips

**Do you repair broken luminaires?**

- Yes, they are repaired and immediately placed back (6 times)
- Yes they are replaced with a new one and the old one is saved as a back-up (5 times)
- No, repair is done by another party (0 times)
- No it is replaced and thrown away (10 times)

The labor costs of letting an installer find the problem and repair the product are more than just replacing the luminaire completely. Therefore, that is done more often.
Also, the luminaires kept as a reserve, might be used to retrieve not broken parts from to repair other lumianires with.

**What do you need to repair most often on a broken waterproof luminaire** *(open question)*

- Cover (14 times)
- Driver (8 times)
- We do not repair (3 times)
- Clips (1 time)
- Cable gland (1 time)

Clips are the enclosure clips of the Sandwich and the Brackets

For the cover, it is often broken due to damages (bumping against it etc)

**Which waterproof is easier to repair?**

- Tubular (5 times)
- Sandwich (6 times)
- Other brand (8 times)

Some choose other brand, as they haven't done repairs on the Sandwich and Tubular. So this question is a bit misjudged.

**What happens with the luminaires beyond repair?** *(open question)*

- Collect and bring to recycler (12 times)
- Disposed (3 times)
- Waste container (2 times)
- Waste bin (2 times)
- No clue (1 time)

Overall we confirmed most of the luminaires are recycled.

**When replacing a broken luminaire, what is being replaced?**

- Luminaire (11 times)
- Kables (0 times)
- Hanging brackets (0 times)
- Electronics (10 times)
- Everything (4 times)

This question was a bit confusing for the installers.

**What problems do you encounter during the repair of the Sandwich waterproof?**

- No experience/no repair done (4 times)
- Nothing (5 times)
- Clips opening (2 times)
- Parts availability (2 times)
- No problem but challenge (1 time)
- Clips are lost (1 time)

**What problems do you encounter during the repair of the Sandwich?**

- No experience/no repair done (4 times)
- Nothing (7 times)
- ....

**What do you want to improve on a waterproof luminaire** *(open question)*

- More colours (4 times)
- Nothing (2 times)
- QR code on luminaire (1 time)
- Same bottom part (1 times)
- Standard repair kit (1 time)
- Suitable for outdoor use (1 time)
- Waterproof (1 time)
- Easy internal connection (1 time)
- Changable driver (1 time)
- Good gable gland (1 time)
- Clips (1 time)

Retrofit kit: leave the bottom plate and insert a new internal framework with components. Might make it easier to install.

# Appendix C: Interview guide questions

## Introductie (10 min)

### Introductie onderzoek:

- Kort voorstellen
- Dit is een afstudeer onderzoek voor de TU Delft en een verlichtingsbedrijf dat kijkt naar de reparatie, het gemak van installatie, onderhoud en de recyclebaarheid van de linear luminaires Sandwich en Tubular. Met dit interview hopen we inzicht te krijgen in hoe reparatie en installatie werkt vanuit uw oogpunt als installateur en willen we achterhalen waar de problemen in deze gebieden zitten en hoe we deze kunnen oplossen.
- Vragen of ze de consent form willen ondertekenen

### Vragen voor participant:

- Welke luminaires installeert u het vaakst/meest en waarom?
- Waar installeert u deze luminaires vooral?
- Zijn er voorzorgsmaatregelen die u moet nemen voordat u aan de luminaires werkt?
- Doet u installatie, repair en onderhoud?
- Welke luminaires vind u prettiger dan andere? En waarom?
- Welke gereedschappen heeft u vaak bij u?

## Vragen over het werk en ervaringen (met luminaire) (30 min)

### Installeren:

- Wat maakt de installatie voor u prettig?
- Met hoeveel mensen wordt de installatie gedaan?
- Hoe lang duurt het om een luminaire te installeren, en hoelang is gewenst?
- Hoe komt u bij de luminaires?
- Ervaart u problemen met de verpakking van de luminaires?
- Gebruikt u de installatie manual?
- Welke voorbereiding vind plaats voordat de installatie kan beginnen? Ophangsysteem? Etc?
- Welke connector wordt het meest gebruikt en welke vindt u het prettigste?
- Vind u een sandwich design of slide out system prettiger voor de installatie?
- Voor een retrofit design, waar zouden we op moeten letten?
- Welk luminaire vind u fijner om te installeren: de Sandwich of deTubular, en waarom?
- Welke problemen komt u tegen bij het installeren van een luminair?

- Ervaart u problemen met de clipjes van de Sandwich?
- Hoe vaak komt feed-through/doorvoer voor? Heeft u feedback daarop?
- Hoe vaak komt noodverlichting voor? Heeft u feedback daarop?
- Wat vindt u van het schuifsysteem van de Tubular, past het overal?
- Wat zou u graag veranderd zien mbt de installatie van de Sandwich/Tubular?

## Onderhoud:

- Doet u ook onderhoud?
  - Ja
    - Hoe vaak wordt onderhoud gepleegd? Hoe vaak worden de luminaires schoongemaakt?
    - Wat wordt er gedaan tijdens onderhoud? Worden onderdelen ook vervangen?
    - Heeft u feedback op het doen van het onderhoud?
  - Nee
    - Is er een reden waarom niet?

## Reparatie:

- Repareert u luminaires? Waarom wel/niet
  - Bij niet
    - Waarom repareert u geen luminaires?
    - Waar gaan de luminaires naar toe die kapot zijn?
    - Stel het zou snel te repareren zijn, zou u het dan wel doen?
    - Wat zou er moeten gebeuren aan het design of in de markt, om te besluiten wel te gaan repareren?
  - Bij wel
    - Wat vervangt u het vaakst aan het luminaire?
    - Waar repareert u het luminaire? Terwijl het luminaire hangt aan het plafond? Of vervangt u het luminaire en repareert u het ergens anders? Waarom? En hoe loopt dat proces van reparatie?
    - Hoe lang duurt een reparatie, en hoe lang is wenselijk?
    - Gebruikt u de reparatie manual?
    - Hoe moeilijk is het om een diagnose van het probleem te stellen?
    - Wat gebeurt er met de gerepareerde luminaires? Worden ze direct teruggeplaatst of als reserve houden of anders?
    - Welk luminaire is prettiger om te repareren en waarom?
    - Heeft u feedback op de reparatiemogelijkheden van deze luminaires?
    - Wat zou u verbeteren in het design van de luminaires om reparatie wel mogelijk te maken?

### Ends-of-life:

- Als u het luminaire vervangt, wat wordt er dan weggehaald? Alleen het luminaire of ook de brackets en de kabel?
- Wat gebeurt er met luminaires wanneer ze weggegooid moeten worden, waar gaan ze naartoe?
- Is het een optie voor u om deze luminaires gescheiden in te leveren?
- Is er een verschil in installatie en de-installatie?
  - Werkt beide even goed voor Sandwich en Tubular?
  - Welke is prettiger voor deinstallatie?
- Wanneer is een luminaire fijn om te deinstalleren?

## Optioneel Hands-on experience Luminaires (15 min)

- We hebben twee luminaires meegenomen, de Sandwich en de Tubular, zou u willen vertellen hoe u de driver en de ledboards zou repareren en wat uw mening daarover is (mag positieve en negatieve punten zijn)
- Wat zou u aan het design veranderen?

## Round off (5 min)

- Zou u in het algemeen voor de Sandwich of Tubular kiezen en waarom?
- Als u één ding voor de Sandwich zou mogen aanpassen en één ding voor de Tubular, wat zou dat zijn?
- Heeft u nog laatste aanvullingen of feedback op deze luminaires?
- Heeft u nog vragen voor ons?
- Bedanken voor de tijd en vragen of we terug mogen komen met evt nieuwe vragen of een redesign

# Appendix D: Installer insights

Due to confidentiality, this Appendix
is not available in this publication

# Appendix E: Additional insights ease of installation

Due to confidentiality, this Appendix
is not available in this publication

# Appendix F: Disassembly steps

Due to confidentiality, this Appendix is not available in this publication

# Appendix G: Hotspot mapping

## G1: Criteria hotspot mapping

| *Name Criteria* | Explanation | Example |
|---|---|---|
| *Type of activity* | The required activity to remove the connector | Unscrew, peel off, cut, unplug etc. |
| *Required tool* | The tools you need to use to remove the connector | Screwdriver, pliers, hands, wrench, cutter etc. |
| *Tool size (if applicable)* | The tool size you need to remove the connector | TH20, PH1 etc. |
| *Task frequency* | The number of these connectors which need to be removed | 2 (screws) |
| *Total time to disconnect* | The time it takes to remove all connectors of this kind | 10 (seconds to remove 2 screws) |
| *Force* | Force required from the user to remove the connector | Level 0: Light, use of only fingertips<br>Level 1: Moderate, force of one hand needed<br>Level 2: Heavy, forearm muscles or 2 hands are needed, |
| *Accessibility* | The degree of accessibility of the connector | Level 0: Clear<br>Level 1: Recessed = accessible but not visible<br>Level 2: Obstructed |

| | | |
|---|---|---|
| *Positioning* | The level of tool placement | Level 0: No-to-low precision<br>Level 1: Moderate precision<br>Level 2: Heavy precision |
| *Failure likelihood* | The likeliness of the product part to fail during the products' lifetime | Level 0: no-to-low maintenance part, will work successfully during product life<br>Level 1: Part wears during use, need maintenance during product life<br>Level 2: High chance of breaking, will most likely fail during its life |
| *Functional relevance* | The degree of importance for the functioning of the product | Level 0: no-to-low functionality, little concern for the functioning of the product<br>Level 1: Sub functionality does not influence primary function but are important for sub functionalities like look and feel and construction.<br>Level 2: Main functionality, without the part the product will fail at its primary function |
| *Material group* | Material group of the removed part | Steel, other electronics, thermoplastics etc. |
| *Weight (g)* | Weight of the removed part | 200 grams |

# G2. Hotspot map Tubular

## HotSpot Mapping Datasheet

### General project information

| | |
|---|---|
| **Brand name** | |
| **Product category** | inear industrial luminair |
| **Authors** | J. Mortier |
| **Date** | Oct/24 |
| **Location** | Eindhoven |

### Overall HotSpot Results

| **Total:** | | **Average:** | | | |
|---|---|---|---|---|---|
| - time to disassemble | 246 sec | - time per step | 8,8 sec/step | | |
| - number of tasks | 83 | - force | | 4 | [1=low .. 5=high .. 10=extreme] |
| - number of steps | 28 | - accessibility | | 2 | [1=clear .. 5=moderate .. 10=difficult] |
| - number of tools | 3 | - positioning | | 3 | [1=easy .. 5=moderate .. 10=difficult] |

| General | | | | Activity | | | | | Accessibility | | Functional | | Material | | HotSpot Indicators | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Step number | Name | Subassembly? | Part of ... | Type of activity | Required tool | Tool size | Task frequency | Total time to disconnect (sec) | Force | Accessibility | Positioning | Failure Likelihood | Funcitonal relevance | Material group | Weigth (g) | Time | Activity | Priority part | Environmental | Economic | Notes |
| 1 | Screws | no | main assembly | Unscrew | Screwdriver | TH20 | 2 | 17 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Steel | 4 | ⚑ | | | | | |
| 2 | End cap assembly | yes | main assembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | No to low precision | | | | | | | | | |
| 3 | Gear tray assembly | yes | main assembly | Disconne | Hands | | 1 | 1 | level 1 - | level 0 - | level 0 - | No to low precision | | | | | | | | | Undo spring for gear tray |
| 4 | Cable plug | no | main assembly | Unplug | Hands | | 3 | 5 | level 0 - | Light re | level 1 - | level 1 - | level 1 - | Other Electronics | ? | | | | | | Unplug from terminal block |
| 5 | Cable plug | no | main assembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 1 - | level 1 - | Other Electronics | | | | | | | |
| 6 | Cable gland | no | End cap assembly | Unscrew | Hands | | 1 | 2 | level 1 - | level 0 - | level 0 - | level 0 - | level 1 - | Thermoplastic | 4,4 | | | | | | |
| 7 | Cable gland gasket | no | End cap assembly | Remove | Hands | | 1 | 7 | level 2 - | level 1 - | level 1 - | level 1 - | level 1 - | Rubber | 2,4 | | ⚐ | | | | |
| 8 | End cap gasket | no | End cap assembly | Other | Lever / Prybar | | 1 | 12 | level 2 - | level 1 - | level 2 - | level 1 - | level 1 - | Rubber | 2,5 | ⚐ | ⚑ | | | | I used tweazers, but it was possible with a iFixit Jimmy |
| 9 | End cap | no | End cap assembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Thermoplastic | 43 | | | | | | |
| 10 | Led assembly | yes | main assembly | Disconne | Lever / Prybar | | 1 | 13 | level 2 - | level 1 - | level 2 - | High precision | | | | ⚐ | ⚑ | | | | |
| 11 | Housing | no | main assembly | Remove | Hands | | 1 | 2 | level 1 - | level 0 - | level 0 - | level 1 - | level 1 - | Thermoplastic | 612 | | | | ⚑ | ⚐ | Has 2 different PC components |
| 12 | Screws | no | Led assembly | Unscrew | Screwdriver | TH10 | 16 | 80 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Steel | 11,9 | ⚑ | | | | | |
| 13 | Lens plates | no | Led assembly | Remove | Hands | | 4 | 3 | level 0 - | level 0 - | level 0 - | level 1 - | level 1 - | Thermoplastic | 156 | | | | ⚐ | | |
| 14 | Ledboards | no | Led assembly | Other | Pliers | | 16 | 24 | level 1 - | level 0 - | level 2 - | level 1 - | level 2 - | PCB | 142 | ⚑ | ⚐ | ⚐ | ⚑ | ⚑ | TEST! Metal connections to the wires |
| 15 | Ledboards | no | Led assembly | Peel off | Hands | | 4 | 6 | level 0 - | level 0 - | level 0 - | level 1 - | level 2 - | PCB | | | | ⚐ | | | |
| 16 | Cables small | no | Led assembly | Remove | Hands | | 4 | 4 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Other Electronics | 1,6 | | | | | | |
| 17 | Grommets | no | Led assembly | Remove | Hands | | 4 | 4 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Rubber | 2,9 | | | | | | |
| 18 | Tiewrap | no | main assembly | Cut | Pliers | | 2 | 2 | level 1 - | level 1 - | level 1 - | level 0 - | level 0 - | Thermoplastic | 0,2 | | ⚐ | | | | |
| 19 | Screws | no | Gear tray assembl | Unscrew | Screwdriver | TH20 | 2 | 11 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Steel | 2,6 | | | | | | |
| 20 | Driver bracket closing spring | no | Led assembly | Disconne | Hands | | 1 | 7 | level 1 - | level 0 - | level 0 - | level 0 - | level 0 - | Steel | 0,6 | | | | | | |
| 21 | Reflector + wires | no | Led assembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 1 - | Mixed materials mainly | 732 | | | | ⚑ | ⚑ | |
| 22 | Gear tray closing spring | no | Gear tray assembl | Disconne | Hands | | 1 | 5 | level 1 - | level 0 - | level 0 - | level 0 - | level 0 - | Steel | 6,7 | | | | | | |
| 23 | Screw | no | Gear tray assembl | Unscrew | Screwdriver | TH20 | 1 | 9 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Steel | 1,3 | | | | | | |
| 24 | Cables long | no | Gear tray assembl | Unplug | Screwdriver | SIM | 5 | 10 | level 0 - | level 0 - | level 1 - | level 0 - | level 0 - | Other Electronics | | | | | | | Remove from driver |
| 25 | Driver | no | Gear tray assembl | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 2 - | level 2 - | Other Electronics | 183 | | | ⚑ | ⚐ | ⚑ | |
| 26 | Cables long | no | main assembly | Unplug | Hands | | 3 | 12 | level 1 - | level 1 - | level 0 - | level 0 - | level 0 - | Other Electronics | 4,5 | ⚐ | | | | ⚐ | Unplug from terminal block by turning the wires |
| 27 | Connector | no | Gear tray assembl | Disconne | Hands | | 3 | 4 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Other Electronics | 17 | | | | | ⚐ | Snap fits |
| 28 | Gear tray | no | Gear tray assembl | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Steel | 269 | | | | ⚐ | | |

# G3. Hotspot map Sandwich

## General project information

| | |
|---|---|
| **Brand name** | |
| **Product category** | inear industrial luminair |
| **Authors** | J.Mortier |
| **Date** | Oct/24 |
| **Location** | Eindhoven |

## Overall HotSpot Results

| **Total:** | | **Average:** | | | |
|---|---|---|---|---|---|
| - time to disassemble | 934 sec | - time per s | | 26,7 sec/step | |
| - number of tasks | 87 | - force | | 3 | [1=low .. 5=high .. 10=extreme] |
| - number of steps | 35 | - accessibility | | 3 | [1=clear .. 5=moderate .. 10=difficult] |
| - number of tools | 4 | - positioning | | 3 | [1=easy .. 5=moderate .. 10=difficult] |

| General | | | | Activity | | | | | Accessibility | | | Functional | | Material | | HotSpot Indicators | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Step number | Name | Subassembly? | Part of ... | Type of activity | Required tool | Tool size | Task frequency | Total time to disconnect (sec) | Force | Accessibility | Positioning | Failure Likelihood | Functinoal relevance | Material group | Weigth (g) | Time | Activity | Priority part | Environmental | Economic | Notes |
| 1 | Ledassembly | yes | main assembly | Disconne | Lever / Prybar | | 12 | 24 | level 2 - | level 1 - | level 1 - | Moderate precision | | | | ⚑ | ⚐ | | | | |
| 2 | Optical cover | no | main assembly | Disconne | Lever / Prybar | | 8 | 30 | level 1 - | level 1 - | level 1 - | level 1 - | level 1 - | Thermoplastic | 362 | ⚑ | ⚐ | | ⚑ | ⚐ | |
| 3 | Tie wrap | no | Ledassembly | Cut | Pliers | | 1 | 1 | level 0 - | level 0 - | level 1 - | level 0 - | level 0 - | Thermoplastic | 0,1 | | | | | | |
| 4 | Screw | no | Ledassembly | Unscrew | Screwdriver | PH1 | 1 | 4 | level 0 - | level 2 - | level 2 - | level 0 - | level 0 - | Steel | 1 | | ⚐ | | | | Screw on reflector |
| 5 | Nut | no | Ledassembly | Remove | Hands | | 1 | 1 | level 0 - | level 1 - | level 0 - | level 0 - | level 0 - | Steel | 0,7 | | | | | | Comes loose with screw (step 4) |
| 6 | Washer | no | Ledassembly | Remove | Hands | | 1 | 1 | level 0 - | level 1 - | level 0 - | level 0 - | level 0 - | Steel | 0,2 | | | | | | Comes loose with screw (step 4) |
| 7 | 2 external tooth lock washer | no | Ledassembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Steel | 0,1 | | | | | | Comes loose with screw (step 4) |
| 8 | Connection cable ledboard side | no | Ledassembly | Unplug | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Other Electronics | 6 | | | | | | Unplugging from driver side cable |
| 9 | Connection cable ledboard side | no | Ledassembly | Cut | Wire cutter | | 4 | 2 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Other Electronics | | | ⚐ | | | | Cut from the ledboards (non-reusable) |
| 10 | Small metal clips | no | main assembly | Other | Hands | | 8 | 30 | level 1 - | level 1 - | level 0 - | level 0 - | level 0 - | Steel | 2,4 | ⚑ | | | | | Disconnect 4 clips from the reflector |
| 11 | Retention cords | no | main assembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 1 - | level 0 - | Thermoplastic | 1,3 | | | | | | Are freed with step above |
| 12 | Gear tray assembly | yes | Ledassembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Steel | 0,8 | | | | | | |
| 13 | Screws | no | Ledassembly | Unscrew | Screwdriver | PH1 | 2 | 12 | level 0 - | level 0 - | level 1 - | level 0 - | level 0 - | Steel | 0,8 | ⚐ | | | | | |
| 14 | Ledboards | no | Ledassembly | Remove | Hands | | 2 | 10 | level 1 - | level 0 - | level 0 - | level 1 - | level 2 - | PCB | 60 | | | ⚐ | ⚑ | ⚑ | |
| 15 | Reflector | no | Ledassembly | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 1 - | Steel | 395 | | | | ⚐ | | |
| 16 | Connection cable driver side | no | Gear tray assembl | Unplug | Screwdriver | 1,5 | 2 | 4 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Other Electronics | 8 | | | | | ⚐ | Cables from the ledboards running to the driver |
| 17 | Connection cable | no | Gear tray assembl | Disconne | Hands | | 1 | 2 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Other Electronics | | | | | | | Snap fit thing |
| 18 | Driver assembly | yes | Gear tray assembl | Unplug | Screwdriver | 1,5 | 3 | 5 | level 1 - | level 0 - | level 1 - | level 2 - | level 1 - | Sub functionality | | | | | | | Cables from the other electronic parts (motion sensor and cable plug) |
| 19 | Screw | no | Driver assembly | Unscrew | Screwdriver | TH20 | 1 | 5 | level 1 - | level 1 - | level 1 - | level 0 - | level 0 - | Steel | 1 | | ⚐ | | | | |
| 20 | 2 external tooth lock washers | no | Driver assembly | Remove | Hands | | 2 | 1 | level 0 - | level 1 - | level 0 - | level 0 - | level 0 - | Steel | 0,2 | | | | | | Comes loose with screw (step 19) also the ground cable shoes come loose |
| 21 | Driver bracket | no | Driver assembly | Remove | Hands | | 1 | 1 | level 1 - | level 0 - | level 0 - | level 0 - | level 0 - | Steel | 13 | | | | | | Remove from driver |
| 22 | Driver | no | Driver assembly | Remove | Hands | | 1 | 1 | level 1 - | level 0 - | level 0 - | level 2 - | level 2 - | Other Electronics | 118 | | | ⚑ | ⚑ | ⚑ | |
| 23 | Cable plug | no | main assembly | Unplug | Hands | | 3 | 9 | level 0 - | level 0 - | level 1 - | level 0 - | level 1 - | Other Electronics | ? | | | | | | |
| 24 | Cable plug | no | main assembly | Remove | Hands | | 1 | 2 | level 0 - | level 0 - | level 0 - | level 0 - | level 1 - | Other Electronics | | | | | | | Pull out of cable gland |
| 25 | Cable gland | no | main assembly | Unscrew | Hands | | 1 | 2 | level 1 - | level 0 - | level 0 - | level 0 - | level 0 - | Thermoplastic | 3,7 | | | | | | |
| 26 | Cable gland gasket | no | main assembly | Remove | Lever / Prybar | | 1 | 12 | level 1 - | level 1 - | level 1 - | level 1 - | level 1 - | Rubber | 1,6 | ⚐ | ⚐ | | | | Remove with tweazers |
| 27 | Connector | no | Gear tray assembl | Unplug | Screwdriver | ? | 4 | 8 | level 0 - | level 1 - | level 1 - | level 0 - | level 0 - | Other Electronics | 10 | | | | | ⚐ | Unplug wires with pointy tool |
| 28 | Connector | no | Gear tray assembl | Unscrew | Screwdriver | TH10 | 2 | 18 | level 0 - | level 1 - | level 1 - | level 0 - | level 0 - | Other Electronics | 1,6 | ⚐ | | | | | Loosen terminal block |
| 29 | Ground wires | no | Gear tray assembl | Disconne | Hands | | 1 | 2 | level 1 - | level 1 - | level 1 - | level 0 - | level 0 - | Other Electronics | 6 | | ⚐ | | | | From a snap fit |
| 30 | Wire | no | Gear tray assembl | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Other Electronics | 3 | | | | | | |
| 31 | Screws | no | Gear tray assembl | Unscrew | Screwdriver | TH10 | 2 | 9 | level 1 - | level 0 - | level 1 - | level 0 - | level 0 - | Steel | 1,2 | | | | | | Loosen motion sensor |
| 32 | Movement sensor | no | Gear tray assembl | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 0 - | level 0 - | Other Electronics | 56 | | | | ⚐ | ⚑ | |
| 33 | Metal hooks | no | Gear tray assembl | Remove | Hands | | 12 | 720 | level 2 - | level 1 - | level 1 - | level 1 - | level 1 - | Aluminium | 30 | ⚑ | ⚐ | | ⚐ | | Hard to remove with tools and/or hands, time is estimated |
| 34 | Housing gasket | no | Gear tray assembl | Remove | Lever / Prybar | | 1 | 10 | level 0 - | level 1 - | level 2 - | level 1 - | level 1 - | Rubber | 39 | | ⚐ | | | | Tweazers |
| 35 | Housing | no | Gear tray assembl | Remove | Hands | | 1 | 1 | level 0 - | level 0 - | level 0 - | level 1 - | level 1 - | Thermoplastic | 535 | | | | ⚑ | ⚑ | |

# Appendix H: Repair insights

Due to confidentiality, this Appendix is not available in this publication

# Appendix I: Sink-float test

To determine where certain plastics and parts end up, a sink-float test was conducted at home. For this 100 ml cold tap water was mixed with 10 grams of salt (to achieve a 1.1 kg/l density (similar to the sink/float separation used in the recycling process). Below the pictures of the test can be found. On the next page, the results are shown.

Sandwich floating plastics | Sandwich floating plastics | Sandwich sinking plastics | Sandwich floating mixed fragment | Sandwich sink-float test | Sandwich sink-float test

*Figure G1: Sink float test Sandwich*

Tubular sinking plastics | Tubular floating plastics | Tubular floating mixed fragment

*Figure G2: Sink float test Tubular*

*Table G1: Results sink float test Sandwich*

| Part | Material | 1.1 kg/L |
|---|---|---|
| Housing | PC | Sink |
| Cover | PC | Sink |
| Flimsy stuff | PC | Float |
| Connector | Multimaterial | Doubt |
| Layer in driver | ? | Sink |
| Retention chords | PA | Float |
| Small ring cable glar | Silicone | Float |
| Thick ring cable glar | Silicone | Sink |
| Housing gasket | Silicone | Float |
| *Gasket in housing* | *Silicone & PC* | *Float* |

*Table G2: Results sink float test Tubular*

| Part | Material | 1.1 kg/L |
|---|---|---|
| Tube | PC | Sink |
| End-caps | PC + GF10% | Sink |
| Thick gasket cable gland | Silicone | Sink |
| Small ring cable gland | Silicone | Sink |
| End-cap gasket | Silicone | Float |
| grommets | Rubber | Sink |
| Connector | Multimaterial | Float |
| Tie wrap | PA | Float |
| Lens plastes | PC | Sink |
| Driver plastic layer | ? | Sink |
| Flimsy stuff | PC | Float |
| *Gasket in housing* | *Silicone & PC* | *Float* |

# Appendix J: Shredded luminaire differences

Due to confidentiality, this Appendix
is not available in this publication

# Appendix K: Weight parts and connection types and numbers in luminaires

In this Appendix, all weights and materials per part can be found per luminaire in sections K1 for the Sandwich and K2 for the Tubular.

# K1: Weights parts Sandwich

| | Material(group) | Same for each product | Number of parts differs | Depends on length product | Varies per product | Weight per part | Number of parts | Total weight for C0 | Total weight for C1 | Total weight for C2 | Total weight for C3 | Notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Internal and external housing & optics** | | | | | | | | | | | | |
| Housing | Plastic: PC | | | x | | 535 | 1 | 535 | 512,7 | 552 | 446 | |
| Cable gland | Plastic: PC | x | | | | 3,7 | 1 | 3,7 | 3,7 | 4,0 | 3,3 | |
| Cable gland gasket | Silicone | x | | | | 1,6 | 1 | 1,6 | 1,6 | 1,6 | 1,6 | |
| Housing gasket | Silicone | | | x | | 39 | 1 | 39 | 39 | 39 | 38 | |
| Reflector | Ferrous metal = Steel | | | x | | 395 | 1 | 395 | 367 | 392 | 310 | * C1 an 2 calculated from ledassembly |
| Optical cover | Plastic: PC | | | x | | 362 | 1 | 362 | 335 | 345 | 307 | |
| Metal plate | Non-ferrous metal: Aluminium | | x | | | 14 | 1 | | | 14 | | |
| | | | | | | | | | | | | |
| **Brackets** | Non-ferrous = Stainless steel | x | | | | 9,8 | 2 | 19,6 | 19,6 | 19,6 | 19,6 | |
| | | | | | | | | | | | | |
| **Electronics** | | | | | | | | | | | | |
| Driver | | | | | x | 118 | 1 | | | | | * to calculate the parts of other drivers a percentage of the overall weight is used |
| *Bottom plate* | Ferrous metal | | | | x | 35% | 1 | 41,7 | 70,4 | 46,7 | 41,7 | |
| *Cover* | Ferrous metal | | | | x | 18% | 1 | 20,8 | 35,1 | 23,3 | 20,8 | |
| *Plastic electrostatic protection layer* | ? | | | | x | 2% | 1 | 2,8 | 4,7 | 3,1 | 2,8 | |
| *PCB* | PCB | | | | x | 45% | 1 | 52,8 | 89,1 | 59,1 | 52,8 | |
| Ledboard | Electronics: ledboard | | | | x | 30 | 2 | 60 | 81 | 65 | 52 | * C3 has one long ledboard, with similar ledboard wire as C0, all weighing 58 gram; **C2 was calculated as a percentage from C3 |
| Connector | Electronics, mainly plastics (PC) and copper | | | | x | 10 | 1 | 10 | 8,2 | 8,2 | 8,2 | * C0 has PI4 connector, the others PI3; ***C1 was 25 mm wide compared to 20 mm of the C2, but had similar led architecture |
| Motion detection sensor + wires | | | x | | | | | | | | | |
| *Housing top* | Plastic: ? | | | | | 8,3 | 1 | 8,3 | | | | |
| *Housing bottom* | Plastic: ? | | | | | 14,4 | 1 | 14,4 | | | | |
| *PCB + cables* | PCB + cables (copper and rubber) | | | | | 33,3 | 1 | 33,3 | | | | |
| Slider PCB | PCB | | x | | | 5 | 1 | | | 5 | | |
| | | | | | | | | | | | | |
| **Wires** | | | | | | | | | | | | |
| Cable plug | Cable (copper, PVC) | | | | x | 178 | 1 | 178 | | | 118 | |
| Connection wire driverside | Cable (copper and rubber) + plastic (PA) | | | | x | 8 | 1 | 8 | 8,3 | | 17 | |
| Connection wire ledboardside | Cable (copper and rubber) + plastic (PA) | | x | | | 6 | 1 | 6 | 6 | | 6 | * Not completely the same as C0 but assumed to be the same weight |
| Ground wires with cable shoes | Cable (copper and rubber) + non ferrous metal (Al) | | | | x | 6 | 1 | 6 | | 5,1 | | |
| Wires connector-driver | Cable (copper and rubber) | | | | x | 3 | 1 | 3 | 11,8 | 5,4 | 5,4 | |
| Wires slider PCB | Cable (copper and rubber) | | x | | | 1,3 | 3 | | | 3,9 | | |
| | | | | | | | | | | | | |
| **Screws, nuts and washers** | | | | | | | | | | | | |
| PH1 screws d3 l5 ledboard/reflector | Ferrous metal = Steel | | x | | | 0,4 | 2 | 0,8 | 12 | | | * 30 pieces for C1 |
| PH1 screw d4 l8 Reflector | Ferrous metal = Steel | | x | | | 1 | 1 | 1 | 1 | | | |
| T10 screws d3 l20 connector | Ferrous metal = Steel | | x | | | 0,8 | 2 | 1,6 | | | | |
| PH2 screw d3 l17 connector | Ferrous metal = Steel | | x | | | 0,8 | 2 | | 1,6 | 1,6 | 1,6 | |
| T10 screws d3 l6 Motion sensor | Ferrous metal = Steel | | x | | | 0,6 | 2 | 1,2 | | | | |
| TH20 screw d4 l8 Driver bracket | Ferrous metal = Steel | | x | | | 1 | 1 | 1 | 1 | | | |
| Th20 screw d4 l12 Driver bracket C1 | Ferrous metal = Steel | | x | | | 1,2 | 1 | | 1,2 | | | |
| PH2 screw (pull safe) d3 l8 | Ferrous metal = Steel | | x | | | 0,4 | 2 | | | 0,8 | 0,8 | |
| PH2 screw d3 l4 (ledboard) | Ferrous metal = Steel | | x | | | | 1 | | | 0,4 | 0,4 | |
| PH2 bolt (ground to reflector) d4 l8 | Ferrous metal = Steel | | x | | | | 1 | | | 1,8 | 0,9 | * for C2 two times (ground metal plate and ground relfector) |
| PH2 screw (driver) d4 l8 | Ferrous metal = Steel | | x | | | | 1 | | | 3,5 | 0,7 | * for C2 five times (2 for driver, 1 for slide button and 2 for metal plate ground) |
| External tooth lock washer D4 | Ferrous metal = Stainless steel | | x | | | 0,1 | 3 | 0,3 | 0,3 | 0,2 | 0,1 | * for C2, two times, for C3 one time |
| Washer D4 | Ferrous metal = Stainless steel | | x | | | 0,2 | 1 | 0,2 | 0,2 | 0,2 | 0,1 | * for C2, two times |
| Nut D3 | Ferrous metal = Stainless steel | | x | | | 0,7 | 1 | 0,7 | 0,7 | 1,2 | 0,6 | * for C2, two times |
| | | | | | | | | | | | | |
| **Other fasteners** | | | | | | | | | | | | |
| Metal clips enclosure | Non-ferrous = Stainless steel | | x | | | 3 | 10 | 30 | 36 | 36 | 31 | * For C1 and C2, 12 clips, for C3 10 clips |
| Retention cords | Plastic: PA? | x | | | | 0,6 | 2 | 1,2 | 1,2 | 1,4 | 1,2 | |
| Small metal clips retention cords | Ferrous metal = Steel | x | | | | 0,6 | 4 | 2,4 | 2,4 | 2,4 | 2,4 | |
| Driver bracket | Ferrous metal = Steel | | | | x | 13 | 1 | 13 | 5 | 2,3 | 13 | |
| Tie wrap | Plastic: PA | | x | | | 0,1 | 1 | 0,1 | 0,2 | | 0,1 | |
| Tube wires | Ferrous metal | | x | | | 36,3 | 1 | | 36,3 | | | |
| Bracket slider PCB | Plastic: PC | | x | | | 3,2 | 1 | | | 3,2 | | |
| Rings | Plastic: PC | | x | | | 0,9 | 2 | | | 1,8 | | |
| Pull safe | Plastic: ? | | x | | | 0,2 | 1 | | | 0,2 | | |
| | | | | | | | | | | | | |
| | | | | Total weight from list | | | | 1854,5 | 1692,2 | 1648,9 | 1503,1 | |
| | | | | Total weight weighted | | | | 1854,6 | 1691,3 | 1647,6 | 1501,8 | |

| Legenda | |
|---|---|
| (green) | Weighted |
| (blue) | Assumed, but same part as weighted part |
| (purple) | Assumed with reasoning |
| (orange) | Number of components differs |
| (grey) | Not applicable for this product |

# K2: Weights parts Tubular

| | Material(group) | Same for each product | Number of parts differs | Depends on length product | Varies per product | Weight per part | Number of parts | Total weight for P0 | Total weight for P1 | Total weight for P2 | Total weight for P3 | Total weight for P5 | Total weight for P6 | Notes | Legenda |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **End cap assembly** | | | | | | | | | | | | | | | |
| End cap | Plastic: PC + GF10% | x | | | | 43 | 1 | 43 | 43 | 43 | 43 | 43 | 43 | | Weighted |
| End cap gasket | Silicone | x | | | | 2,5 | 1 | 2,5 | 2,5 | 2,5 | 2,5 | 2,5 | 2,5 | | Assumed, but same part as weighted part |
| Cable Gland | Plastic: PC | x | | | | 4,4 | 1 | 4,4 | 4,4 | 4,4 | 4,4 | 4,4 | 4,4 | | Assumed with reasoning |
| Cable gland gasket ring | Silicone | x | | | | 2,4 | 1 | 2,4 | 2,4 | 2,4 | 2,4 | 2,4 | 2,4 | | Number of components differs |
| | | | | | | | | | | | | | | | Not applicable for this product |
| **Bracket** | Ferrous metal: Stainless steel | x | | | | | 2 | 62 | 62 | 62 | 62 | 62 | 62 | | |
| | | | | | | | | | | | | | | | |
| **Internal and external housing & optics** | | | | | | | | | | | | | | | |
| Housing Tube with glued end-cap parts | Plastic: PC (& PC + GF10%) | | | | x | 612 | 1 | 612 | 876 | 942 | 662 | 665 | 615 | | |
| Reflector + wire + ground cable | | | | x | | | | | | | | | | | |
| *Reflector* | Ferrous metal: Steel prepainted | | | x | | 732 | 1 | 732 | 1084 | 1083 | 725 | 727 | 727 | * to calculate the reflector the assembly has been weighted and other parts have been subtracted | |
| *Retention cord* | Plastic: PES | x | | | | 0,7 | 1 | 0,7 | 0,7 | 0,7 | 0,4 | 0,4 | 0,7 | * some have smaller ropes (2x as thin) as others | |
| *Ground cable* | Cable (copper and rubber) | x | | | | 1,4 | 1 | 1,4 | 1,4 | 1,4 | 1,4 | 1,4 | 1,4 | | |
| *Cable shoes* | Non-ferrous metal | x | | | | 0,6 | 4 | 2,4 | 2,4 | 2,4 | 2,4 | 2,4 | 2,4 | | |
| Lensplates/optica | Plastic: PC | | x | | | 39 | 4 | 156 | 234 | 234 | 156 | 156 | 156 | * For no1 and 2, six lensplates | |
| Geartray | Ferrous metal: Steel + Zink | x | | | | 269 | 1 | 269 | 270 | 270 | 270 | 270 | 270 | | |
| Driver bracket closing spring | Ferrous metal: Stainless steel | x | | | | 1,6 | 1 | 1,6 | 1,6 | 1,6 | 1,6 | 1,6 | 1,6 | | |
| Gear tray closing spring | Ferrous metal: Stainless steel | | | | | 6,7 | 1 | 6,7 | 6,7 | 6,7 | 6,7 | 6,7 | 6,7 | | |
| | | | | | | | | | | | | | | | |
| **Electronics** | | | | | | | | | | | | | | | |
| Driver | | | | | | | | | | | | | | * to calculate the parts of other drivers a percentage of the overall weight is used | |
| *Bottom plate* | Ferrous metal | | | | x | 64,7 | 1 | 64,7 | 92,3 | 64,7 | 85,9 | 64,0 | 64,7 | 35% | |
| *Cover* | Ferrous metal | | | | x | 32,3 | 1 | 32,3 | 46,1 | 32,3 | 42,9 | 31,9 | 32,3 | 18% | |
| *Plastic electrostatic protection layer* | ? | | | | x | 4,3 | 1 | 4,3 | 6,1 | 4,3 | 5,7 | 4,3 | 4,3 | 2% | |
| *PCB* | PCB | | | | x | 81,9 | 1 | 81,9 | 116,8 | 81,9 | 108,8 | 81,0 | 81,9 | 45% | |
| Ledboards | Electronics: ledboard | | x | | | 35,5 | 4 | 142 | 213 | 213 | 142 | 142 | 142 | * For no1 and 2, six ledboards | |
| Connector | Electronics, mainly plastics (PC) and copper | | | | x | 14,4 | 1 | 14,4 | 14,4 | 14,4 | 7,3 | 19,9 | 19,9 | | |
| Motion sensor | | | | | | | | | | | | | | | |
| *Housing* | Plastics: PCABS | | | | x | 4,6 | 1 | 4,6 | | | 4,6 | | | | |
| *Lid* | Plastics: PCABS | | | | x | 3,4 | 1 | 3,4 | | | 3,4 | | | | |
| *Transparent part* | Plastics: PVC? | | | | x | 0,4 | 1 | 0,4 | | | 0,4 | | | | |
| *PCB* | PCB | | | | x | 6,3 | 1 | 6,3 | | | 6,3 | | | | |
| | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | |
| **Wires** | | | | | | | | | | | | | | | |
| Cable plug | Cable (copper, PVC) | | | | x | 160 | 1 | 160 | 236 | | | | | | |
| Wires connector to driver | Cable (copper and rubber) | x | | | | 1,3 | 2 | 2,6 | 2,6 | 2,6 | 2,6 | 2,6 | 2,6 | | |
| Cables small ledboard | Cable (copper and rubber) | | x | | | 0,6 | 3 | 1,7 | 2,8 | 2,8 | 1,7 | 1,7 | 1,7 | * For no1 and 2, five cables | |
| Cables long 30 cm driver to ledboard | Cable (copper and rubber) | x | | | | 2,5 | 2 | 5 | 5 | 5 | 5 | 5 | 5 | | |
| Cables 97 cm for motion sensor | Cable (copper and rubber) | | x | | | 7,9 | 2 | | | | 15,8 | | | * Length compared to cables long 30 cm, from that weight is calculated | |
| Ground cable extra | Cable (copper and rubber) | | x | | | 1,7 | 1 | | | | | | 1,7 | | |
| Cable shoe | Non-ferrous metal: Aluminium | | | | | 0,6 | 1 | | | | | | 0,6 | | |
| | | | | | | | | | | | | | | | |
| **Screws** | | | | | | | | | | | | | | | |
| T10H screws D3 L10 optics/ledboard | Ferrous metal: Steel | x | | | | 0,7 | 16 | 11,9 | 11,9 | 11,9 | 11,9 | 11,9 | 11,9 | | |
| T20H screws D4 L10 driver & reflector/gear tray | Ferrous metal: Steel | x | | | | 1,3 | 3 | 3,9 | 3,9 | 3,9 | 3,9 | 3,9 | 3,9 | | |
| T20H screws D4 L20 end-cap | Ferrous metal: Steel | x | | | | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | | |
| TH10 screws motion sensor | Ferrous metal: Steel | | x | | | 0,5 | 2 | | | | 1 | | | | |
| TH20 screws connector bracket | Ferrous metal: Steel | | x | | | 1,3 | 2 | | | | | 2,6 | 2,6 | | |
| TH20 screws ground cable | Ferrous metal: Steel | | x | | | 1,3 | 1 | | | | | | 1,3 | | |
| | | | | | | | | | | | | | | | |
| **Other fasteners** | | | | | | | | | | | | | | | |
| PCB Grommets | Rubber: EPDM | | x | | | 0,7 | 4 | 2,4 | 4,35 | 4,35 | 2,9 | 2,9 | 2,9 | * For no1 and 2, six grommets | |
| Wire enclosure | Silicone-coated fiberglass fabric | x | | | | 4,9 | 1 | 4,9 | 4,9 | 4,9 | 4,9 | 4,9 | 4,9 | | |
| Tie wraps | Plastic: PA | x | | | | 0,1 | 2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | 0,2 | | |
| Motion sensor bracket | Ferrous metal: Steel | | x | | | 8,6 | 1 | | | | 8,6 | | | | |
| Connector bracket | Ferrous metal: Steel | | x | | | 4 | 1 | | | | | 4 | 4 | | |
| Black rings | Ferrous metal: Steel | | x | | | 2,3 | 2 | | | | | 4,6 | | | |
| | | | | | | | | | | | | | | | |
| **Stickers (Two on the reflector and one on reflector)** | | | | | | | | | | | | | | | |
| | | | **Total weight from list** | | | | | | **3354,9** | **3105,9** | **2409,4** | **2336,0** | **2287,0** | | |
| | | | **Total weight weighted** | | | | | | **3347,3** | **3107** | **2410** | **2327** | **2287** | | |

# Appendix L: Analyses mixed fragments

In this appendix an in-depth analysis on the recyclability of the luminaires can be found. It starts with where material losses occur in L1, then the mixed fragments are analysed and categorized in L2. It finalises with the liberation rate of all connections present in the luminaire in L3. This is done for the Tubular as well in sections L4, L5 and L6.

## L1: Weights parts Sandwich

In Table L1, the input and output weight per material category have been weighted. The material loss has been calculated per material and as a percentage of the total weight of the luminaire. The greatest material losses are in the PCB (49%) and other electronics (76%). Compared to the total weight, the most losses are present in the PC (12%) and ferrous fraction (10%).

*Table L1: Sandwich material flow*

| | Input | Output | Material loss | Material gain/loss compared to total weight |
|---|---|---|---|---|
| **Homogenous fragments** | | | | |
| **Ferrous** | 1403,7 | 920,0 | -34% | -10% |
| **Non-ferrous** | 175,8 | 106,0 | -40% | -1% |
| **Floating plastics** | | | | 0% |
| Silicone | 120,8 | 91,0 | -25% | -1% |
| Flimsy PC | 0,0 | 11,8 | | 0% |
| **Sinking plastics** | | | | 0% |
| PC | 2513,7 | 1935,0 | -23% | -12% |
| Other (PA + plastic driver) | 14,9 | 9,0 | -39% | 0% |
| | | | | |
| **Electronics** | | | | |
| Led boards | 198,0 | 141,0 | -29% | -1% |
| PCB | 205,9 | 104,7 | -49% | -2% |
| Copper (wires/cables) | 186,9 | 148,0 | -21% | -1% |
| Other | 24,6 | 6,0 | -76% | 0% |
| | | | | |
| **Other** | | | | |
| Mixed fragments | | 437,0 | | 9% |
| Too small to sort | | 413,0 | | 9% |
| Lost * | | 521,8 | | 11% |
| | | | | |
| **Total** | **4844,3** | **4322,5** | **-11%** | |

## L2: Mixed fragments Sandwich

In Table L2 and Figure L1 an overview of the mixed fragments can be found, together with their occurrence and what is likely to happen with the fragments (based on recyclers interviews). For the Sandwich, the silicone in PC is the biggest problem, followed by the screws and the ferrous material folding problem.

*Table L2: Sandwich mixed fragments*

| | End fraction | Amount | Weight |
|---|---|---|---|
| **Steel mix** | | | |
| Ferrous metal - PC | Ferrous fraction | 5 | 16 |
| Ferrous metal - led board | Ferrous fraction | 6 | 33 |
| Ferrous metal - PCB | Ferrous fraction | 5 | 25 |
| Ferrous metal - plastic layer Driver | Ferrous fraction | 8 | 28 |
| Ferrous metal - Cable | Ferrous fraction | 3 | 13 |
| Ferrous metal - magnet stuff | Ferrous fraction | 4 | 12 |
| | | | |
| **Connections** | | | |
| Connectors - wire | Or copper fraction or sinking plastics | 18 | 27 |
| Screws | *See section below* | 19 | 51 |
| Bolts | Ferrous fraction | 4 | 25 |
| Cable shoes - wire | Copper fraction | 5 | 2,7 |
| Soldered ledboard connections | Copper fraction | 6 | 8 |
| Metal clips in PC housing | Sinking plastics: burn | 3 | 17 |
| | | | |
| **Silicone in materials** | | | |
| Silicone in PC | Floating plastics | 34 | 132 |
| Silicone in ferrous metal | Ferrous fraction | 2 | 13 |
| | | | |
| **Other** | | | |
| Metal + tape | | 1 | 13 |
| PCB in plastic | Or copper fraction or sinking plastics | 1 | 0,7 |
| Stickers on PC | Sinking plastics | 4 | 6,7 |
| | | | |
| | **Total** | **128** | **423,1** |

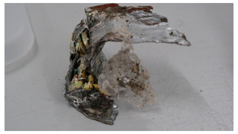
## Metal folding

Problem: Metal reflector folds around led board
Result: Precious materials on led board will be lost

Number of fragments: 6
Weight fragments: 33 gram

Problem: Metal driver folds around plastic layer driver
Result: Plastic will be lost

Number of fragments: 8
Weight fragments: 28 gram



Problem: Metal driver folds around PCB
Result: Precious materials on PCB will be lost

Number of fragments: 5
Weight fragments: 25 gram

Problem: Metal reflector folds around PC
Result: PC will be lost

Number of fragments: 5
Weight fragments: 16 gram

Problem: Metal reflector folds around cable
Result: Copper will be lost

Number of fragments: 3
Weight fragments: 13 gram

Problem: Metal magnet grains stay on ferrous fraction
Result: Both will end up in ferrous stream

Number of fragments: 4
Weight fragments: 12 gram

## Silicone remains

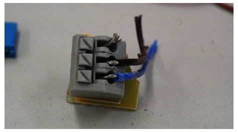
Problem: Silicone stays in PC
Result: Fragments contaminate plastic float fraction or PC fraction

Number of fragments: 34
Weight fragments: 132 gram

Problem: Silicone stays in metal
Result: Silicone burned

Number of fragments: 2
Weight fragments: 13 gram

## Connections



Problem: Cables remain in plastic connector
Result: Either plastics or PCB lost *

Number of connections remained: 18 out of 36
Weight fragments: 27 gram

Problem: Screws remain
Result: Materials will be lost???

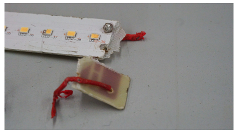
Number of connections remained: 20 out of 50
Weight fragments: 51 gram

Problem: Nut/bolt connections remain
Result: Alu cable shoe will be lost

Number of connections remained: 3 out of 3
Weight fragments: 25 gram

Problem: Cables shoes remain on cable
Result: Aluminum will be lost

Number of connections remained: 3 out of 5
Weight fragments: 2,7 gram



Problem: Cable-ledboard connection remains
Result: Both go into copper fraction

Number of connections remained: 6 out of 11
Weight fragments: 8 gram

Problem: Clips remain in PC housing
Result: Either plastics or aluminium lost *

Number of connections remained: 3 out of 34
Weight fragments: 17 gram

## Other

Problem: Tape on metal tube remains
Result: Tape will burn

Number of connections remained: 1 out of 1
Weight fragments: 13 gram

Problem: Stickers remain on PC
Result: Stickers will burn

Number of fragments: 4
Weight fragments: 6,7 gram

Problem: PCB remains in plastic part
Result: PCB will be lost

Number of fragments: 1
Weight fragments: 0,7 gram

* (dependent on orientation on conveyer)

*Figure L1: Sandwich mixed fragments*

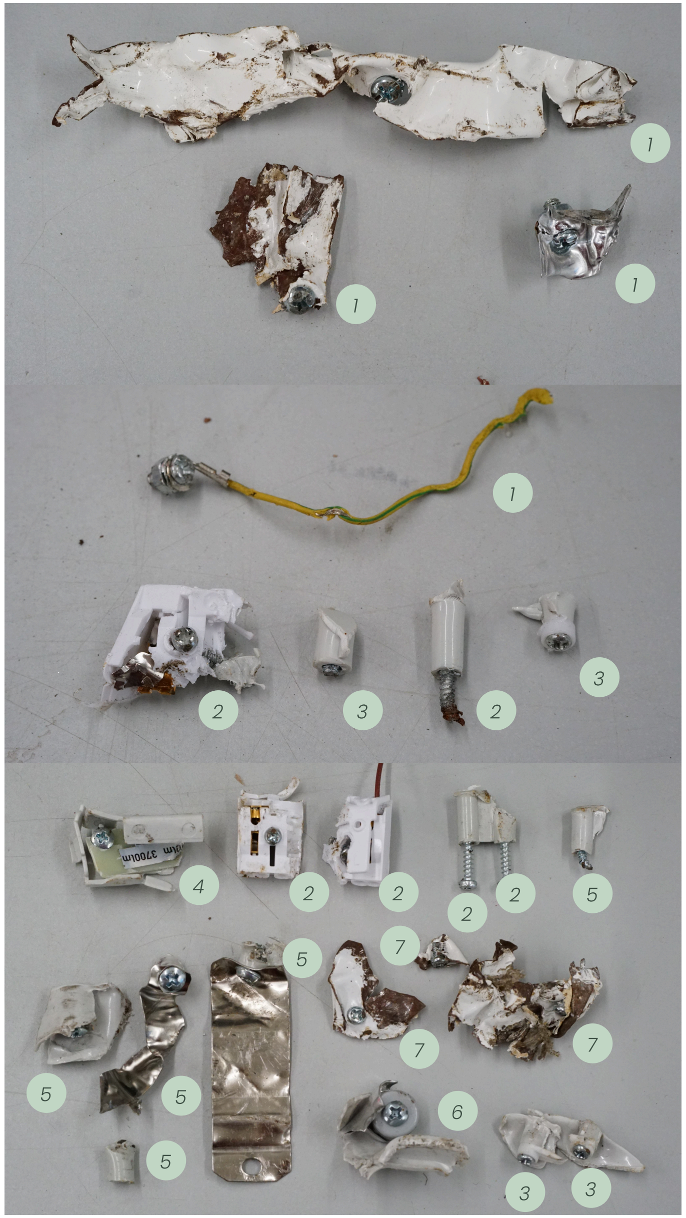


*Figure L2: Screws Sandwich analysed*

1. Nut/bolt connections (4x)
2. Connector screws (6x)
3. Pull safe screws (4x)
4. Slider screw (1x)
5. Driver bracket screws (5x)
6. Metal plate (1x)
7. Ledboard screw (3x)

In L2, the screws present in the Sandwich are analysed further to see where they would end up in the recycling process. The nut and bolt combinations will all end up in the ferrous fraction, just as the LED board, metal plate driver bracket screws. The rest ends up in the sinking plastics fraction and will be lost completely (10 screws).

## L3: Sandwich individual connections liberation

In Table L3, the liberation percentages can be found for every connection present in the Sandwich. The problematic connections are all screws except for the ledboard screws, the nut-and-bolt connections and the friction fit gaskets. After that, the soldered led board connections and connector-wire connections are low liberated ones. A summary is given in Table L4.

*Table L4: Liberation connections Sandwich summary*

| | C1 | C2 | C3 | Total Connections | Total remained | Liberation rate | Notes |
|---|---|---|---|---|---|---|---|
| **Screws** | 34 | 10 | 6 | **50** | **20** | **60%** | Almost all non-ledboard screws |
| **Nut/bolt** | 1 | 2 | 1 | **4** | **4** | **0%** | All nut-bolt connetions |
| **Soldering** | 4 | 5 | 2 | **11** | **6** | **45%** | 6 ledboard connections |
| **Snap fits** | 48 | 48 | 43 | **139** | **3** | **98%** | 3 metal clips in PC housing |
| **Tie wraps** | 2 | 0 | 1 | **3** | **0** | **100%** | |
| **Friction fit** | 4 | 4 | 5 | **13** | **4** | **69%** | All housing gaskets and one cable gland gasket |
| **Connector-wire** | 12 | 12 | 12 | **36** | **17** | **53%** | |
| | | | | | | | |
| **Total** | | | | **256** | **54** | **79%** | |

*Table L3: Liberation connections Sandwich*

| | C1 | C2 | C3 | Total | Remained | % remained | Liberation | |
|---|---|---|---|---|---|---|---|---|
| **Screws** | Connector - housing (2) | Connector - housing (2) | Connector - housing (2) | 6 | 6 | 100% | 0% | * 2 screws in connector only, 2 in PC only, 2 half in PC only |
| | Leboard - reflector (30) | Ledboard - reflector (1) | Ledboard - reflector (1) | 32 | 3 | 9% | 91% | * 1 screw still connects the led board, the other 2 are only in the reflector |
| | Driver bracket & ground wire - housing (2) | Driver bracket & ground wire - housing (2) | Driver bracket & ground wire - housing (1) | 5 | 5 | 100% | 0% | * 3 with metal, 2 only screw in PC |
| | | Pull safe - housing (2) | Pull safe - housing (2) | 4 | 4 | 100% | 0% | * 1 found in fragments |
| | | Metal plate - housing(2) | | 2 | 1 | 50% | 50% | |
| | | Slider pcb - slider casing (1) | | 1 | 1 | 100% | 0% | |
| | | | | | | | | |
| **Nut/Bolts** | Ground wire - reflector (1) | Ground wire - reflector (1) | Ground wire -reflector (1) | 3 | 3 | 100% | 0% | |
| | | Ground wire - metal plate (1) | | 1 | 1 | 100% | 0% | |
| | | | | | | | | |
| **Soldering** | Ledboard - wire (4) | Ledboard - wires (2) | Ledboard - wires (2) | 8 | 6 | 75% | 25% | |
| | | Slider pcb - wires (3) | | 3 | 0 | 0% | 100% | |
| | | | | | | | | |
| **Snap fits** | Retention cords - metal clips (4) | Retention cords - metal clips (4) | Retention cords - metal clips (4) | 12 | 0 | 0% | 100% | |
| | Metal clips enclosure - cover (12) | Metal clips enclosure - cover (12) | Metal clips enclosure - cover (10) | 34 | 0 | 0% | 100% | |
| | Ledboard - optical cover (8) | Ledboard - optical cover (8) | Ledboard - optical cover (6) | 22 | 0 | 0% | 100% | |
| | Metal clips enclosure - housing (12) | Metal clips enclosure - housing (12) | Metal clips enclosure - housing (10) | 34 | 3 | 9% | 91% | |
| | Driver top case - Driver bottom case (6) | Driver top case - Driver bottom case (6) | Driver top case - Driver bottom case (6) | 18 | 0 | 0% | 100% | |
| | Driver PCB - Driver bottom (4) | Driver PCB - Driver bottom (4) | Driver PCB - Driver bottom (4) | 12 | 0 | 0% | 100% | |
| | Wires ledboard side - wire Driver side (1) | | Wires ledboard side - wire Driver side (1) | 2 | 0 | 0% | 100% | |
| | Wires - housing (1) | | Wires - housing (2) | 3 | 0 | 0% | 100% | |
| | | Slider pcb - casing pcb (1) | | 1 | 0 | 0% | 100% | |
| | | | | | | | | |
| **Tie wraps** | Ledboard cables - housing (1) | | | 1 | 0 | 0% | 100% | |
| | Ledboard cables - reflector (1) | | Ledboard cables - reflector (1) | 2 | 0 | 0% | 100% | |
| | | | | | | | | |
| **Friction fit** | Gasket - housing (1) | Gasket - housing (1) | Gasket - housing (1) | 3 | 3 | 100% | 0% | |
| | Gasket - cable gland (1) | Gasket - cable gland (1) | Gasket - cable gland (1) | 3 | 1 | 33% | 67% | |
| | Driver bracket - driver (1) | Driver bracket - driver (1) | Driver bracket - driver (1) | 3 | 0 | 0% | 100% | |
| | | | Cable - cable gland (1) | 1 | 0 | 0% | 100% | |
| | | Ledboard - reflector (1) | Ledboard- reflector (1) | 2 | 0 | 0% | 100% | |
| | Metal tube - wires (1) | | | 1 | 0 | 0% | 100% | |
| | | | | | | | | |
| **Connector-wire** | Connector - wire (6) | Connector - wire (6) | Connector - wire (6) | 18 | 3 | 17% | 83% | |
| | Driver - wire (5) | Driver - wire (6) | Driver - wire (5) | 16 | 7 | 44% | 56% | |
| | Click cable connection ledboard - driver (1) | | Click cable connection ledboard - driver (1) | 12 | 7 | 58% | 42% | *wires in connection pieces |

## L4: Tubular material flow

In Table L5, the input and output weight per material category have been weighted. The material loss has been calculated per material and as percentage of the total weight of the luminaire. The greatest material losses are in the rubber (83%), wire enclosure (80%), other plastics (65%), PCB (59%) and silicone fraction (55%). Compared to the total weight, the most losses are present in the PC (6%) and ferrous fraction (14%).

*Table L5: Tubular material flow*

| | Input | Output | Material loss | Material gain/loss compared to total weight |
|---|---|---|---|---|
| **Homogenous fragments** | | | | |
| **Ferrous** | 6730,4 | 4834,1 | -28% | -14% |
| **Non-ferrous** | 12,6 | 10,0 | -21% | 0% |
| **Floating plastics** | | | | 0% |
| Silicone | 24,5 | 11,0 | -55% | 0% |
| Flimsy PC | 0,0 | 24,0 | | 0% |
| **Sinking plastics** | | | | 0% |
| PC | 4933,0 | 4113,0 | -17% | -6% |
| Rubber | 17,4 | 2,9 | -83% | 0% |
| Wire enclosure | 24,5 | 5,0 | -80% | 0% |
| Other (PA + plastic driver) | 37,0 | 13,0 | -65% | 0% |
| | | | | |
| **Electronics** | | | | |
| Led boards | 852,0 | 550,0 | -35% | -2% |
| PCB | 476,7 | 197,0 | -59% | -2% |
| Copper (wires/cables) | 309,2 | 215,0 | -30% | -1% |
| Other | 75,9 | 63,0 | -17% | 0% |
| | | | | |
| **Other** | | | | |
| Mixed fragments | | 964,0 | | 7% |
| Too small to sort | | 1098,0 | | 8% |
| Lost * | | 1393,1 | | 10% |
| | | | | |
| **Total** | **13493,1** | **12100,0** | **-10%** | |

## L5: Tubular mixed fragments

In Table L6 and Figure L3 and overview of the mixed fragments can be found, together with their occurrence and what is likely to happen with the fragments (based on recyclers interviews). For the Tubular, ferrous material folding problem is the most problematic one. After that, the mixed PC fragments because of the glue and the silicone in PC are the problematic ones.

The screws are the 8th biggest problem. Looking at those 8 screws in Figure L4 it becomes clear that they all end up in the ferrous fraction as they are all stuck in steel. Only some cables, cable shoes and rope pieces will be lost.

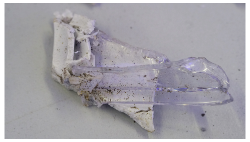

1. Cable/rope and cable shoe to gear tray (4x)
2. Connector/sensor bracket (4x)

*Figure L4: Screws Sandwich analysed*

*Table L6: Tubular material flow*

| | Assumed end-fraction | Amount | Weight |
|---|---|---|---|
| **Steel mix** | | | |
| Ferrous - Sticker | Ferrous fraction | 2 | 24 |
| Ferrous - Driver plastic | Ferrous fraction | 21 | 52 |
| Ferrous - PCB + driver plastic | Ferrous fraction | 26 | 128 |
| Ferrous - Led-boards | Ferrous fraction | 4 | 28 |
| Ferrous - Rubber + cable | Ferrous fraction | 14 | 63 |
| Ferrous - PC | Ferrous fraction | 34 | 213 |
| Ferrous - PC+PCB | Ferrous fraction | 3 | 22 |
| Ferrous - PCB | Ferrous fraction | 4 | 18 |
| Ferrous - Cable | Ferrous fraction | 2 | 17 |
| Ferrous - Connector | Ferrous fraction | 1 | 7 |
| | | | |
| **Connections** | | | |
| Lens plates - Screws | Sinking plastic fraction: Burn | 9 | 32 |
| Led board - Metal connection | Copper fraction | 4 | 5 |
| PC - ledboard connection | Sinking plastic fraction: Burn | 7 | 11 |
| Rubber - ledboard wires | Copper fraction | 11 | 5,9 |
| End-cap screws | Sinking plastic fraction: Burn | 9 | 46 |
| Screws | Ferrous fraction | 8 | 36 |
| Connector - PCB | Or copper fraction or sinking plastics | 8 | 9,9 |
| Connector - Wires | Sinking plastic fraction: Burn | 3 | 5,9 |
| Rope - cable shoe | Copper fraction | 5 | 2,3 |
| Cable - cable shoe | Copper fraction | 7 | 6 |
| Enclosure rope - cables | Copper fraction | 1 | 23 |
| Tie wrap | Ferrous fraction | 1 | 4 |
| Rivet | Ferrous fraction | 2 | 9 |
| | | | |
| **PC mix** | | | |
| PC - Silicone | Floating plastics fraction | 79 | 102 |
| Mixed PC | Sinking plastic fraction | 65 | 103 |
| Led board - PC | Or copper fraction or sinking plastics | 5 | 8 |
| | | | |
| | | | |
| | **Total** | **335** | **981** |

## PC mixed

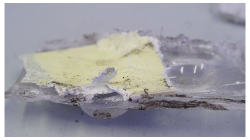


Problem: Mixed PC fragments
Result: Glue & GF will contaminate PC fraction

Number of fragments: 65
Weight fragments: 103 gram

Problem: Silicone gaskets remain on/in PC
Result: Fragments contaminate plastic float fraction or PC fraction

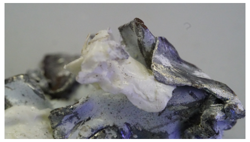
Number of fragments: 79
Weight fragments: 102 gram



Problem: Led board remains on the lens plates
Result: Either the led board or PC will be lost?

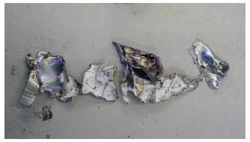
Number of fragments: 5
Weight fragments: 8 gram

## Metal folding



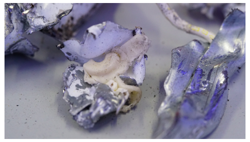
Problem: Metal driver folds around a connector
Result: Plastic will be lost

Number of fragments: 1
Weight fragments: 7 gram



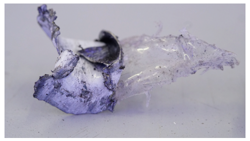
Problem: Metal driver folds around PCB
Result: Valuable PCB materials will be lost

Number of fragments: 4
Weight fragments: 18 gram



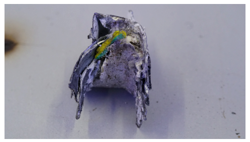
Problem: Metal driver folds around rubber grommets & ledboard cables
Result: Rubber & copper will be lost

Number of fragments: 14
Weight fragments: 63 gram



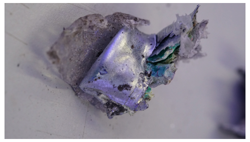
Problem: Metal driver folds around PC
Result: PC will be lost

Number of fragments: 15
Weight fragments: 66 gram



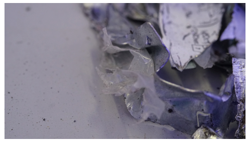
Problem: Metal driver folds around a cable
Result: Copper will be lost

Number of fragments: 2
Weight fragments: 17 gram



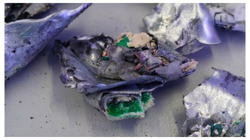
Problem: Metal driver folds around PC and PCB
Result: Valuable PCB materials and PC will be lost

Number of fragments: 3
Weight fragments: 22 gram



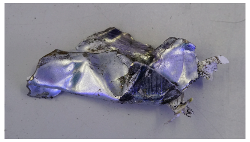
Problem: Metal driver folds around plastic layer driver
Result: Plastic from driver will be lost

Number of fragments: 21
Weight fragments: 52 gram



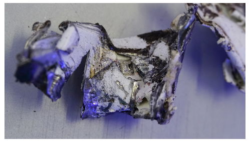
Problem: Metal driver folds around plastic layer driver and PCB
Result: Plastic from driver and valuable PCB materials will be lost

Number of fragments: 26
Weight fragments: 128 gram



Problem: Stickers remain on ferrous metal
Result: Stickers will burn away

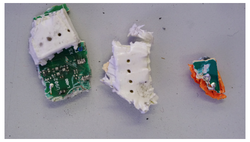
Number of fragments: 2
Weight fragments: 24 gram



Problem: Metal driver folds around led board
Result: Led board materials will be lost

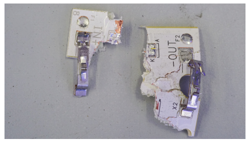
Number of fragments: 4
Weight fragments: 28 gram

## Connections



Problem: Connector stays on PCB
Result: Either plastics or PCB lost (dependent on placement on conveyer)

Number of fragments: 8
Weight fragments: 9,9 gram



Problem: Led board metal connection remains in the led board
Result: Led board metal connection (alu or rvs) will be lost

Number of connections remained: 4 out of 28
Weight fragments: 5 gram

Problem: Led board metal connection remains in the lens plates
Result: Led board metal connection will be lost, too small to detect

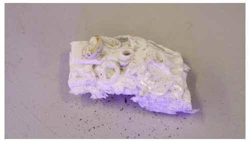
Number of connections remained: 7 out of 28
Weight fragments: 11 gram

Problem: Connection between rubber grommets and cables remain
Result: Rubber will be lost

Number of connections remained: 11 out of 24
Weight fragments: 5,9 gram

Problem: Enclosure remains around cable
Result: Probably enclosure rope is lost, enclosure rope is fume

Number of fragments: ??
Weight fragments: 23 gram



Problem: Cable remains in connector
Result: Copper is lost

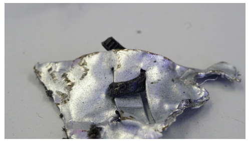
Number of fragments: 3
Weight fragments: 5,9 gram

Problem: Cable shoe remains on cables
Result: Cable shoe (aluminium) will be lost

Number of connections remained: 7 out of ??
Weight fragments: 6 gram

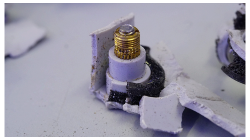
Problem: Cable shoe remains on the rope and cables
Result: Rope burned

Number of fragments: 5
Weight fragments: 2,3 gram



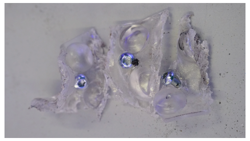
Problem: Tie wrap remains on ferrous metal
Result: Plastic tie wrap will be lost

Number of connections remained: 1 out of 4
Weight fragments: 4 gram



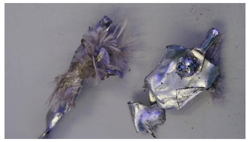
Problem: Screws and metal inserts remain in PC end-cap
Result: Most likely all materials lost

Number of connections remained: 9 out of 10
Weight fragments: 46 gram



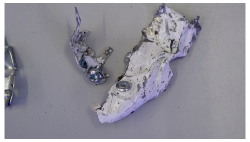
Problem: Screws remain in PC lensplates
Result: All burned

Number of connections remained: 9 out of 96
Weight fragments: 8 gram



Problem: Screws in metal
Result: All in ferrous fraction, nothing lost

Number of connections remained: 10 out of 31
Weight fragments: 39,7 gram



Problem: Rivets remain
Result: Rope or cable attached lost, aluminium lost

Number of connections remained: 2 out of 10
Weight fragments: 9 gram

*Figure L3: Screws Sandwich analysed*

## L6: Tubular individual connections liberation

In Table L7, the liberation percentages can be found for every connection present in the Sandwich. The problematic connections are the metal inserts and screws in the end cap, the glued connections, the wire into the wire enclosure and the gaskets in the end cap. After that, the screws for the rope, cables and connector and motion sensor brackets are problematic together with the wire into the rubber grommets' friction fits.

A summary of the liberation of the connections is shown in Table L8

*Table L7: Tubular liberation connections*

| | P1 | P2 | P3 | P5 | P6 | total | remained | % remained | Liberation |
|---|---|---|---|---|---|---|---|---|---|
| **Screws** | Ledboards - optics - reflector (24) | Ledboards - optics - reflector (24) | Ledboards - optics - reflector (16) | Ledboards - optics - reflector (16) | Ledboards - optics - reflector (16) | 96 | 9 | 9% | 91% |
| | End-cap - housing (2) | End-cap - housing (2) | End-cap - housing (2) | End-cap - housing (2) | End-cap - housing (2) | 10 | 9 | 90% | 10% |
| | Driver - Gear tray (1) | Driver - Gear tray (1) | Driver - Gear tray (1) | Driver - Gear tray (1) | Driver - Gear tray (1) | 5 | 0 | 0% | 100% |
| | Rope - Gear tray (1) | Rope - Gear tray (1) | Rope - Gear tray (1) | Rope - Gear tray (1) | Rope - Gear tray (1) | 5 | 2 | 40% | 60% |
| | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | 5 | 2 | 40% | 60% |
| | | | Motion sensor - Reflector (2) | Connector - Gear tray (2) | Connector - Gear tray (2) | 6 | 4 | 67% | 33% |
| **Rivets** | Rope - Reflector (1) | Rope - Reflector (1) | Rope - Reflector (1) | Rope - Reflector (1) | Rope - Reflector (1) | 10 | 2 | 20% | 80% |
| | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | Ground wire - Gear tray (1) | | | | |
| **Snap fits** | Driver top case - Driver bottom case (6) | Driver top case - Driver bottom case (6) | Driver top case - Driver bottom case (6) | Driver top case - Driver bottom case (6) | Driver top case - Driver bottom case (6) | 30 | 0 | 0% | 100% |
| | Driver PCB - Driver bottom (4) | Driver PCB - Driver bottom (4) | Driver PCB - Driver bottom (4) | Driver PCB - Driver bottom (4) | Driver PCB - Driver bottom (4) | 20 | 0 | 0% | 100% |
| | Connector - Gear tray (2) | Connector - Gear tray (2) | Connector - Gear tray (2) | | | 6 | 0 | 0% | 100% |
| **Tie wraps** | Wires/wire enclosure - Gear tray (1) | Wires/wire enclosure - Gear tray (1) | Wires/wire enclosure - Gear tray (1) | Wires/wire enclosure - Gear tray (1) | Wires/wire enclosure - Gear tray (1) | 10 | 1 | 10% | 90% |
| | Wires/wire enclosure - Reflector (1) | Wires/wire enclosure - Reflector (1) | Wires/wire enclosure - Reflector (1) | Wires/wire enclosure - Reflector (1) | Wires/wire enclosure - Reflector (1) | | | | |
| **Glue** | End cap part - tube (2) | End cap part - tube (2) | End cap part - tube (2) | End cap part - tube (2) | End cap part - tube (2) | 10 | 10 | 100% | 0% |
| **Friction fit** | Metal spring - Gear tray (1) | Metal spring - Gear tray (1) | Metal spring - Gear tray (1) | Metal spring - Gear tray (1) | Metal spring - Gear tray (1) | 5 | 0 | 0% | 100% |
| | Metal spring - Reflector (1) | Metal spring - Reflector (1) | Metal spring - Reflector (1) | Metal spring - Reflector (1) | Metal spring - Reflector (1) | 5 | 0 | 0% | 100% |
| | Gear tray - reflector (1) | Gear tray - reflector (1) | Gear tray - reflector (1) | Gear tray - reflector (1) | Gear tray - reflector (1) | 5 | 0 | 0% | 100% |
| | Ledboard - wire (12) | Ledboard - wire (12) | Ledboard - wire (8) | Ledboard - wire (8) | Ledboard - wire (8) | 28 | 0 | 0% | 100% |
| | Small wires - Grommets (6) | Small wires - Grommets (6) | Small wires - Grommets (4) | Small wires - Grommets (4) | Small wires - Grommets (4) | 24 | 11 | 46% | 54% |
| | Gasket - Cable gland (1) | Gasket - Cable gland (1) | Gasket - Cable gland (1) | Gasket - Cable gland (1) | Gasket - Cable gland (1) | 5 | 1 | 20% | 80% |
| | Gasket - end-cap (1) | Gasket - end-cap (1) | Gasket - end-cap (1) | Gasket - end-cap (1) | Gasket - end-cap (1) | 5 | 5 | 100% | 0% |
| | Driver - Gear tray (1) | Driver - Gear tray (1) | Driver - Gear tray (1) | Driver - Gear tray (1) | Driver - Gear tray (1) | 5 | 0 | 0% | 100% |
| | Cables - wire enclosure (1) | Cables - wire enclosure (1) | Cables - wire enclosure (1) | Cables - wire enclosure (1) | Cables - wire enclosure (1) | 5 | 5 | 100% | 0% |
| | Cable - cable gland (1) | | | | | 1 | 0 | 0% | 100% |
| **Connector-wire** | Connector - wires/Cable (5) | Connector - wires/Cable (5) | Connector - wires/Cable (5) | Connector - wires/Cable (2) | Connector - wires/Cable (6) | 23 | 2 | 9% | 91% |
| | Driver - wires (4) | Driver - wires (4) | Driver - wires (6) | Driver - wires (4) | Driver - wires (4) | 22 | 1 | 5% | 95% |
| | | | Motion sensor - wires (2) | | | 2 | 0 | 0% | 100% |
| **Metal inserts** | Metal insert - housing (2) | Metal insert - housing (2) | Metal insert - housing (2) | Metal insert - housing (2) | Metal insert - housing (2) | 10 | 9 | 90% | 10% |

*Table L8: Tubular liberation connections*

| | P1 | P2 | P3 | P5 | P6 | Total Connections | Total remained | Liberation rate | |
|---|---|---|---|---|---|---|---|---|---|
| **Screws** | 29 | 29 | 23 | 23 | 24 | **128** | **26** | **80%** | 9 endcap, 9 on lensplates, 4 for connector or motion sensor brackets, 4 for rope/cable to gear tray |
| **Rivets** | 2 | 2 | 2 | 2 | 2 | **10** | **2** | **80%** | |
| **Snap fits** | 12 | 12 | 12 | 10 | 10 | **56** | **0** | **100%** | |
| **Tie wraps** | 2 | 2 | 2 | 2 | 2 | **10** | **1** | **90%** | |
| **Glue** | 2 | 2 | 2 | 2 | 2 | **10** | **10** | **0%** | |
| **Friction fit** | 26 | 25 | 19 | 19 | 19 | **108** | **27** | **75%** | all end cap gaskets (5), 1 cable gland gasket, 11 grommets/cables, all wire-enclosure |
| **Connector-wire** | 9 | 9 | 13 | 7 | 11 | **49** | **3** | **94%** | 2 running to connector, 1 running to driver connector |
| | | | | | | | | | |
| **Total** | | | | | | **371** | **69** | **81%** | |

## L7: Tubular Liberation silicone

Looking at the mixed fragments with extruded silicone (total weight of 148 gram), a short analysis was conducted to see how much of these fragments would still exist, if a gasket was used over an extruded silicone. 110 grams of total 148 gram mixed silicone fragments would not be mixed, if a gasket was used. This was determined by looking at the fragments and see if the silicone is clamped in two sides (see Figure L4) or is solely glued (see Figure L5). 32 grams of the mixed fragments would for sure be problematic, the leftover 6 grams were debatable. From the 32 grams, four fragments existed because the gasket in the cable gland remained, two because the screws clamped the silicone in and two because of the curvature of the end cap (see Figure L6). Therefore, there can be assumed that a silicone gasket would liberate much better than the extruded version. The design of the end cap prevents clamping of silicone due to one edge and one block at the other side. For the Sandwich, the gasket was placed in between 2 edges, resulting this to clamp the silicone in in some cases when shredded.

*Figure L4: Clamped in silicone Tubular*

*Figure L5: Tubular solely glued silicone*

*Figure L6: Fragments which will remain mixed when using a gasket (top 4 due to cable gland, left bottom 2 due to curvature end-cap, right bottom 2 due to screws)*

## L8: Tubular metal folding

In total 572 gram mixed steel fragments were present for the Tubular. To see which metal part creates the biggest problem, the fragments have been analysed more

- 294 gram of the mixed fragments is caused by the reflector
  - 6.8% of the reflector parts is a mixed fragment
- 126 gram of the mixed fragments is caused by the driver casing
  - 22.6% of the driver casing is a mixed fragment
- 99 gram of the mixed fragments is caused by the gear tray
  - 7.3% of the gear tray is a mixed fragment

In percentages, the driver casing is causing the most problems, in absolute weights the reflector.

# Appendix M: Redesign directions defined

From all analyses conducted an overview has been made of all redesign directions for the Sandwich, Tubular and both combined.

| Sandwich | Tubular | Both |
|---|---|---|
| **Installation** | | |
| Reduce cluttering inside the luminaire because of feed-though and emergency batteries | Improve the accessibility of the connector resulting from the slide-out system and metal spring mechanism | Facilitate disassembly for recycling |
| Avoid clamped parts during luminaire closure | Improve the accessibility and positioning of the emergency batteries | Standardise spare parts |
| Improve low-effort entry into the luminaire | | Reduce packaging |
| **Repair/ease of disassembly** | | |
| Allow easy entry into the luminaire through low force metal enclosure clips | Allow easy entry into the luminaire, through minimizing high intensity actions of undoing the metal springs | |
| Allow quick and intuitive access to the LED board | Improve accessibility of the internal components on the ladder | |
| Improve the disassembly of the LED boards by using reusable connections only | Allow intuitive access to the driver | |
| Prevent the use of many fasteners and small parts in one fastening connection (O-rings, nuts and bolts) | Allow quick accessibility to the LED boards, by avoiding too many screws | |
| | Improve the disassembly of the LED boards by using reusable and intuitive LED board connections | |
| **Recycling** | | |
| Improve the liberation rate of steel screws from plastic parts | Improve the liberation rate of metal inserts and screws from the plastic end caps and the tube | Minimise pollution of the floating plastics fraction as a result of the silicone seal |
| | Minimize pollution of the plastic stream because of glue and glass fibres in the end cap | Improve the recovery rate of precious materials like PCBs and LED boards, by minimizing steel folding |
| | Improve the practical material recyclability of the wire enclosure and liberation rate of the wires held together with this enclosure | Improve the practical material recyclability of Polycarbonate |

# Appendix N: List of requirements and wishes

From the analysis in chapters 3, 4, 5 and 6, criteria have been created. Together with product-related criteria and wishes from the company, a program of requirements and wishes can be generated. In the tables, the criteria are mentioned together with the reasoning why they are important and where they originate from.

## N1 List of requirements

| Requirement | Explanation | Source |
|---|---|---|
| Keep IP66 and IK08 ratings | Application requirements, to withstand water, dust, chemicals and mechanical hits in the environment | Ch6, Product manager |
| The luminaire can be installed with existing cables on the spot | Allow retrofit installation, where cables are present on site | Ch3, installers |
| The luminaire can be pre-installed with a cable on a table before bringing it on site | To allow installation in more extreme applications (to limit time on site) and where cables on site are not present | Ch3 |
| The batteries are accessible and replaceable every four years on site, on the spot | Repair is allowed this way, and less time needed for repairs. Less waste will be created | Ch3 & 4 |
| Installation can be done by one person for luminaires <1.8m | To limit installation time and labour costs and make installation easy | Ch3 |
| The driver and led board are accessible and replaceable | Repairability of the luminaire will be allowed, and is required by the right to repair directive | Ch4 |
| The quality of the product is good, so it does not break when handling it | To avoid faults during instalment and during product lifetime | Ch3 |
| The product parts can be made in the factory | To make sure the product is feasible | Product architect |

## N2 List of wishes

| Wishes | Explanation | Source |
|---|---|---|
| **Installation** | | |
| The installation time is as little as possible and requires only a few steps | To improve the ease of installation and limit time on site | Ch3, Installers |
| There is enough flexibility in the mounting system attachment | To ease the mounting steps, precise marking is not needed anymore | Ch3, installers |
| The mounting system is consistent over different generations of the product | Mentioned by installers as a pre in retrofit installation | Ch3, installers |
| The connector is easily accessible when working above your head | To improve the ease of installation of the cable | Ch3, installers |
| The number of spare parts and amount of packaging is minimized as much as possible | Mentioned by installers as a hassle, also packaging waste will be minimized | Ch3, installers |

| Accessibility for maintenance & disassembly | | |
|---|---|---|
| Quick diagnosis of the problem on site, after which repair can immediately take place. | The problem diagnosis should be quick and easy to limit time on site and labour costs and this way make repair profitable | Ch3, Ch4 installers |
| The battery, driver and led board should be quickly, easily and intuitively accessible and replaceable on the spot | Parts should be replaceable by directive and in need of replacement most often. Allow proper access makes repair costs profitable over replacing the complete luminaire | Ch3, Ch4 |
| The number of steps to reach the battery, driver and led board is no more than 5 | | Ch4 |
| Spare parts are standardized | A spare part can always be ordered and will always fit in the luminaire and thus be replaced on the spot | Ch3, Ch4 |
| Parts in need of maintenance are within a few steps accessible on the spot | To limit time on site and limit labour costs | Ch3 & 4 |
| The product allows upgradability of parts | To facilitate Interact pro and Dali components, in need of upgrading every 2 years | Ch3 |

| | | |
|---|---|---|
| The luminaire allows easy and low effort entry to all internal components | Access to all components at once improves the accessibility and limits repairability time | Ch4 |
| The opening and closing of the luminaire can be done quick and easy and requires little effort and tools | Improves installation, maintenance and repairability time | Ch3, Ch4, installers |
| Parts are prevented from getting in between the closure of the luminaire (e.g. wires) | Avoid failing parts and improve installation, maintenance and repairability efficiency | Ch3, 4, installers |
| The parts can be reassembled the same way and is straightforward | Avoid parts to be dislocated, not fully waterproof and facilitate good repair | Ch4 |

| **Fasteners and tools** | | |
|---|---|---|
| The connectors are visible from the position of the installer (below the luminaire) | To improve ease of installation, repair and maintenance on the spot | Ch4 |
| The connectors can be accessed while standing on one spot | To facilitate repair and maintenance on the spot | Ch4 |

| | | |
|---|---|---|
| The connectors that need to be undone to reach a repairable part are all reusable | To allow reassembly of the parts keeping technical, and application requirements intact | Ch4 |
| The use of fasteners per part is minimized | To improve time needed for repair & maintenance | Ch4 |
| Undoing connectors requires little time and low effort | To improve efficiency repair & maintenance | Ch4 |
| Little different tools are needed | | Ch4 |
| The number of tools needed to undo one connector is maximized to one | To improve efficiency repair & maintenance | Ch4 |
| Small loose parts cannot be lost easily | Facilitate successful repair and maintenance on the spot at the ceiling | Ch4 |

| **Deinstallation** | | |
|---|---|---|
| The luminaire can be quickly deinstalled and removed | Allow efficient deinstallation | Ch3 |
| Disassembly of the luminaire to prepare for recycling can be done quickly without requiring extra tools | Allow better part liberation in recycling | Ch 3, Ch5, installers |

| **Recyclability liberation** | | |
|---|---|---|
| Homogenous liberation of valuable, non-recyclable and incompatible materials should be as high as possible | Improve material recovery and limit pollution of fractions | Ch5 |
| The PCB and led boards should liberate completely | Improve material recovery of valuable materials | Ch5 |
| The silicone seals should liberate completely | Avoid material pollution in the floating plastics fraction | Ch5 |
| Glue should dissolve in the separation phase of the recycling process | Avoid material pollution in the floating plastics fraction | Ch5 |
| Metal inserts, screws and nuts-and-bolts should liberate completely from plastics | Improve material recovery of plastics | Ch5 |
| The batteries are easy to identify, access and remove in the depollution phase of recycling | Avoid dangerous situations in the recycling process | Ch5, recycler |
| The use of additives and coatings in plastics and metals should be minimized as much as possible | Improve material recovery and avoid material pollution | Ch5 |

| **Recyclability material use** | | |
|---|---|---|
| If possible, make use of plastics with a density < 1.1 kg/l | Improve practical material recyclability of the product | Ch5 |
| For plastics with a density >1.1 kg/l, an end-of-life process plan is set up to recycle these materials further | Increase material recovery of all materials | Ch5 |
| Materials (apart from PP, PS, ABS and PE) ending up in the plastic fraction with a density smaller than 1.1 kg/l are minimized | Avoid material pollution in the floating plastics fraction | Ch5 |
| There are no non-recyclable materials used, or, if used, they liberate completely. E.g. silicone, rubber, silicone impregnated fibreglass fabric and ropes | Improve recyclability of the product and avoid material pollution | Ch5 |

| **Feasibility** | | |
|---|---|---|
| The redesign fits (with only small changes) within the current luminaire dimensions and shapes | This way implementation can be done easily and quickly, and the design language stays similar, desired by product manager and architect | Product manager, product architect |
| Little new parts have to be added to the luminaire | This way implementation can be done easily and quickly, desired from product manager and architect | Product manager, product architect |
| The number of parts and materials can be reduced | To improve recyclability and manufacturing of the product | |
| The redesign can fit in different lengths of the product | Giving more options to the user and it can be placed in more locations | Product portfolio |

| **Costs** | | |
|---|---|---|
| The costs should be as low as possible | Keep sales up and gain profits | Product architect |
| Extra costs made weigh up against the benefits it brings | Create value for more money, so price increases can be explained | Product architect |

| **Look and feel** | | |
|---|---|---|
| The redesign language of the tube stays as intact as possible | Keeping the unique selling point of the Tubular intact | Product manager |
| The optics of the luminaire remain unchanged | Allow different product configurations and look & feel for the client | Product architect |

| **Innovation** | | |
|---|---|---|
| The redesign shows inspiring solutions | To use this research within the team and use it in further research | The company |
| The redesign fits within current or upcoming research within the company | Research can be used later on within the company | The company |

# Appendix O: Problem selection

After the choice has been made to redesign the Tubular, a few problems need to be selected to continue with. This has been done by looking at how much impact the problem has, if it influences the installation, recycling or ease of disassembly, and how complex and innovative it is.

**Severity problem:**
For installation, it is determined by how many times the problem was mentioned and how much impact this problem has on the installation. For repair, it is determined by how it hinders the repairability process and how well a priority part can be repaired. For recycling, it is determined by how much impurities occur, how much materials are lost and how often it occurs as mixed fragment.

**Installation, recycling, and disassembly:**
This tells if the problem is present in more domains than 1 (score 2), or will influence another domain if changed (score 1).

**Complexity**
Tells how complex the problem is to solve. Ideally, a more complex problem is more interesting to solve, a disadvantage can be that it is hardly possible to solve. For now, a high complexity is preferred, until proven impossible to solve.

**Innovation**
For the company, it is valuable to select problems which are innovative if solved.

The slide-out system, the emergency batteries, access to internal components, the silicone seal and the metal folding problem have been selected as the most interesting problems.

The scores given are shown in Table O1.

*Table O1: Redesign direction selection Tubular*

| | Severity problem | Installation | Recycling | Disassembly | Complexity | Innovation | |
|---|---|---|---|---|---|---|---|
| | 2x | 0 = no impact, 1 = will be influenced, 2 = great impact | | | 1x | 1x | |
| **Installation** | | | | | | | |
| Slide out system | 5 | 2 | 0 | 2 | 5 | 5 | **24** |
| Emergency batteries | 5 | 0 | 2 | 2 | 5 | 5 | **24** |
| Disassembly end-of-life | 3 | 0 | 2 | 2 | 3 | 4 | **17** |
| Packaging | 3 | 2 | 0 | 0 | 1 | 1 | **10** |
| | | | | | | | |
| **Repair** | | | | | | | |
| Undo metal springs | 4 | 2 | 0 | 2 | 3 | 3 | **18** |
| Internal component access | 5 | 0 | 1 | 2 | 4 | 4 | **21** |
| Access LED board | 3 | 0 | 1 | 2 | 3 | 3 | **15** |
| Metal LED board connections | 4 | 0 | 1 | 2 | 2 | 3 | **16** |
| Access gear tray | 3 | 0 | 0 | 2 | 1 | 2 | **11** |
| | | | | | | | |
| **Recycling** | | | | | | | |
| Silicone seal | 5 | 0 | 2 | 0 | 5 | 5 | **22** |
| Steel folding | 5 | 0 | 2 | 0 | 5 | 4 | **21** |
| Use of PC | 4 | 0 | 2 | 0 | 5 | 4 | **19** |
| Metal inserts | 4 | 0 | 2 | 1 | 4 | 4 | **19** |
| Glue PC | 3 | 0 | 2 | 1 | 4 | 3 | **16** |
| Cables in enclosure and rubber | 2 | 0 | 2 | 1 | 2 | 1 | **10** |

# Appendix P: Competitor analysis

To gather inspiration for the ideation phase, a competitor analysis has been conducted. Below competitors Glamox, Etap, Sammode and Trilux will be discussed

## P1: Access to the battery

Glamox (n.d.) makes use of a battery hatch, which can be opened, de-plugged and where several small batteries can be removed.

They also make use (in another luminaire) of a hatch to access the connector.

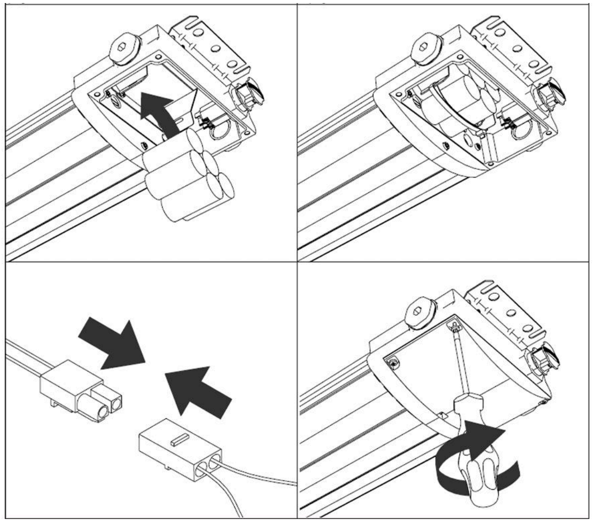


*Figure O1: Battery hatch*

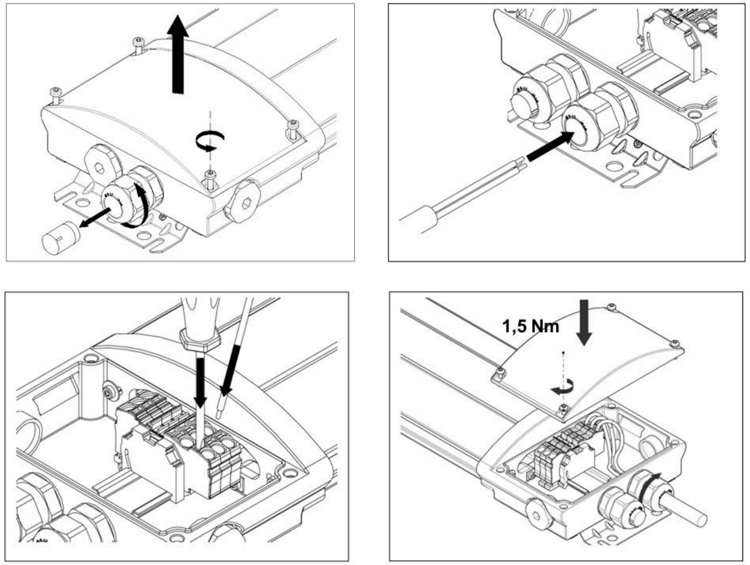



*Figure O2: Connector hatch*

## P2: Access to the connector

Etap uses a removable hatch keeping the tray with the connector in place. It also uses a slide mechanism to access the connector (ETAP Lighting International, 2015).

Trilux (n.d.) makes use of a loose connector which can be pulled out

Sammode (2024) has different connectors, including this connector, which is placed on the end cap and consists of two parts. In one of the parts, the cables are installed and clicked into the other part.

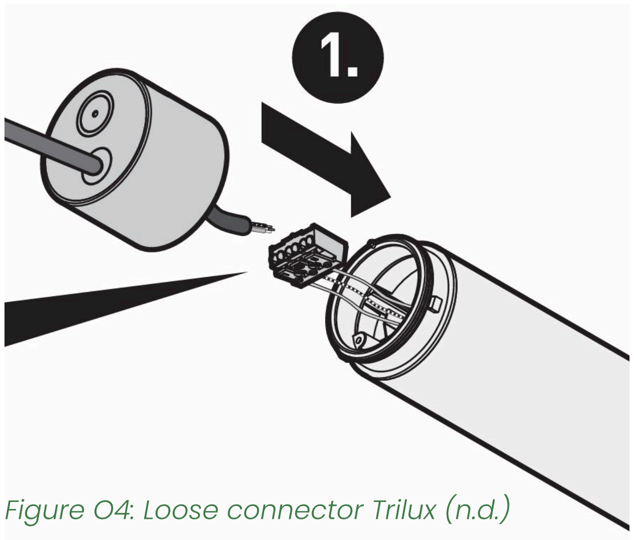



*Figure O4: Loose connector Trilux (n.d.)*

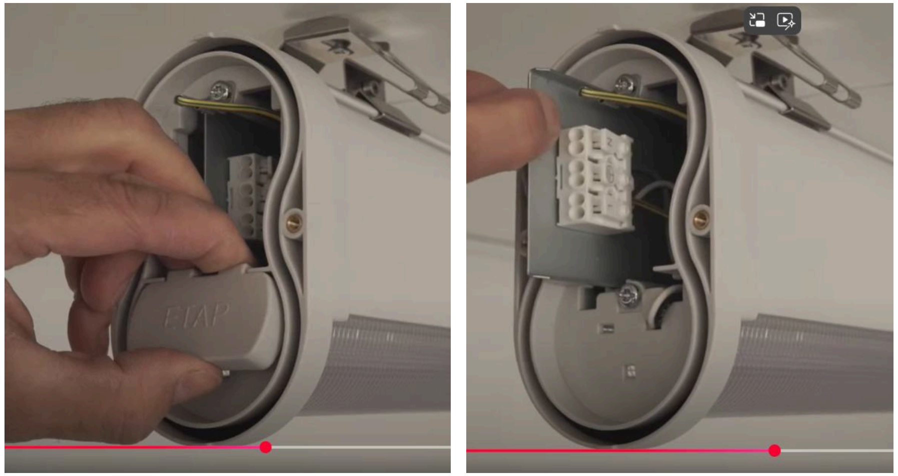


*Figure O3: Removable hatch and slide mechanism Etap*

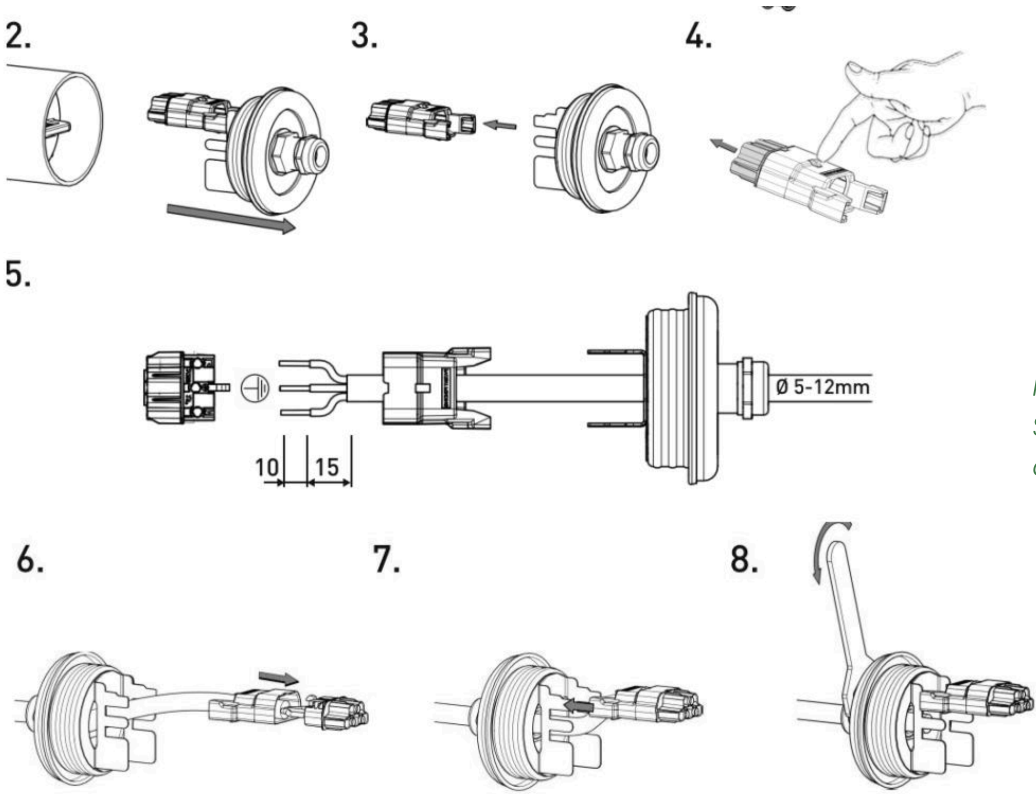



*Figure O5: Sammode connector*

# Appendix Q: Ideation and idea rejection

Due to confidentiality, this Appendix
is not available in this publication

# Appendix R: Pugh matrix

Due to confidentiality, this Appendix is not available in this publication

# Appendix S: Exploded view and BOM redesign

Due to confidentiality, this Appendix is not available in this publication

# Appendix T: Turning mechanism

Due to confidentiality, this Appendix
is not available in this publication

# Appendix U: Iteration on closing mechanism

Due to confidentiality, this Appendix
is not available in this publication