Design for refurbishment of child car seats

Towards circular safety critical products

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Abstract

This graduation project investigates the challenges of designing a safety critical consumer product suitable for the refurbishment loop of the circular economy through a case study on child car seats. Currently when child car seats are reused or resold on the second-hand market, their safety cannot be guaranteed as it is unknown whether the child car seat has previously been involved in a car accident. When child car seats are integrated in a refurbishment system, their safety can be guaranteed and thus their lifespan of safe use can be elongated.

The refurbishment of child car seats starts with determining whether the child car seat has been in a crash, for example by integrating impact sensors in the child car seat through which the history of a child car seat can be known. Subsequently, it consists of inspecting all priority parts which are the parts most relevant for refurbishment because of their functional importance, failure frequency, and economic and environmental value. Based on these aspects, the priority parts of baby car seats are determined. The parts with the highest functional priority in child car seats are the parts that fulfil a safety critical function: either the part is responsible for the absorption of the crash impact, or the part contributes to the correct installation of the child in the child car seat or of the child car seat in the car.

Three existing baby car seats and ISOfix bases are assessed on their ease of disassembly following the Hotspot Mapping method and the results are visualised in a Disassembly Map showing their disassembly sequence and product architecture. Based on this analysis it can be concluded that currently not all priority parts of both baby car seats and ISOfix bases are removable and that the product architecture of these product can be further improved for ease of disassembly and thus for refurbishment. The Disassembly Depth Index is developed to illustrate the level of parallelism within a product's disassembly sequence.

A set of guidelines is established which can be used to design safety critical consumer products tailored to refurbishment. This set of guidelines firstly incorporates guidelines specifically for safety critical products and furthermore consists of guidelines for product architecture, materials, and fasteners. To illustrate these guidelines a redesign of a baby car seat and of an ISOfix base has been made. These products are improved for refurbishment through the elimination of non-priority parts, by making safety critical parts removable and bringing them to the surface, by increasing the level of parallelism in the disassembly sequence, and by substituting materials with alternatives better suited for refurbishment.

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1 Introduction

The world is slowly starting to transition from a linear to a circular economy, as we realise that with the current system, the limits of the earth's resources are reached. The circular economy represents a system where the values of materials and products are maintained by repeatedly cycling through different uses, replacing the current 'end-of-life' concept.

The integration of products into circular business models has increased in the past years and so has the research regarding the implementation of the principles of the Circular Economy on product design. There is, however, one type of product currently underexposed in relation to their suitability for the Circular Economy, namely safety critical consumer products. Examples of safety critical products are helmets, safety glasses, climbing gear, and protective clothes.

Safety critical consumer products form a special case since it is of utmost importance that they function up to their originally intended standard. It is not acceptable for safety critical products to function 'somewhat', unlike how a vacuum cleaner can still be seen as functional even though it misses a wheel. For this reason, the safety critical functioning of these products need to be guaranteed before they can be reused again by someone else and this could be achieved through refurbishment. However, it is unclear how well current safety critical products fit refurbishment and thus the main research question of this graduation project will be:

> *"What are the challenges of designing a safety critical consumer product suitable for the refurbishment loop of the Circular Economy?"*

This main research question will be answered by conducting a case study on child car seats, or more specifically on baby car seats and their ISOfix bases. Child car seats fit this research project because of the high safety standards they are subject to, leading to valuable products with high quality but only a short usage period. In other words, it appears that child car seats are not used up to their optimal extend in the current linear system.

Throughout this report the following secondary research questions will be answered:

1. What ensures the safety critical functionality of child car seats?
   - Which parts of child car seats are safety critical?
   - How can safety be guaranteed for second use?
2. What is the current state of child car seats regarding refurbishability?
   - What are the most often recurring failures?
   - What is the current state regarding disassemblability?
   - What is the current ecological impact?
3. How can child car seats be redesigned for refurbishment?

First, the context of this graduation project is described, consisting of an introduction to child car seats, information about the current market, an introduction to the company Code Product Solutions, and a brief explanation of the circular economy. The chapter ends with a more extensive reflection on the refurbishment of child car seats.

In the next chapter, current baby car seats and ISOfix bases are assessed on several aspects related to refurbishment. The safety critical parts of baby car seats and ISOfix bases are determined, as well as other priority parts, and the question how safety can be guaranteed for second use is answered. The ease of disassembly of the current products is determined with the use of the method Hotspot Mapping and the disassembly sequence of these products is visualised in Disassembly Maps. The newly developed Disassembly Depth Index makes use of the Disassembly Maps to determine the level of parallelism within a product's architecture. Lastly, the environmental impact of both baby car seats and ISOfix bases is determined.
The fourth chapter introduces guidelines for design for refurbishment of child car seats, based on the findings of the previous chapters. These guidelines are divided into four categories: safety critical products, product architecture, materials, and fasteners. The guidelines are used to develop redesigns of a baby car seat and an ISOfix base, which are presented in chapter five. The sixth chapter consists of recommendations and this report ends with a conclusion.

2

Context Analysis

This chapter describes the context of this graduation project by firstly presenting what the function of child car seats is, what types of child car seats currently exist, and to what regulations they are subject to. Next is a short description of the company Code Product Solution which is one of the stakeholders of this project. Since this project has the goal of designing a more circular child car seat, a literature study of the framework of the circular economy is presented in the third part of this chapter. Lastly, the potential of refurbishment in relation to retaining the value of child car seats is outlined.

2.1 Child car seats

2.1.1 Types of child car seats

Child car seats ensure the safety of a child when travelling by car. They are also called 'Child Restraint Systems' and were originally designed with the purpose of keeping the child from crawling around the car. Unlike regular car seats, child car seats are designed to be ergonomic for the small bodies of children and nowadays they are optimised for impact resistance caused by car crashes.

There are three types of child car seats, categorised by the type of child: infant carriers, toddler seats, and booster seats. Figure 2.1 shows the approximate age children will have when they use the three types of seats. The actual moment for a child to switch from one type of seat to another, depends on their height or weight and this can vary per manufacturer. The time a child will use a child car seat can also vary per country, as countries have different types of regulations obligating children to travel in a child car seat up to a certain age or height.

The **baby car seat**, or infant carrier is the first of the three types of child car seats and is used, as the name suggests, for babies. A baby car seat is more cradle-like than a toddler seat and the baby is positioned lying on its back, in a supine position. Baby car seats feature a handle and can often be attached to the frame of a stroller. Most baby car seats can be used until the child has a weight of 13 kg or a length of 85 cm. A baby car seat is fastened inside the car either by a seatbelt already present in the car, or by a special base called an ISO-fix base which makes use of ISO-fix points in the seats of the car. The child is restrained inside the seat by an "integral" system such as a harness, as opposed to being restrained by "means connected directly to the vehicle" (UN ECE, 2018).

The **toddler seat** is the second type of child car seat. These types of seats the child will have a sitting position. Toddler seats can be both rear and forward facing. A toddler seat can only be fastened inside the car by an ISO-fix base. Most toddler seats can be used until the child has a weight of 18 kg or a height of 105 cm.

The **booster seat** is the last child car seat a child will use. Booster seats can either consist of just a booster cushion, or of a booster cushion and a high back rest. Booster seats with a high back rest will provide more protection against side impact. According to the R129 regulations (UN ECE, 2018), a child should no longer use a booster seat when it has reached a height of 150 cm. National regulations may allow children to stop using child car seats before they reach a height of 150 cm. In booster seats, the child is restrained by the adult seat belt already present in the car, which is adjusted by the booster seat to be in a suitable position for a child.

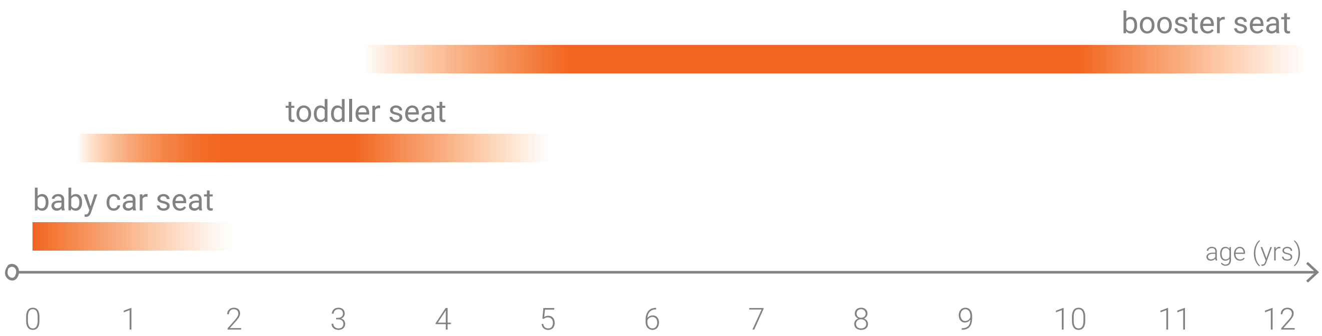


Figure 2.1: the approximate age of children using a baby car seat, a toddler seat or a booster seat

Figures 2.2 - 2.4: from top to bottom, a toddler seat front and rear facing on an ISOfix base (courtesy of Maxi Cosi, n.d. A), a baby seat, a booster seat (courtesy of Maxi Cosi, n.d. B)

There are seats that integrate all three types of child car seats into one seat. These seats are often expensive and bulky, and they make use of inserts and sliding parts to accommodate the child through all of its growing stages.

An **ISOfix base** can be used to fixate baby car seats and toddler seats into seats of a car. Car seats suitable for ISOfix bases feature two anchor points between the seating and the backrest to which corresponding anchorages, of the ISOfix base can be attached (UN ECE, 2018). Child car seats and bases which are suitable for the ISOfix system are often referred to as being "I-Size". In addition to the anchorages, ISOfix bases feature either a top-tether or a support-leg to provide rotation limitation during impact (UN ECE, 2018). Figure 2.5 shows a forward-facing toddler seat with a support leg, a forward-facing toddler seat with a top tether and a rearward-facing toddler seat with a top tether. ISOfix bases with a support leg cannot be used in cars with storage compartments in the floor of the back seats.

2.1.2 Scope: baby car seats and ISOfix bases

The analysis performed for this graduation project is limited to baby car seats and ISOfix bases. Because of the relative short duration of a graduation project, it was preferred to analyse two types of products more thoroughly than to analyse four types of products more generally, assuming that being able to analyse more of the same type of product would yield results more universally applicable.

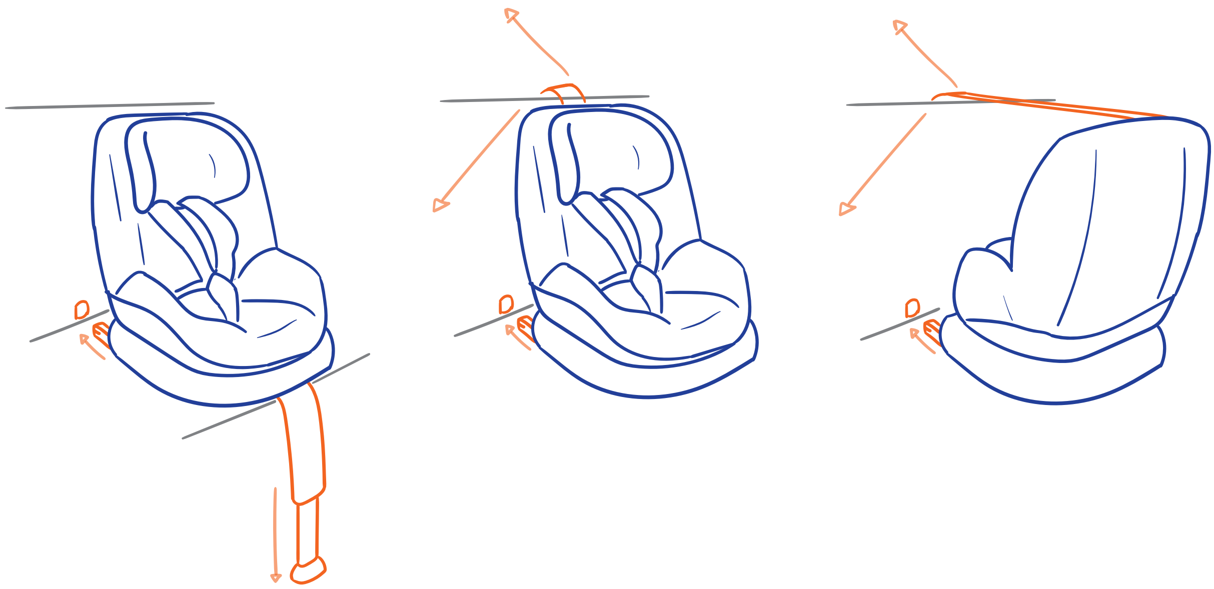


Figure 2.5: from left to right: a forward facing toddler seat on an ISOfix base with a support leg, a forward facing toddler seat with a top tether, and a rearward facing toddler seat with a top tether

2.1.3 Current market

Around half of the Dutch pregnant women buy a baby car seat for their child (Baby Wereld, 2018), which results in around 85.000 bought baby car seats per year in the Netherlands. The same amount of baby car seats is directly reused, for example because there already was a baby car seat available from a previous child or a baby car seat could be received for free from friends or family. Of these 85.000 baby car seats that are bought each year, around one third is bought second-hand (BabyWereld, 2018). The origin of the child car seats used for the new-born children in 2018 in the Netherlands is shown in figure 2.6.

In an interview with Derrick Barker who is a designer at the UK-based studio JMDA specialised in child car seats, he explains that in the UK it is not even allowed to resell child car seats (see appendix E for the interview with Derrick Barker). The warranty on child car seats is only for the first customer buying the seats, using a resold second-hand seat would mean that the user will not be insured in the case of an accident. A second problem in the lifetime of child car seats in the UK indicated by Derrick Barker is that they have to be exposed of with the general waste, which means there is no way for consumers to separate parts of the seat according to their materials, and in the end the seats will end up in landfill. In the Netherlands, child car seats will generally end their life in the incineration ovens.

The Scandinavian insurance company IF offers its customers and even non-customers (for an extra fee) in Norway and Sweden the chance to lease baby car seats (Lammers, 2017). The customers receive a baby car seat and will switch to a toddler and booster seat when the child outgrows the previous seat. Returned seats are "checked, repaired and updated if possible" and all soft goods are washed or replaced (Lammers, 2017).

The only other similar service that appears to exist is by the small Dutch company called Babyloop which offers several types of baby products in a monthly lease system. Through Babyloop it is possible to lease a Maxi Cosi CabrioFix or Pebble Plus baby car seat and optionally a suitable ISOfix base (Babyloop, n.d. A). Prices vary from €5,90 per month for a refurbished baby car seat to €13,90 for a new baby car seat. The "refurbishing" of the baby car seats entails checking the foams for cracks and making sure that the seat is not older than 8 years (Babyloop, n.d. B).

To conclude, in the Netherlands the majority of child car seats are reused directly or resold through second-hand marketplaces. This is not necessarily the case in other countries, such as in the UK where resold child car seats are not allowed. At the same time, existing services stimulating reuse of child car seats with a safety guarantee are scarce and in the case of Babyloop, this safety guarantee might even be questioned. Together, this means that more of the value of child car seats can be maintained when the stimulation of reuse of child car seats is validated with an improved safety guarantee.

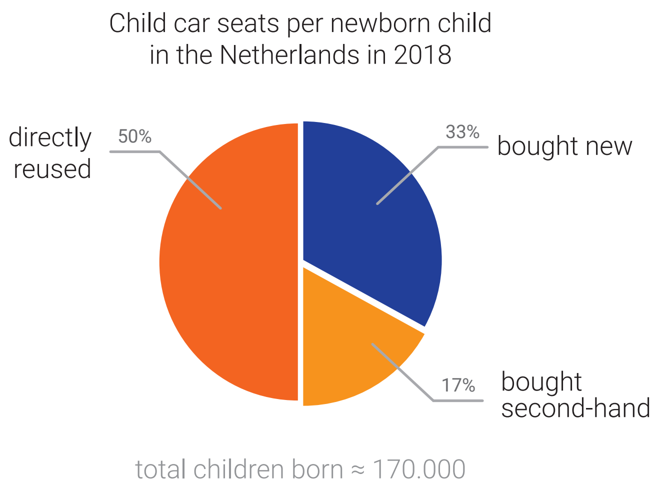


Figure 2.6: percentage reused, new, and second-hand child car seats in the Netherlands in 2018

2.2 Code Product Solutions

This graduation project was set up in collaboration with Code Product Solutions. Code Product Solutions, also called Code PS, was founded around ten years ago by Harold van Aken and Tim Dassen in the Netherlands as an engineering and design agency. Code PS applies its expertise in design, materials, and processing mainly to the design of child car seats and lightweight design. Clients of Code PS are often tied to the automotive industry, for example, the company developed a lightweight sunroof for a manufacturer of car roof systems. In the market of child car seats, Code PS works for brands such as Dorel-Juvenile (which Maxi Cosi is part of), Uppababy, and Swandoo.

The company's design approach involves Computer Aided Engineering, which enables the easy adjustment of structural design aspects and makes iteration and testing faster. For child car seats, Computer Aided Engineering is applied by Code PS to make and analyse crash simulations in order to optimise a redesign of a child car seat. An example of a crash simulation is shown in figure 2.7.

Among others, child car seats are one type of product currently not designed from a circular perspective, which means that its life cycle takes on the linear form of making, using, and discarding the product instead of a circular life cycle. By analysing how child car seats can be redesigned to fit a circular business model, Code PS can contribute to a circular world.

Figure 2.7: a crash simulation of a forward facing toddler seat and an ISOfix base (courtesy of Code Product Solutions, n.d.)

2.3 The circular economy

2.3.1 Definition

The circular economy is a conceptual economic model and opposes the current linear economic situation, characterised by being "take, make, dispose" oriented (Ellen MacArthur Foundation, 2013). An extensive, literature review-based definition of the circular economy is given by Kirchherr, Reike & Hekkert (2017, p.229):

> *The circular economy is "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/ distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers."*

2.3.2 Resource loops and design strategies

A key concept of the circular economy is the concept of 'loops' through which resources flow from one utilisation to another, making them retain their value over their lifetime. In the current linear economy, resources are not yet part of this system of closed loops, which means that they end up as waste with no value. There are several strategies to design out this waste and to make resources flow in loops. As stated by Bocken, De Pauw, Bakker, & Van der Grinten (2016), resource loops can be slowed, narrowed, and closed:

- **Slowing resource loops** can be achieved by designing for a long product lifespan (Bocken et al., 2016), for example by applying the design strategies of designing for attachment and trust (Bakker, Den Hollander, Van Hinte, & Zijlstra, 2014a; Bocken et al., 2016), designing for reliability and physical durability (Bocken et al., 2016), and designing for product life extension (Bocken et al., 2016).
- **Narrowing resource loops** can be achieved by reducing the amount and the variety of resources used in one product (Bocken et al., 2016).
- **Closing resource loops** can be achieved either by making sure the product solely consists of natural, biodegradable resources, or by recycling all resources post-use (Bocken et al., 2016).

The aforementioned strategy of designing for product life extension can be realised with the aid of several strategies, namely through design for standardisation, design for ease of maintenance and repair, design for refurbishment, design for upgradability and adaptability, and design for dis- and reassembly (Bakker et al., 2014 A; Bocken et al., 2016; Bakker, Wang, Huisman, & Den Hollander, 2014 B). The strategy of designing for dis- and reassembly is in itself not a strategy that reduces the quantity of 'waste' at the end of a product's lifetime, but it aids the successful integration of the other strategies. Designing for dis- and reassembly is also beneficial for the recyclability of a product and its resources (Boothroyd & Alting, 1992), since being able to take everything apart means it is possible to make the resource stream as pure as possible. Thus, designing for dis- and reassembly is important for both the slowing and closing of resource loops.

Together, all the design strategies enable products, their parts, or their resources to flow through the loops of the circular economy, as is shown in figure 2.8. These strategies can be categorised following a hierarchy of 'product integrity' (Bakker et al., 2014 A), relating to how much of the product is still original. "The product integrity index is rooted in the assumption that every change made to a product requires energy and raw materials" (Bakker et al. 2014 A, p.83), which means that strategies with a high product integrity are preferred over strategies with a low product integrity from an environmental perspective. The definition of these strategies are given in the next section.

Reuse is "any operation by which products or parts thereof are used again for the same purpose

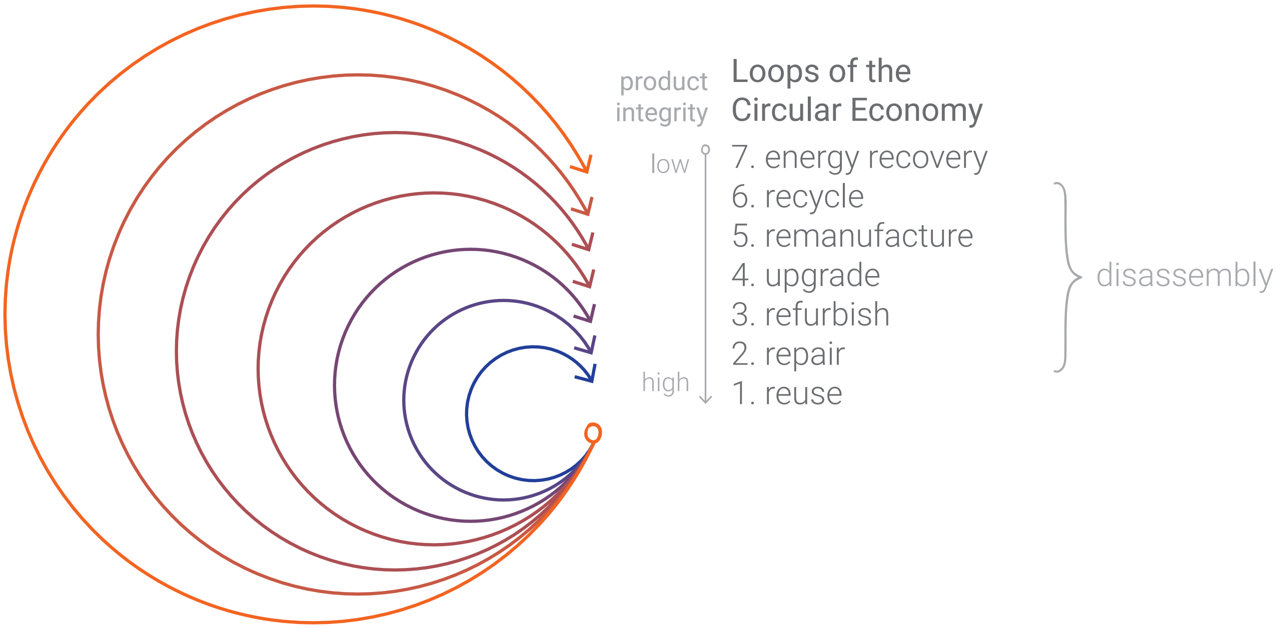


Figure 2.8: design strategies enabling resources to flow in loops through the circular economy

for which they were conceived" as defined by the EN 45554 European Standard (CEN/CENELEC, 2020). This standard speaks of direct reuse when a product as a whole is used by another person than its first owner, without any alterations (CEN/CENELEC, 2020). Bakker et al. (2014 B) state that repair, refurbishing, and remanufacturing are product life extension strategies within the waste management approaches of 'reuse' and 'prevention'.

Repair can be defined as returning a product to working condition after a failure has occurred and is characterised as being corrective as opposed to maintenance, which is characterised as being preventive (CEN/CENELEC, 2020; Flipsen, Bakker, & van Bohemen, 2016).

Refurbish relates to "functional or aesthetical maintenance or repair of an item to restore to original upgraded, or other predetermined form and functionality" (EN 45554 European Standard by CEN/CENELEC, 2020).

Upgrade is a type of life extension strategy where a product's functionality, performance or capacity is enhanced by the replacement of certain parts (EN 45554 European Standard by CEN/CENELEC, 2020), after which the product will better live up to present requirements.

Remanufacture is a "production process that creates products using parts taken from previously used products" (EN 45554 European Standard by CEN/CENELEC, 2020).

Recycle regards resource value maintenance through waste management and refers to "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes" (Bakker et al., 2014 B).

Energy Recovery is not really a strategy as it regards energy generation by burning waste and should be avoided.

2.3.3 The Value Hill

To visualise the value embodied in a product, Achterberg, Hinfelaar, and Bocken (2016) defined the concept of the Value Hill where added value in the pre-use stage by manufacturing, distributing and retailing the product and destroyed value after use are represented in the shape of a hill as shown in figure 2.9. In a circular economy, however, the value after use is kept as high as possible for as long as possible through circular strategies.

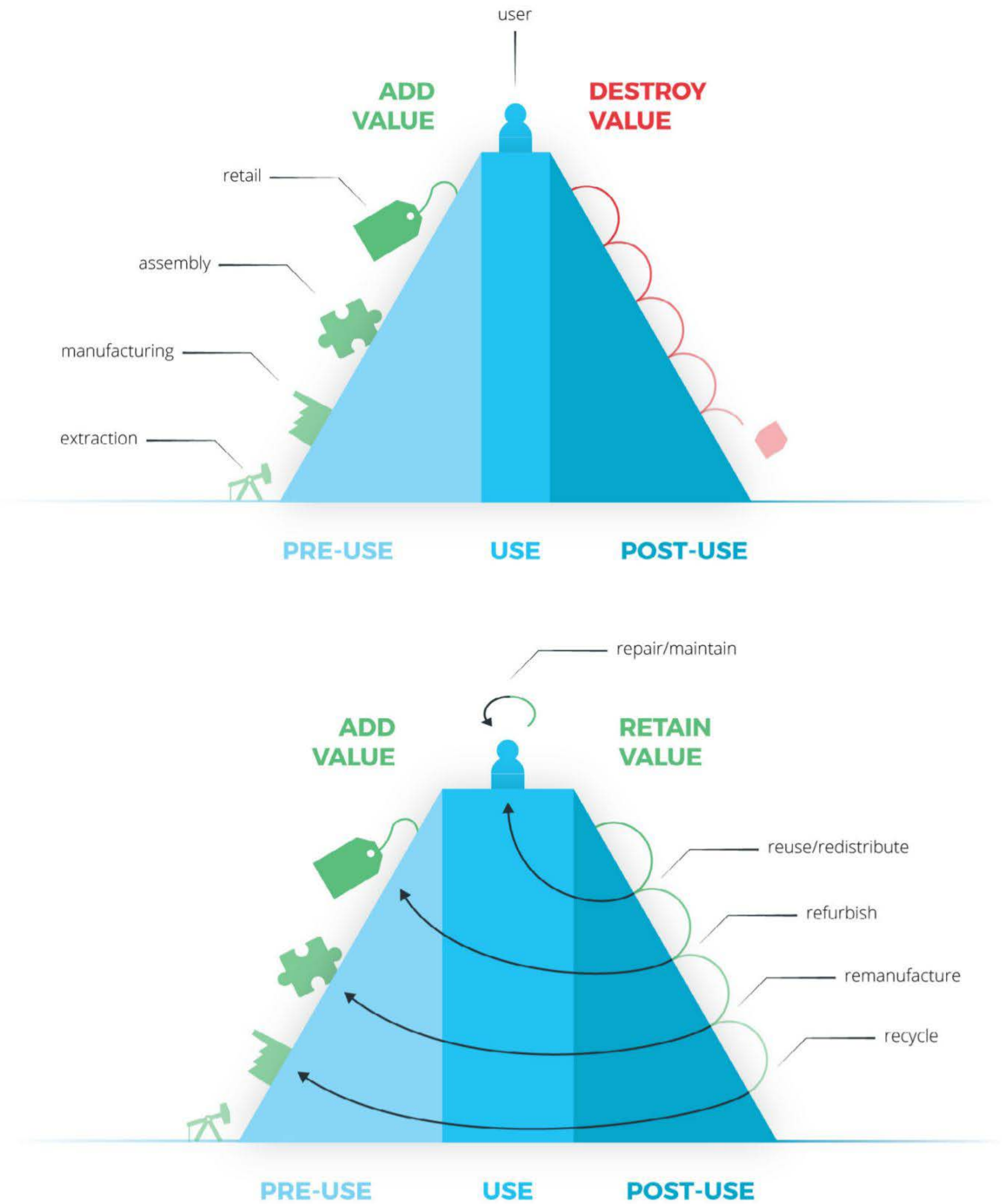


Figure 2.9: the value hill in a linear economy (top) and a circular economy (bottom) (courtesy of Achterberg et al., 2016)

2.4 Refurbishment of child car seats

The first question regarding child car seats and circularity (or sustainability) is how to cultivate the value of the resources embodied by the seat, while also guaranteeing its safety critical functionality. As shown in figure 2.1, baby car seats are used up to 1.5 years. ISOfix bases are either used only with one module, which means either a baby car seat or a toddler seat, or used with both a baby car seat and a toddler seat, which makes its usage period from 1.5 years up to 6 years. The usage period of child car seats is longer when they are reused within a family for a second or even a third child.

Child car seat manufacturers indicate that child car seats have a potential lifespan of up to 7 – 10 years (ANWB, n.d.). The actual lifetime of a child car seat remains vague and is dependent on a range of factors that mainly have to do with how it is used. A reason for the limited lifespan often indicated by manufacturers is the degradation of plastic parts by UV-radiation (Nine Klaassen, personal communication), it seems unknown, however, how much and how fast plastics are affected by UV radiation and whether different usage with different exposure to sunlight affects this further.

It is clear, however, that child car seats in their current form have a longer potential lifespan than their actual usage period, since a large part of the lifespan of child car seats is spent stored in the attic or garage. This is especially the case for baby car seats as their use period for one child is less than 1.5 years, after which they may get used for another child. Thus, extending the usage period of the seats and limiting the storage period to ensure slowing resource loops is a suitable circular strategy to cultivate the value of the resources embodied in the seat, while also maintaining a high product integrity.

Used child car seats are currently sold to new customers through the second-hand market, and in this way the usage period of the seat is already elongated. Nonetheless, the safety of a second-hand seat is not guaranteed, since it is unknown what the seat has endured in its first life. Reparation of child car seats back to working condition by consumers brings the same uncertainty about whether the safety of the product is up to standards. However, refurbishment of products includes checks and tests in order to restore the product to a certain standard. From a product's perspective, refurbishment of child car seats gives the opportunity to extend the usage period of the seat, while also guaranteeing its safety critical functionality. From a system perspective, refurbishment of child car seats gives the opportunity to cultivate resource value on a large scale, for example by harvesting parts from otherwise discarded products, or by generating large resource streams to be recycled into new applications. For these reasons, this project will focus on how refurbishment with the intent of extending its usage period of a safety critical consumer product such as a child car seat could be made possible through the design of the product.

Refurbishment generally consists of an inspection of the product by an official party, after which it can be sold or leased for a second usage period. Often the inspection of the product consists of only checking certain priority parts of the product for failures, to save time and thus costs. There are three reasons why a part might fail to meet its standards, namely functional, visual, or emotional reasons (Bakker et al., 2014 A). Examples of functional reasons are when the part is broken, or when it no longer performs as it should, like the battery of a smartphone after several years of use. Examples of visual reasons are scratches or dents on surfaces. An example of emotional reasons is having concerns about hygiene, like one might have with second-hand clothes. When a part is determined as being unfit for the product in its current state, there are three actions that can be performed, depending on the reason and the degree of of failure, namely replacing, repairing, or cleaning the part. Figure 2.10 illustrates the inspection of parts for refurbishment in a flow diagram.

It is possible to choose a lower level of performance or quality for refurbished products compared to as-new products. An example of this are refurbished smartphones which are resold in different grades, ranging from looking as new to having clear scratches and dents. For some parts, performance should always be as high as possible, for example all refurbished smartphones will be supplied with a new battery. For child car seats, it is probable that for most of its parts a reduction in quality and performance is not acceptable.

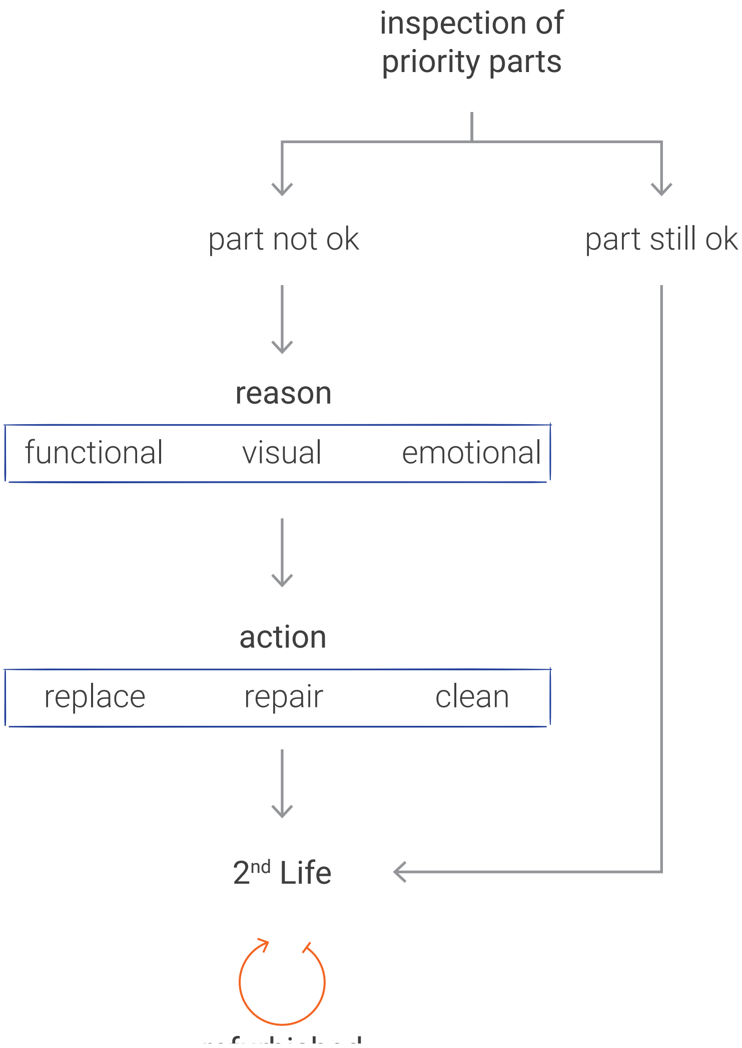


Figure 2.10: Flow diagram of refurbishment

Key insights

Chapter 2: Context Analysis

- There are three types of child car seats: baby car seats, toddler seats, and booster seats. They can be attached via the ISOfix system in a car or with a car seat belt.
- This project focuses on baby car seats and ISOfix bases.
- In the Netherlands, about one third of the child car seats sold each year are second-hand seats of which the safety is not guaranteed. In the UK, it is not allowed to resell seats and they can only be discarded in the general waste, which results in a loss of valuable resource streams.
- The circular economy is about slowing, narrowing, and closing resource loops and strategies to accomplish this can be categorised according to their product integrity.
- This project focuses on retaining the value of baby car seats and ISOfix bases through refurbishment.

3

Assessment of current child car seats

In this chapter, current child car seats are assessed on several aspects related to refurbishment, with the aim of determining how well the current products are fit for refurbishment. First, the questions of what makes child car seats safe and of how their safety can be guaranteed over their lifetime are researched. Then, the priority parts and the failure frequency of parts are described. Thirdly, the ease of disassembly of three baby car seats and three ISOfix bases is analysed using the method Hotspot Mapping. The disassembly sequence and its hotspots of all six products are visualised in Disassembly Maps and based on these maps the accessibility of priority parts is determined, as well as the newly developed Disassembly Depth Index. The chapter concludes with a breakdown of the environmental impact of the materials of the six products.

3.1 A safety critical consumer product

3.1.1 Which parts of child car seats are safety critical?

Child car seats are complex products as they are designed to withstand the variety of dynamic loads to which they are exposed in the case of car accidents and crashes. In short, some aspects of the design will distribute the load of the impact and others will absorb this impact, all with the goal of minimising the impact on the child. Compared to adults, the bodies of children can withstand less impact, which means they need extra protection. This is especially the case for a baby's head and thus the impact in that area should be limited most which is also specified by the regulations for child car seats.

Figures 3.1a and 3.1b are stills of a video by Britax Römer (2016) showing what happens to a baby and a baby car seat in a crash situation with side impact, which is mainly that the seat gets compressed on the side of the impact.

Firstly, the seat as a system, consisting of its structural integrity and the properties of materials that are applied in specific places, is what makes child car seats safe. However, this system is only able to function accordingly if the child car seat is used correctly. For example, the impact on the child cannot be limited optimally when the seatbelts are not tightened properly. So secondly, the correct installation of the seat inside the car (either by the car seat belt or the ISOfix base) and the correct installation of the child inside the seat is what makes child car seats safe. Figures 3.2 to 3.5 show the parts of baby car seats and ISOfix bases that make correct usage and impact absorption possible.
Research conducted in the Netherlands also marks the correct installation of the child in the seat and the seat in the car as safety critical factors (VeiligheidNL, 2018) and based on observations on 470 children it was concluded that in 49% of the cases the child car seat was not installed correctly into the car and in 59% of the cases the child was not installed correctly into the seat (VeiligheidNL, 2018). In total, **83% of the children** were not transported safely in their child car seat (VeiligheidNL, 2018).

Figures 3.1a and 3.1b: Video stills showing side impact on a baby car seat; SICT is the name Britax Römer gives to their part facilitating extra side impact protection (courtesy of Britax Römer, 2016)

Installation of the baby car seat with an ISOfix base

Figure 3.2: parts of a baby car seat and an ISOfix base facilitating correct installation of the seat inside the car with an ISOfix base

Installation of the baby car seat with the car seat belt

Figure 3.3: parts of a baby car seat facilitating correct installation of the seat inside the car with the car seat belt

Installation of the infant in the baby car seat

Figure 3.4: parts of a baby car seat facilitating the correct installation of a baby inside the seat

Absorption of crash impact

Figure 3.5: parts of a baby car seat and an ISOfix base facilitating absorption of crash impact (picture of side impact protector courtesy of Cybex, n.d.)

3.1.2 How can safety be guaranteed for second use?

Refurbishment of a safety critical product

In addition to the inspection of certain parts as described in chapter 2.4, it is necessary for the refurbishment of child car seats to know whether a seat has been in a crash, for when it has been in a crash it is likely that the structural integrity of the product is no longer adequate. The question whether the seat has been in a crash marks the safety critical aspect of the product within the process of refurbishing; this question distinguishes the child car seat as a safety critical product and plays a crucial role in guaranteeing safety for second use. The next section explores different ways of answering this question.

The generic flow diagram of refurbishment can be adapted to child car seats, as shown in figure 3.6. When it is known that the product has been in a crash, the structural integrity of the product as a whole can be inspected, after which the product is either judged as unsafe and disposed of as a whole, or judged as fully or partially fit for second use.

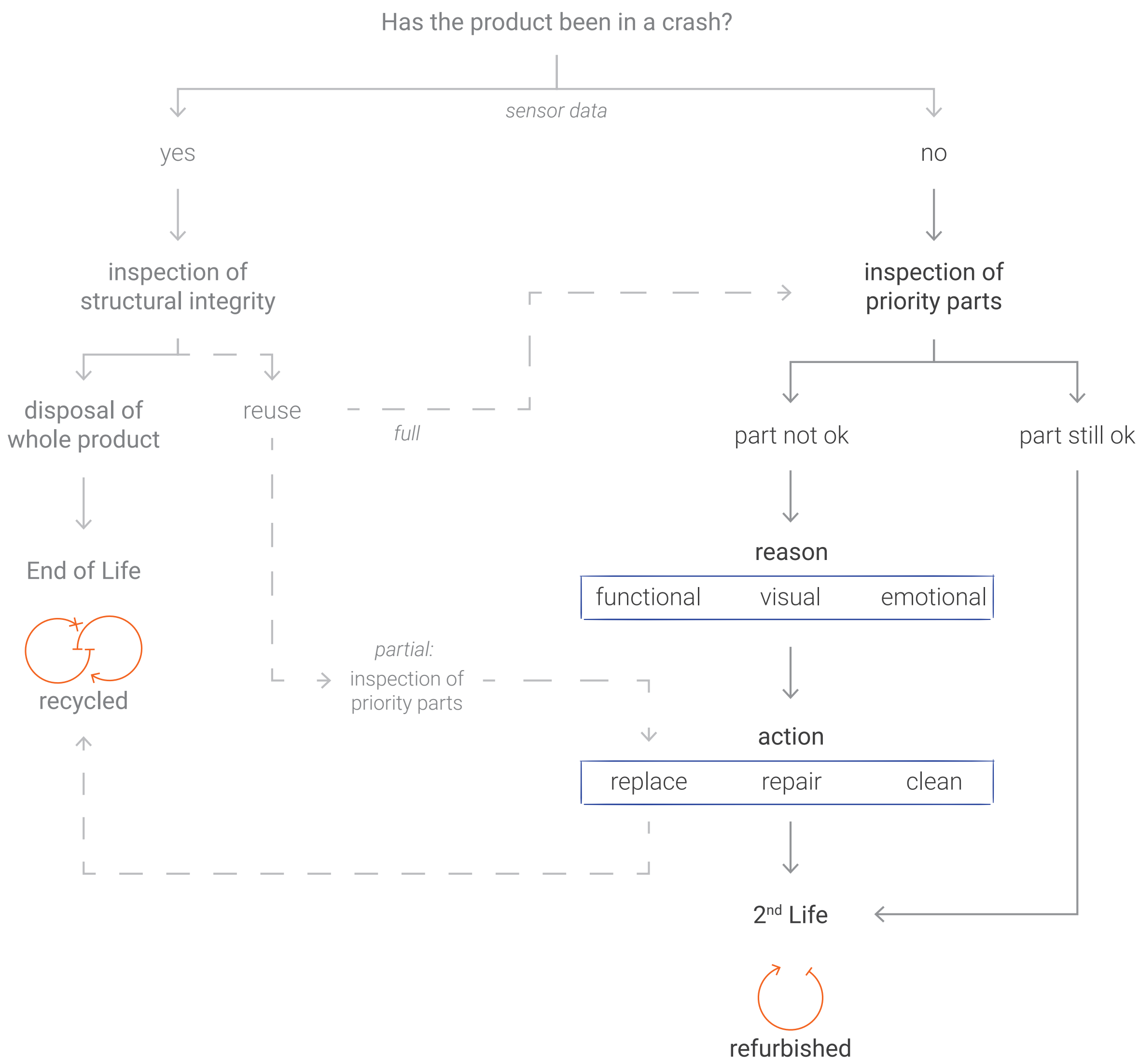


Figure 3.6: Flow diagram of refurbishment of child car seats

How to determine whether the seat has been in a crash?
The question whether a child car seat has been in a crash can either be answered based on information gathered during usage or on information gathered after usage.

During usage, the data that is most valuable to know for determining whether the seat has been in a crash is data about acceleration or deceleration of the baby car seat, or in other words the impact a seat is exposed to. Both the severity and the duration of this impact influences the possible damage to the child car seat. This data about the impact can be compared to characteristic impact values of crashes to conclude whether a seat has been in a crash or not. Either passive or active sensors could be used to gather this information. Examples of passive sensors that can be integrated in the design of child car seats are are:

- The Omni G shock indicator (Impactograph, n.d.), as shown in figure 3.8, is resettable and multidirectional. They are available in a range of impact values from 2 to 500 G. Spring loaded balls get displaced when a certain impact threshold is exceeded. It is quite a big sensor as its diameter is around 5 centimetres.
- The Drop N Tell shock indicator (Telatemp, n.d.), as shown in figure 3.7, which is single directional and can be bought as either resettable or non-resettable. Two mass weighted leaf springs actuate the shock indicator when a certain G-force is exceeded. These indicators come in a range of impact values from 5 to 100 G and they are accurate to ±20% of their rating. Using several of these indicators allows for multidirectional monitoring.
- The ShockWatch shock indicator (SpotSee, n.d.), as shown in figure 3.9, which is non-resettable and single directional. It is very similar to the Drop N Tell indicator, as both are developed to monitor impact on products during transport. The ShockWatch indicators come in a range of impact value from 2 to 75 G. Again, using several of these indicators allows for multidirectional monitoring.

Benefits of passive sensors are that they are relatively cheap and small and that they do not need electronic components to operate, which makes integration in a product uncomplicated.

Figure 3.7: Drop N Tell impact indicator (courtesy of International Plastics, n.d.)


Figure 3.8: Omni G impact indicator (courtesy of Sercalia, n.d.)

Figure 3.9: ShockWatch impact indicator (courtesy of SpotSee, n.d

Drawbacks are that they will only record an impact once, resulting in limited information about the crash namely only that, yes, this product has been exposed to an impact larger than a certain threshold.

Using active sensors opens up the possibility to use several types of sensors simultaneously to better depict the different impacts a child car seat is exposed to in its lifetime. For example, impact sensors or accelerometers could be combined with gyroscopes. An example of a product utilising this benefit of active sensors is the ANGI crash sensor for cyclists (figure 3.10). It is attached to the cyclist's helmet and will automatically send a warning message and the cyclist's location in case the sensor perceives that a crash has happened (Specialized, n.d.). The main benefit of active sensors is that several types of sensors can be combined to create an accurate reconstruction of all of impacts on child car seats over their lifetime, resulting in a detailed conclusion about a crash. Drawbacks are that they need power and other electronic components to operate.

When no information is known about the impact levels during usage, it is still possible to know whether the child car seat has been in a crash. This should be achieved in a non-destructive manner because it is no use for refurbishment to know whether that the seat has been in a crash or not, if the tests results in components that are no longer usable.

An example of non-destructive analyses are 3D imaging techniques used in forensic engineering or engineering failure analysis, where scans of a whole product, including its internals, are used to analyse the product for failures. The goal of forensic engineering is to determine the cause of a failure when it is already known that it has occurred (Bhaumik, 2009). A downside to using imaging techniques for failure analysis is that it is currently very expensive and thus it is generally used to inspect one specific part or small product from a batch in order to improve its design, instead of using it just to check every single product for possible defects. For this reason, the integration of sensors in child car seats appears the best solution to determine whether a seat has been in a crash.

Figure 3.10: Specilized ANGI impact sensor for cyclists (courtesy of Specialized via Bikeshop.nl, n.d.)

3.2 Current state of refurbishability

3.2.1 Priority parts

During the refurbishment of a product not all parts of the product will be inspected, but only those parts that have a higher level of priority than the others, otherwise refurbishment would take up too much time and be too costly. These priority parts of a product can be determined according to Bracquené et al. (2018) and Cordella, Sanfelix, and Alfieri (2019) based on the functional importance and the failure frequency of the parts.

Cordella et al. (2019) state that environmental and economic aspects of parts are not relevant to determine their level of priority in the case of consumer repair, however, in the case of refurbishment these aspects are of importance. For example, environmental aspects of parts play a role in refurbishment when parts do not pass the inspection and have to be discarded, which means that recyclability of parts could affect the level of priority. Similarly, the economic value of parts plays a role in refurbishment when parts of high value have a high failure frequency and the costs of continuously replacing these parts are high.

The priority parts of baby car seats and ISOfix bases have not been determined at present and thus functional importance, failure frequency, environmental aspects and economic value have been analysed in order to establish a priority hierarchy of the parts in baby car seats and ISOfix bases.

Functional importance

For baby car seats and ISOfix bases there are three types of functions a part can have determining their importance, namely a safety critical function, an ergonomic function or an aesthetical function.

Parts with the highest functional importance are the parts that fulfil the main function of child car seats, namely keeping the child safe from injuries caused by car crashes. These parts are described in paragraph 3.1.1 and consist of parts fulfilling the function of absorbing crash impact, installing the baby car seat into the car, and installing the child into the baby car seat.

Next to parts with a safety critical function, there are parts that have an ergonomic function, for example the soft goods and the sun canopy of a baby car seat and the plastic button covers of an ISOfix base. When these parts fail, the product can still fulfil its main function in theory, but the experienced usability of the product will be significantly lower than when these parts function properly.

Lastly, it is possible that parts have a strictly aesthetic function. In the case of child car seats, however, almost every single part contributes to the safety critical functionality even though aesthetics is kept in mind during the design.

It is important to note that child car seats have two different users, namely the parent and the child, with different roles towards the product and thus different experiences and expectations. The main function of the seat towards the child is of course to keep it safe from harm from crashes, and secondly, the seat has an ergonomic function of providing comfort. The level of comfort is affected amongst others by the firmness of the support, temperature regulation, and overall shape of the seats.

Towards the parent, the child car seat only has an ergonomic function concerning the handling of the product in a comfortable manner.

Failure frequency

Due to a lack of actual data about failure frequency from child car seat manufacturers, information about failure frequency has been obtained through two alternatives. Firstly, two experts from the field of child car seat design and manufacturing have been interviewed and secondly a small user test has been conducted, which consisted of seven short interviews with parents who are currently using baby car seats to transport their children in a car.

The interviews with the experts can be found in appendix C and D. They, Cyril Smals and Adriaan Siewertsen, both expect the soft goods of baby car seats to be most prone to wear and tear. Furthermore, Cyril Smals expects the foams to get damaged most often and Adriaan Siewertsen thinks moving parts and especially the buckle will fail frequently because of sand or dirt obstructing their mechanism from working properly.

The interviews with parents currently using baby car seats and ISOfix bases can be found in appendix B. Firstly, all parents who owned an ISOfix base indicated that next to no failures occur with this type of product, since the ISOfix base is often installed into the car once and then left there for the duration of using the baby car seat (and sometimes also the toddler car seat). This means that the base does not get moved around and the only failure that has a probable chance of occurring is scratches on the plastic shells caused by installing child car seats on top, next to getting damaged because of being in a crash.

Secondly, the parents indicated the failures occurring with baby car seats as shown in table 3.1 (including the failures occurring according to the experts), categorised by the type of failure. This list of failures should not be perceived as indicating the only failures occurring with baby car seats, nevertheless it does provide insights in what kind of failures occur more often than others when more parents indicated the same type of failure. The failures that were mentioned most often were the wear of the soft goods (referring to all of the fabrics of the seat) and the scratching of the handle and the outer shell.

Table 3.1: parts that are prone to failure according to experts and parents

Functional		Visual		Emotional	
part	failure	part	failure	part	failure
Handle	◦ increase of resistance in adjusting the handle over time	Handle	◦ scratches by bumping against car or walls or door posts	Soft goods	◦ stains because of spilling food or drinks and because of puking or similar accidents
Soft goods	◦ wear through use	Outer shell	◦ scratches on the sides by bumping against the car or walls or door posts ◦ scratches on the bottom by placing on the ground dirt by using outside ◦ dirt by using outside	Shoulder straps	◦ stains because of spilling food or drinks and because of puking or similar accidents
Shoulder straps	◦ tension slackens through use				
Shoulder pads	◦ get lost because they are not tightly secured to the shoulder straps				
Buckle	◦ tension slackens through use				
Warning labels	◦ detach from soft goods or shell				

Priority hierarchy

Tables 3.2 and 3.3 show a priority hierarchy of the parts of baby car seats and ISOfix bases, respectively. Parts that have the most marks are parts with the highest priority, and these are displayed at the top of the table. Parts are marked for their functional importance, either being safety critical, ergonomic, or both in some cases. Parts are marked as having a high failure frequency based on the information obtained through the interviews and user research. The parts are estimated as having a high environmental or economic value relative to the other parts present in baby car seats and ISOfix bases based on the outcomes of the method Hotspot Mapping. This method is applied for this graduation project to three baby car seats and three ISOfix bases and is further explained in the next subchapter. When in a majority of the assessed products the part was marked by the Hotspot Mapping method as having environmental value or economic value, which is mainly based on the material and weight of each part, this part is also marked in the priority hierarchy tables.

These priority hierarchy tables represent an estimate of the level of priority per part since they are not based on 'hard' data and also because it is the average within the product category of baby car seats and ISOfix bases. The actual priority parts of a baby car seat or ISOfix base will differ from product to product. For example, the installation of the seat into the car can either be done by using the car seat belt or by using the ISOfix base, resulting in different priority parts. Similarly, it is not necessarily the case that a product has all parts listed in these tables, or products will have parts that are not even listed. For example, a baby car seat can have a separate side impact protector in order to comply with the regulations or it can have none when the integrated cushioning already provides enough protection against side impact.

Table 3.2: priority hierarchy of the parts of baby car seats

part	safety critical function	ergonomic function	frequent failures	environmental value	economic value
soft goods		x	x	x	x
load distribution structure (shell)	x		x	x	x
foams	x	x	x		x
shoulder pads	x	x	x		
infant insert	x	x		x	
handle	x		x	x	
head pillow	x	x			
shoulder straps	x		x		
buckle	x		x		
warning labels	x		x		
locking mechanism (with ISOfix base)	x				
belt guides	x				
installation icons	x				
side impact protector	x				
sun canopy		x			
mechanism & button covers		x			

Table 3.3: priority hierarchy of the parts of ISOfix bases

part	safety critical function	ergonomic function	frequent failures	environmental value	economic value
shell	(x)		x	x	x
load distribution structures	x			x	x
top tether/support leg	x			x	x
locking mechanism (with the seat)	x		x		
ISOfix anchors	x				
installation indicators	x				
mechanism & button covers		x			

Note: the shell is marked as (x) because it can be part of the load distribution structure, but this is not necessarily the case

3.2.2 Ease of disassembly

As stated in chapter 2.3.2, the ease of disassembly plays a part in how well products can be refurbished, ultimately affecting the successful integration of a product into the circular economy. In order to design baby car seats and ISOfix bases for refurbishment, their current state regarding ease of disassembly is analysed.

Assessment Setup

Products

Three baby car seats and three ISOfix bases have been analysed on their ease of disassembly. The products were chosen to create a diverse selection of products that are currently popular and available in the Netherlands. All seats and bases have a comparable price, around €230 and €200, respectively. The six products are shown in figures 3.11 to 3.16. Both the Cybex and the Maxi Cosi ISOfix bases are part of a family system which means that a toddler seat can also fit on the same base. The Cybex Cloud Z features a lay-flat function and its base features a rotating mechanism contributing to an easier installation of the seat on the base.

Assessment Method

The ease of disassembly of the six products has been analysed following the Hotspot Mapping method developed by Bas Flipsen (Flipsen, Bakker, & De Pauw, 2020). Hotspot Mapping is a spreadsheet-based method making use of input about disassembly actions and product components to assess the product's architecture and to indicate certain hotspots affecting ease of disassembly.

The Hotspot Mapping method consists of completely disassembling a product and recording each disassembly step. For each step, the following information is filled into the spreadsheet (Flipsen, Bakker, & De Pauw, 2020):

- General properties: name of part or subassembly involved, removal from main assembly or subassembly
- Activity properties: type of activity, type of tool, time needed for activity
- Difficulty of activity: required force, accessibility, required precision (scaled low-medium-high)
- Functional sensitivity: need for maintenance, risk of failure, impact of failure (scaled low-medium-high)

The last step of the Hotspot Mapping method is to make a disassembly tree based on the spreadsheet where the sequence of all steps and their hotspots are visualised.

Figure 3.11: Swandoo Albert

Figure 3.12: Cybex Cloud Z (courtesy of Babypark, n.d.)

Figure 3.13: Maxi Cosi Pebble Pro (courtesy of Pink or Blue, n.d.)

Figure 3.14: Swandoo Albert base (courtesy of Babyhuys, n.d.)

Figure 3.15: Cybex Z base (courtesy of Harrods, n.d.)

Figure 3.16: Maxi Cosi 3wayfix (courtesy of Maxi Cosi, n.d.)

Like other methods assessing ease of disassembly such as eDiM (Vanegas et al., 2016) or the method developed by Bracquené et al. (2018), Hotspot Mapping indicates disassembly depth, disassembly sequence, disassembly time and type of tools and fasteners to affect the ease of disassembly of products. The parts are also categorised by the researcher into priority parts and non-priority parts in the Hotspot Map (see paragraph 3.2.1 for the priority parts of baby car seats and ISOfix bases).*

Unlike other methods, Hotspot mapping makes use of real-time data for disassembly time based on timing each disassembly step from video footage instead of standardised data.*

Research protocol

First, the product was disassembled step by step. Since the focus of this project is on design for refurbishment, disassembly is limited to reversible actions, which means that the product should be reassemblable as well, as is the case in refurbishing. While disassembling, a DSLR camera was used to film the process. Second, the disassembly process was documented in the Hotspot Mapping spreadsheet based on the video footage and in an accompanying disassembly diary, where all steps were described, and pictures were added where necessary. Thirdly, all components were weighed and this together with their materials was filled into a Bill of Materials. Lastly, the Hotspot Mapping spreadsheet was used to create a disassembly tree in the form of a Disassembly Map (DeFazio, 2019). The Disassembly Maps of all six products and conclusions that can be based on them are presented in paragraph 3.2.3.

Tools

The tools available to use for disassembling the products for this analysis are common tools as defined in the EN 45554 standard (CEN/CENELEC, 2020):

- Hammer, steel head
- Combination pliers
- Half-round nose pliers
- Multigrip pliers
- Diagonal cutters
- Combination pliers for wire stripping & terminal crimping
- Combination wrench
- Hexagon socket keys (Allen keys)
- Screwdriver for slotted heads
- Screwdrivers for cross-recessed heads (Phillips & Pozidriv)
- Screwdrivers for hexalobular recess heads (Torx)
- Multimeter
- Utility knife with snap-off blades

** Priority parts vs. complete assembly*

The aforementioned disassembly assessment methods state that ease of disassembly of products is best analysed for priority components only. However, for the product category of child car seats, priority components were not yet defined and thus the ease of disassembly analysis is performed for the whole product.

** Real-time data vs. standardised time data*

The advantage of using standardised data over real-time data is that all disassembly assessments using the same data can be compared, whereas real-time data is dependent on the skill of the researcher. The disadvantage is that standardised data needs to be available, reliable, and also applicable to that specific type of product. For this graduation project, I preferred using real-time data over standardised data, because it appeared standardised data was unavailable for certain actions (such as removing fabric), non-reliable (such as removing adhesives) or non-applicable to child car seats (for example, standardised data used in the aforementioned disassembly assessment methods were developed to be used on Energy Related products, which generally have smaller dimensions than child car seats). I preferred having data reflecting the real situation with the disadvantage of it also being dependent on the skills of the researcher (me). Moreover, I think it is more important for this graduation project to be able to compare the child car seats to each other in the best way possible, than to be able to compare the child car seats to other (Energy Related) products.

Results

The results of the ease of disassembly analysis are shown in figures 3.17 to 3.20 for all six products and are further elaborated on in the following paragraphs. The filled in spreadsheets of the Hotspot Mapping method are shown in appendix F and the disassembly diaries for each product in appendix G. An overview picture of all components per product are shown in figures 3.25 to 3.30 on pages 39 to 41.

*Disassembly time**

The disassembly times of the six products range from around 7 minutes to more than 20 minutes, as shown in figure 3.17. The disassembly time in real life, however, would be higher than the disassembly time calculated in the Hotspot Mapping method, as only the time it takes to perform each step is taken into account and the time it takes to inspect or manipulate the product or the time mistakes take up are left out. In other words, only value-adding time is taken into account. The Maxi Cosi 3wayfix has the highest disassembly time of the ISOfix bases and of all products, while the Maxi Cosi Pebble Pro has the lowest disassembly time of the baby car seats and of all products.

Disassembly depth & sequence

Figure 3.19 shows that the Swandoo Albert has the highest number of steps but the Cybex Cloud Z has the highest number of actions of the baby car seats. For the bases in both cases the Cybex Z base has the highest number. The disassembly depth and sequence of the products are only partly demonstrated in the number of steps and number of actions shown in figure 3.18, because this figure does not represent any steps that could be performed in parallel.

The disassembly of the Cybex Cloud Z and the disassembly of the Swandoo Albert, both baby carriers, take around the same number of steps and actions. While the Swandoo Albert has 48 components, the Cybex Cloud Z has 29 components, which could indicate that the Swandoo Albert is easier to disassemble than the Cybex Cloud Z. This conclusion is supported by the fact that the Cybex Cloud Z had a large number of resulting components still assembled together, compared to the Swandoo Albert.

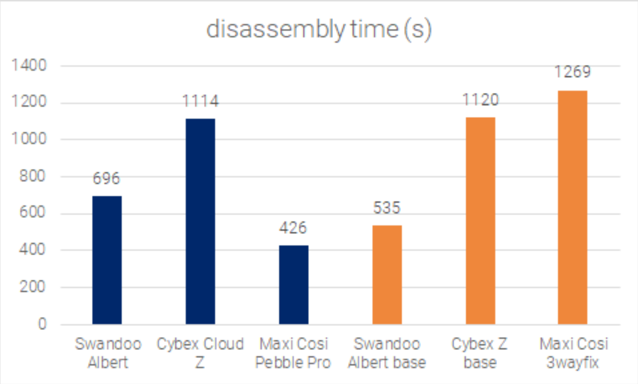
Overall, it appears that the ISOfix bases have a lower number of steps and actions than the baby carriers.

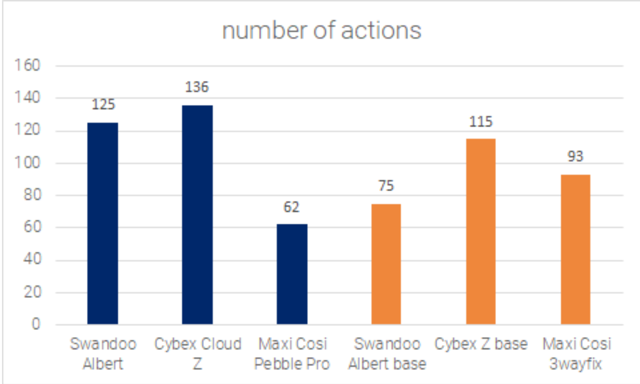
Generally, the disassembly sequence of the baby car seats consists of first removing all of the soft goods (figures 3.21 and 3.22), then removing all foams (figure 3.23), and then being able to reach other components (figure 3.24). An exception is the Maxi Cosi Pebble Pro which allowed the removal of the handle and the side belt guides from the complete assembly.

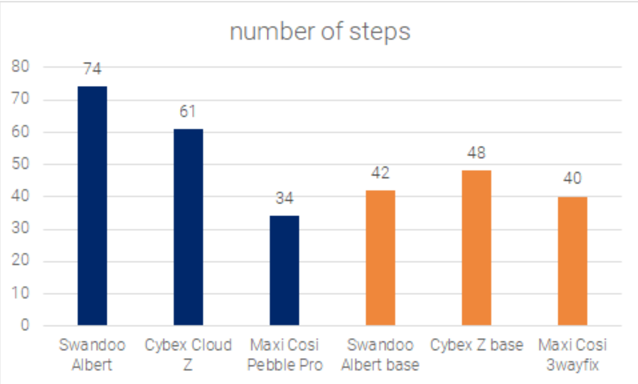
The disassembly sequence of the ISOfix bases consists of removing the shells surrounding the structural components, such as the support leg and a load bearing frame. The Maxi Cosi 3wayfix does not feature a load bearing frame but has a load bearing bottom shell.

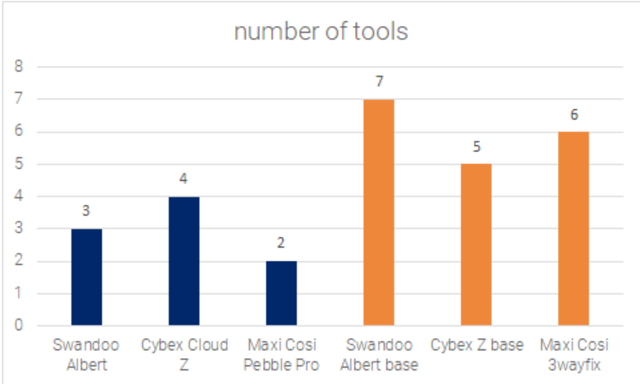
** Disassembly time as an indicator*

I think disassembly time on its own should never be used as an indicator for ease of disassembly, as the result is highly influenced by the skill of the researcher and by the tools that are used. The researcher influences the results since the familiarity with the tools and the product play a role; an experienced official repairer will probably take less time than me in disassembling products, but how much faster a professional would be is unknown. Furthermore, the tools that are used can skew the results. For example, by looking only at disassembly time, screws would be considered as reducing the ease of disassembly since it takes a long time to disconnect. Since my analysis was performed without the aid of power tools, the time to disconnect screws affects the total time even more than when power tools were used. However, the use of screws is generally considered as increasing the ease of disassembly as it allows for dis- and reassembly for several times.









Figures 3.17 to 3.20: a comparison between the three baby car seats and the three ISOfix bases of disassembly time, number of actions, number of steps, and number of tools

Figures 3.21 to 3.24: removing upholstery, removing foams, reaching other components

Tools & Fasteners
Figure 3.20 shows that in general more types of tools are needed for the disassembly of the ISOfix bases than for the baby car seats. For the Swandoo Albert base seven different tools are needed apart from the hands of the disassembler and for the Maxi Cosi Pebble Pro only two tools were needed.

The tools that were used for the disassembly of the six products are shown in figure 3.31 on page 42, with the exception of the electric drill, one small plier and my hands. The number of fasteners for each product are shown in table 3.4. The Swandoo Albert has the largest number of fasteners (and also the largest number of parts) and the Swandoo base has the fewest fasteners. Noteworthy is the low number of screws of the Maxi Cosi Pebble Pro.

Most of the actions of both the baby carriers and the ISOfix bases could be performed with the use of hands and fingers. The type of fasteners that could be undone by using hands were most often friction fits, such as foams fitting inside a shell, and loop and hook fasteners, such as elastic loops of a sun canopy around hooks of a shell, and snap joints, such as snap buttons of the soft goods or snap fits between two plastic parts.

Screws were also a common type of fastener both in baby car seats as in ISOfix bases. The two Swandoo products both used Phillips screws, while the other two brands made use of Torx screws. The advantage of Torx screws over Phillips screws became clear during disassembly, as generally less force was needed, the screwdriver stayed in place more easy, and the durability of the screwhead was better as well (allowing more cycles of re- and disassembly).

A wrench was needed to undo bolts or nuts in three of the products and then only in size 10 or 13. Spudgers, prybars, or levers came in handy several times as they provide a more precise way to apply more force compared to using your hands. They were especially useful for disconnecting snap joints. Pliers were used to remove springs from hooks or to remove axes that required a lot of force to undo friction fits.

It was possible to disassemble all products using common tools except for the Cybex Z base which required an electric drill to remove rivets. The first action of the disassembly of the Cybex Z base actually consisted of drilling out rivets, and without this action, the product could not be disassembled at all.

For the connection between the ISOfix anchors and the installation indicators, the Cybex Z base and the Swandoo Base make use of Bowden cables, while the Maxi Cosi 3wayfix is fully electronic.

Lastly, flexible materials like fabrics bring about new types of fasteners and also have unique features such as stretching around something to be a fastener that way.

Table 3.4: the number of fasteners per type and in total of the six analysed products

	number of screws	number of snap fits	number of friction fits	number of nuts & bolts	other	total
Swandoo Albert	28	16	28	2	29	**103**
Cybex Cloud Z	37	19	9	0	21	**86**
Maxi Cosi Pebble Pro	5	23	21	0	13	**62**
Swandoo Albert base	23	4	1	6	17	**51**
Cybex Z base	21	26	24	1	23	**95**
Maxi Cosi 3wayfix	33	15	32	0	2	**82**

Figure 3.25: the componts of the Swandoo Albert baby car seat

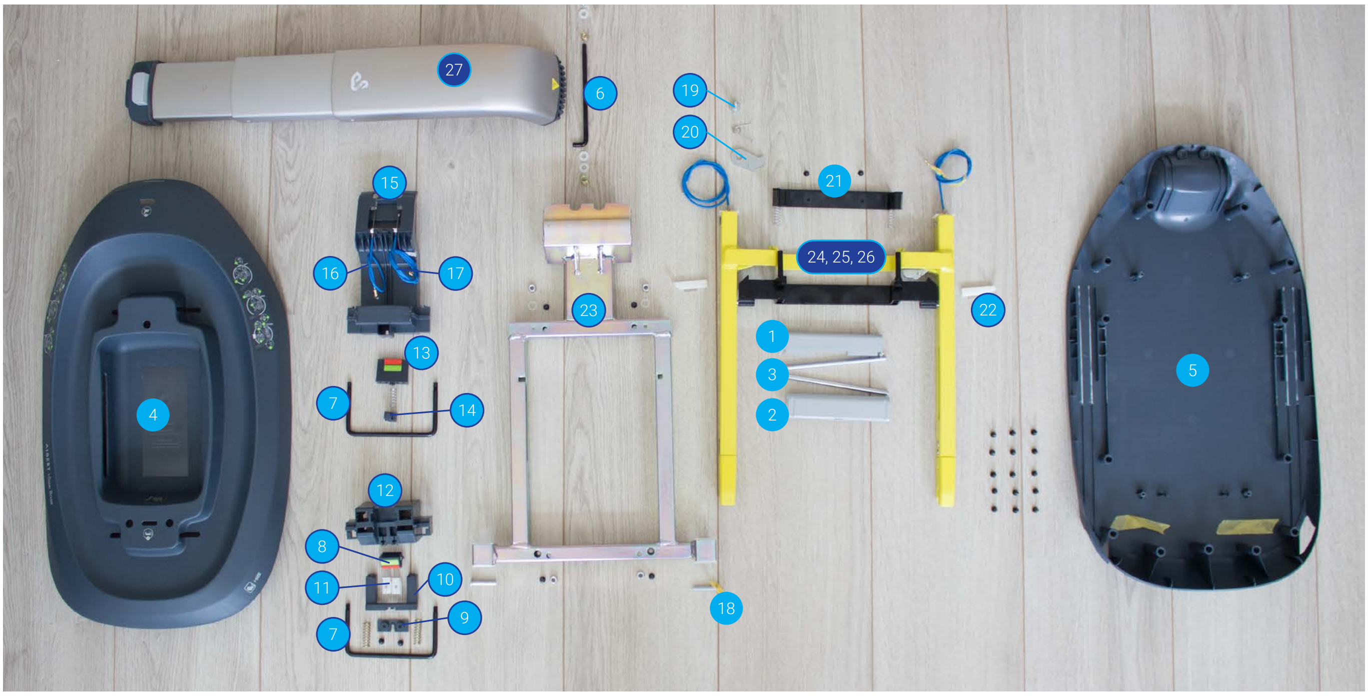


Figure 3.26: the componts of the Swandoo Albert ISOfix base

Figure 3.27: the componts of the Cybex Cloud Z baby car seat

Figure 3.28: the componts of the Cybex Z base

Figure 3.29: the componts of the Maxi Cosi Pebble Pro baby car seat

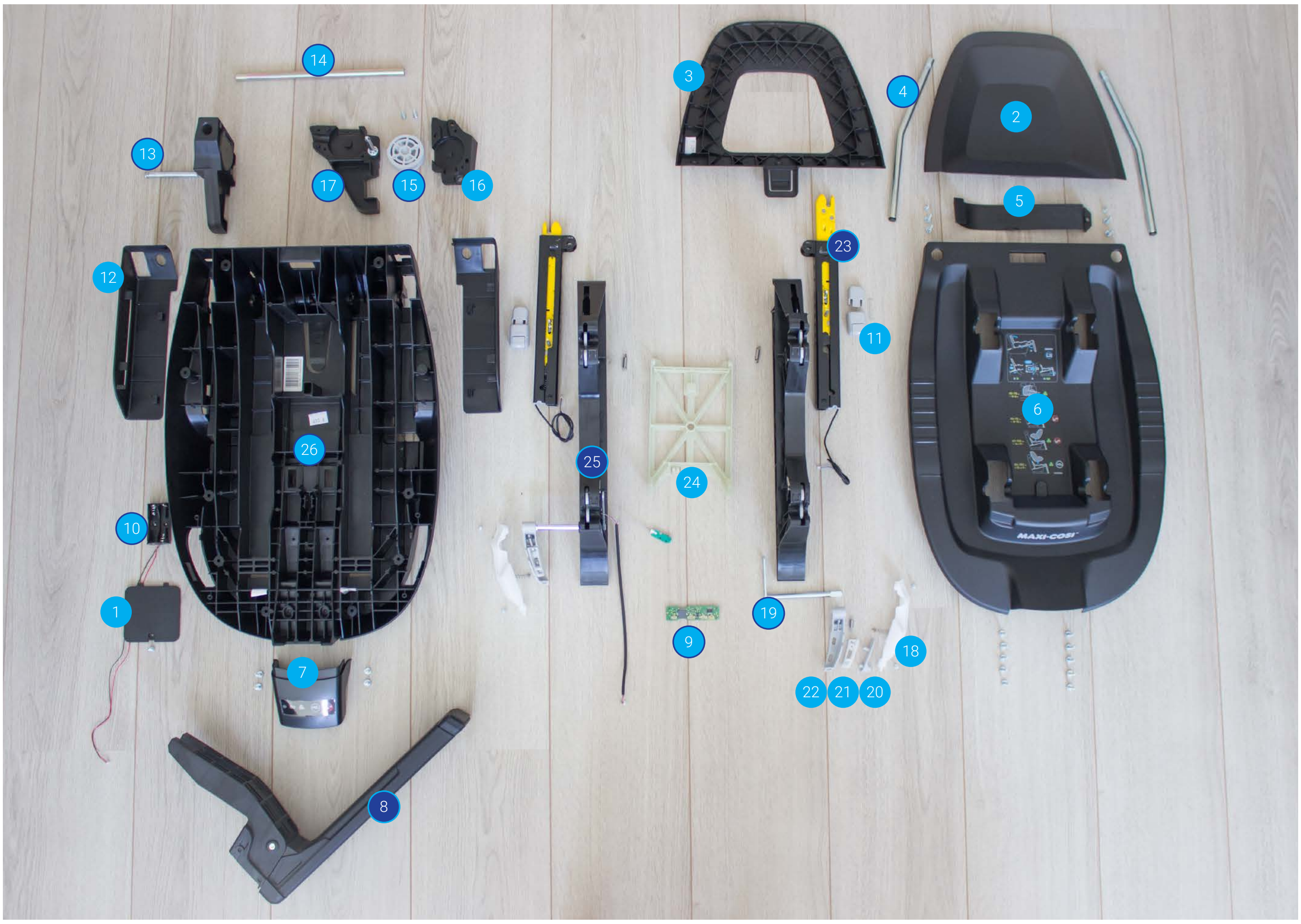


Figure 3.30: the componts of the Maxi Cosi 3wayfix ISOfix base

Hotspots
Generally, the spreadsheets of the baby car seats indicate parts consisting of foam as being both environmental and economic hotspots, as well as the soft goods, the handle, the shell, the shoulder straps, and the buckle. For the ISOfix bases parts that are environmental and economic hotspots are the shells, the support leg, ISOfix anchors, and metal frames. It is highly probable that the environmental and economic hotspots correspond because they are often the heaviest components and the more material, the higher the price and impact.

Time intensive actions are actions involving screws (in my case around 10 seconds per screw) or other actions involving precision. Removing tape from foams, as was the case both for the Cybex Cloud Z and the Maxi Cosi also took up quite some time (around 60 seconds). For the Cybex Cloud Z, the most time intensive action was removing the foam from the shell by prying it loose from glue (figure 3.32), this took around 6 minutes. Only one other single action from the disassembly of all six products took up more time, which was drilling out all rivets from the shell of the Cybex Z base (figure 3.33), which took around 9 minutes. Lastly, removing the pins from the shell of the Maxi Cosi 3wayfix actually took longer than drilling out the rivets of the Cybex Z base, but this is probably due to the tool that was used (figure 3.34), while other tools suitable precisely for this task do exist but were not at hand.

Figure 3.31: tools that were used to disassemble the six products

Figure 3.32: removing foam from the s
Cloud Z

Remarks about Hotspot Mapping

The version of the Hotspot Mapping spreadsheet used in this analysis allowed parts to be distinguished based on functionality in the following categories: "works without", "won't function without", or "aesthetically important". Based on the disassembly assessment performed for this graduation project, it is recommended to add a category of "ergonomically important". This categorisation of functionality could be levelled from level 4 "works without" as being least important, to level 3 "aesthetically important", level 2 "ergonomically important", and lastly level 1 "won't function without" as being the most important. Alternatively, one could argue that a product will function without parts that have a purely aesthetical function, resulting in a combination of these two categories.

A second remark is that flexible materials such as fabrics are not typically representable in a way which screws and other standard fasteners are representable since they can be both a component and fastener at the same time. An example of this is upholstery with sewn in loops of which the fabric itself functions as a fastener around hooks due to it being elastic. It is currently difficult to indicate features like this in the Hotspot Mapping tool and thus it is recommended to add a category to the type of fasteners in the Hotspot Map for parts that are their own fasteners. This could then also be used to indicate parts that are fastened to the main assembly through a friction fit.

shell of the Cybex

Figure 3.33: drilling out rivets of the Cybex Z base

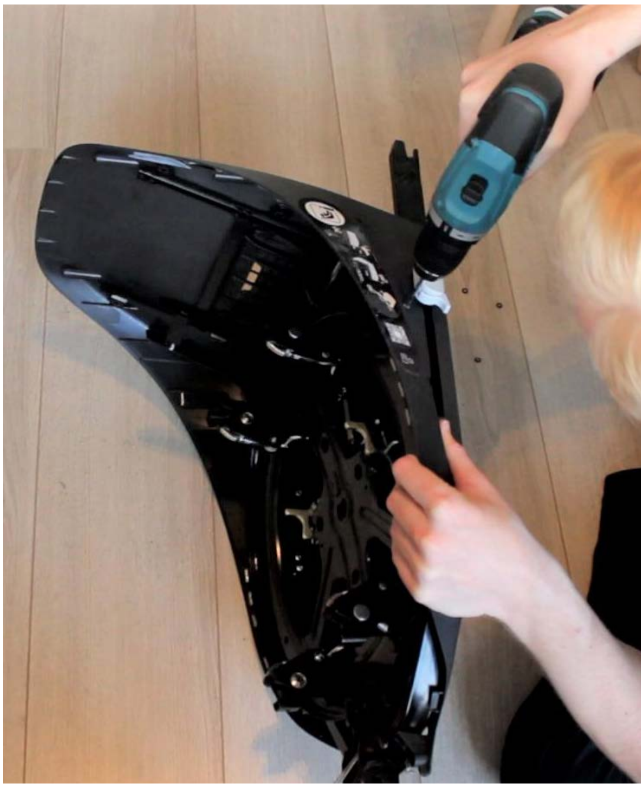


Figure 3.34: removing a pin from the Maxi Cosi 3wayfix

3.2.3 Disassembly Maps

To visualise all characteristics of the disassembly of the different products, the method developed by DeFazio (2019) called 'disassembly mapping' is used.* A disassembly map is a type of disassembly tree, which is a visualisation of the disassembly sequence but with additional information. DeFazio developed this method for his graduation project analysing the ease of disassembly of vacuum cleaners and it was based on several other (dis) assembly representation methods such as the Reverse fish-bone diagram by Ishii & Lee (1996).

The goal of this disassembly map is to make the disassembly sequence and depth and the position of priority components visible at a glance (DeFazio, 2019). Additional information is provided about the type of actions necessary to reach each component and indicators are used to mark special actions and hotspots. The map shows the disassembly sequence from the top, starting with a complete product, to the bottom, often ending in parts that cannot be further taken apart. The map can be read in reverse to show the assembly sequence, when starting from the bottom of the map.

Logic of the disassembly map

Parts and activities

The disassembly map makes use of two building blocks, namely parts and activities. Parts are represented by a part number in a blue circle and activities are represented by a label containing information about the tool used, the type of fastener and the number of fasteners (DeFazio, 2019). Each type of tool is represented by its own colour. For example, figure 3.35 shows that part number 6 can be removed from the main assembly after unscrewing three Philips screws with a screwdriver. In addition to the blue circle, safety critical priority parts (see paragraphs 3.1.1 and 3.2.1) are represented with a dark blue border as shown in figure 3.36.

In the disassembly map only the safety critical priority parts are marked and not parts that have an ergonomic function or are of economic or environmental value, to prevent the map from being cluttered with additional information. As stated above, the main goal of the disassembly map is to visualise the disassembly sequence.

Linear and parallel sequences

The disassembly map visualises a linear sequence vertically and a parallel sequence horizontally.

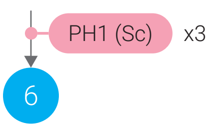


Figure 3.35: an activity label and a parts label

Figure 3.36: a priority part label

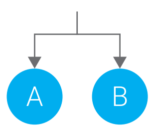


Figure 3.37: a parallel sequence

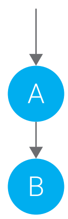


Figure 3.38: a linear sequence

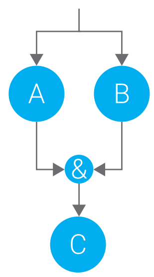


Figure 3.39: a combined sequence showing the OR logic and the AND logic

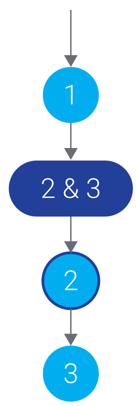


Figure 3.40: a subassembly containing priority parts 2 and 3

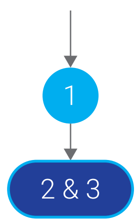


Figure 3.41: a resulting subassembly

Parallel activities are activities that can be performed in any order, for example in figure 3.37, it does not matter whether part A or part B is removed first. For linear activities, the order does matter and in figure 3.38 this means that part A needs to be removed before part B.
In order to increase the ease of disassembly, parallel sequences within a product architecture are preferred over linear sequences as this generally means that it is easier to reach a specific part because less actions have to be performed and less parts have to be removed.

And/or logic
In parallel sequences, it is possible to first remove A or remove B, as shown before in figure 3.37. Figure 3.39 shows a parallel sequence where it is necessary to remove both A and B, the order does not matter, before being able to reach C. The 'or' logic is visualised by splitting the path into branches and the 'and' logic is visualised by the use of an ampersand (DeFazio, 2019). Arrows indicate the direction of paths.

Subassemblies
Sometimes it is possible to remove parts in a group from the main assembly, these parts form a subassembly. A subassembly is represented in the disassembly map by an oval label with all part numbers of the subassembly. Figure 3.40 shows a subassembly that can be removed as a whole after removing part 1 consisting of priority part 2 and non-priority part 3. Figure 3.41 shows a subassembly that can be removed as a whole after removing part 1, consisting of two parts that cannot be separated any further.

** Further development of Disassembly Mapping*
Some alterations to the disassembly map have been made compared to the map originally proposed by DeFazio:

- *The distinction of priority parts with a border around the part label is added.*
- *The component indicator is made more pronounced. A more saturated blue is used compared to DeFazio's disassembly map to make the product architecture stand out more, as I think that is the most important information the disassembly map communicates to the viewer at a glance.*
- *New types of tools were added: next to hands, screwdriver, and spudger which were the only tools in DeFazio's disassembly map, now also wrench, pliers, and an electric drill are represented with their own labels.*
- *The type of tool is now only indicated by a separate colour and a textual indicator, leaving out a separate shape per type of tool, to make the disassembly map more coherent.*
- *Originally the force intensity was represented with colour grading, but this made the disassembly map overly complex. With the addition of new types of tools, the possibilities for colour grading for each tool was also diminished and instead I choose to represent the force intensity with a separate indicator, leaving out the colour grading altogether.*
- *The category of 'other' action is added, for when an action does not consist of removing/releasing a connector, but of something else (e.g. putting shoulder belts through holes in the fabric).*
- *The new version of the disassembly map is tailored more towards the Hotspot Mapping method instead of eDiM.*

Activity indicators
Activity indicators are used to point out difficulties or possible problems in the disassembly process. In this version of the disassembly map, five types of activity indicators are used based on the activity information that was filled into the Hotspot Mapping excel sheet during disassembly. They are marked with the indicators shown in figure 3.42. The activity indicators are similar to but not the same as the Hotspot Indicators of the Hotspot method.

1. Time indicator: marking activities that take longer than 30 seconds to perform.
2. Force indicator: marking activities that require a high level of force to perform, corresponding to the hotspot mapping spreadsheet.
3. Precision indicator: marking activities that require a high level of precision, corresponding to the hotspot mapping spreadsheet.
4. Non-reusable fastener: marking fasteners that are damaged beyond reuse during the process of disassembling.
5. Uncommon tool: marking activities that require tools other than listed as a common tool for the type of product.parts because less actions have to be performed and less parts have to be removed.

Results
Disassembly maps
The disassembly maps of the six products are shown on pages 50 to 55.

Safety critical priority parts
Table 3.5 shows the disassembly depth of the safety critical priority parts of the three baby car seats. The disassembly depth is calculated by counting all activities including removing other parts before the priority part is reached, while taking into account the “or” logic of parallel sequences. The ease of disassembly of all safety critical priority parts is further discussed below.

- The handle of the Maxi Cosi Pebble Pro can be reached in a few steps from the complete assembly. This is because the handle is attached to the shell with one TX20 screw on each side, which is covered by a lid. Removing the lid and the screws allows for the complete removal of the handle. From a refurbishment perspective, this design aspect is favourable over the way the Cybex and the Swandoo baby car seats have integrated the handle.
- The three products have different design approaches to the integration of the foams. The Swandoo Albert has two large EPP foam pieces that are fixed in place because they fit tightly in the shell. In addition, the Swandoo Albert has a head pillow and an infant insert made of a soft PU foam. The infant insert is kept in place by the upholstery and the head pillow by one screw. The Cybex Cloud Z has several thin and small pieces of EPS foam, which are glued to the shell. As mentioned before, removing these foam pieces took a lot of time and the chance of damaging or breaking off parts of the thin pieces was high.

Figure 3.42: the five activity indicators: time indicator, force indicator, precision indicator, unreusable fastener indicator, uncommon tool indicator

The Maxi Cosi also uses several pieces of EPS foam, which are kept in place by a friction fit between the shape of the foams and the shell. In addition, the Pebble Pro uses a soft, flexible foam around the sides of the head, again kept in place due to the shape of the parts surrounding it. Foams fixated with a friction fit were easiest to disassembly. Unlike the Swandoo Albert, the infant insert and head pillow of the Cybex Cloud Z and the Maxi Cosi Pebble Pro are not filled with foams, but with some type of fabric cushioning.

- Only the buckle of the Cybex Cloud Z is removable from the shell, while the buckles of the other two products are sewn in place and thus not removable at all.
- Only the shoulder straps of the Swandoo Albert are removable. Both the Cybex and the Maxi Cosi seats make use of a belt to tighten the shoulder straps, which is sewn into place in the buckle and shell and is thus not removable.
- The shoulder pads of Maxi Cosi are not as easy to reach as those of the Cybex and Swandoo seats. From a refurbishment perspective, this is a bad thing, however the safety problem of these shoulder pads is that they get lost and Maxi Cosi solves this by attaching them to the shell which consequently leads to more steps before removal. So, from a safety perspective, the design solution used by Maxi Cosi is preferable over the shoulder pads of the Cybex and Swandoo seats.
- The locking mechanism of the Swandoo Albert is the most complex of the three, mainly due to having the “hook side” of the mechanism on the baby car seat and having the axes on the ISOfix base. The other two products have the axes on the baby car seat and the hooks on the base. The mechanism around the hooks brings complexity. The axes that are part of the locking mechanism of the Maxi Cosi Pebble Pro are not removable from the shell.
- Only the side belt guides of the Swandoo Albert are removable, they are attached to the shell with screws. The side belt guides of the Cybex and Maxi Cosi seats are moulded as one with the cradle and shell, respectively. However, an additional part to the side belt guides of the Maxi Cosi Pebble Pro is removable and this part would probably be the part that receives the most wear and tear during use. The back belt guides are integrated in a similar way for all three products, being screwed on to the back of the shell.
- Only the Cybex Cloud Z features a side impact protector (which means that the Swandoo Albert and the Maxi Cosi Pebble Pro do not need one to pass the safety tests) and it can be unscrewed from the shell after removing the foams.
- The load distribution structure consisting of the shell (or the cradle in the case of the Cybex Cloud Z) in the three baby car seats is mainly what is left after disassembling all other parts.

Table 3.5: depth of the safety critical priority parts of the baby car seats

	handle	foam	head pillow	new-born insert	buckle	shoulder straps	shoulder pads	locking mechanism (seat-base)	belt guides sides	belt guide back	side impact protector	load distribution structure
Swandoo Albert	22	19	11	5	not removable	25	1	33	22	22	not present	35
Cybex Cloud Z	not removable	15	6	3	40	not removable	1	35	not removable	19	23	39
Maxi Cosi Pebble Pro	4	13	2	4	not removable	not removable	15	not removable (28)	1 (partly removable)	22	not present	28

Table 3.6 shows the disassembly depth of the safety critical priority parts of the ISOfix bases. The ease of disassembly of all safety critical priority parts is further discussed below.

- Only the ISOfix anchors of the Maxi Cosi base are removable from the main assembly. For the Swandoo base and the Cybex base they are integrated within (part of) the load distribution structure.
- The support leg of all products can be removed after removing the top shell. Since the Maxi Cosi base makes use of electronic components to indicate whether the seat and base are installed correctly, the connectors of the PCB also need to be removed before being able to remove the support leg. In the Swandoo and the Cybex bases, the support leg is attached to the bottom shell with an axis which functions as the pivot point of the leg. The support leg of the Maxi Cosi base has an integrated pivot point and an additional part is screwed into place on the bottom shell.
- The Swandoo and Cybex base make use of Bowden cables, making the system of the installation indicators fully mechanical. The installation indicator system of the Maxi Cosi 3wayfix is fully electronic.
- The locking mechanism of the Swandoo base is less complex than that of the other two products, because the “axis side” is on the base, as was mentioned before. The locking mechanism of the Cybex Z base is not removable from the load distribution frame. The locking mechanism of the Maxi Cosi base is part of a subassembly that can be removed from the load distributing bottom shell and then further disassembled, making the locks of the mechanism the last part that is left after a complete disassembly.
- The Swandoo and Cybex bases make use of metal frames for load distribution (although the shells will also take up part of this role), but as mentioned before the Maxi Cosi base has a load distributing bottom shell. For the Cybex base, the frame is the last part left after complete disassembly. For the Swandoo base, the two metal frames can be separated from the construction of the installation indicators after removing two “loops” (the two axes of the locking mechanism).

Table 3.6: depth of the safety critical priority parts of the ISOfix bases

	ISOfix anchors	Support leg (or top tether)	installation indicators	locking mechanism (seat-base)	load distribution structure
Swandoo Albert base	not removable	10	17	14	17
Cybex Z base	not removable	9	13	not removable	48
Maxi Cosi 3wayfix	19	19	17	37	26

Activity indicators
The number of indicators on each disassembly map are shown in table 3.7. Based solely on this table, it seems the Cybex Z base scores lowest on ease of disassembly as it has earned the most indicators with a total of 25. It is also the only product making use of uncommon tools. The two Cybex products make use of non-reusable fasteners by using glue or rivets. The Maxi Cosi Pebble Pro received the fewest hotspot indicators with a total of only 2.

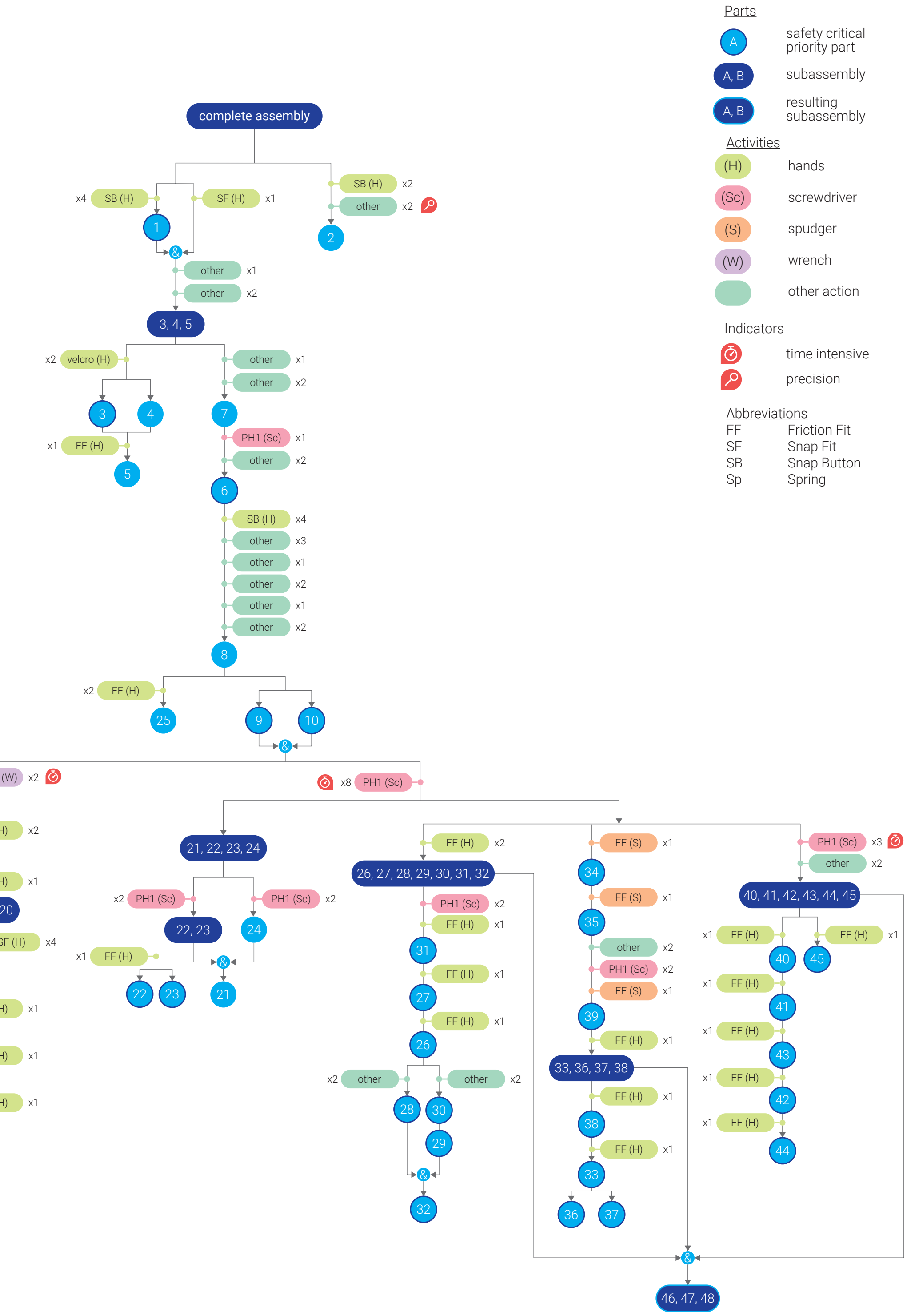
Product architecture
Since the disassembly map is a visualisation of the disassembly sequence, it can also be used to analyse the product architecture. The disassembly map of the Cybex Z base for example, shows a very linear disassembly sequence, indicating a product architecture of parts stacked on top of each other. Even though there are parallel sequences throughout the process, for a complete disassembly the sequence is linear up to part 24 on the map, because of the parallel options that both have to be performed.

A linear disassembly map like the Cybex Z base looks simple compared to a disassembly map with more parallel sequences like that of the Swandoo Albert. However, the Swandoo Albert consists of several subassemblies that can be taken out as a whole. This results in a reduced disassembly depth when the goal is not to disassemble the whole product, but to replace a certain part. In this sense, 'clumping' parts in subassemblies that can be removed from the main assembly is beneficial for design for refurbishment.

Table 3.7: number of hotspot indicators for each of the six products

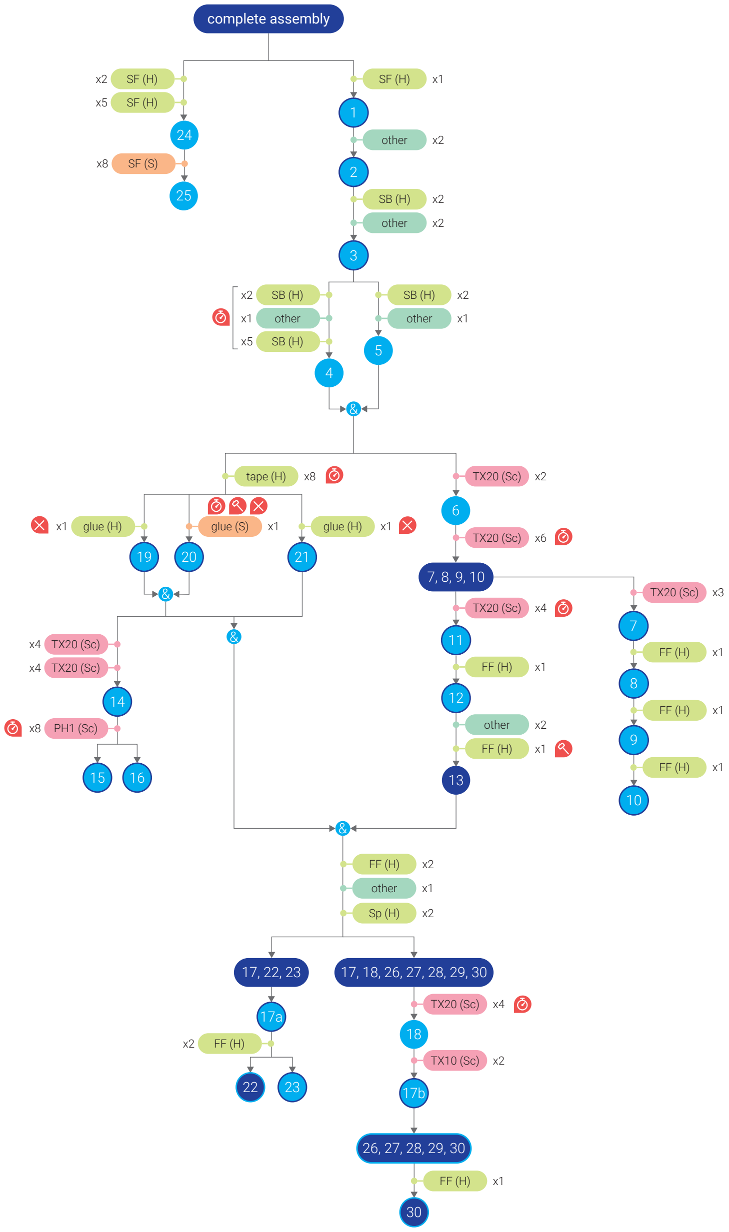
	time indicators	force indicators	precision indicators	non-reusable fasteners	uncommon tool	total
Swandoo Albert	5	0	1	0	0	**6**
Cybex Cloud Z	7	2	0	3	0	**12**
Maxi Cosi Pebble Pro	2	0	0	0	0	**2**
Swandoo Albert base	6	1	6	0	0	**13**
Cybex Z base	9	4	4	4	4	**25**
Maxi Cosi 3wayfix	7	2	1	0	0	**10**

Disassembly Map
Swandoo Albert
Baby carrier



1. shoulder pads (L+R)
2. sun canopy
3. infant insert foam
4. infant insert upholstery
5. infant insert spoon
6. head pillow
7. head pillow upholstery
8. upholstery
9. foam left
10. foam right
11. belt guide opaque (L+R)
12. belt guide transparent (L+R)
13. handle
14. handle axes (L+R)
15. handle spacer (L+R)
16. handle light grey bit (L+R)
17. handle dark grey bit (L+R)
18. handle white bit (L+R)
19. handle metal bit (L+R)
20. handle spring (L+R)
21. shell bottom
22. shell bottom handle transparent
23. shell bottom handle opaque
24. shell bottom bracket
25. snap sticks
26. Unlocking Mechanism top axes
27. UM top hooks (L+R)
28. UM top black metal (L+R)
29. UM top black plastic
30. UM top strings (L+R)
31. UM top torsion spring (L+R)
32. UM top grey part
33. UM bottom hooks (L+R)
34. UM bottom POM A
35. UM bottom POM B
36. UM bottom black
37. UM bottom axis
38. UM bottom sticks (L+R)
39. UM bottom washer axes (L+R)
40. slider axis
41. slider POM A
42. slider POM B
43. slider spring
44. slider guide
45. shoulder straps (L+R)
46. shell main
47. buckle
48. belt surfaces (L+R)

Disassembly Map
Cybex Cloud Z
Baby carrier



Parts
- safety critical priority part
- subassembly
- resulting subassembly

Legend
- (H) hands
- (Sc) screwdriver
- (S) spudger
- other action

Indicators
- time intensive
- force intensive
- unreusable fastener

Abbreviations

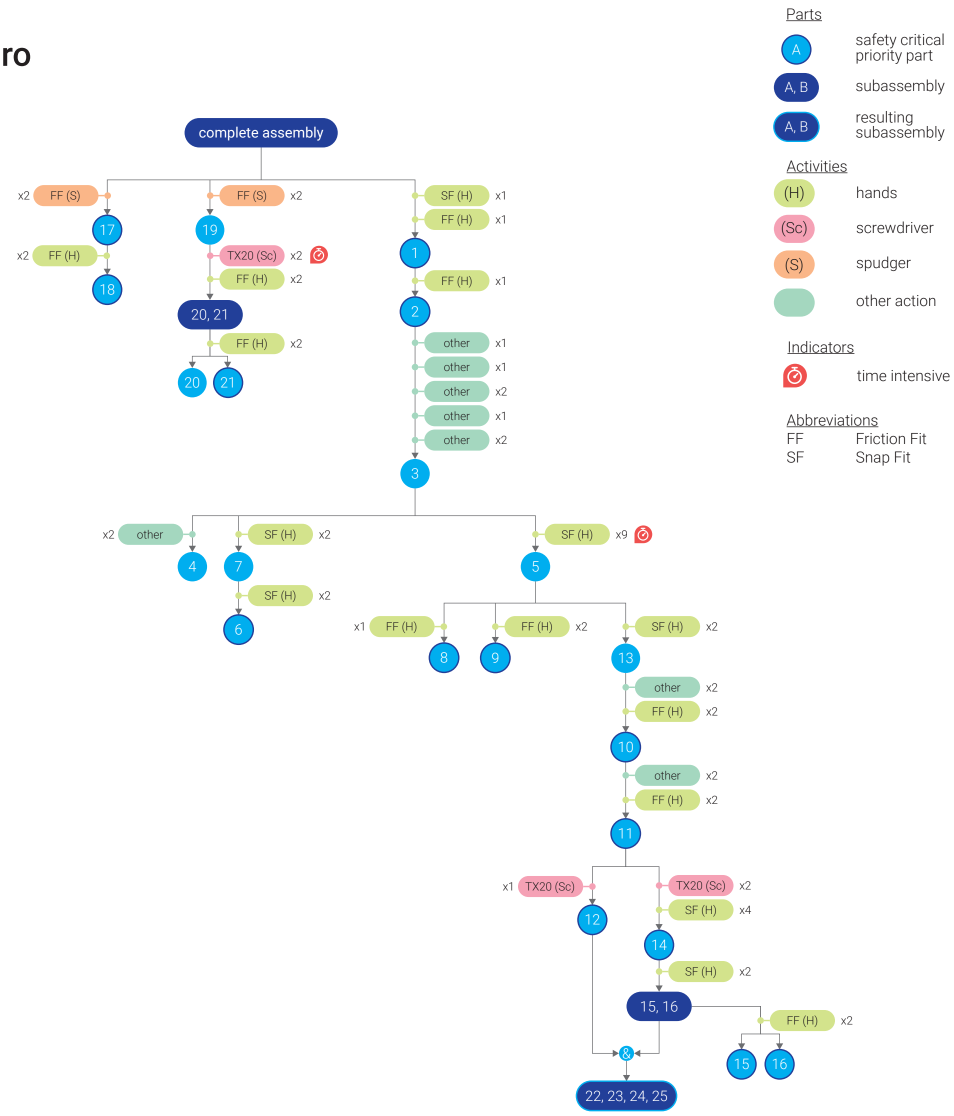
FF	Friction Fit
SF	Snap Fit
SB	Snap Button

1. shoulder pads (L+R)
2. infant insert
3. headrest
4. backrest upholstery
5. leg support upholstery
6. reclined position handle
7. belt guide back plate
8. belt guide grip
9. belt guide blue
10. belt guide black
11. slider back plate
12. slider lever
13. slider subassembly
14. side impact silver (L+R)
15. side impact screw on (L+R)
16. side impact rest (L+R)
17. ISOfix axes
18. booklet holder
19. foam head center
20. foam head (L+R)
21. foam legs
22. shell leg part
23. shell back part
24. sun canopy hard plastic
25. sun canopy fabric
26. cradle
27. front belt guides (L+R)
28. handle assembly
29. reclined position system
30. buckle

Disassembly Map

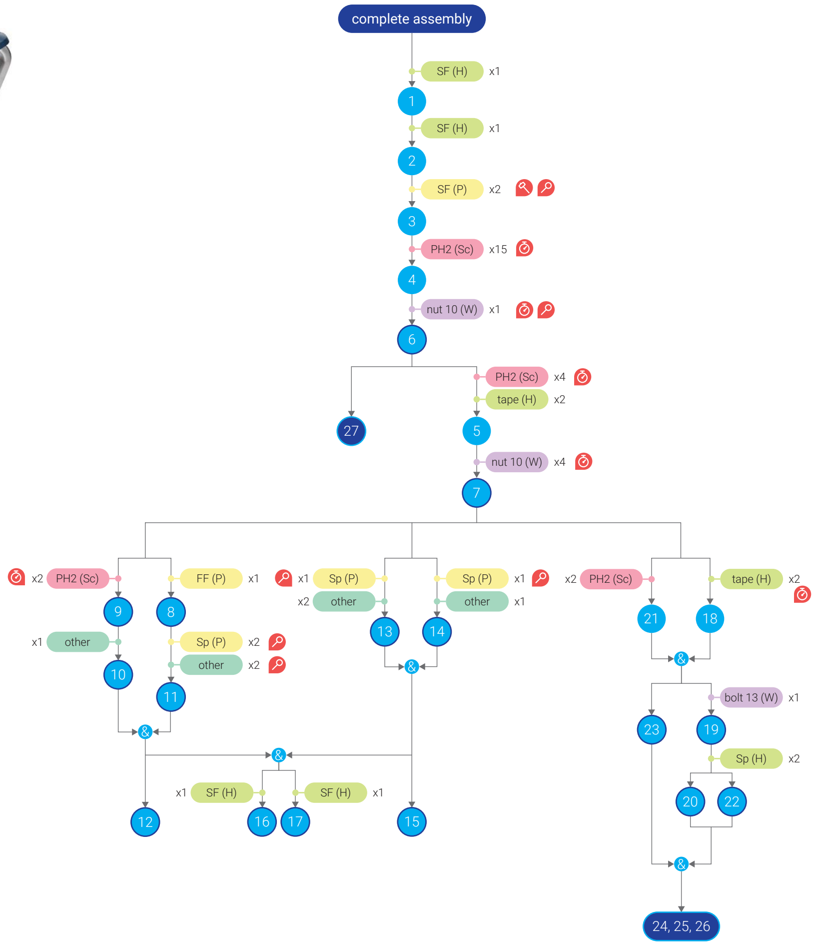
Maxi Cosi Pebble Pro

Baby carrier



1. head pillow
2. infant insert
3. upholstery
4. sun canopy
5. flexible cover
6. shoulder pads (L+R)
7. shoulder pad holder (L+R)
8. foam legs
9. foam sides (L+R)
10. foam back
11. foam head (L+R)
12. back belt guide
13. foam holder (L+R)
14. strap height adjuster front
15. strap height adjuster back
16. strap height adjuster knob
17. side belt guides black (L+R)
18. side belt guides blue (L+R)
19. handle cover (L+R)
20. handle button (L+R)
21. handle
22. shell
23. buckle
24. shoulder straps (L+R)
25. ISOfix axes

Disassembly Map
Swandoo Albert base
ISOfix base



Parts
- A: safety critical priority part
- A, B: subassembly
- A, B: resulting subassembly

Activities
- (H): hands
- (Sc): screwdriver
- (P): pliers
- (W): wrench
- other action

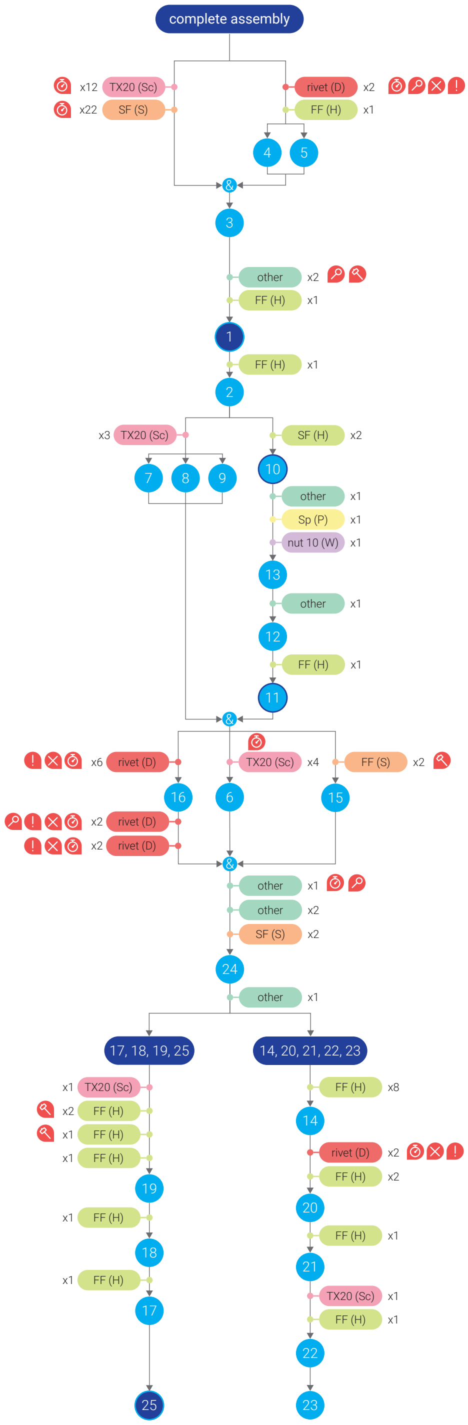
Indicators
- time intensive
- force intensive
- precision

Abbreviations

FF	Friction Fit
SF	Snap Fit
SB	Snap Button
Sp	Spring

1. grip large
2. grip small
3. axes
4. top shell
5. bottom shell
6. leg axis
7. loops
8. back indicator
9. back ABS part
10. back push button
11. back white sliders
12. back mount
13. front indicator
14. front push button
15. front mount
16. Bowden cable A1
17. Bowden cable A2
18. tape axes (L+R)
19. bolt 13 (L+R)
20. bolted hook (L+R)
21. slider female
22. small white sliders (L+R)
23. metal frame
24. yellow frame + slider male + ISOfix anchors
25. Bowden cable B1
26. Bowden cable B2
27. support leg

Disassembly Map
Cybex Z base
ISOfix base



Parts

- A — safety critical priority part
- A, B — subassembly
- A, B — resulting subassembly

Activities

- (H) — hands
- (Sc) — screwdriver
- (S) — spudger
- (P) — pliers
- (W) — wrench
- (D) — electric drill
- other action

Indicators

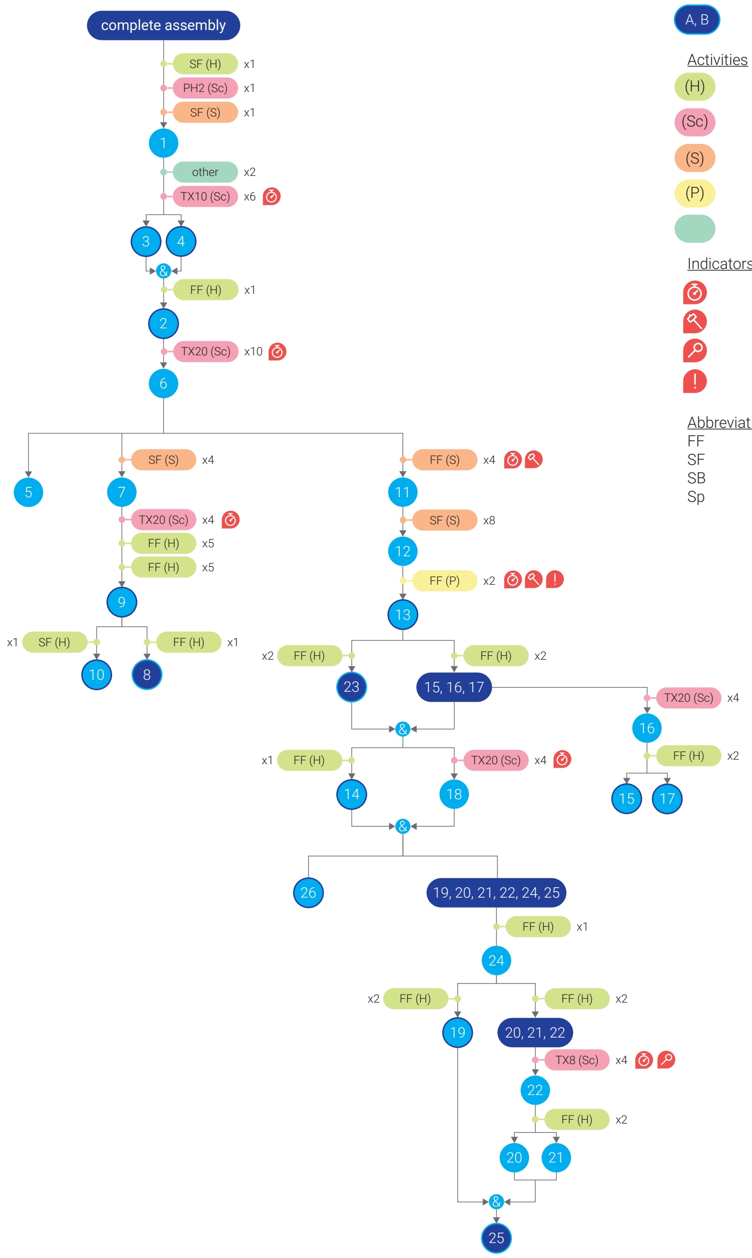
- time intensive
- force intensive
- precision
- unreusable fastener
- uncommon tool

Abbreviations

FF	Friction Fit
SF	Snap Fit
SB	Snap Button
Sp	Spring

1. support leg
2. finger protector
3. top shell
4. release button green part
5. release button grey part
6. rotation guide hooks (4x)
7. Anti Rebound Bar main
8. Anti Rebound Bar back
9. Anti Rebound Bar buttons
10. installation indicators
11. front attachment plastic
12. front attachment metal male
13. front attachment metal female
14. wheels (8x)
15. ISOfix slider buttons (L+R)
16. booklet holder
17. rotating mechanism main
18. rotating mechanism cylinder
19. rotating mechanism small hook
20. bottom shell metal bits (L+R)
21. bottom shell white lever
22. bottom shell black lever
23. bottom shell
24. bottom shell lid
25. frame + ISOfix anchors

Disassembly Map
Maxi Cosi 3wayfix
ISOfix base



Parts

- A — safety critical priority part
- A, B — subassembly
- A, B — resulting subassembly

Activities

- (H) — hands
- (Sc) — screwdriver
- (S) — spudger
- (P) — pliers
- other action

Indicators

- time intensive
- force intensive
- precision
- uncommon tool

Abbreviations

FF	Friction Fit
SF	Snap Fit
SB	Snap Button
Sp	Spring

1. battery lid
2. Anti Rebound Bar front
3. Anti Rebound Bar back
4. Anti Rebound Bar rods (L+R)
5. Anti Rebound Bar tongue
6. top shell
7. leg cover
8. support leg
9. PCB
10. battery holder
11. ISOfix slider button (L+R)
12. ISOfix slider shell (L+R)
13. pins (L+R)
14. main axis
15. ARB angle system wheel (L+R)
16. ARB angle system cover (L+R)
17. ARB angle system main (L+R)
18. front axis cover (L+R)
19. front axis (L+R)
20. release button slider (L+R)
21. release button main (L+R)
22. release button connector (L+R)
23. ISOfix anchors (L+R)
24. middle connector
25. locks (L+R)
26. bottom shell

Quantification of the product architecture

The disassembly maps visually indicate the complexity of different products by the overall size of the map, the number of parts, and the linear and parallel connections between these parts. However, through a quantification of the disassembly map it would be possible to actually grade the complexity of the product architecture and make a numerical comparison in addition to a visual comparison between different products.

This quantification of the disassembly map has been explored, with a focus on capturing the positive impact that parallel sequences have on the ease of disassembly, because they generally decrease the depth of the product architecture. As described above in the case of the disassembly map of the Cybex Z base, a map of which the disassembly sequence is easy to understand because it is linear, does not signify a product with an architecture optimised for disassembly.

Several methods of calculating the parallelism of the product architecture have been explored, by analysing which parameters best illustrate this parallelism and the related complexity and depth of disassembly sequences.

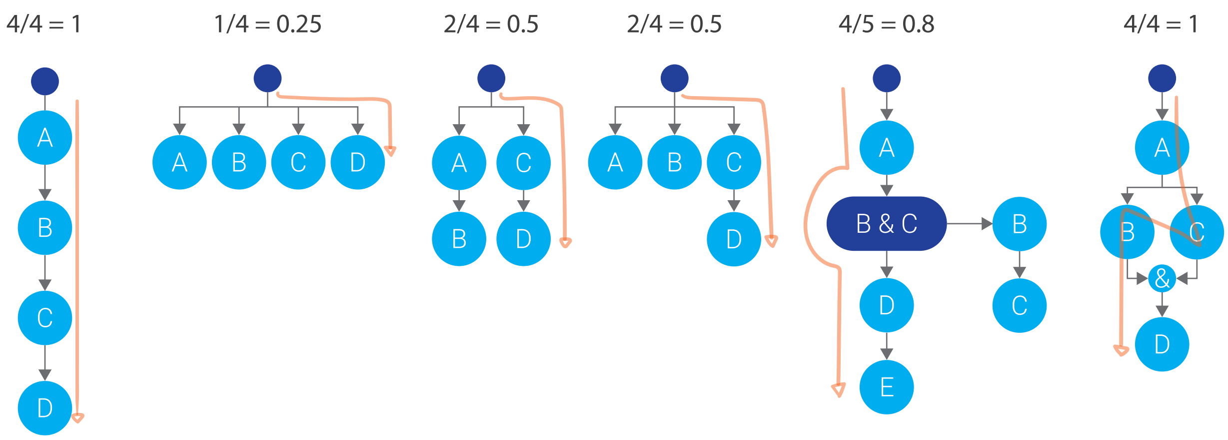
D.D.I. = max. part depth / total # parts

Dividing the maximum part depth by the total number of parts is concluded to be the best method. This method results in an index score from 0 (or actually close to 0 as it depends on the total number of parts) to 1 in which closer to 0 is better, representing the relative disassembly depth of the product. In this method, the perfect product architecture regarding ease of disassembly would be all parallel, because parallelism decreases the depth of the sequence, (see figure 3.43a) and the worst would be all linear, because linearity results in a maximum disassembly depth (see figure 3.43b). Dividing the maximum part depth, or the absolute disassembly depth, by the total amount of parts allows for a comparison between different products, therefore this 'disassembly depth index' represents the disassembly depth that can be compared relatively to other products.

The maximum part depth is calculated by counting all parts that need to be removed before reaching the deepest part. In this way, parallelism is awarded with a lower score, because parallel sequences are not in the way to reach the deepest part. Only the parts and not their fasteners are considered in this quantification of the disassembly map, because the main goal is to capture the product architecture, so how parts are stacked, in the simplest way possible. Taking into account fasteners as well would introduce unnecessary complexity to the method.

Figure 3.43 shows six examples of disassembly sequences and how the maximum part depth is calculated for each example. Figure 3.43a is a fully linear sequence resulting in a score of 1 and figure 3.43b is a fully parallel sequence resulting in the lowest score possible for this number of parts, which is 0.25. Figure 3.43c and 3.43d show two partially parallel sequences both resulting in the same score of 0.5, because they have the same maximum part depth of 2. Figure 3.43e shows a sequence with a subassembly consisting of two parts but counting as 1 for the maximum part depth since it is not necessary to separate the parts in the subassembly to reach the deepest part. Figure

Figure 3.43: six examples of the calculation of the disassembly depth index



3.43f shows a partially parallel sequence that is not beneficial for the ease of disassembly of the deepest part. Since both part B and C have to be removed before reaching the deepest part, they both count for the calculation of the maximum part depth.

Applying this quantification method of the disassembly map results in the following 'disassembly depth index' of the baby car seats and ISOfix bases as shown in table 3.8. The Swandoo Albert and the Maxi Cosi Pebble Pro have the lowest indexes of all six products, indicating that their product architecture features the least linear sequences and the most parallel sequences and thus that ease of disassembly is universally higher for these products compared to the others. The Cybex Z base has the highest index of 0.84, as was expected based on its predominantly linear disassembly sequence, which means that the designers of this product could greatly improve the product architecture to increase the ease of disassembly.
A drawback of this method is that the lower limit of the index is dependent on the total number of parts, which means that for products with more parts this minimum is lower than for products with less parts. However, this minimum is only reached when the disassembly sequence is fully parallel, which is unlikely to be accomplished in reality especially for products with a higher number of parts. As this method is intended for products of which the disassembly map indicates a complex product architecture of which the disassembly depth cannot be understood just by visual cues, this method is most useful to product with a higher number of parts. Furthermore, the disassembly depth index is meant as an additional metric to disassembly time, number of activities, etc., to recognise a product's ease of disassembly as a product designer and to stimulate this designer to adjust the product architecture to aid disassembly.

Table 3.8: the disassembly depth index of the six analysed products

	number of parts	max part depth	depth index
Swandoo Albert	48	15	0.31
Cybex Cloud Z	30	17	0.57
Maxi Cosi Pebble Pro	25	11	0.44
Swandoo Albert base	27	14	0.52
Cybex Z base	25	21	0.84
Maxi Cosi 3wayfix	26	18	0.69

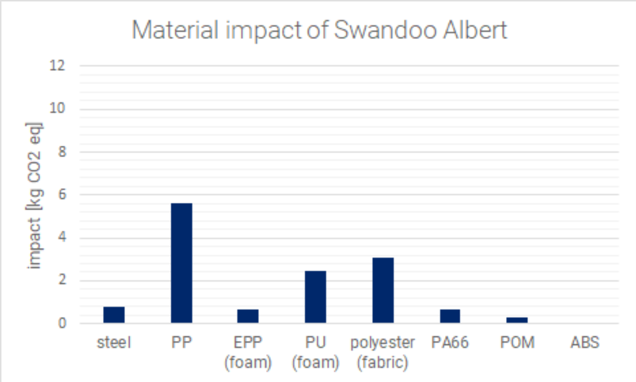
3.2.4 Environmental impact

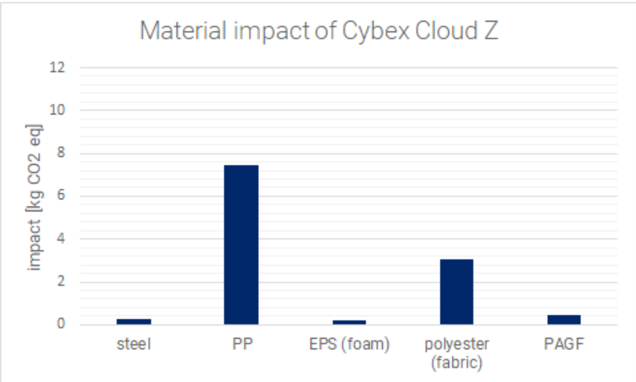
The material use of the current products has been analysed as it influences the environmental impact of a product. During the disassembly of the six products, a Bill of Materials for each product was set up. These BOM's can be found in appendix H. Together with these BOM's, the Idemat database (Vögtlander, 2020) was used to calculate the carbon footprint of the materials used in each product (in kg CO_2 equivalents). In figures 3.44 to 3.49 the outcomes of these calculations are shown. These graphs show what kind of materials are used in each product and which materials have the most environmental impact. Overall, the materials with the highest weight percentage in the product are the materials with the highest impact.

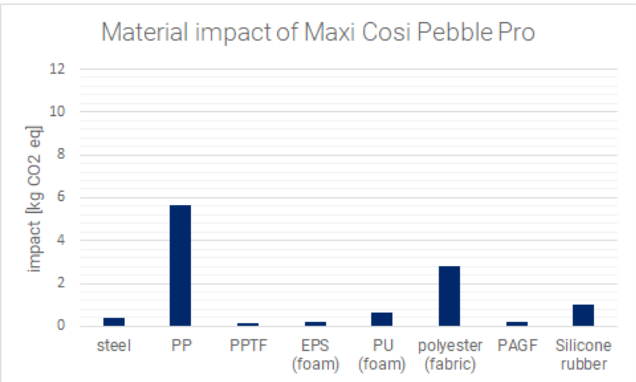
For the baby car seats, polypropylene generally has the highest impact percentage. The soft goods have the second highest impact, with the assumption that all of the soft goods of all products are made from polyester (not all parts specified their materials, but it was likely all fabrics were polyester because of their look and feel).

The material usage in the ISOfix bases illustrates the different design approaches of the products. The Swandoo Albert base is a simple product in which the steel and aluminium frame parts have the highest impact. The Cybex Z base features a rotation mechanism made entirely of steel and uses more polypropylene than the Swandoo base mainly because it has a larger shell due to the Anti Rebound Bar. The Maxi Cosi 3wayfix uses a lot less metal, but this is replaced by a shell that is enforced with a crosshatch pattern, using more polypropylene, and by using glass-filled PA for other important structural parts.

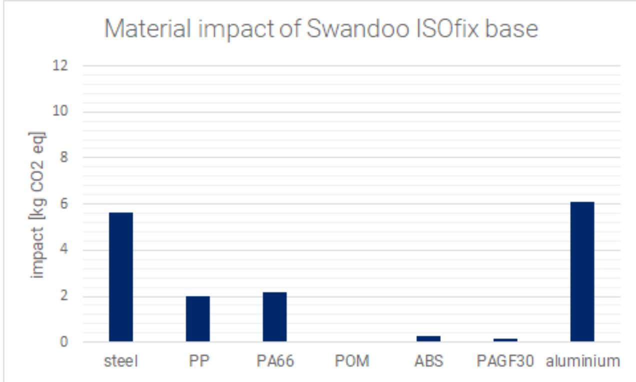
When comparing all carbon footprints for all six products, it shows that the Maxi Cosi 3wayfix has the highest impact and the Maxi Cosi Pebble Pro the lowest (figure 3.50). When comparing the impact of the products to the weight of the products (figure 3.51), it can be stated that the impact of the baby car seats seems to correspond to their weight. For the ISOfix bases this is not the case.

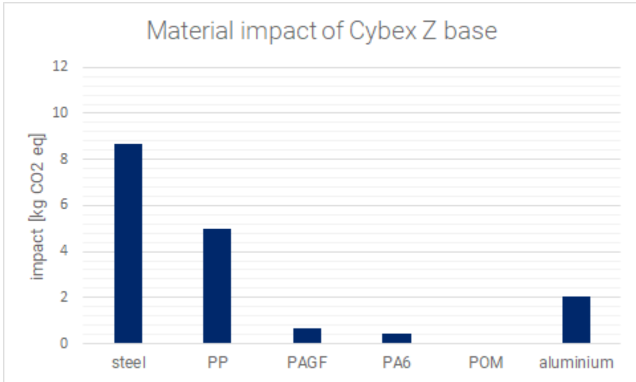


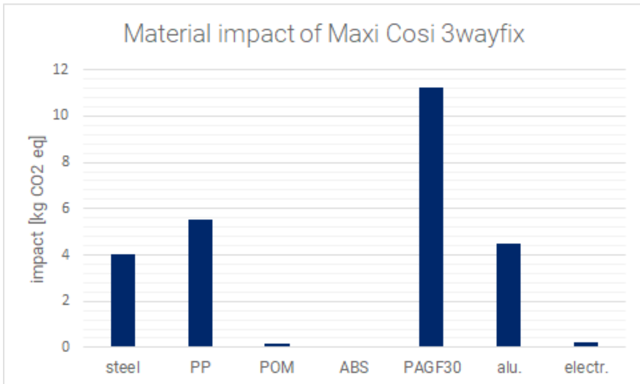




Figures 3.44, 3.45 and 3.46: material impact of the Swandoo Albert, the Cybex Cloud Z, and the Maxi Cosi Pebble Pro







Figures 3.47, 3.48 and 3.49: material impact of The Swandoo Albert ISOfix base, the Cybex Z base, and the Maxi Cosi 3wayfix

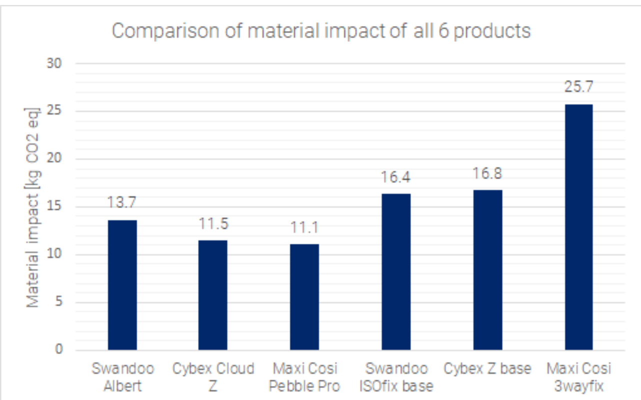


Figure 3.50: total material impact of all six products

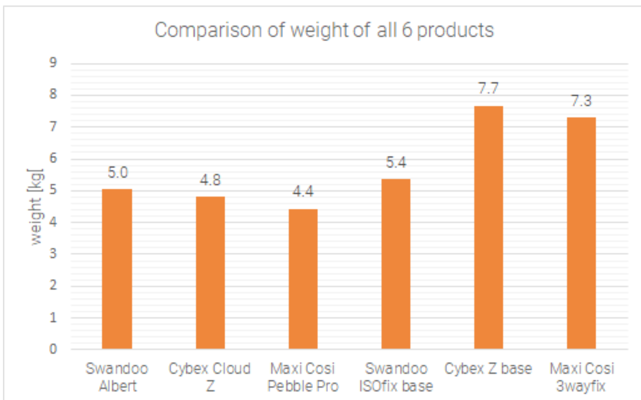


Figure 3.51: weight of all six products

Some remarks about this presentation of the carbon footprint of the products are in place. It should be kept in mind that while it is good from an environmental perspective to always aim for a product with as little impact as possible, there are situations in which a material with a higher impact should be preferred over others, for example when a material with a higher impact results in a product with a longer lifespan (slowing loops, see paragraph 2.3.2), ultimately resulting in a lower total impact.

Another remark is that representations like this do not capture the real situation of the impact of a product. For example, unfilled PA66 has an impact factor of 8.34, while 30% glass filled PA66 has an impact factor of 5.98 (for Carbon footprint in kg CO_2 equivalents, Idemat 2020), simply because the filler has a lower impact than the PA66. When looking only at this material impact, it would be smart to use more glass filled polymers! When aiming for circularity however, it is necessary to look at the whole life cycle of a product and its materials.*

The problem with composite materials such as glass filled PA is the end-of-life stage, as they typically end up in landfill or incineration plants. The reason for this is that recycling processes for composite materials are not yet developed in a satisfactory manner, mainly having to do with high costs and high levels of material degradation (personal communications with Joost Vögtlander, June 12th 2020; Van Oudheusden, 2019). The same is the case for the foams used in the baby car seats, which are EPP, EPS and PUR.

To conclude, it would be beneficial towards a circular design to eliminate non-recyclable materials, which currently means eliminating the foams and any glass filled plastics. Secondly, there are currently no materials with recycled content used and at the end of life no recovering and recycling of materials takes place, which means there is a lot of room for improvement. Lastly, reducing the amount of different materials used in the products would aid the recyclability of the product as a whole as it will be easier to create pure resource streams.

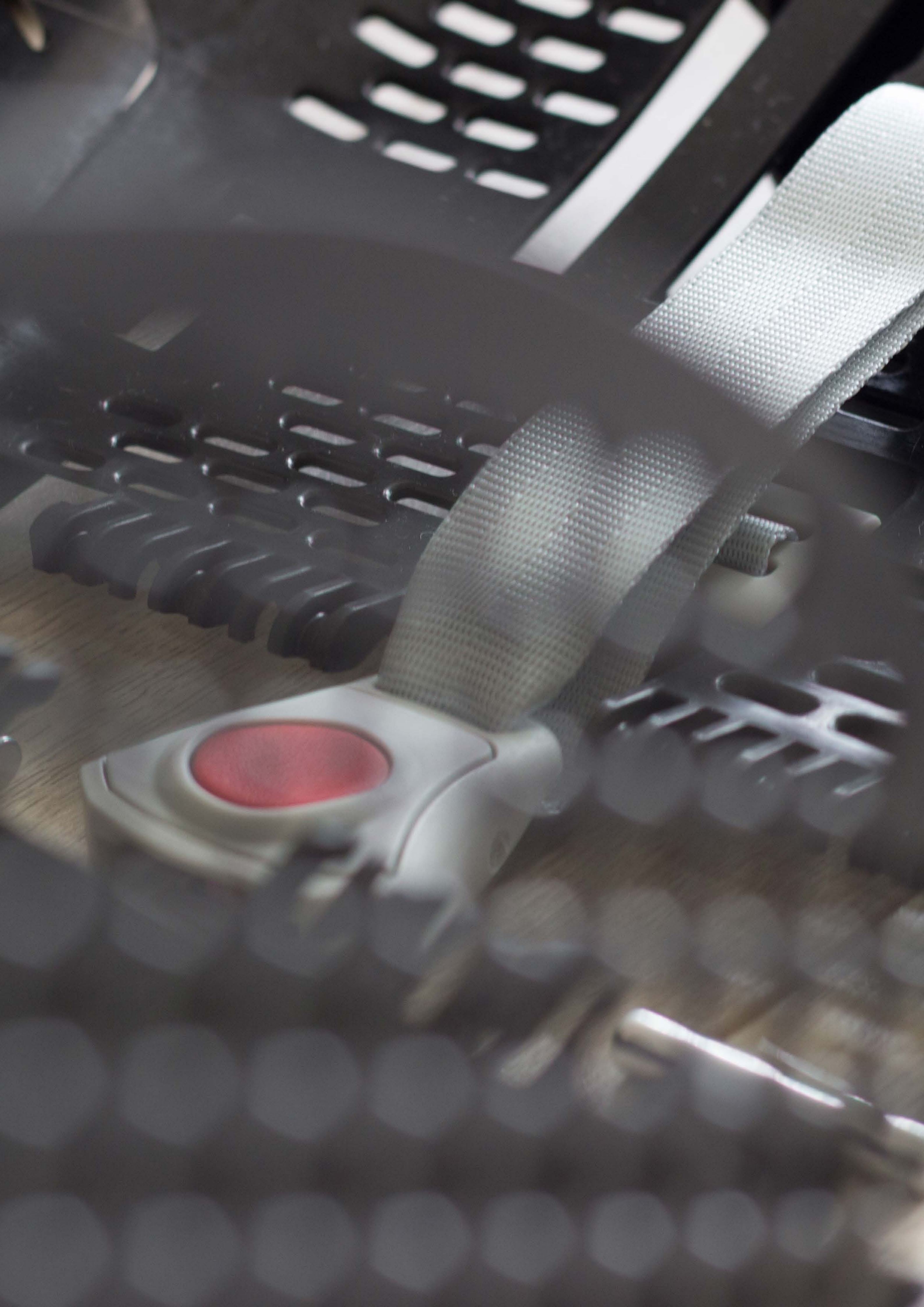
** Life Cycle Analysis*

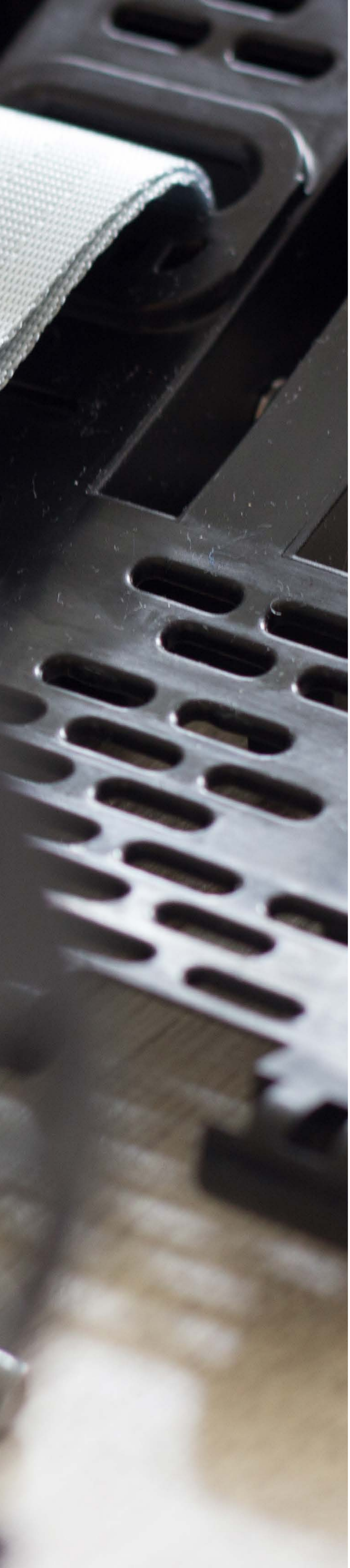
I explored the option of using a fast-track Life Cycle Analysis to further evaluate the environmental impact of baby car seats and ISOfix bases, but it appeared that to many variables were unknown without valid substitutes. I concluded that the results of an LCA would be too skewed to represent the real situation and I think it might be unhelpful to present the outcomes in this situation. That is why the environmental analysis is limited to the impact of the materials only, excluding data of manufacturing, transport, packaging, and end-of-life.

Key insights

Chapter 3: Assessment of current child car seats

- The safety critical parts of baby car seats and ISOfix bases are what makes them safe and these parts can be divided into three categories: parts that fulfil the function of 1) installing the baby car seat inside the car either by using the ISOfix base or by using the car seat belt, 2) installing the child inside the seat, 3) absorbing crash impact.
- Active or passive sensors that should be included in the design of child car seats can be used to inform about whether the seat has been in a crash, which is crucial for the refurbishment of child car seats and their safety guarantee.
- The priority of parts depends on several factors: their functional importance, their failure frequency, and their economic and environmental value. Parts of baby car seats with the highest priority are the soft goods, the load distribution structure, the shoulder pads, the foams, the infant insert, and the handle. Parts of ISOfix bases with the highest priority are the load distribution structures and the support leg.
- Almost all parts of baby car seats and ISOfix bases have a safety critical function, which means they are of high functional importance.
- The disassembly process of three baby car seats and three ISOfix bases has been documented following the method of Hotspot Mapping.
- The disassembly time of the six products range from 7 minutes (Maxi Cosi Pebble Pro) to 20 minutes (Maxi Cosi 3wayfix).
- For the disassembly of the Maxi Cosi Pebble Pro only two different tools were needed, while for the Swandoo Albert Base seven different tools were needed.
- The disassembly maps of the six products show that different design approaches result in an increase or decrease in the complexity of the product architecture and the disassembly sequence.
- Not all safety critical priority parts of both baby car seats and ISOfix bases are currently removable, which means that with the current design when one of these parts fails, the product cannot be refurbished and will be discarded. Other safety critical priority parts lie very deep within the product architecture.
- The disassembly of the Cybex Z base receives the most 'activity indicators' of all six products, which was mainly due to the rivets that needed to be drilled out, which are unremovable fasteners demanding uncommon tools, and which also takes a lot of time and precision.
- The 'disassembly depth index' is introduced and then used to quantify the product architecture of the six products. Based on the disassembly map, this disassembly depth index is calculated, and the results indicate that the Swandoo Albert has the lowest relative disassembly depth and thus also the most parallel disassembly sequence of the six products. The Cybex Z base has the worst score and has the highest relative disassembly depth, indicating that there is still a lot of room for improvement in the design for ease of disassembly.
- The material impact of the three baby car seats and ISOfix bases range from 11.1 to 25.7 kg CO_2 equivalents. Generally, the use of PP is responsible for the largest percentage of this impact for the baby car seats and for the ISOfix bases the biggest contributors are steel and aluminium.
- Current non-recyclable materials used in baby car seats are glass-filled polymers and EPS, EPP, or PU foams. When parts made of these materials need to be discarded during refurbishment, they will end up incinerated and their value is lost.





4

Guidelines for design for refurbishment

This chapter introduces guidelines that can be used to design safety critical products suitable for the refurbishment loop of the circular economy, based on the analyses presented in the previous chapters. The main focus of the guidelines is enabling design for refurbishment, in order to retain the value embodied within these products, while guaranteeing their safety critical functionality.
The guidelines are categorised into four categories, namely guidelines specifically for safety critical products, and guidelines for product architecture, materials, and fasteners. Each guideline consists of three parts, firstly an explanation of the guideline is given, secondly a reflection of the guideline on the current baby car seats and ISOfix bases is given, and lastly a set of questions is given designers can ask themselves to improve their design for refurbishment. The chapter ends with a summary of all guidelines which can be used as a checklist when designing safety critical products for refurbishment.

4.1 Safety critical products

1. Safety above all else

The most important principle to keep in mind when designing safety critical products is simply that this safety aspect is more important than anything else. When choices based on sustainability, ergonomics, aesthetics, or other drivers compromise the design in terms of safety, these choices should be revisited because the main goal of the product is not met: providing safety for the user

2. The history of a safety critical product should be known

In order to determine whether a safety critical product is still safe to use, its history should be known. In the case of child car seats, it needs to be known whether the product has been in a crash, as explained in paragraph 3.1.2. This can be achieved by using sensors to collect data about the usage of a safety critical product, indicating when a child car seat has been in a crash. This history of the product and of its parts should be logged during inspection to create an overview of the whole lifetime.

The main question a designer should ask themselves is whether they have applied the principle 'safety above all else' throughout the entire design. A risk, however, comes forth when designers use this principle as an excuse so as not to explore any alternatives that both comply with safety criticality and improve upon other drivers, resulting in stagnation of innovation.

Questions designers can ask themselves are: Can someone in the future check the history of the product? Are all potential events impacting the safety of the product known? And can you investigate the effects they might have had on the product as a whole and on its parts?

3. Safety critical parts should be removable

A safety guarantee can only be given when all safety critical parts of a product can be inspected and are OK, as stated in paragraph 3.1.2. This means that safety critical parts are parts with the highest level of priority in refurbishment. When one safety critical part fails and is not removable, the safety of the whole product is compromised and thus the whole product should be discarded. This is a great loss of value compared to when a safety critical part is removable and thus is replaceable, leading only to the disposal of said priority part and to the reuse of the rest of the product (see figure 3.6 in paragraph 3.1.2). Recyclability is also decreased when parts of several materials cannot be separated.

As shown in table 3.5 on page 47, the following safety critical priority parts of baby car seats are not always removable from the main shell, posing a problem for refurbishing:

- Buckle
- Shoulder straps
- Side belt guides

As shown in table 3.6 on page 48, the following priority parts of ISOfix bases are generally not removable:

- ISOfix anchors
- Locking mechanism

When designing for refurbishment, designers should investigate whether all safety critical parts are removable from the main assembly. If not, can you think of changing fasteners or product architecture in a way that allows removal? Or if nothing else is possible, maybe it is possible to integrate the non-removable part into a subassembly that is removable, at least diminishing the loss of value compared to discarding the whole product when a safety critical part fails?

4. Safety critical parts should be reachable within a reasonable number of steps

Refurbishment is not only improved by making safety critical parts simply removable, but it is also improved when these parts are reached during disassembly within a reasonable number of steps. The farther a safety critical part is within a disassembly sequence, the longer it takes to reach and a longer disassembly time results in higher costs for refurbishment. This 'reasonable number of steps' in which a part should be reached will differ per product category, depending on the number of parts, the product complexity and product specific requirements. Guideline 8 explains several ways of increasing the reachability of parts.

As shown in table 3.5 on page 47, the following safety critical priority parts of baby car seats are often deep within the disassembly sequence:

- Buckle (either removable or part of remaining assembly)
- Shoulder straps (either removable or part of remaining assembly)
- Locking mechanism
- Back belt guide
- Side impact protector (if applicable)
- Load distribution structure

As shown in table 3.6 on page 48, the following safety critical priority parts of ISOfix bases are often deep within the disassembly sequence:

- ISOfix anchors
- Locking mechanism
- Load distribution structure

Designers can ask themselves the following questions: Do you believe all safety critical parts are easy to reach and easy to inspect in the current design? Can you determine the reasonable number of steps for your product category? Do you know which parts take the most steps to reach? Can you think of a different path to get to the critical components?

5. Refurbishment protocol

For safety critical products it might be the case that some parts always need to be replaced during refurbishment, mainly when their safety cannot be guaranteed. This might be the case if there is no way to test the part, or if the test would be too expensive, such as using 3D imaging techniques described in paragraph 3.1.2. Similarly, some parts will always be cleaned during refurbishment.
It may seem like a step back from circularity when parts will always be replaced during refurbishment, however, if through this replacement the rest of the product can still be used another time and only the replaced part will be discarded, it is better than discarded the whole product because a single part has failed.

Adriaan Siewertsen (see appendix D) expects it to be necessary to always replace the buckle during refurbishment, because through use, sand, dust, and similar residue can build up within the mechanism. This might not hinder the functioning of the buckle immediately, but it might in a later stage which means that its correct functioning might not be guaranteed during refurbishment. For similar reasons other parts with safety critical mechanisms inside might need to be replaced, such as the ISOfix anchors of the base, the locking mechanism between the baby car seat and the ISOfix base, and the height adjustment system of the shoulder straps.
Parts that will always need to be cleaned are all of the soft goods, because of concerns about hygiene as indicated in paragraph 3.2.1 by parents currently using baby car seats. This includes the main upholstery, the infant insert, the head pillow, and the shoulder straps and pads.

Designers should investigate whether all safety critical parts can actually be checked and guaranteed to be safe. For how long can a safety guarantee for a safety critical part be given? After how many use cycles or how much time do you think the parts to be at their end of life relative to their safety critical function? Are there parts that will always be replaced or cleaned?

4.2 Product Architecture

6. A parallel disassembly sequence is preferred over a linear sequence

As pointed out in the section about quantifying a product's architecture on page 56 and 57, parallel disassembly sequences will result in shorter total disassembly sequences when partial disassembly is performed. This occurs, for example, when only a certain part needs to be replaced, which is often the case during refurbishment. The disassembly maps (pages 50 to 55) and the disassembly depth index (pages 56 & 57) of the six products show that linear disassembly sequences often occur and that there is still room for improvement.

As stated before, the Cybex Z base is the best example of having a mainly linear disassembly sequence of the six analysed products. Figure 4.1a shows an extremely simplified representation of the disassembly sequence of the Cybex Z base and figure 4.1b shows an alternative product architecture were parts A, B, and C are parallel instead of linear, decreasing the maximum part depth and thus increasing the ease of disassembly.

The soft goods of baby car seats are a clear example of parts that increase the linearity of the disassembly sequence, because in all three analysed products the soft goods are a part behind which the majority of the other parts of

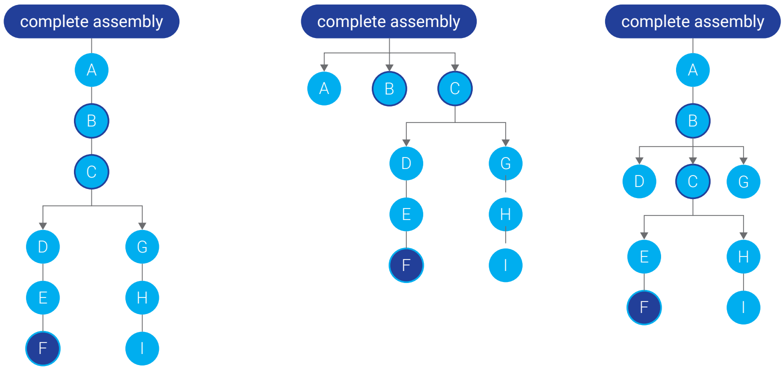


Figure 4.1: extreme simplification of the disassembly sequence of the Cybex Z base and two more parallel alternatives

As can be concluded from the disassembly maps on pages 50 to 52, the following parts bring about linearity to the disassembly sequence of baby car seats:

- Soft goods (main upholstery, head pillow, and baby insert)
- Foams
- Locking mechanism (axes)
- Back belt guide

As can be concluded from the disassembly maps on pages 53 to 55, the following parts bring about linearity to the disassembly sequence of ISOfix bases:

- Shells
- Support leg
- Locking mechanism
- Bowden cables or electric cables of indicators

Designers can ask themselves the following questions: Can you minimise the maximum depth of your disassembly sequence/product architecture? You can check whether you are improving the overall design by calculating the disassembly depth index. Are there parts that act as a bottleneck to reaching other parts? Can you implement design solutions minimising the restrictions these parts bring to other parts? Can you minimise the linearity these parts bring?

the product are hidden. Since the soft goods first have to be removed before the bulk of the parts are reachable, they act as a bottleneck to the disassembly. Parallelism will be increased when moving parts from beneath the soft goods above or next to the soft goods. Figure 4.1c illustrates the increased level of parallelism when part D and G are positioned from beneath bottleneck part C to being parallel to part C.

Figures 4.2 to 4.4 are simplified disassembly maps of the three analysed baby car seats showing only their parts and the disassembly sequence. The location of the main upholstery of the soft goods is marked (in orange) on these maps, illustrating it being a bottleneck for the parts that lie underneath it. Two other parts are marked (in orange) as well, showing that both the Swandoo and Cybex baby car seat have positioned the sun canopy above the soft goods and the Maxi Cosi has not, and that the outer part of the belt guides of the Maxi Cosi are positioned above the soft goods, while those of the Swandoo are positioned below the foams and those of the Cybex are entirely at the bottom of the map. If all these parts would be positioned above the soft goods, the disassembly sequence would become more parallel.

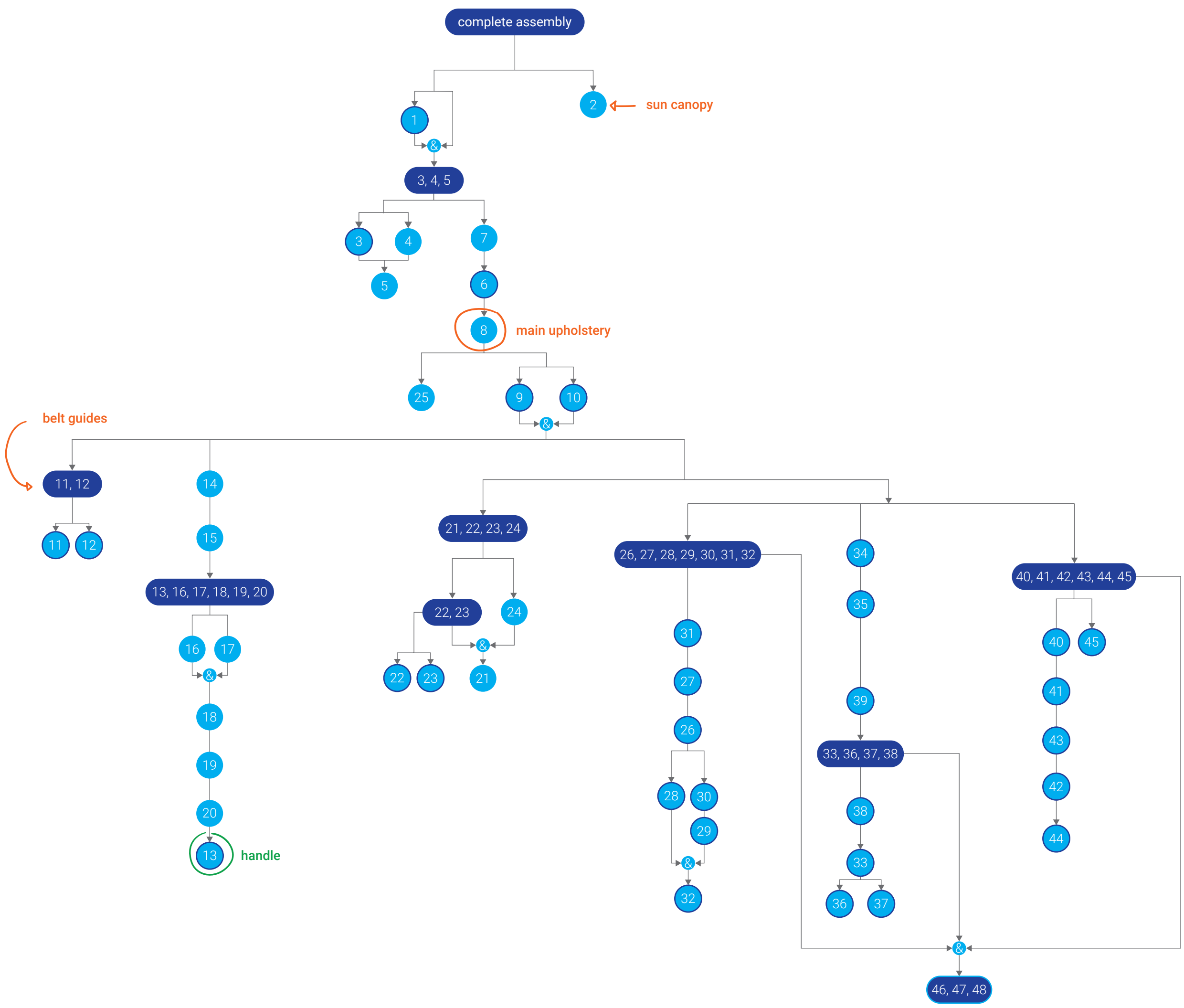


Figure 4.2: simplified disassembly map of the Swandoo Albert baby car seat

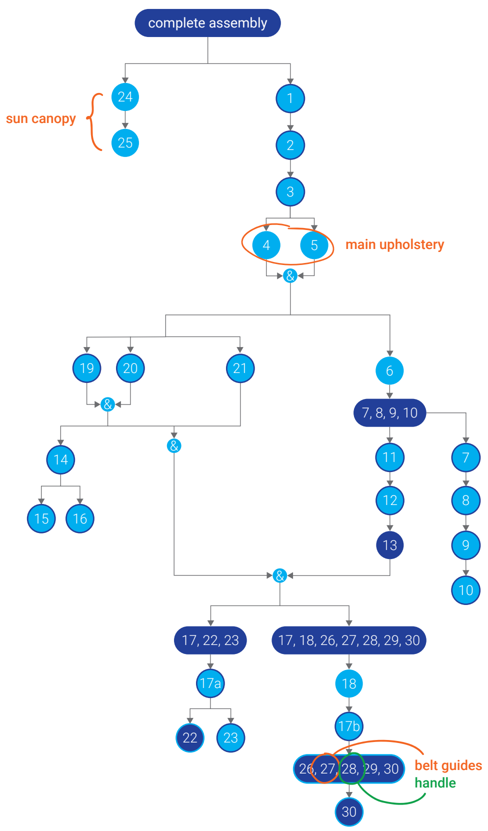


Figure 4.3: simplified disassembly map of the Cybex Cloud Z baby car seat

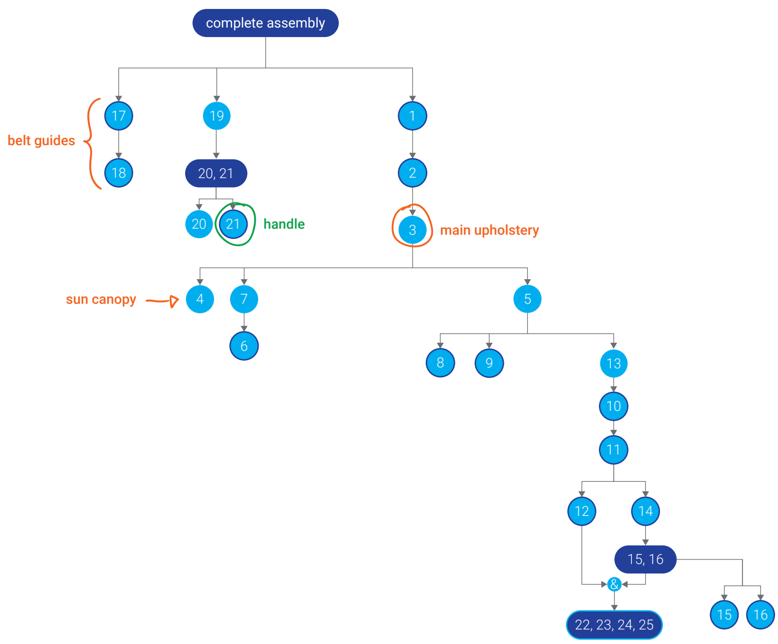


Figure 4.4: simplified disassembly map of the Maxi Cosi Pebble Pro baby car seat

7. Priority parts should be removable

Next to guideline 3 which states that safety critical parts should be removable, all of the other priority parts should be removable as well. For example, when a functionally important part fails frequently but cannot be removed from the product, the lifespan of the whole product will be diminished to the lifespan of this single part as the whole product gets discarded when this non-removable part fails.

For both baby car seats and ISOfix bases all of the non-safety critical priority parts are removable.

The main question designers should ask themselves is whether all priority parts are removable. However, be aware that priority parts should not get removed accidentally during use, because this means parts might get lost. Make sure that priority parts are removable only when intended.

8. Priority parts should be reachable within a reasonable number of steps

Next to guideline 4 which states that safety critical parts should be reachable within a reasonable number of steps, this is also the case for all other priority parts. There are several ways to decrease the number of steps before reaching a certain part. Next to making the disassembly sequence more parallel, in the manual of Hotspot Mapping, Flipsen discerns three methods to improve the product architecture for disassembly of priority parts, namely surfacing, clumping, and trimming.
Surfacing consists of repositioning a part more to the top of the product architecture, and subsequently more to the front of the disassembly sequence. Clumping consists of making subassemblies of parts that are stacked on top of the priority part to be able to take them out in one go, shortening the disassembly sequence. It could also be beneficial for disassembly to include the priority part in this subassembly. Both surfacing and clumping can be achieved through changing the product architecture or changing the way a part or subassembly is attached to the main assembly. Trimming consists of decreasing the number of activities that need to be performed before reaching a priority part.

The handle of the Maxi Cosi Pebble Pro is a good example of locating a priority part at the surface of the product, in contrast to the handles of the Swandoo and Cybex baby car seats. The disassembly maps in figures 4.2 and 4.3 show the location of the handle subassembly (in green) for the Swandoo Albert and the Cybex Z base, at the end of the disassembly sequence. The handle of the Maxi Cosi is immediately reachable from the surface of the product, no other parts need to be removed first, as shown in figure 4.4. This is achieved by designing the handle assembly in such a way that it can be unscrewed from the outside of the shell (see figure 4.5), instead of from the inside as is the case with the Swandoo Albert. This screw is covered with a small plastic part which features the Maxi Cosi logo, as shown in figure 4.6, and which can be removed from the handle with a small flatheaded screwdriver.

Figure 4.5: the screw of the handle of the Pebble Pro

Figure 4.6: the cover of the handle of the Pebble Pro

Priority parts other than the safety critical parts of baby car seats and ISOfix bases mentioned in guideline 4 are the soft goods, the sun canopy, the mechanism- and button covers. These three types of parts are positioned relatively early in the disassembly sequence of the current designs and no problems seem to occur.

Questions for designers: Can you minimise the number of steps it takes to reach a certain part? Can you simplify the product and its architecture? For example, can you eliminate parts, fasteners or functions of the product that are not necessary for the safety criticality of the product? Before hiding a part underneath another part, can you think about whether the disassembly sequence matters for this part? Is it instead possible to introduce parallelism? Would clumping parts into subassemblies decrease the disassembly depth of certain priority parts?

4.3 Materials

9. Long-lasting materials are preferred over short-lived materials

Long-lasting materials contribute to a longer product lifespan, slowing its resource loops and maintaining the value of the materials inside the product on top of the value hill (see chapter 2.3). The longer materials, parts, and thus products last, the lower the effort for reuse and refurbishment. When products are used again and again by different users following the principles of the circular economy, economic reasons for choosing short-lived materials are surpassed by durability reasons of long-lasting materials.

Generally speaking, metals are longer lasting materials compared to plastics, for example. However, the selection of materials should not only be made based on these generalisations, because the suitability of a material is also dependent on its application on a specific part and its function. To eliminate short-lived materials, one can look at the failure frequency of parts and the reason of failure to find out whether using a different material might solve the issue, preventing disposal and thus elongating the product's lifespan. When a product's lifespan is elongated and the product is part of a closed loop, more expensive materials could again be financially attractive.

As shown in table 3.1 on page 31 the parts of baby car seats that fail the most frequent are:

- Handle
- Soft goods
- Shoulder straps
- Shoulder pads
- Buckle
- Warning labels
- Shell

And the parts of ISOfix bases that fail the most frequent are:

- Shell
- Locking mechanism

Questions designers can ask themselves are: Can I change the materials of the product to elongate the lifespan of the product? Are there any short-lived materials that I can substitute with longer-lasting materials? Are there any parts that fail because of the material that is used? Would this failure be eliminated or at least less frequent when another material is used?

10. Limit the environmental impact over a product's total lifetime

Using materials with a low environmental impact means that the overall impact of the product is minimised. Next to choosing virgin materials with a lower environmental impact, recycled materials, or materials with a percentage of recycled content could be used as a resource with a lower impact.

Furthermore, the environmental impact will also be less when making use of materials that are recyclable, opening up new end-of-life possibilities other than incineration or landfill. The choice for materials with a higher initial environmental impact can be substantiated or justified when the total lifetime of the product is elongated and it can be reused for more use cycles.

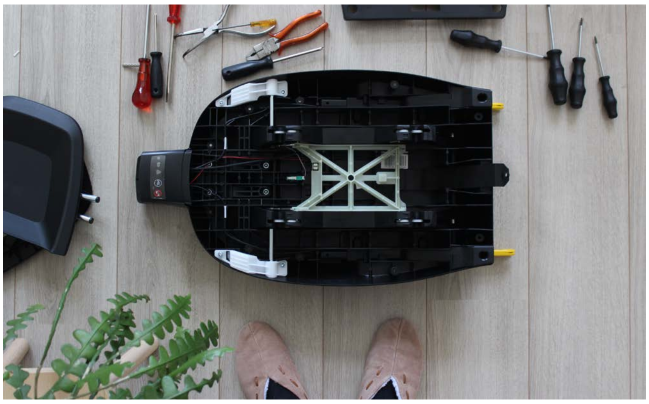


Figure 4.7: bottom shell of the Maxi Cosi 3wayfix with a locking mechanism largely made of glass-filled PA

Figure 4.8: foams in the Cybex Cloud Z

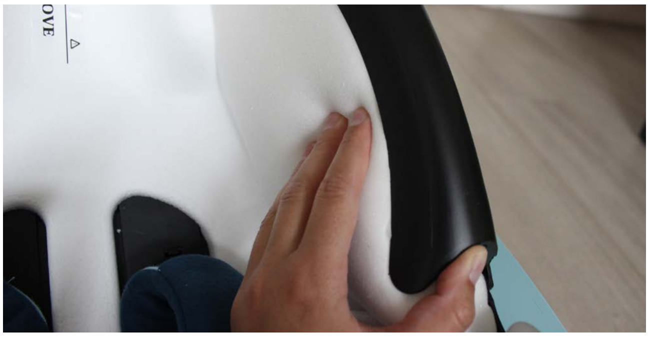


Figure 4.9: foams in the Maxi Cosi Pebble Pro

Figure 4.10: PU foam baby insert of the Swandoo Albert

Both the baby car seats and the ISOfix bases do not feature any recycled materials nor materials with recycled content (apart from the metals, which can be assumed to contain at least some recycled content).

The following materials that are not recyclable are currently used in the design of baby car seats and ISOfix bases (see figures 4.7 to 4.10 for some examples in the current products):

- Foams such as EPS, EPP and PU
- Glass-filled polymers

Questions for designers: Do you know the impact of the materials used in the product? Do you know which materials have the highest and which have the lowest impact? Can you substitute materials with a high impact for materials with a lower impact? Can you substitute virgin materials with recycled materials? Can you set up a resource loop from your own materials to be reused in new products?

11. Limit the number of materials in one product and in subassemblies

Limiting the number of different materials in one product is beneficial for recycling, because less parts need to be separated in order to create a pure waste stream (see chapter 2.3). For the same reason, the number of materials in one subassembly should also be limited. 'Clumping' parts (see guideline 8) consisting of the same materials into subassemblies makes separation of materials for recycling quicker as well. Parts with a high failure frequency are most important because they will find their end of life quicker than other parts.

Figure 4.11: the different types of polymer-based materials of the Maxi Cosi Pebble Pro

Currently both the baby car seats and the ISOfix bases use several types of thermoplastics, several types of synthetic fabrics, three types of foams, and two types of metals. Since the two metals are relatively easy to separate from the other materials and from each other, the possibilities for improvement mainly seem to lie in reducing the different types of plastic. As an example, figure 4.11 shows all polymer-based materials of the Maxi Cosi Pebble Pro. It should be kept in mind however, that the variety of plastics is partly due to the inclusion of small, standardised parts with a specific mechanical function, such as sliders.

Questions for designers: Do you know the number of different materials that are used in the product? Can you lower this number by eliminating materials and making more parts from the same material? Have you thought about how easy it is to separate parts with different materials? Do the parts that fail frequently consist of a single material or can the materials be separated easily?

4.4 Fasteners

12. Limit the fasteners in total and limit different types of fasteners

Limiting the number of fasteners will generally decrease the disassembly time, because less time is spent identifying and unfastening (Vanegas et al., 2016). Similarly, limiting the number of different types of fasteners that need different types of tools will decrease the disassembly time as well. Ideal would be if only hands were needed for the disassembly of a product because no time is spent on identifying and picking up the right tool (Vanegas et al., 2016), making the disassembly sequence as smooth as possible.

For the ISOfix bases, the largest number of fasteners in one place were used to fixate the shells, for example the shell of the Swandoo ISOfix base took 15 screws (see figure 12). For the baby car seats the soft goods generally take the largest number of fasteners, as snap buttons and elastic loops are used to attach the soft goods to the main assembly. The Maxi Cosi Pebble Pro features a rubber cover which appears to be the only part of all six analysed products with a purely aesthetical function and which is attached to the shell with 9 separate snap fits as shown in figure 13.

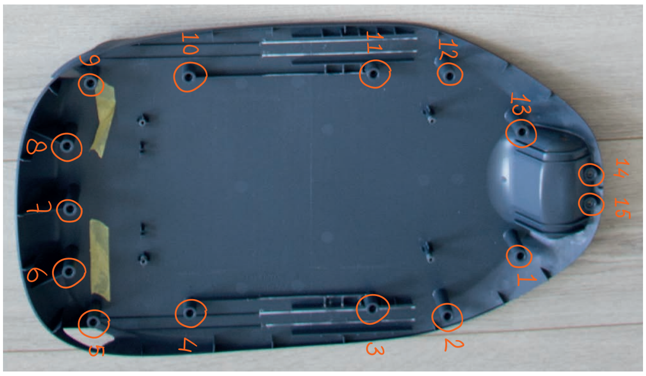


Figure 12: bottom shell of the Swandoo ISOfix base

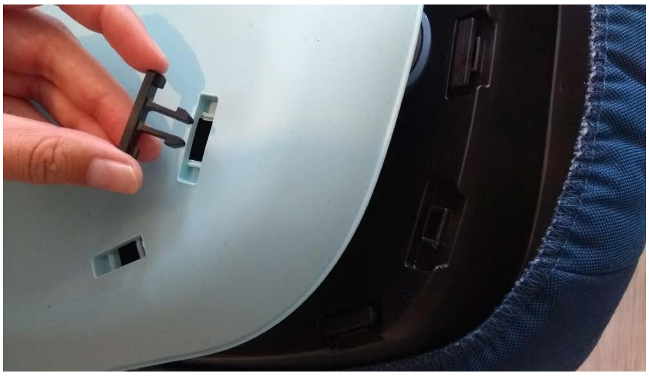


Figure 13: snapfit to fasten rubber cover to Pebble Pro

As table 3.4 of the fasteners used (page 38) and the disassembly maps (page 50 to 55) in chapter 3 show, the current child car seats and ISOfix bases could be optimised on their usage of fasteners.

Single parts of baby car seats that took the most fasteners are:

- The soft goods
- The rubber cover of the Maxi Cosi Pebble Pro

Single parts of ISOfix bases that took the most fasteners are:

- Shells
- Anti-Rebound Bar

Designers should ask themselves whether they can decrease the number of fasteners used in the product. Do you know the total number of fasteners in your product? Do you know which single part uses the most fasteners and can you redesign the part or the fasteners in such a way that less are required? Is it possible to combine the fasteners of several parts and decrease the total number this way? Do you know how many and which tools are needed for the assembly and disassembly of the product? Can you decrease the number of tools? Can you substitute uncommon or complex tools for more common and less complex tools? Can you substitute complex fasteners for fasteners that are less complex? Can you redesign your product so that no tools are needed at all for disassembly?

13. Fasteners should be reusable or replaceable

To allow reassembly after refurbishment, fasteners should either be reusable or replaceable where the former is preferred over the latter. Standardised fasteners such as screws have the advantage of replacements being widely available.

Theoretically all three fasteners mentioned below are replaceable. However, in the case of rivets the risk of damaging the product itself during disjointing is high and for both glue and tape removing all of the residue left after removal will often prove to be difficult.

As shown in table 3.4 on page 38 in chapter 3, most of the fasteners used for the baby car seats and ISOfix bases are reusable, but not all.

The following non-reusable fasteners are currently in use:
- Rivets
- Glue
- Tape

Designers should question the type of fasteners they have chosen and check if all fasteners are reusable. Are there any snap fits that are prone to breakage that you should redesign? If a fastener fails, is there a replacement fastener available to the refurbisher? Can you make use of standard fasteners to improve availability of replacement fasteners?

Key insights

Chapter 4: Guidelines for design for refurbishment

Safety critical products

1. **Safety above all else:** Make sure that safety is never compromised in favour of something else, such as aesthetics, sustainability, or ergonomics.
2. **The history of a safety critical product should be known:** Collect data about the use of the product, for example through sensors, and log the history.
3. **Safety critical parts should be removable:** Enable refurbishment for reuse of the whole product by making safety critical parts removable.
4. **Safety critical parts should be reachable in a reasonable number of steps:** Improve refurbishment by decreasing the disassembly time of safety critical parts through surfacing, trimming, or clumping.
5. **A refurbishment protocol** might include parts that always need to be replaced to guarantee their safety.

Product architecture

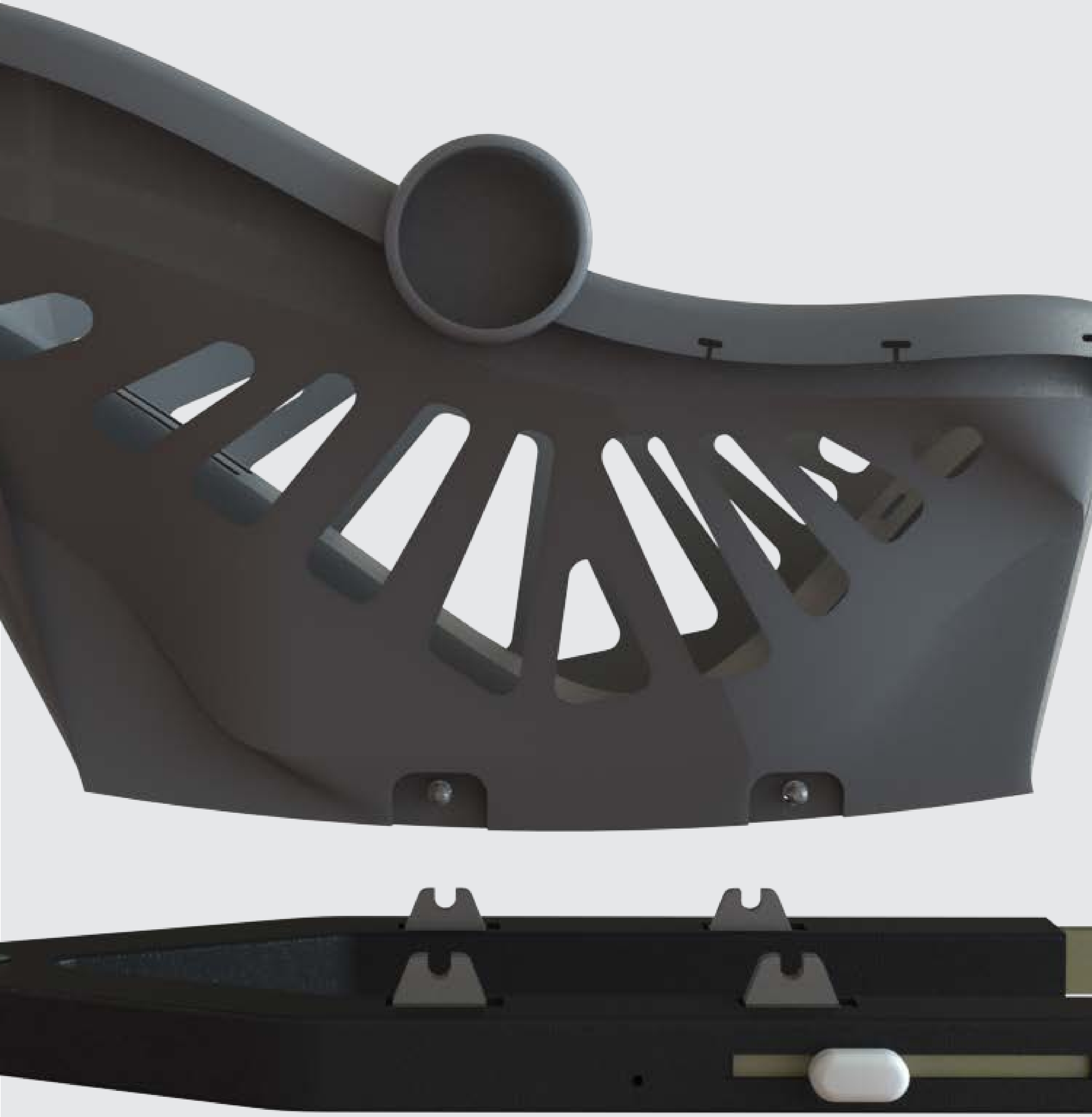
6. **A parallel disassembly sequence is preferred over a linear sequence:** Parallel disassembly sequences contribute to ease of disassembly through shortening disassembly sequences and decreasing the maximum part depth.
7. **Priority parts should be removable:** Enable refurbishment for reuse of the whole product by making priority parts removable.
8. **Priority parts should be reachable within a reasonable number of steps:** Improve refurbishment by decreasing the disassembly time of priority parts through surfacing, trimming, or clumping.

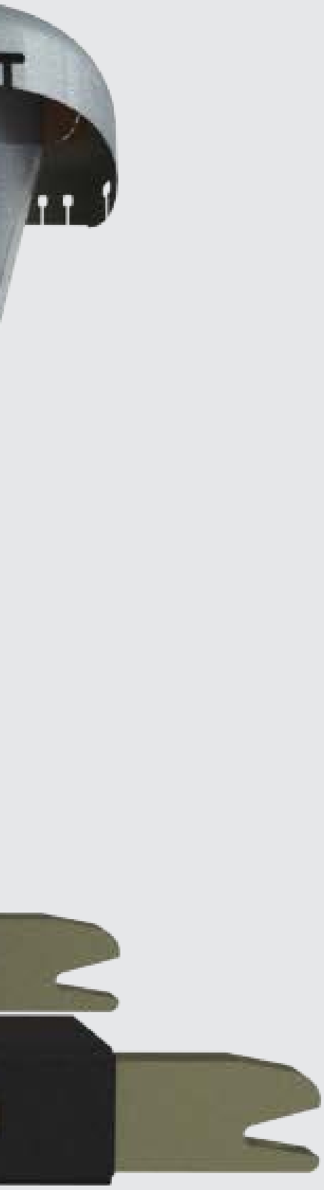
Materials

9. **Long-lasting materials are preferred over short-lived materials:** Long-lasting materials increase a product's lifespan and allow its value to be maintained at the top of the value hill.
10. **Limit the environmental impact over a product's total lifetime:** To minimise the environmental impact of the product use virgin materials with a low impact or choose recycled materials, next to making sure that materials are recyclable and elongate a product's lifespan.
11. **Limit the number of materials in one product and in subassemblies:** Improve recyclability by minimising the number of materials, the less different materials used, the easier it will be to separate a product into resource waste streams for recycling.

Fasteners

12. **Limit the fasteners in total and limit different types of fasteners:** Decrease disassembly time by limiting the number of fasteners in a product and increase ease of disassembly by reducing the number of different tools needed for disassembly.
13. **Fasteners should be reusable or replaceable:** Enable reassembly after refurbishment by implementing reusable or at least replaceable fasteners.





5

Illustrative redesign

This chapter presents a redesign of the ISOfix base and the baby car seat for refurbishment. These redesigns were developed based on the guidelines in the previous chapter. First, the redesign of the ISOfix base is presented and next the redesign of the baby car seat is presented. Both redesigns are further elaborated upon with a disassembly map and brief costs analysis and analysis of the environmental impact. Both redesigned products have been evaluated which is described in the third subchapter.

5.1 A redesign of the ISOfix base

5.1.1 Trimming parts and materials

When looking at the current ISOfix bases, these products incorporate extra functionalities that do not support the safety critical function, such as the rotation functionality of the Cybex Z base. From a refurbishment perspective, it is preferable to have as few parts as possible in one product, because the fewer parts in a product, the fewer parts can fail, the shorter the disassembly sequences will be and the less time is spent on refurbishment. This way, 'trimming' parts supports guideline 4/8, making priority parts better reachable.

The parts of an ISOfix base that do contribute to safety criticality are the load distribution structure, a top tether or support leg, the locking mechanism with the seat, the ISOfix anchors, and the indicators signalling correct installation, as was also shown in table 3.3 on page 33. As mentioned above, the Cybex Z base features a rotation functionality which should be left out when designing for refurbishment. Similarly, the Cybex Z base and the Maxi Cosi 3wayfix feature an Anti-Rebound Bar, or ARB in short, which prevents the baby car seat and ISOfix base to rebound against the backrest of the car seat in the case of a crash, see figure 5.1. The Swandoo Albert base, however, does not feature this ARB, but uses the handle of the baby car seat locked in a position towards the backrest of the car seat to function in the same manner, as also shown in figure 5.1. This last approach is preferable from a refurbishment perspective as it makes use of an already existing part, resulting in less parts and less materials used for the ISOfix base (guidelines 4/8 and 11). Lastly, the shells of both the Cybex Z base and the Swandoo Albert base mainly have an aesthetical function, while they are prone to failure through wear and tear. Only in the Maxi Cosi 3wayfix the bottom shell is the main part of the load bearing structure, in the other ISOfix bases, the load bearing structure consists of a steel frame. Following guideline 9, indicating that long-lasting materials are preferred over short-lived materials, the best option would be to eliminate the shells and use a steel frame as a load bearing structure and simultaneously as the 'outer surface' of the ISOfix base, because steel is less prone to wear and tear than the current plastic shells shells and does not degrade due to UV exposure.

The current design of the ISOfix bases can also be improved following guideline 11, which states that limiting the number of different materials in one product is beneficial for recycling of product or parts discarded after refurbishment. So not only the plastic shells should be substituted, but also other parts such as the support leg should be made of steel or aluminium, with the goal of making the entire ISOfix base of metals.

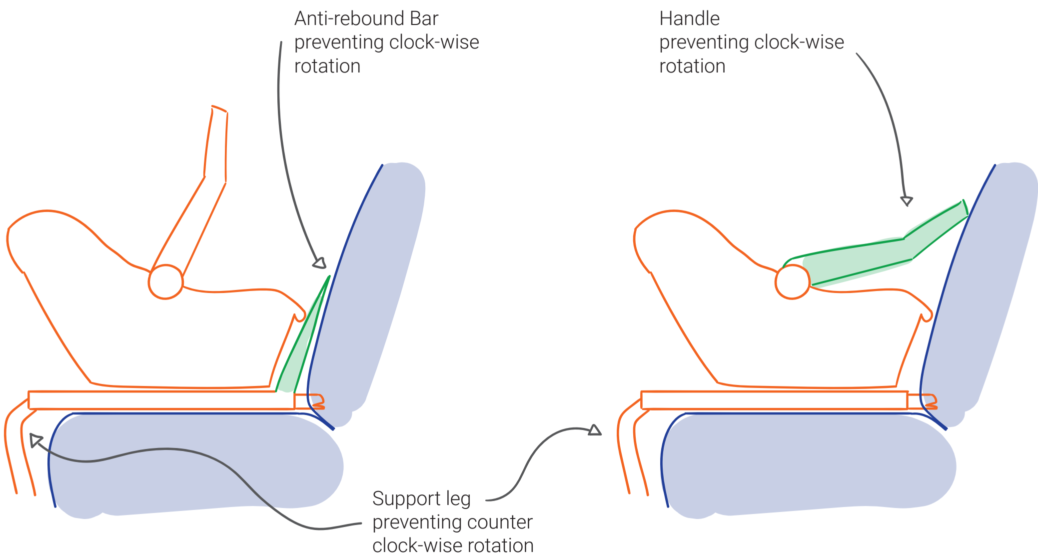


Figure 5.1: an ISOfix base featuring an Anti-Rebound Bar (left) and an ISOfix base without an ARB but where the handle fulfills this function

5.1.2 A minimalistic ISOfix base

Based on this trimming of parts and materials the challenge of further redesigning the ISOfix base for refurbishment constitutes of making a minimalistic design incorporating only a load distribution structure, a support leg or top tether, a locking mechanism, ISOfix anchors, and installation indicators. The main focus was to increase ease of disassembly compared to the current ISOfix bases, by making sure that all previously non-removable priority parts are now removable (guideline 3/7), by making these parts better reachable (guideline 4/8) and by making the disassembly sequence more parallel (guideline 6).

Figure 5.2 shows the redesigned ISOfix base. It features a Y-shaped steel frame made of hollow tubes which is load bearing and at the same time houses the ISOfix anchors, the locking mechanism, and the installation indicators. The support leg is attached to one end of the frame. The support leg, ISOfix anchors, and locking mechanism are connected to the installation indicators via Bowden cables. A passive impact indicator is integrated on the front of the frame.

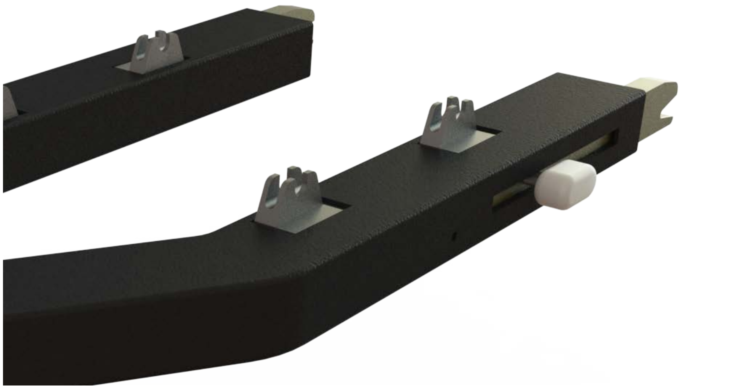
The frame is Y-shaped because it is the simplest way to join the ISOfix anchors to the support leg and because it can easily be made by bending standard size tubes and welding them together at the front. All ends of the hollow tubes are open (see figure 5.6) to allow easy removal of the parts and enabling modularity (guideline 3/4 or 7/8). Both **the ISOfix anchors** and **the locking mechanism** slide inside the back ends of the tube and can then be fastened to the frame through a friction fit and by using a couple of nuts and bolts. More information about the locking mechanism can be found in paragraph 5.2.2 about the redesign of the baby car seat. The bottom surface of the frame is left free of holes and fasteners so as not to damage the car seat underneath. The cross-section of the tubes of the frame is dependent on the size of the ISOfix anchors and the size of the locking mechanism, which need to fit inside (see figure 5.7). For the best load-distribution between the parts and the frame, the parts fit tightly inside the frame. **The support leg*** is attached to the front of the frame with an axis and retaining rings (see figure 5.4), which can be removed from the outside of the frame. The support leg consists of two sliding parts that can be rotated to a horizontal position parallel to the frame for storage. It is made of aluminium, because it is lighter than steel and it only needs to be stiff in one direction. **The installation indicators** signal to the user when the support leg is folded out correctly, when the baby car seat is installed correctly in the locking mechanism, and when the ISOfix anchors are fastened correctly to the anchor points in the back seat of the car. The system for these indicators can be implemented fully mechanically by making use of Bowden cables (see figure 5.8) and springs, similar to the system of the Swandoo Albert base.

The impact sensor is integrated in the mid-front part of the frame because it is preferred to have the sensor on the symmetrical axis of the product (see figure 5.5). A passive sensor is favoured over an electronic sensor because it has a lower environmental impact and no extra electronic components need to be integrated into the base.

** Support leg vs. top tether*

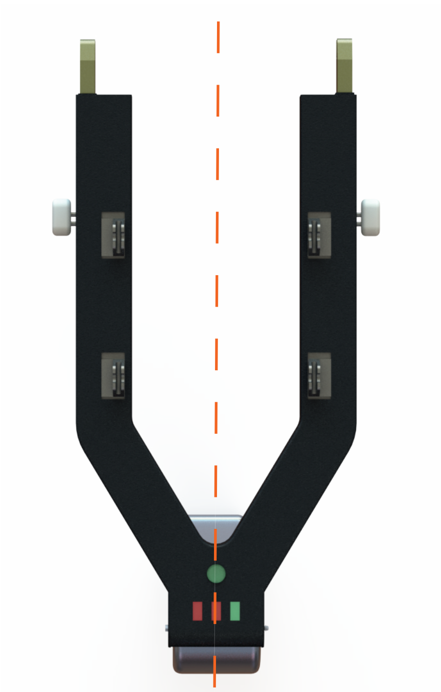
The choice between a support leg and a top tether depends on the environmental impact and the safety criticality of both options. Compared to a support leg, the top tether will use way less material and is easier to manufacture resulting in a lower environmental impact. However, the risk of incorrectly installing the top tether is higher, because the top tether needs to be hooked in the right way on the right anchor point on the back of the car seat while this location can differ per car, in contrast, the support leg only need to be slid out to the floor of the car. Following guideline 1, safety above all else, the support leg is thus favoured over a top tether.

Figure 5.2: the redesigned ISOfix base



Figures 5.3: a close up of the locking mechanism and ISOfix anchors of the redesigned ISOfix base

Figures 5.4: a close up of the front of the redesigned ISOfix base



Figures 5.5: top view of the redesigned ISOfix base

Figure 5.6: the hollow ends of the tubes into which the locking mechanism and the ISOfix anchors fit.

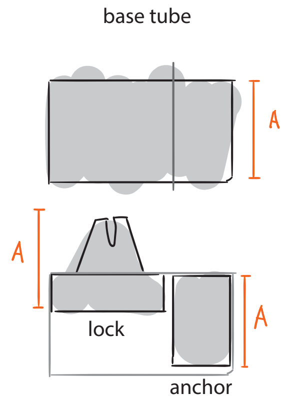


Figure 5.7: the cross-section of the tubes are dependent on the size of the locks and anchors

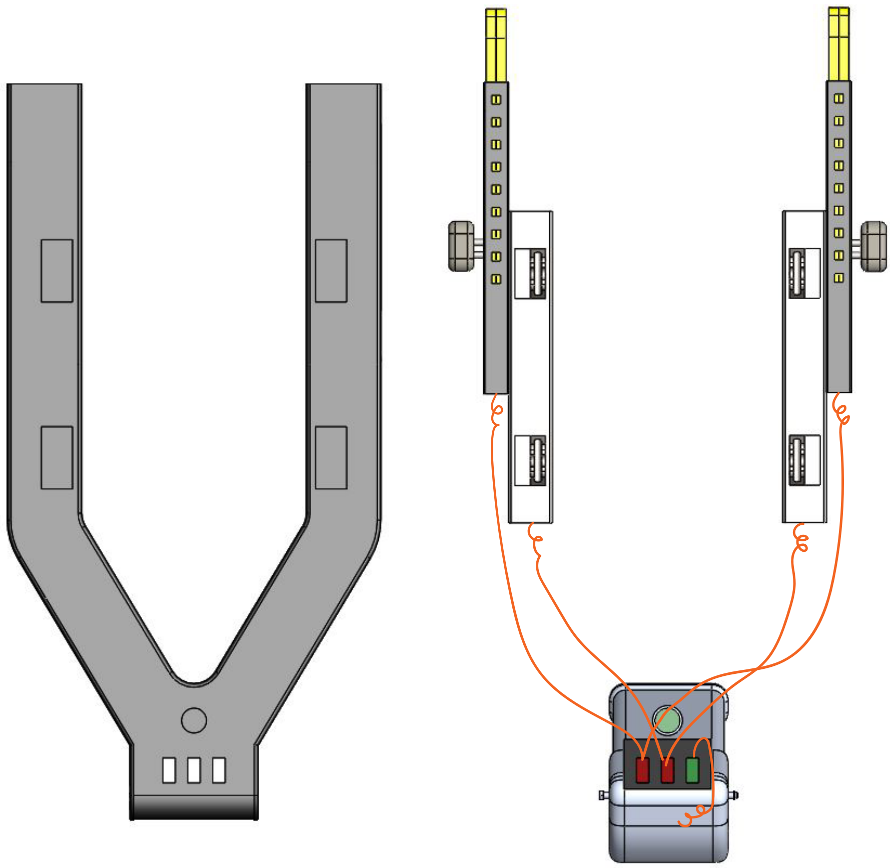


Figure 5.8: topview of the ISOfix base with on the left the Y-shaped frame and on the right all other parts connected to the installation indicator via Bowden cables

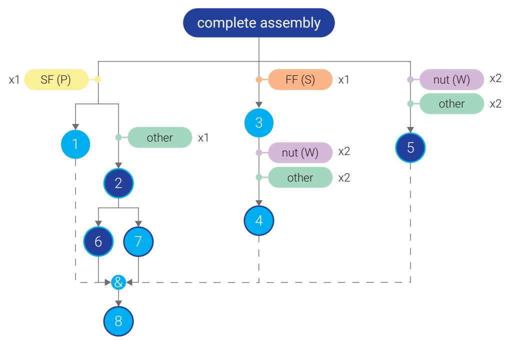
5.1.3 Disassembly map of the redesign

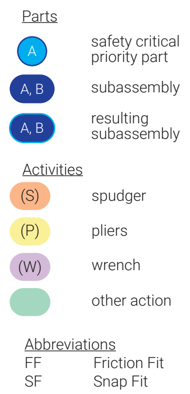
A disassembly map of the redesigned ISOfix base has been made to visualise its product architecture and disassembly sequence, which is shown in figure 5.9. An overview of the components of the redesigned ISOfix base is shown in figure 5.10.

The main difference between the redesigned ISOfix base and the three analysed ISOfix bases is that the redesign contains a lot less parts, which makes the disassembly map of the redesigned ISOfix base a lot shorter. This is primarily due to the elimination of non-safety critical parts but also to the fact that the redesign is not a hundred percent complete. For example, not all fasteners are thought through yet and it is still unknown of how many parts the subassemblies of the installation indicator and the locking mechanism will consist.

Nevertheless, a comparison between the disassembly maps of the redesign and the other ISOfix bases can still be made. The map of the redesign clearly shows the advantage of the hollow-tube frame because it introduces a disassembly sequence that is more parallel compared to the archetypical use of a shell (guideline 6). Instead of first having to go through a linear sequence to open up the product to reach all other parts, in the redesign the support leg, the ISOfix anchors, and the locking mechanism can immediately be reached via the open ends of the frame. In the redesign, the main linearity comes from first having to remove the support leg (part #2) to reach both the installation indicator subassembly (part #6) and the impact sensor (part #7). Of course, all parts need to be removed in the case were the frame needs to be separated from everything else. The ISOfix anchors were not removable for the Cybex Z base and the Swandoo Albert base and had a part depth of 9 out of a total of 26 in the Maxi Cosi 3wayfix. In the redesign, the ISOfix anchors have a part depth of 2 out of a total of 8, which confirms the surfacing of the ISOfix anchors compared to the 3 analysed products (guidelines 3/7 and 4/8). Similarly, the support leg and locking mechanism are brought to the surface of the product in the redesigned ISOfix base.

Disassembly Map
Redesigned ISOfix base
ISOfix base





1. axis of support leg
2. support leg
3. anchor slider button covers (L+R)
4. ISOfix anchors (L+R)
5. locking mechanism (L+R)
6. installation indicators & Bowden cables
7. impact sensor
8. frame

Figure 5.9: the disassembly map of the redesigned ISOfix base

To determine **the disassembly depth index** of the redesigned ISOfix base, the frame of the product has to be considered. The frame is the deepest part in the product architecture and to isolate it, all other parts need to be removed from the frame, which would make the maximum part depth 8 out of 8, resulting in a disassembly depth index of 1 (which indicates a fully linear sequence). However, it is clear from the disassembly map that the disassembly sequence is very parallel, but the index score does not reflect this. This indicates that the method to determine the disassembly depth index should be further developed. For now it can be argued that the isolation of the frame only occurs during refurbishment when either all parts on top of the frame need to be replaced, or when the frame itself has failed and needs to be replaced, which brings about the philosophical question of Theseus ship examining whether a ships is still the same ship when all of its parts are replaced. Based on this, it follows that isolating the frame for either of the two reasons does not correspond to refurbishment for reuse, but to parts harvesting and subsequently to determine the disassembly depth index the objective is to reach the frame. In that case, the disassembly depth index for the redesigned ISOfix base is 4 out of 8 resulting in a **score of 0.5**.

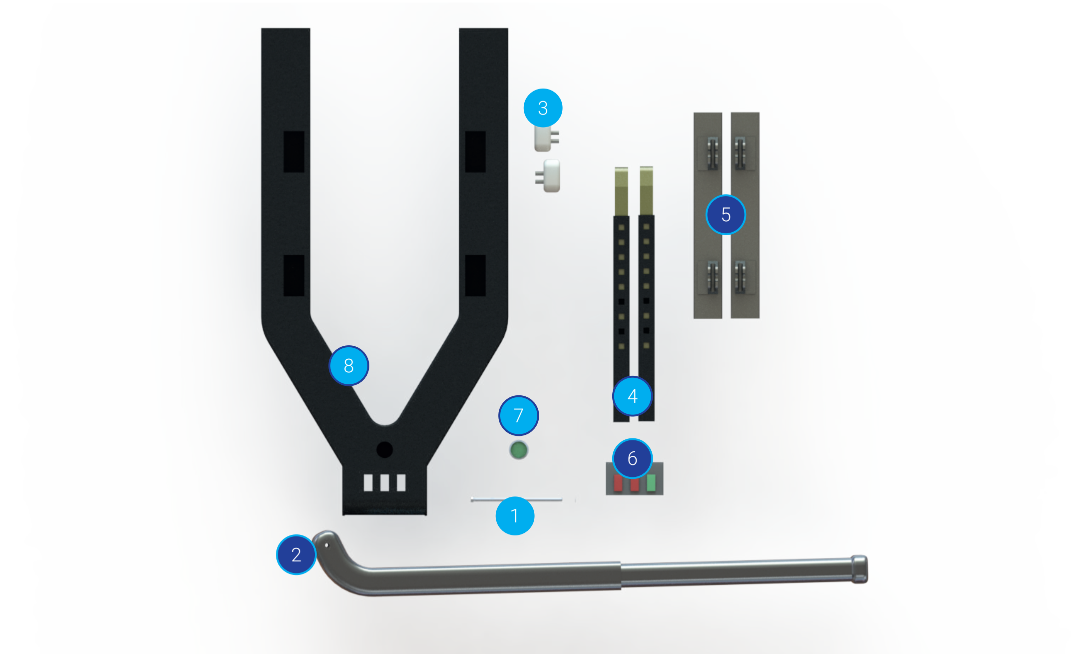


Figure 5.10: the components of the redesigned ISOfix base

5.1.4 Economic & environmental costs

The main difference between the redesign and the existing product is the approach to designing a frame as a shell instead of covering a frame with a shell. A small cost-analysis is performed comparing the approach to the shell and frame of the three existing products and the redesigned ISOfix frame. This comparison is limited to the costs of the raw materials. The price per kilogram material is based on the CES EduPack database (Granta Design Limited, 2019) and the weight of all parts were determined by measuring them on a scale (see also the Bill of Materials in appendix H). The weight of the redesign is determined based on the CAD-model in SolidWorks, where the frame has a wall thickness of 2 mm. Table 5.1 shows the results of this analysis. The shells of the Maxi Cosi 3wayfix have the lowest costs for raw materials and the shells and frame of the Cybex Z base have the highest. The costs of the redesign and the Swandoo Albert are comparable, but they are about 3.25 times higher than the raw material costs of the Maxi Cosi 3wayfix. This means that the redesigned ISOfix frame will need to be reused at least three times when the Maxi Cosi 3wayfix is used once to have comparable costs for the raw materials of the frame and shells.

A comparison between the products and the redesign regarding the environmental impact of the shells and frame has been made as well. Table 5.2 shows the embodied energy and CO2 footprint through primary production and further processing per kilogram material based on data from CES EduPack (Granta Design Limited, 2019). It is assumed that stainless steel parts will be extruded and further machined and that polypropylene parts are injection moulded. Table 5.3 shows the calculated environmental impact in energy consumption and CO2 footprint of the three products and the redesign. Again, the shells of the Maxi Cosi 3wayfix have the lowest impact compared to the shells and frames of the other products. The redesigned ISOfix base has an impact which is between 1.6 and 1.8 times as high as the Maxi Cosi 3wayfix.

The conclusions that can be drawn based on these two comparisons are very limited as only the shells and the frame are taken into account, while other parts in the current design might support the same functions. For example, the stiffness and load-bearing properties of the Maxi Cosi 3wayfix are not entirely due to the bottom shell, as quite a part of it is due to the large locking mechanism that slides inside the shell. This locking mechanism is made of glass-filled PA moulded over a steel core and which in total weighs more than 600 grammes. Parts like these are responsible for a large portion of a product’s total environmental impact (as can be seen in figure 3.49 in paragraph 3.2.4). Of course, including all parts of all ISOfix bases would have been preferable for these comparisons, however due to time limitations this was not possible for now.

Table 5.1: raw material costs of the shells and frames of the three existing products and the redesigned ISOfix base

			Swandoo Albert base		Cybex Z base		Maxi Cosi 3wayfix		Redesign	
part	material	EUR/kg	kg	EUR	kg	EUR	kg	EUR	kg	EUR
top shell	PP	€ 1.21	0.45	€ 0.54	0.50	€ 0.61	0.57	€ 0.69	0.00	€ -
bottom shell	PP	€ 1.21	0.39	€ 0.48	1.10	€ 1.33	1.60	€ 1.94	0.00	€ -
frame	stainless steel	€ 2.69	2.88	€ 7.75	4.80	€ 12.91	0.00	€ -	3.18	€ 8.55
total			3.72	€ 8.77	6.40	€ 14.85	2.17	€ 2.63	3.18	€ 8.55

Table 5.2: energy usage and CO2 footprint per kilogram material of primary production and further processing

material	process	energy [MJ/kg]	CO2 footprint [kg/kg]
stainless steel	primary production	72.7	5.45
stainless steel	extrusion	9.9	0.75
stainless steel	fine machining	7.3	0.55
PP	primary production	69.3	2.92
PP	molding	1.6	3.22

Table 5.3: energy usage and CO2 footprint of primary production and further processing of the shells and frames of the three existing products and the redesigned ISOfix base

	Swandoo Albert base	Cybex Z base	Maxi Cosi 3wayfix	Redesign
energy [MJ]				
primary production	267.6	459.5	150.5	230.9
processing	51.0	85.3	3.5	54.8
total [MJ]	318.6	544.8	154.0	285.7
CO2 footprint [kg]				
primary production	18.1	30.8	6.3	17.3
processing	6.4	11.4	7.0	4.1
total [kg]	24.6	42.2	13.3	21.4

5.1.5 Conclusion

The redesigned ISOfix base (figure 5.11) is improved for ease of disassembly by trimming parts that do not have a safety critical function and by making all safety critical parts removable and reachable within a maximum of four activities (including unfastening and removing other parts). This is mainly accomplished through combining the function of a shell with that of a load bearing structure into a hollow metal frame which houses all other parts. The redesign has a disassembly depth index of 0.5. The ease of recycling is improved by limiting the different materials used so that the ISOfix base can almost completely be made out of metal.

Figure 5.11: the redesigned ISOfix base and its components

5.2 A redesign of the baby car seat

5.2.1 Alternative soft goods & foams

The soft goods of the current baby car seat have a high environmental impact (guideline 10) and the foams are not recyclable (guideline 10), as described in paragraph 3.2.4. Currently the soft goods include the main upholstery, the head pillow, and the infant insert and contain polyester fabrics on the outside and wadding or foam as a filling. Foams are also used throughout the shell to locally improve the impact absorption. Foams lessen the impact on the body of the child by deforming and by filling up the holes between the shell and the body to prevent peak impact. So, foams can have a safety critical function in absorbing impact and also an ergonomic function by providing comfort to the child. The main function of the soft goods is providing comfort as well as hygiene, because they are always washable either by hand or in a washing machine.

An online brainstorm has been carried out together with two experts and two non-experts in the field of child car seats to explore alternative solutions to current child car seats. This brainstorm was focused on four questions related to providing impact absorption, comfort, hygiene, and security about safety. The Mural tool was used for this brainstorm and the results can be found in Appendix I. A selection of promising alternative materials and solutions based on this brainstorm and a further exploration are described in the following section.

- Expanded PLA: This foam has similar material properties to EPS and EPP foams, which are currently the main foams used in baby car seats (BeWiSynbra, n.d.; Parker et al., 2011). In contrast to EPS and EPP, E-PLA is made of renewable resources instead of being oil-based. The expanded PLA by BeWiSynbra have a bronze cradle to cradle certification (BeWiSynbra, n.d.; C2C Certified, 2019).
- EVA partly made from algae: this foam was originally developed for footwear where EVA is often used to make a flexible sole (Boom, n.d.). The company Bloom uses “excess algae biomass harvested from ecosystems in need of algae management” to create an EVA mix that consists “for at least 45%” out of renewable content (Bloom, n.d.). Consequently, the drawback to this material is that bio-based and petrochemical resources are mixed to make this material and the environmental benefits may be questioned.
- 3D polymer network: this is a non-woven and non-foamed material that behaves similarly to foams. It is made by extruding polymers that “fall together in a spaghetti like structure” (ENKEV, n.d. A). The company ENKEV currently uses it in layers in mattresses because of its durability and because its open structure allows for temperature control (ENKEV, n.d. A). A sample of this material is in my possession (see figure 5.12) and it really is a comfortable material. This specific sample is quite flexible

Figure 5.12: 3D polymer network

and really nice to touch. Opportunities lie in fine-tuning the density of the network for crash impact and producing it directly in the desired shape instead of layers. Its advantage over ‘real’ foams is precisely that this 3D polymer network is not foamed, meaning that recycling is possible and relatively easy because it is a pure material.

- Spacer mesh: a similar material to the 3D polymer network is spacer mesh. This material is woven and consists of three layers woven at once from the same polymer: two layers of mesh sandwich an inner layer of vertical polymer filaments, adding thickness and flexibility. This spacer mesh is currently often used as a breathable back panel of backpacks and similar applications. The thickness of the spacer mesh is limited to about 8 mm by the inner layer because of its tendency to buckle it is not possible to further elongate the vertical filaments. However, it is possible to combine several layers (figure 5.13) and sew them together to create a thicker, cushion-like material (figure 5.14). The outer mesh layers of this material are quite soft, which would mean that no separate outer layer would be necessary for the comfort of the child.
- Mycelium: is a bio-based composite and results “from the growth of filamentous fungi on organic materials such as agricultural waste streams” (Appels et al., 2019, abstract). The material is foam-like and can be produced ranging in flexibility. Figure 5.15 shows mycelium make-up sponges (Ecovative, n.d.) which are very flexible compared to the sample I obtained shown in figure 5.16. Mycelium is currently being researched to better understand the effects of using different strands of fungi and different growth materials on the properties of the material. Because the precise mechanical properties of mycelium are currently unknown, its application in safety critical products is consequently not yet desirable.
- Coconut husk network: a similar material to the 3D polymer network can be made from coconut husk fibres, a by-product from coconut harvesting, bound together by natural rubber (ENKEV, n.d. B), a sample of this is shown in figure 5.17. A similar technique is used by

Figure 5.13: several layers of spacer mesh

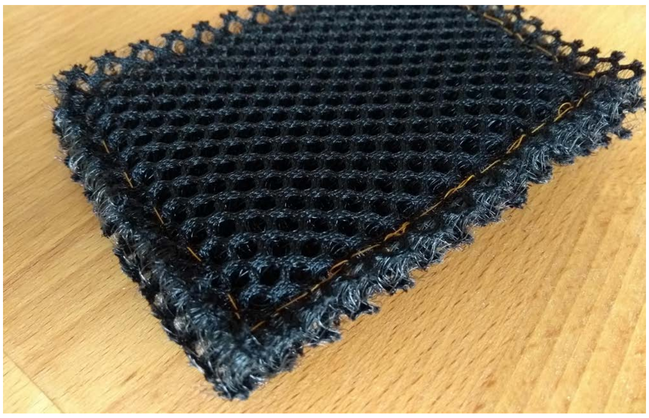


Figure 5.14: two layers of spacer mesh sewn together

Figure 5.15: mycelium make-up sponges (courtesy of Ecovative, n.d.)

Figure 5.16: samples of rigid mycelium foam

ENKEV to create networked mats from all kinds of natural fibres, such as horsehair and hemp.

- Recycled fabrics: the current soft goods do not contain any recycled content, while there are recycled fabrics available from the same materials and with the same qualities as the current fabrics. For example, the soft goods of the GreenTom strollers are made from recycled PET fibres made by Repreve (GreenTom, n.d.; Repreve, n.d.). The Danish company Gabriel using post-consumer waste as a resource for some of its fabrics, such as the Web mesh fabric (Gabriel, n.d. A) which consists for 76% of post-consumer waste and is self-supporting (see below), or the Repetto fabric which consists for 100% of post-consumer waste (Gabriel, n.d. B).
- Self-supporting fabrics: an alternative to providing comfort without the need for foams or wadding would be to use so-called self-supporting fabrics. Examples of self-supporting fabrics can be found in office chairs such as the Cosm chair by Herman Miller in figure 5.19. The name is misleading because the fabrics are not really supporting themselves, but no further filling is necessary to provide support to the user. The key advantage of self-supporting fabrics is the combination of comfort and breathability in one layer of material.
- Coating for foams: CooLoo coatings have developed a way to directly coat foams with waste material from leather or cork, shown in figure 5.18, creating a waterproof and UV-resistant finishing (CooLoo, n.d.). It is applicable to all kinds of foams and even other materials (although PP and PE are difficult) and utilises a water based 'glue' which, in theory, would make the coating edible (personal communication with Ricco Fiorito of CooLoo coatings, July 21st, 2020). Refurbishment of the coated foams happens through sanding of the coating and reapplying a new coat; theoretically the sanded of coating can be reused (personal communication with Ricco Fiorito of CooLoo coatings, July 21st, 2020).

Figure 5.17: a sample of coconut husk 'foam'

Figure 5.18: CoolCork coating applied to furniture (courtesy of CooLoo coatings, n.d.)

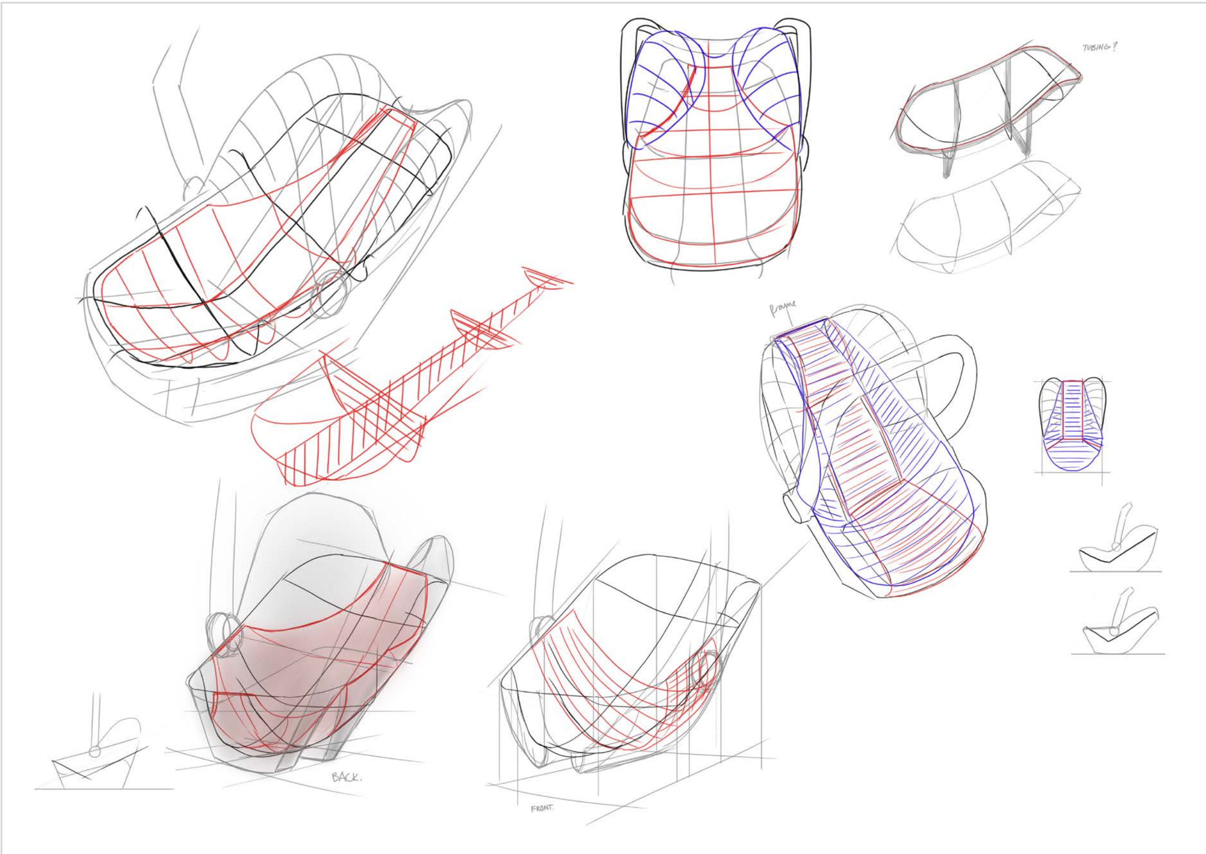
Figure 5.19: the COSM office chair using self-supporting fabrics (courtesy of Herman Miller, n.d.)

Implementation in the redesign
Through brainstorms and sketches the suitability of several of the alternatives regarding design for refurbishment has been further explored. Some of these sketches are shown in figures 5.21, 5.22, 5.23. A wireframe model was constructed to better understand the shape of baby car seats, as shown in figure 5.20.

It became apparent that using 3D polymer networks as local impact abosorption, combined with a self-supporting main upholstery and a spacer mesh infant insert and head pillow would have the advantage of limiting the materials to one type of polymer (guideline 11) as well as making the product easier to clean and more breathable than the current baby car seats. All soft goods and impact absorbing materials can be made of polypropylene, as well as the shell of the baby car seat, limiting the number of waste streams and improving recyclability.

Figure 5.20: a wireframe model of a baby car seat

Figure 5.21 sketches of the redesign of the baby car seat throughout the process



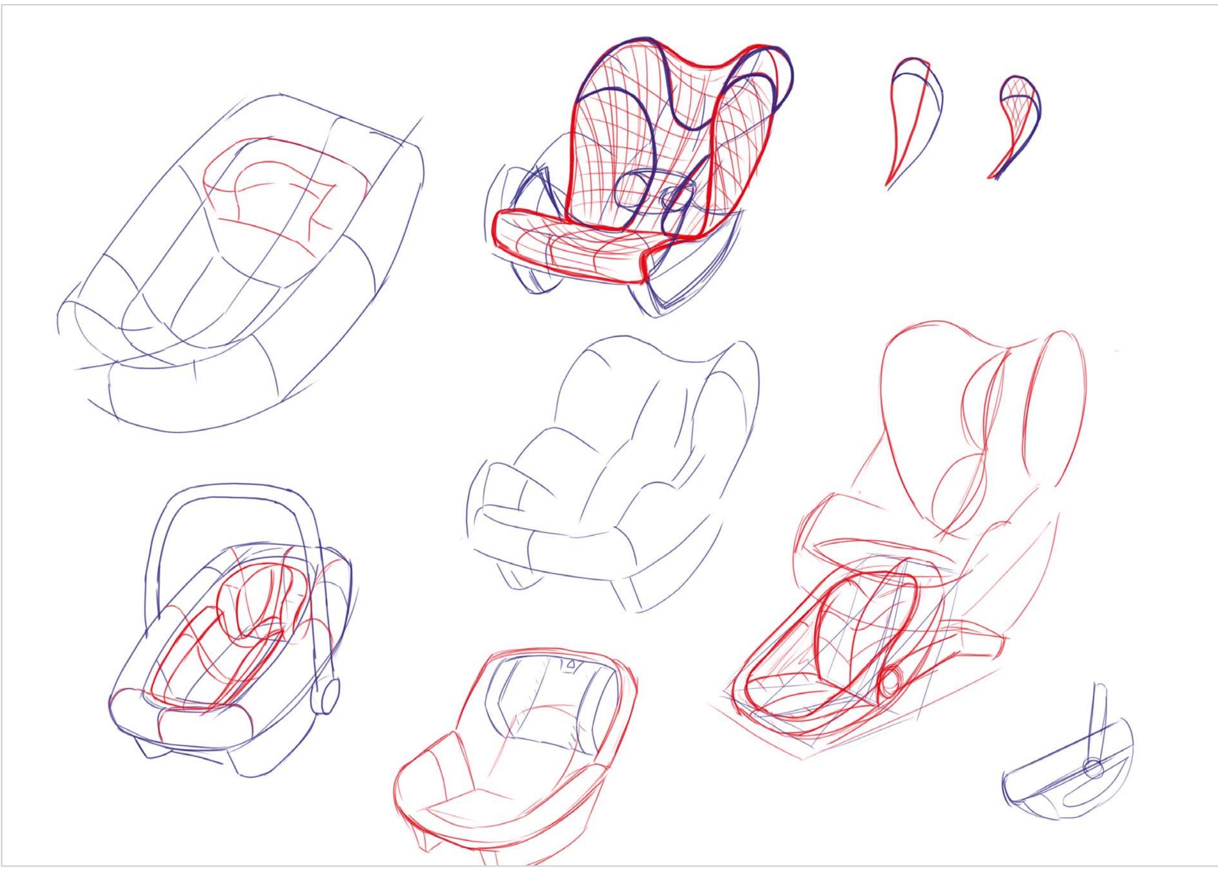


Figure 5.22 and 5.23: digital sketches of the redesign of the baby car seat throughout the process

Figures 5.25 and 5.26 show the redesigned baby car seat. The idea of using **a self-supporting main upholstery** was tested in a prototype, shown in figure 5.24. The main forces on the fabric will be in a direction parallel to the spine of the child, which means that the fabrics should be as stiff as possible in this direction. This can be achieved by putting tension on the fabric in the desired direction. The prototype was used to test whether this tension can be put on the fabric by using the axis of the locking mechanism, with the idea of improving ease of disassembly, while also creating a curved surface adapted to the child's body. While the prototype features only a fixation towards one axis, the redesign will also feature a fixation to the second axis, allowing a smoother curvature and a stiffer fabric. Figure 5.27 shows a cut through side view of the redesigned shell and main upholstery indicating with green arrows how the fabric will be pulled towards the ISOfix axes. The advantage of using a self-supporting

Figure 5.24: a prototype to test the application of self-supporting upholstery put under tension by fastening to an axis

Figure 5.25: the redesigned baby car seat (not showing the buckle and the shoulder straps)

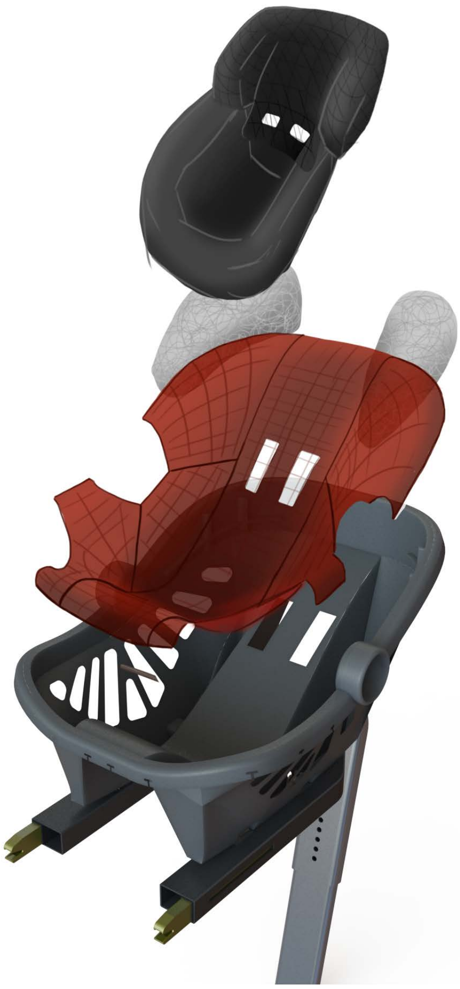


Figure 5.26: the redesigned baby car seat from top to bottom: head pillow and infant insert, 3D polymer network impact absorption, self-supporting main upholstery, shell, ISOfix base

main upholstery is the elimination of filling and the opportunity to optimise the fabric for breathability, for example by using a mesh fabric. The main upholstery is attached to the shell in several places by hooking special fasteners in holes on the edge of the shell, as shown in figures 5.29 and 5.30. **The shell** further improves breathability because of the cut-outs on the sides, allowing fresh air to move through the seat. **The head pillow and infant insert** can be sewn in a conventional manner from spacer mesh (as was shown in figure 5.14) and then filled with more spacer mesh to provide the desired cushioning. Figure 5.26 shows how these two parts will fit inside the baby car seat. The advantage of using spacer mesh for the head pillow and infant insert compared to the current situation, is that only one material is necessary instead of two for the outer layer and filling. Furthermore, the spacer mesh also improves breathability due to its open structure. Lastly, to ensure **local impact absorption**, parts made from 3D polymer network can be implemented, shaped to fill the cavity between the shell and the head of the child. The head of the child is the most vulnerable and peak impact caused by sudden contact with the shell should be prevented (personal communication with Mervyn Compen, July 24th, 2020). Figure 5.28 indicates the location of these impact absorpting parts. The two parts will be fastened inside the shell through a specifically shaped friction fit consisting of an extended shape on the inside of the shell corresponding to a cut-out shape in the polymer part (see figure 5.31) and by folding the main upholstery around the top of the impact absorbing part and fastening it to the shell. This method of fastening the impact absorbing parts to the shell complies to guidelines 11 and 12, making sure that fasteners are limited and reusable, in contrast to most of the current methods for fastening foams to the shell. It also accomodates modularity, as other types of impact absorbing materials could be developed to fit the same friction fit.

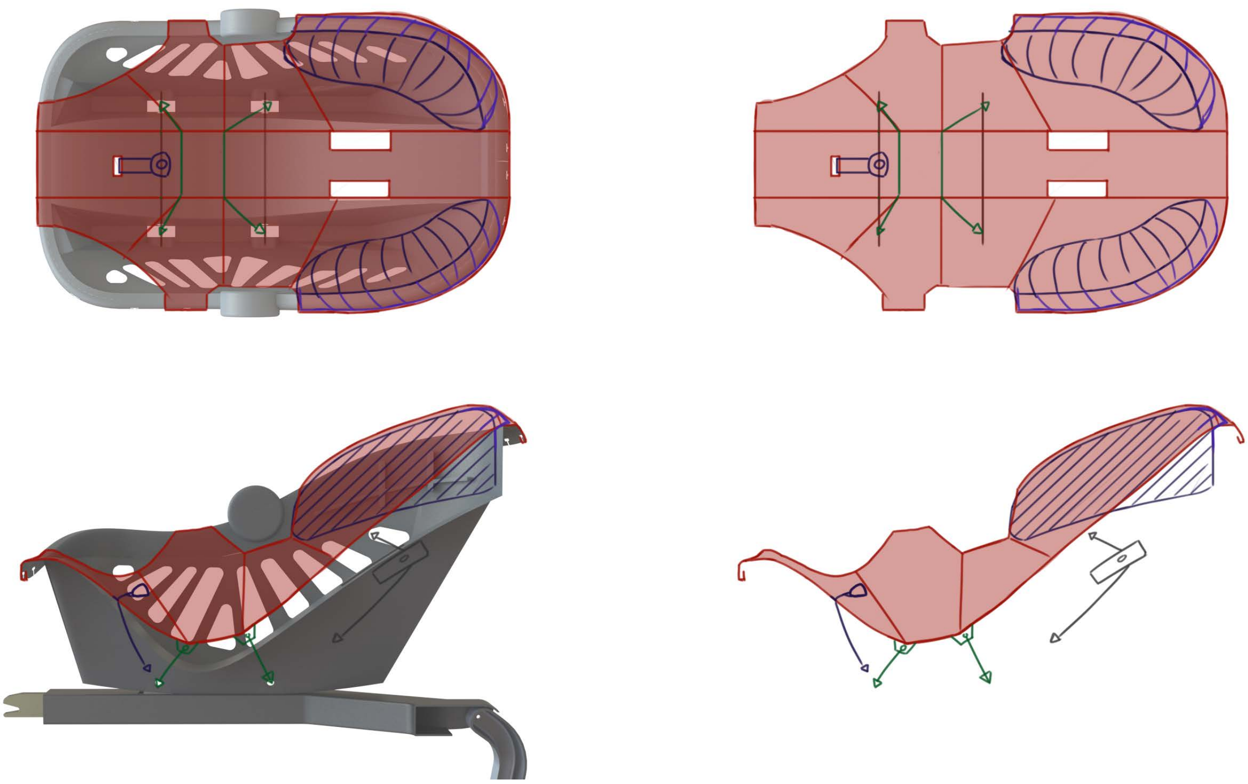


Figure 5.27: side view of the redesigned baby car seat with the self-supporting main upholstery fixated around the edges of the shell and pulled tight with straps fixated around the ISOfix axes

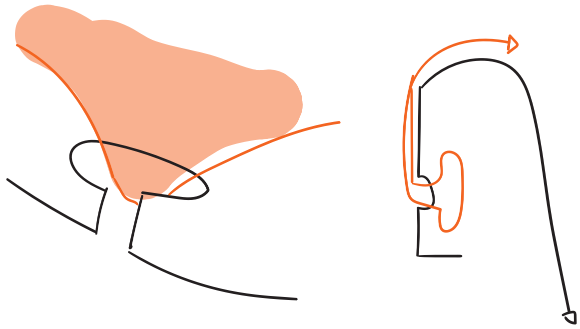


Figure 5.29: schematic representation of fastening the upholstery to a hole in the shell

Figure 5.30: holes in the shell of the redesigned baby car seat to fasten the upholstery

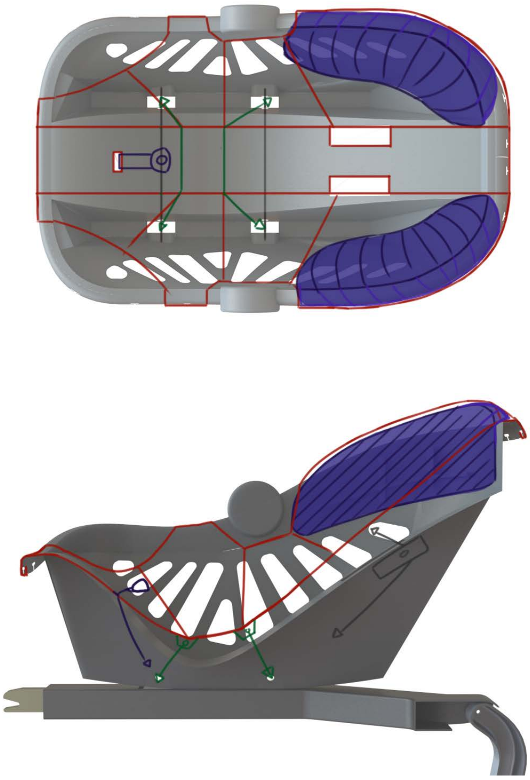


Figure 5.28: the location of the impact absorbing parts made from a PP 3D network

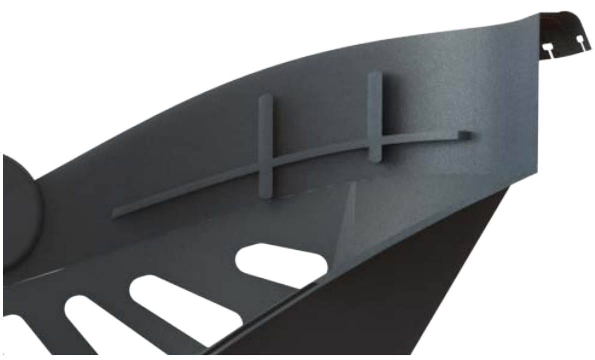


Figure 5.31: “male” part of the friction fit on the shell which fits the “female” part on the PP 3D network parts

5.2.2 Surfacing of safety critical parts

As indicated in guideline 3 and 4, not all safety critical parts are removable, or they are not easy to reach. For the redesign of the baby car seat, a design solution is proposed to bring two of these safety critical parts to the surface of the product architecture. These two parts are the buckle and the locking mechanism. For both the buckle and the locking mechanism a separate cycle of exploring alternatives was performed, after which the most suitable solution resulted in combining the assembly of the parts through the use of axes. The following paragraphs further elaborate upon this exploration of alternatives and lastly the implementation of the solution in the redesign is described.

The buckle assembly

The buckle of the baby car seat is currently either not removable at all or not very accessible (guidelines 3/7 and 4/8). In the disassembly maps of the three baby car seats that were analysed for this project, the buckle is always at the bottom of the map and so it can only be reached after removing almost everything else. Only the buckle of the Cybex Cloud Z is removable; the buckle of the Swandoo Albert is sewn into place and the buckle of the Maxi Cosi is attached to the shell with hard plastic and metal parts.

Generally, the buckle assembly consists of the buckle itself, a strap and a stopper that are all sewn together as shown in figure 5.33 and figure 5.32 of the Swandoo Albert buckle. When a force (the red arrow in figure 5.32) is applied to the buckle, the stopper keeps the buckle in place and distributes the force to the shell of the baby car seat, because the stopper is larger than the hole (in green in figure 5.32) through which the straps of the buckle pass.

The following sections discuss several alternative methods to (dis)assemble the buckle of baby car seats. The first two methods are methods found in the current design and the second two methods are new design alternatives.

Method 0: cut and resew the strap

The buckle of the Swandoo Albert cannot be removed without irreversible damage, in other words the buckle cannot be removed unless the strap is cut. This means that theoretically the buckle is removable and can be reassembled

Figure 5.32: the buckle of the Swandoo Albert

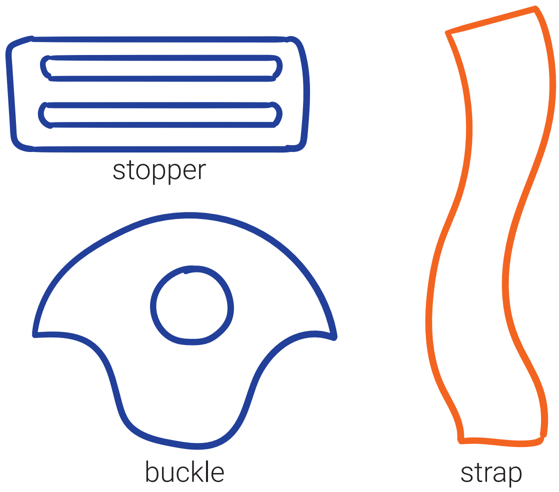


Figure 5.33: components of the buckle assembly

if a new buckle is sewn back into place. The drawbacks, however, are that sewing takes quite some time and that dis- and reassembly is only possible when both sides of the surface through which the strap passes are free to reach. In the case of the Swandoo Albert this still means that the buckle is reachable as one of the last parts in the disassembly sequence.

Method 1: stopper through hole

The buckle of the Cybex Cloud Z is removable because it makes use of the fact that the stopper can be forced through the hole in the shell when you use your hands to turn the buckle sideways. Figure 5.34 shows how the stopper will fit through the hole if you force it and how it is unable to fit through it when not forced. This means that the stopper will not accidentally slip through the hole, not even when a lot of force is put on the buckle. A drawback of this method of assembling and disassembling the buckle is that two hands are needed, one on the top and one on the bottom of the surface the hole for the strap is in. This is why the buckle is only removable as one of the last parts of the disassembly sequence of the current products.

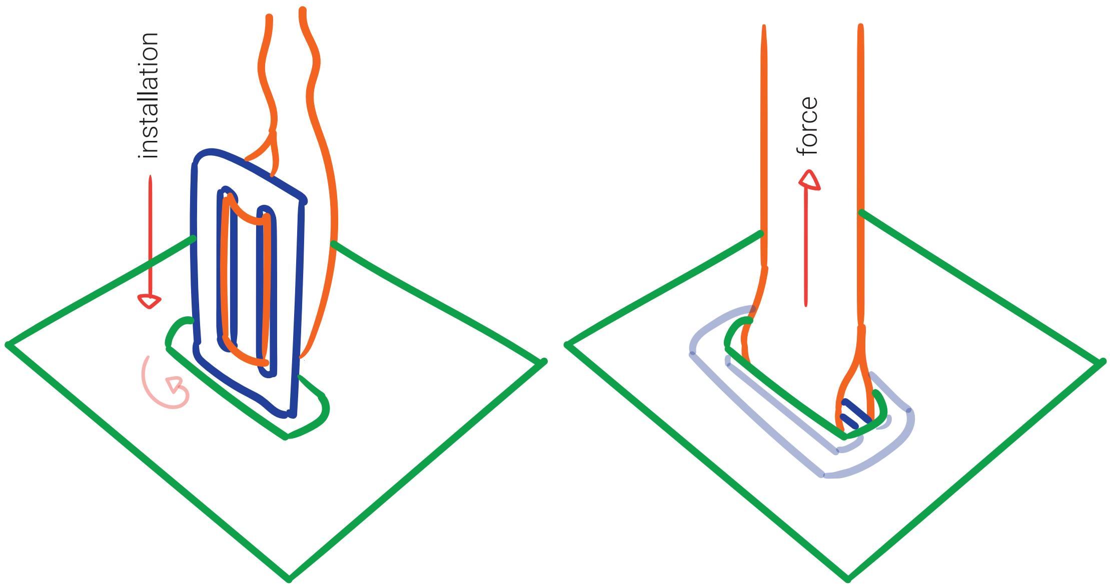


Figure 5.34: schematic representation of method 1: stopper through hole

Method 2: slide the strap through a split in the surface
Figure 5.35 shows an alternative method of assembling the buckle to a surface of the main assembly. The strap of the buckle assembly is slid through a split in the surface and turned into the right position so that the strap cannot accidentally slip loose again. There are a couple of benefits to this method compared to the previous one:

- The size of the hole and of the split are only dependent on the size of the strap, which means that a smaller hole can be used compared to the previous method, and that a larger stopper can be used, which will result in a better distribution of the force on the buckle to the surface.
- The accessibility of the buckle for disassembly is hugely improved since only the top of the surface needs to be reachable. For conventional baby car seats this could move the buckle in the disassembly sequence almost all the way to the top, after the removal of the soft goods.

A drawback to the split in the surface is a local reduction in stiffness. When a force is put on the buckle, the sides of the split will bend, as illustrated in figure 5.37a, with the risk of bending to a point where the stopper might slide between the two sides of the split or of the breakage of the surface around the split. This can be averted by ensuring the sides are kept together, of which figure 5.37b and 5.37c are possible design solutions for this. Figure 5.37b shows that a C shaped insert can be slid into the split after sliding the strap of the buckle into the split. Figure 5.37c shows how the forces on the surface are redirected around the split, resulting in a stiffness similar to a surface without a split. Furthermore, the surface area can be strengthened by implementing ribs around hotspots.

Method 3: loop and axis
The buckle assembly could be kept in place in a similar way to the method currently in use for the Cybex Cloud Z. Instead of pushing the strap and the stopper through the hole, only the strap is put

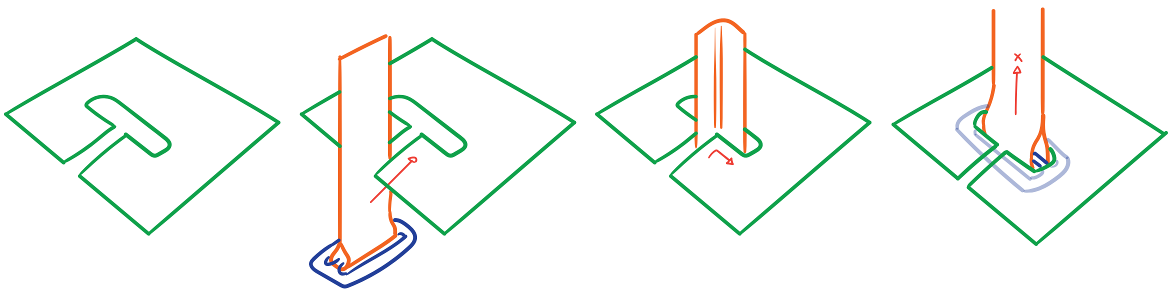


Figure 5.35: illustration of method 2 where the strap slides through a split in the surface

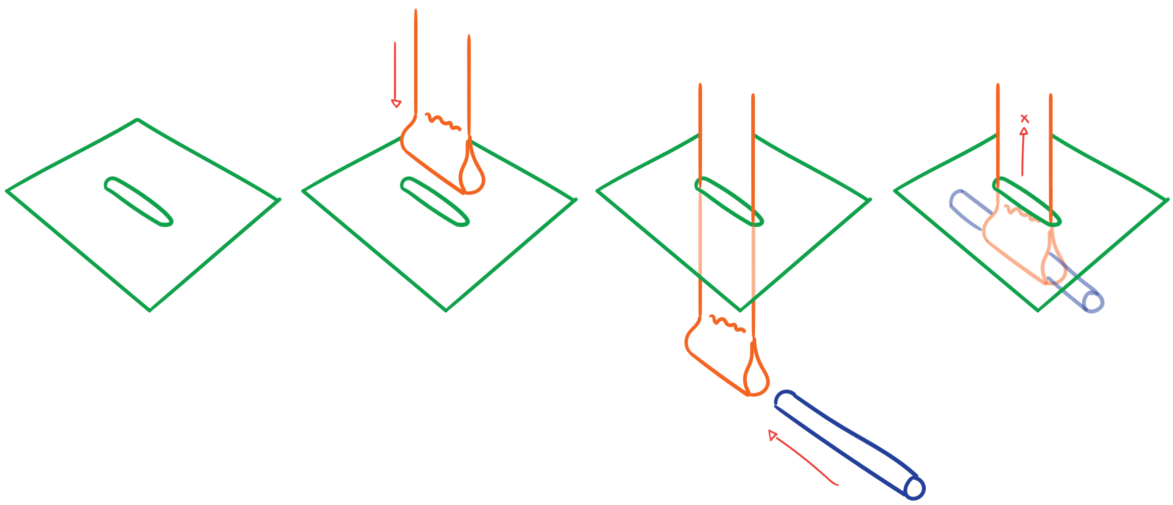


Figure 5.36: illustration of method 3 where the strap of the buckle is fastened with an axis

through the hole and kept in place with an axis that slides through the end loop of the strap (see figure 5.36). This axis can then be prevented from sliding out of the strap by retaining rings or it is possible to fixate the axis to both side of the shell for an even stiffer construction. From a load-distribution perspective, this last method of fixating the buckle to the baby car seat is favourable, because it means that the strength of the fixation does not depend on the surface, but on the axis. This method does have the same drawback that both sides of the surface need to be reachable by hand.

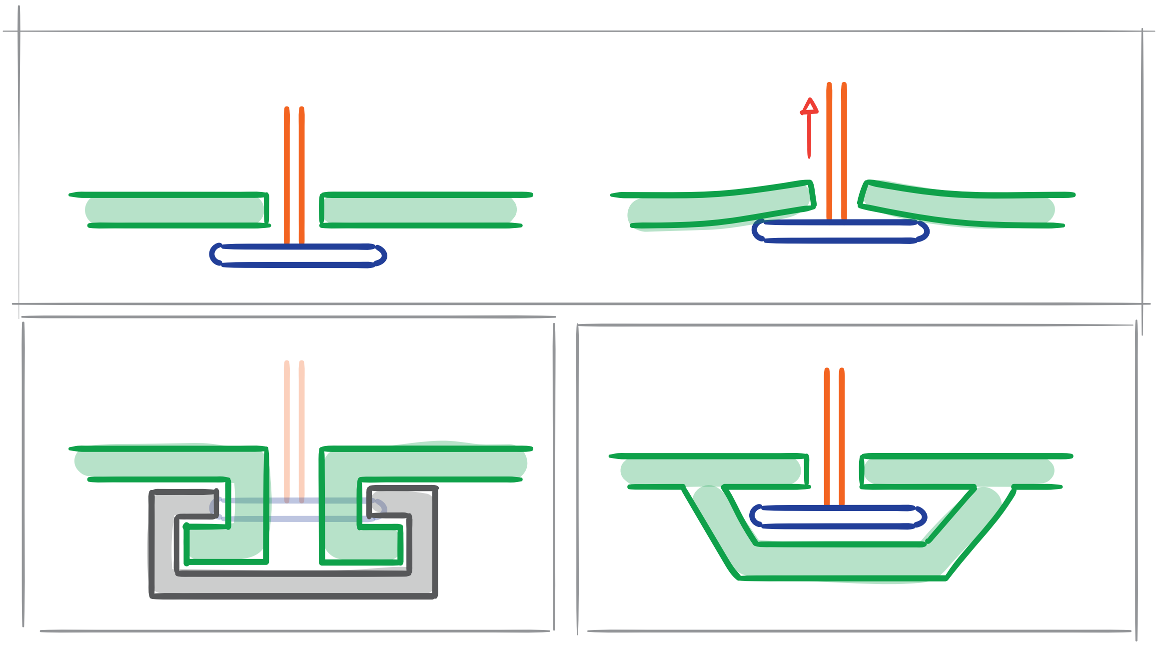


Figure 5.37: a: the risk of the surface bending under a load, b: a C-shaped insert to prevent bending, c: elongation of the surface to redirect the load

The locking mechanism

The locking mechanism between the baby car seat and the ISOfix base currently consists of a pair of hooks and axes at the front and back of the products. Generally, the hook-part is more complex than the axis-part because they are the moving component in this locking mechanism (the whole system also needs to unlock, obviously).

Alternative methods to lock the baby car seat and ISOfix base have been explored, which is shown in figure 5.38. Through this brainstorm it became clear, however, that the direction of the connection between the seat and the base is important. It is preferred to have this connection in a different direction than the direction of crash impact. Figure 5.39 illustrates this; car crashes or accidents most often generate impact force in the x and y direction and also create moments around these axes. This means that a connection between the seat and the base in the z direction should be most secure in the case of a crash.

The current solution of using axes and hooks as a locking mechanism appears to be the best, mainly because there is a low risk of usage error (you simply 'click' the seat on top of the base), the connection is in the right direction, and it is also relatively simple to integrate into the products. Although the current designs all make use of this axis and hook connection, they do have a different approach to integrating them into the products. In contrast to the other two products, the Swandoo Albert features the axes inside the base and the hooks inside the seat, with the result of adding extra complexity to the baby car seat. Integrating the hooks inside the baby car seat brings extra parts necessary to operate the system through the seat, compared to integration in the base. Because of this it was decided to integrate the axes inside the redesigned seat and the hooks inside the redesigned base, with the main focus on locating the parts as high in the product architecture as possible.

At this point the idea came up of combining the locking mechanism axes with the third method of fastening the buckle to the main assembly: by using the front axis to secure the buckle in place, parts (or fasteners) and thus materials can be trimmed.

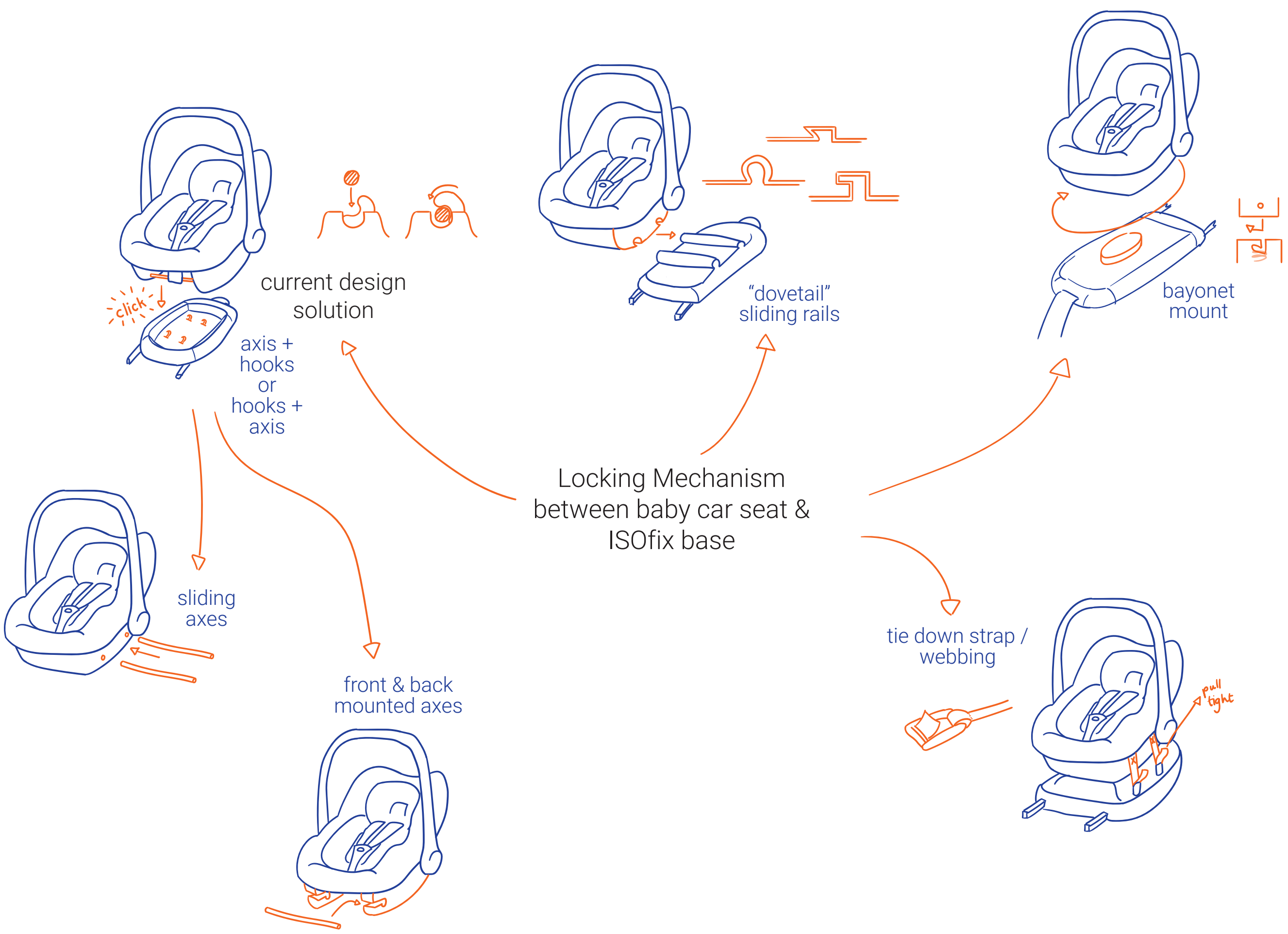


Figure 5.38: brainstorm of alternative methods to lock the base and the seat together

Implementation in the redesign

A prototype was made to test, among others, the idea of fastening the buckle with the front ISOfix axis. This prototype is shown in figure 5.40 and shows how the 'buckle' of the prototype passes through the fabric and is anchored to the front axis. In the case of a crash, the load on the shoulder straps and buckle will pass through this axis to be distributed over the shell and ISOfix base.

In the redesign, the shell accommodates the surfacing of the buckle and locking mechanism in the product architecture by allowing them to be reached from the outside. The bottom surface of the shell is left open, aiding the installation of the buckle because now both surfaces through which its strap need to pass are free to reach. Figure 5.42 shows the front of the shell and the hole through which the strap of the buckle can pass. Figure 5.41 shows how the axes of the baby car seat fit in the locking mechanism of the ISOfix base. The axes are kept in place by retaining rings which are accessible at the notches on the outside of the shell, as shown in figure 5.43. Retaining rings are chosen because they are easy to implement, install and disassemble, either with a specific tool or with a small screwdriver. Furthermore, their advantage over other simple fasteners such as nuts are that there is no risk of them unfastening accidentally caused by vibrations or inquisitive kids.

The depth of the locking mechanism and the buckle in the redesign and their location on the disassembly map is described in paragraph 5.2.5.

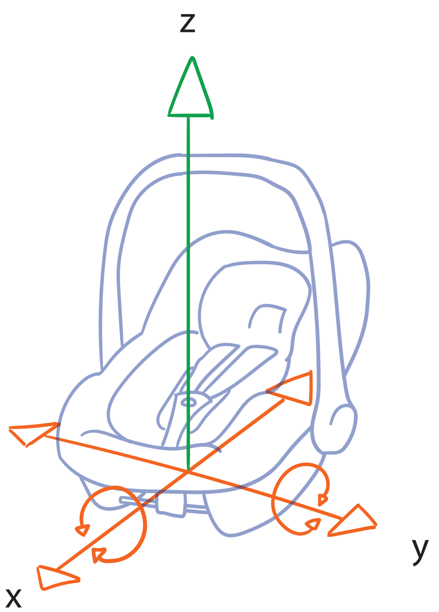


Figure 5.39: the directions of impact forces and moments (orange) and the desired locking direction (green)

Figure 5.40: a prototype to test the fixation of the buckle with an axis at the bottom of the baby car seat

Figure 5.41: side view of the redesigned shell of the baby car seat and the redesigned ISOfix base

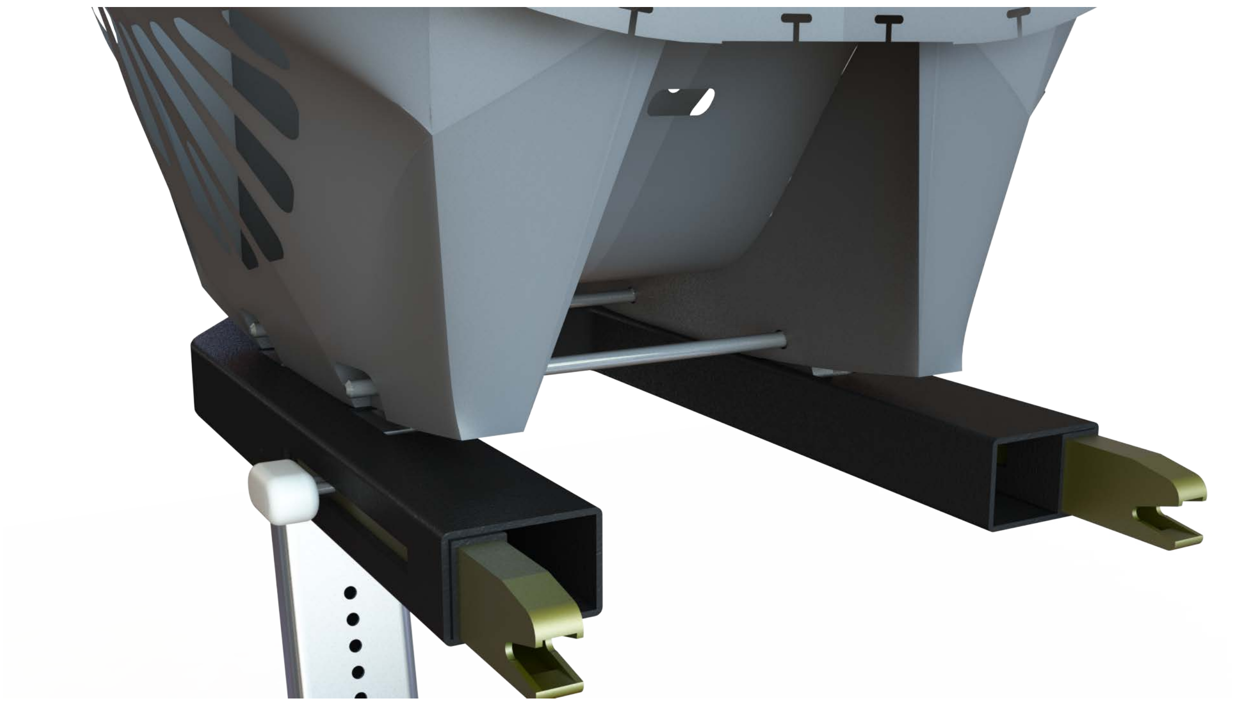
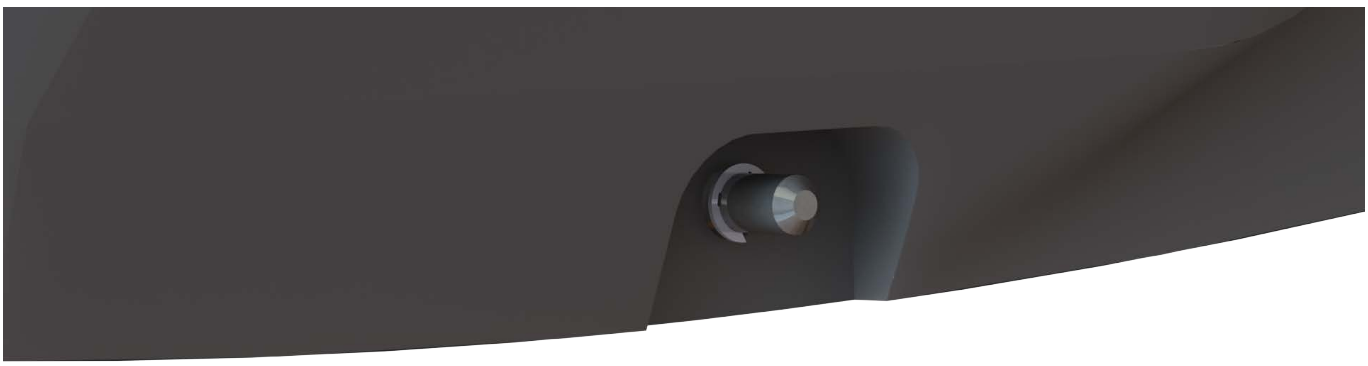


Figure 5.42 the front of the redesigned shell including the hole for the buckle and the axes of the locking mechanism



Figures 5.43: notches on the outside of the shell and an axis of the locking mechanism kept in place by a retaining ring

5.2.3 Implementation of the impact sensor

To know whether the baby car seat has been in a crash (guideline 2), an impact sensor is implemented in the back of the seat. As was stated before about the impact sensor of the ISOfix base, a passive sensor is preferred over an active sensor, because it is easy to implement and requires no additional electronic components. The placement of the sensor is again on the plane of symmetry parallel to the spine of the child, close to the head area because it is the most sensitive area of the child (see figure 5.44). The passive sensor will measure impact in all three directions and its sensitivity can be tuned separately for these directions. By using two sensors in total, on in the ISOfix base and one in the baby car seat, the certainty of the crash impact is increased.

5.2.4 Other parts

Not all parts have been attended to in the redesign of the baby car seat. The handle of the Maxi Cosi Pebble Pro already shows how a handle can be integrated optimised for ease of disassembly and thus **the handle** (figure 5.45) of the redesign will be the same (for pictures of the Maxi Cosi handle see figure 4.5 and 4.6 on page 71). For the redesign it is assumed that **the shoulder strap assembly**, consisting of the straps themselves and a system to adjust the height and length of these straps, will be similar to the one on the Swandoo Albert (this part is called 'slider' in the disassembly map). In this design the head pillow is attached through holes in the main upholstery to the height adjustment slider, which is located at the other side of the shell, as shown in figure 5.46. In the Swandoo Albert these parts were fastened by a

Figure 5.44: the impact sensor on the plane of symmetry of the baby car seat

Figure 5.45: the redesigned baby car seat including the handle

screw but since the head pillow of the redesign is made of spacer mesh, snap buttons are more likely to be used. The shoulder straps pass through this slider and through holes in the head pillow. If the infant insert is also used, the shoulder straps will also pass through holes in this infant insert (again similar to the design of the Swandoo Albert). To optimise this design for disassembly, the axis to which the shoulder straps are attached will be reachable from the outside of the shell, like the axes of the locking mechanism. This way the shoulder straps can be easily replaced in only a few steps. **The shoulder pads** can be made out of spacer mesh like the head pillow and infant insert.

To decrease the risk of losing the shoulder pads, they could be attached to the head pillow with Velcro, for example. Unlike the current products, the redesign does not feature any **belt guides**. They could be added to the outside of the shell, however the question arises whether using belt guides for the installation of the baby car seat instead of an ISOfix base is desirable in light of safety, especially when so many child car seats are installed incorrectly into the car (see paragraph 3.1.1). The sun canopy is not taken into account in the redesign, but it would be a simple part to integrate a into the shell.

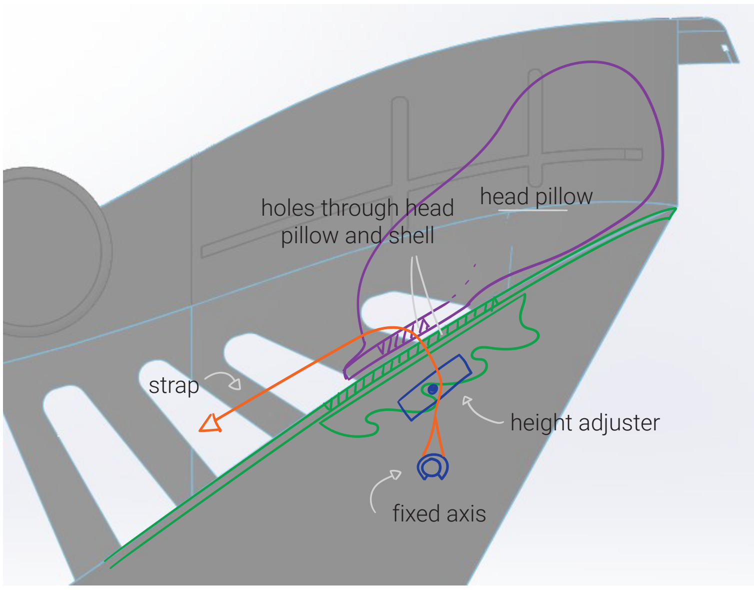


Figure 5.46: schematic representation of the shoulder straps and the height adjustment system

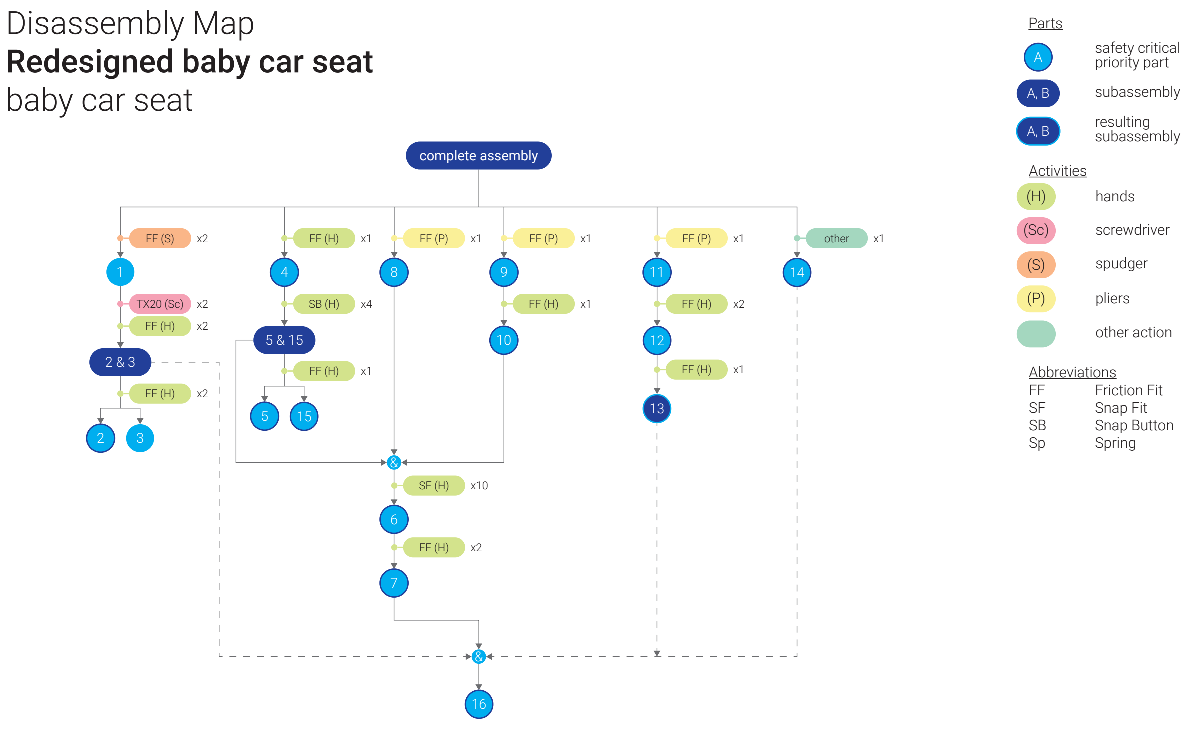
Figure 5.47: the components of the redesigned baby car seat

5.2.5 Disassembly map of the redesign

A disassembly map of the redesigned baby car seat has been made to visualise its product architecture and disassembly sequence, which is shown in figure 5.48. An overview of the components of the redesigned baby car seat is shown in figure 5.47.

Compared to the existing baby car seats, the redesign contains less parts and priority parts have been brought to the surface, which makes their disassembly sequence shorter. The disassembly depth index of the redesigned baby car seat is 0.5 (a maximum depth of 8 to reach the deepest part which is the shell, out of a total of 16 parts). This score is actually worse than both the score of the Maxi Cosi Pebble Pro and the Swandoo Albert and this is due to the fact that the method only considers the maximum part depth. Apparently, the maximum depth for baby car seats has a minimum of around 8 parts, mainly due to the linear sequence present in all baby car seats of removing the head pillow, the infant insert, the shoulder pads and the main upholstery. When reducing the total amount of parts while this minimum for a “bottleneck linear sequence” is reached results in a lower disassembly depth index, even though the ease of disassembly is improved.

The disassembly map of the redesign does show how all priority parts are close to the surface of the product architecture. For example, the buckle now has a part depth of 2, this is a significant improvement compared to the Cybex Cloud Z where it was 17 and compared to the other two products where the buckle was not removable at all. The locking mechanism of the redesigned baby car seat has a similar improved, going from around 15 to having a part depth of 1, meaning that the parts are removable directly from the surface of the product architecture. The greatest improvement is that 6 parallel paths are reachable directly from the surface of the product, meaning that reaching a single component can often be achieved without removing many other parts.



1. handle cover (L+R)
2. handle
3. handle button (L+R)
4. infant insert
5. head pillow
6. main upholstery
7. 3D polymer network (L+R)
8. ISOfix axis A
9. ISOfix axis B
10. buckle
11. shoulder strap axis
12. shoulder straps (L+R)
13. strap height adjuster
14. impact sensor
15. shoulder pads
16. shell

Figure 5.48: the disassembly map of the redesigned baby car seat

5.2.6 Economic & environmental costs

A similar calculation to that of the ISOfix base has been performed to compare the economic and ecological costs of the redesign and the current baby car seats. The comparison has been made only for the soft goods and the 'foams' of the product. Some assumptions were made, such as that all filling of the soft goods that did not consist of foam, consisted of polyester filling. All prices per kilogram material are based on the average price in the CES Edupack database (Granta Design Ltd, 2019) except for the price of PP spacer mesh which was determined based on the average price for large quantities of the material on Alibaba.com. CES Edupack was also used to determine the energy and CO2 impact of the primary production and further processing of the materials. The quantity per material in each product is based on the Bill of Materials (appendix H) which in its turn was based on the weight of the disassembled parts. Since the precise quantity of soft goods and impact absorbing materials for the redesign is unknown, these quantities are estimated based on the existing product and on the samples of the new materials.

The costs of the soft goods and impact absorbing materials of the redesign are similar to the Swandoo Albert and Maxi Cosi Pebble Pro, as shown in table 5.4. The Cybex Cloud Z, however, has way lower costs for these materials, which is mainly due to the low quantity of foams used. Table 5.5 shows the embodied energy and CO2 footprint through primary production and further processing of all the materials. This data is used to calculate the embodied energy and CO2 footprint of the soft goods and impact absorbing materials of all four products, shown in table 5.6. Generally, the redesigned baby car seat has a slightly lower environmental impact than the Swandoo Albert and the Maxi Cosi Pebble Pro, but its impact is around 1.8 times more than the Cybex Cloud Z, meaning that the redesign should be reused twice, when the Cybex Cloud Z is used once. Again, the conclusions that can be drawn based on these comparisons are very limited, because they are limited to only a few parts and only take the raw materials into account and because the material use of the redesign is not precisely determined.

Table 5.4: raw material costs of the soft goods and impact absorbing materials of the three baby car seats and the redesign

		Swandoo Albert		Cybex Cloud Z		Maxi Cosi Pebble Pro		Redesign	
material	EUR/kg	kg	EUR	kg	EUR	kg	EUR	kg	EUR
polyester	€ 1.30	0.97	€ 1.26	0.96	€ 1.25	0.88	€ 1.14	0.50	€ 0.65
PU	€ 6.86	0.49	€ 3.33	0.00	€ -	0.13	€ 0.89	0.00	€ -
EPP	€ 1.64	0.33	€ 0.53	0.00	€ -	0.00	€ -	0.00	€ -
EPS	€ 2.50	0.00	€ -	0.10	€ 0.24	0.97	€ 2.43	0.00	€ -
PP network	€ 1.21	0.00	€ -	0.00	€ -	0.00	€ -	0.30	€ 0.36
PP fibre	€ 1.92	0.00	€ -	0.00	€ -	0.00	€ -	0.50	€ 0.96
PP spacer mesh	€ 2.54	0.00	€ -	0.00	€ -	0.00	€ -	0.90	€ 2.29
total		1.78	€ 5.12	1.06	€ 1.49	1.98	€ 4.46	2.20	€ 4.26

Table 5.5: energy usage and CO2 footprint per kilogram material of the primary production and further processing (no data available for foaming of material)*

material	process	energy [MJ/kg]	CO2 footprint [kg/kg]
polyester	primary production	85.0	4.5
	fabric production	2.6	0.2
PU	primary production	85.1	4.0
	extrusion & molding*	24.8	2.0
EPP	primary production	79.1	3.1
	extrusion & molding*	25.8	2.1
EPS	primary production	87.8	2.4
	extrusion & molding*	29.1	2.3
PP Network	primary production	69.3	2.9
	processing	27.6	2.1
PP fibre	primary production	69.0	3.1
	fabric production	2.6	0.2
PP spacer mesh	primary production	69.0	3.1
	fabric production	2.6	0.2

Table 5.6: energy usage and CO2 footprint of primary production and further processing of the soft goods and impact absorbing materials of the three baby car seats and the redesign

	Swandoo Albert	Cybex Cloud Z	Maxi Cosi Pebble Pro	Redesign
energy [MJ]				
primary production	149.3	89.9	170.8	159.9
processing	23.0	5.3	33.7	13.2
total [MJ]	172.3	95.2	204.5	173.1
CO2 footprint [kg]				
primary production	7.3	4.5	6.8	7.4
processing	1.8	0.4	2.7	1.0
total [kg]	9.1	5.0	9.5	8.4

5.2.7 Conclusion

The baby car seat redesigned for refurbishment (figure FXIME) is improved for ease of disassembly by the surfacing of safety critical parts, most notably the buckle, the locking mechanism, and the shoulder straps. The disassembly sequence of these parts is shortened in such a way that their part depth now is maximal 2 and that they are reachable within 3 activities (including unfastening and removing other parts). The product architecture is simplified, and the overall disassembly sequence made more parallel, mainly through the redesign of the shell which allows the parts to be reached from the outside. The disassembly depth index of the redesigned baby car seat is 0.5.
The soft goods and foams of the current baby car seat are substituted in the redesign by a self-supporting mesh fabric made of recycled PP and parts made of PP 3D networks acting as local impact absorption. Instead of the traditional outer fabric filled with wadding, the head pillow and infant insert are now made of layers of PP spacer mesh sewn together in the right shape. These reimagined soft goods and foams improve the ease of recycling of the product, because they are all made from the same polymer as the shell of the baby car seat, namely PP, which means that the number of waste streams from this baby car seat is decreased. Furthermore, they improve breathability, modularity, and cleanability through the choice of materials and methods of fastening.
The redesigned baby car seat features a passive impact sensor that together with the impact sensor on the ISOfix base can be used to determine whether the products have been in a crash.

PP 3D spacer mesh
head pillow
(& infant insert)

buckle
fastened to axis

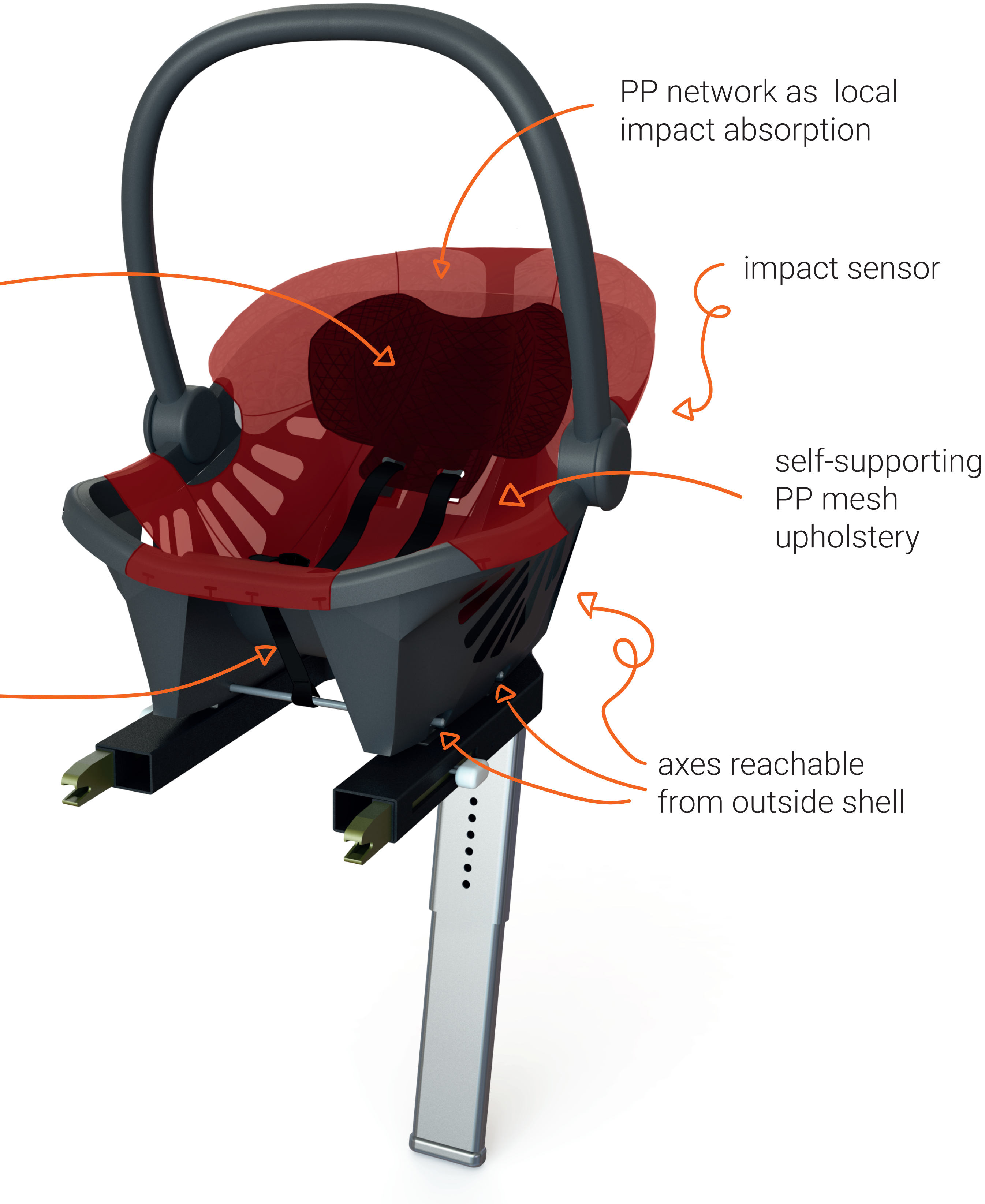


Figure 5.49: the redesigned baby car seat attached to the redesigned ISOfix base

5.3 Evaluation of the redesigns

The redesigned ISOfix base and baby car seat have been evaluated with Cyril Smals and Mervyn Compen of Code Product Solutions. The main question was whether the proposed changes are feasible regarding safety criticality and refurbishment.

The main critique from the experts on the redesign of the ISOfix base is that the risk is high of creating a heavy product when the goal is to use metal wherever possible. Furthermore, the current design is not detailed enough to estimate whether production of the metal parts bring about a lot of further processing and shaping after the extrusion of the metal tubes, compared to the conventional use of a frame covered by a plastic shell. Lastly, it is desirable for the two locks and axes of the locking mechanism to be as far away from each other as possible and in the redesign it seems there is still space to position one of the locking points more towards the leg and the other more towards the anchors in the car seat (figure 5.50).

Both experts indicated that further research is necessary about the use of impact sensors in these products, especially about how the impact is measured, and which values should be determined as critical. The experts think the location of the impact sensor on the baby car seat close to the head of the child is well chosen. However, the location of a second impact sensor is changed from the handle of the seat to the ISOfix base in consultation with the experts. They state that using more than two sensors might even be better. Lastly, the point out the importance of sensitivity to fraud of the impact sensor for the acceptance and successful integration in a product fit for refurbishment.

The main concern of the two experts about the redesigned baby car seat relates to the self-supporting main upholstery. This kind of 'hammock' poses the risk of peak loads when the fabric is not stiff enough causing the structure to swing and causing the body of the child to hit the shell of the seat. Furthermore, the redesign now features a shell very similar to the existing baby car seats, while the load paths are entirely different, because the loads will pass through the self-supporting main upholstery. Despite that the experts think using a self-supporting upholstery is tricky in relation to safety, they are of the opinion that in theory it should be possible to create a safe baby car seat using such a design, but the shell and other load bearing parts of the baby car seat should be redeveloped for this specific situation. Using an axis of the locking mechanism to fixate the buckle to the baby car seat is regarded as an improvement both for refurbishment and for the load path through the buckle, as this path will now be shorter compared to current baby car seats. Using polypropylene moulded into a 3D network to take over the function of foams is considered beneficial for the recycling, without any notable drawback to safety.

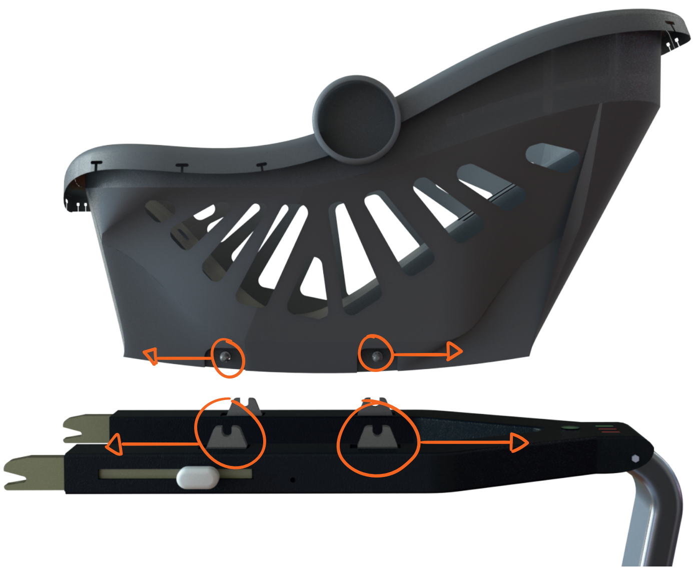


Figure 5.50: the locking mechanism between the base and the seat could be located further apart

Key insights

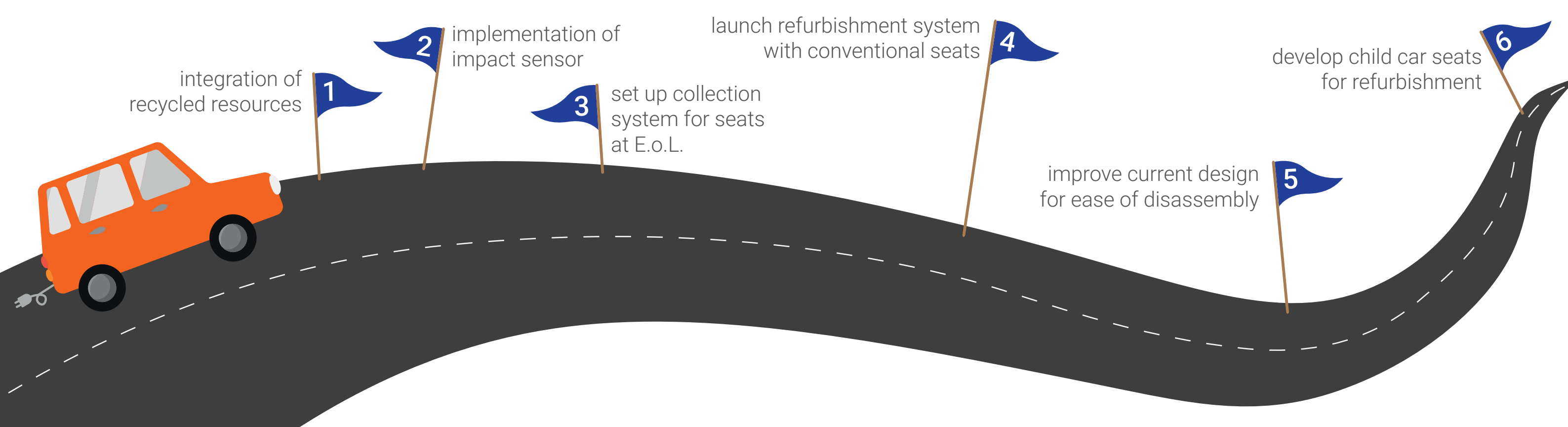
Chapter 5: illustrative redesign

- The redesigned ISOfix base is improved for disassembly by trimming parts and surfacing safety critical parts. All safety critical parts of the redesigned ISOfix base are reachable within four steps.
- The redesigned ISOfix base can almost completely be made out of metal, which is beneficial for recycling, and this is mainly due to the substitution of the conventional plastic shells with a load-bearing metal frame which also houses all components.
- The costs of the metal frame used for the ISOfix base is around €8,50, which is similar to the costs of the Swandoo Albert base's shells and metal frame.
- The material impact on the environment is lower than the impact of the shells and frames of the Swandoo Albert base and the Cybex Z base, but around 1.75 times higher than those of the Maxi Cosi 3wayfix.
- The disassembly sequence of the redesigned ISOfix base is more parallel than the current products and the redesign has a disassembly depth index of 0.5.
- The redesigned baby car seat is improved for disassembly by surfacing the buckle, the locking mechanism, and the shoulder straps, which are all safety critical parts. The surfacing of these parts makes the disassembly sequence of the redesigned baby car seat more parallel compared to the current baby car seats. Its disassembly depth index is 0.5.
- The redesigned baby car seat is improved for recycling, breathability, cleaning, and modularity through the use of a self-supporting PP mesh main upholstery, 3D PP network impact absorption, and a PP spacer mesh head pillow and infant insert.
- The substitution of the soft goods and foams by the materials mentioned above makes these parts costs less than the Swandoo Albert and the Maxi Cosi Pebble Pro, but more than the Cybex Cloud Z. The effect of this substitution to the parts' environmental impact are the same; the redesign has a lower impact than the Swandoo and Maxi Cosi seats, but a higher impact than the Cybex Cloud Z.

6 Recommendations

This chapter briefly discusses some recommendations arising from this graduation project. Firstly, the methods used to assess the current products should be further developed. As stated in paragraph 3.2.2, the Hotspot Mapping method should be extended to include the function of 'ergonomically important'. Additionally, the integration of atypical methods of fastening parts should be considered, such as parts that do not contain any separate fasteners but are fastened through a friction fit, a shape fit or elasticity of the part itself. It is recommended for Disassembly Mapping to apply this method for several types of products to find out whether it is universally suited to depict a product's architecture and disassembly sequence. Furthermore, the way how subassemblies are represented in the disassembly map could be reconsidered. Likewise, during the calculation of the Disassembly Depth Index based on the disassembly maps of the redesigned products, it became apparent that most products feature one or two parts like a frame or base, which functions as the foundation onto which other parts are assembled. The representation of this special part in the disassembly map and its inclusion in the calculation for the Disassembly Depth Index is something to further discuss, mainly because from this part's perspective the total disassembly sequence will be linear, even when partial disassembly is mostly parallel. The guidelines developed in this graduation project should be put into practice during the design of products for refurbishment to verify and further develop them.

Figure 6.1: the road towards child car seats for refurbishment



Secondly, to reach child car seats that will be refurbished and reused with a safety guarantee, the following steps are recommended, and a summary is shown in figure 6.1. Initially, the suitability to apply resources consisting of recycled materials should be researched. Through the integration of recycled resources, the first loops in the lifetime of child car seats will be established. Next, it is most important to set up a collection system for child car seats at the end of their lifetime. By collecting these seats, waste streams can be set up and coordinated to establish more loops. Furthermore, data can be collected about the usage and failures of these seats and this data can be used to develop the refurbishment protocol of child car seats. At the same time, the implementation of impact sensors should be further researched to determine the right sensitivity and critical values. Consumer acceptance and perceived safety regarding refurbished child car seats affect the successful integration of child car seats into a circular system and should be researched before determining the value proposition of a refurbishment service. After the refurbishment service is established, which could be done with the current design of child car seats, in the short-term these design could be improved for ease of disassembly and in the long-term an unconventional design for child car seats tailored to refurbishment should be developed.

7 Conclusion

This graduation project set out to investigate the challenges of designing a safety critical consumer product suitable for the refurbishment loop of the circular economy through a case study on child car seats. This main research question was answered through finding out what ensures the safety critical functionality of child car seats, what the current state of child car seats regarding refurbishment is, and how child car seats can be redesigned for refurbishment.

A first challenge is that to guarantee the safety of a child car seat for reuse it needs to be known whether the child car seat has been in a car crash. For if the product has been in a crash, the impact of it could have affected the structural integrity of the child car seat as a whole and the functioning of its parts. This means that both need to be inspected. To determine whether the child car seat has been in a crash, impact sensors could be implemented into the product. A further challenge is that almost all parts of child car seats have a safety critical function and that they all need to be inspected during refurbishment. Parts with a safety critical function of baby car seats are parts which support the correct installation of the child in the child car seat, or parts which support the correct installation of the child car seat in the car (either with an ISOfix base or the car seat belt), and lastly, parts which are responsible for the absorption of the crash impact. Next to these safety critical parts, the priority parts of child car seats consist of parts with an ergonomic function, parts with a high failure frequency, and parts with a high economic or environmental value.

A further challenge is the product architecture of child car seats which affects the ease disassembly, and which is an important factor for refurbishment. The ease of disassembly of three baby car seats and three ISOfix bases has been analysed by using the Hotspot Mapping method. The main conclusions based on this analysis are that not all safety critical priority parts of both baby car seats and ISOfix bases are currently removable, which means that with the current design when one of these parts fails, the product cannot be refurbished and will be discarded as a whole. Furthermore, other safety critical priority parts lie very deep within the product architecture. The method of Disassembly Mapping was used to visualise the disassembly sequence of all six products and these maps show that different design approaches result in an increase in the complexity of the product architecture and the disassembly sequence. Parallel sequences are preferred for refurbishment and to compare different products on their level of parallelism, the Disassembly Depth Index was developed as an additional metric to recognise a product's ease of disassembly. The material use is another challenge affecting refurbishment because they influence the lifetime of the product and the ease of recycling.

A set of guidelines for design for refurbishment of safety critical products have been developed based on the analyses of this graduation project. This set of guidelines firstly incorporates guidelines specifically for safety critical products and furthermore consists of guidelines for product architecture, materials, and fasteners. To illustrate the application of these guidelines, a redesign of the ISOfix base and baby car seat has been made. The products are improved for refurbishment through the elimination of non-priority parts, by making safety critical parts removable and bringing them to the surface, by increasing the level of parallelism, and by substituting materials with alternatives better suited for refurbishment.

Lastly, recommendations for further development of the methods used and the next steps for reaching child car seats suitable for refurbishment are described.

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Appendices

Appendix A
Design Brief

DESIGN FOR our future

IDE Master Graduation
Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name	Vermaat
initials	B.M.
given name	Bente
student number	4375998
street & no.	
zipcode & city	
country	
phone	
email	

Your master programme (only select the options that apply to you):

IDE master(s):	★ IPD ◯ DfI ◯ SPD
2nd non-IDE master:	x
individual programme:	- - (give date of approval)
honours programme:	◯ Honours Programme Master
specialisation / annotation:	◯ Medisign
	◯ Tech. in Sustainable Design
	◯ Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair	Bas Flipsen / R van Heur (Mentor)	dept. / section:	DE / CPD
** mentor	Rudolf van Heur	dept. / section:	ID / AED
2nd mentor	Nine Klaassen		
	organisation: Code Product Solutions		
	city: Schinnen / Eindhoven	country:	Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Bas Flipsen / R van Heur (Mentor) date 02 - 04 - 2020 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 27 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 27 EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name J. J. de Bruin (SPA-IO) date 07-04-2020 signature JdB

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name date - - signature

Initials & Name B.M. Vermaat Student number 4375998

Title of Project Improving circularity of Child Restraint Systems

Improving circularity of Child Restraint Systems — project title

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

start date 30 - 03 - 2020 — 31 - 08 - 2020 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The world is slowly starting to transition from a linear to a circular economy, as we realise that with the current system the limits of the earth's resources are reached. The circular economy represents a system were the value of materials and products are maintained through unlimited times of use, by ensuring closed life cycle loops.

Code Product Solutions is a design company with an expertise in using computer aided design to resolve complex design problems, which is exemplified by their experience in light-weight design, optimisation of orthoses and design of child car seats.

Among others, child car seats are one type of product currently not designed from a circular perspective, which means that its life cycle takes on the linear form of making, using and discarding the product instead of a circular life cycle (see figure 1). By analysing how child car seats can be redesigned to fit a circular business model, Code Product Solutions can contribute to a circular world.

The stringent regulations which child car seats are subject to might complicate the implementation of child car seats into a circular business model. Similarly, the safety and quality which these regulations ensure, are of utmost importance to the customers of child car seats and this will thus form the main consideration when redesigning for a circular economy.

Code Product Solutions designs child car seats for companies such as Dorel-Juvenile, Uppababy, and Swandoo. For Code, analysing child car seats regarding circularity might result in new business opportunities, as it provides them with experience and knowledge in implementing circular strategies in their design practice. Their positions towards child car seat brands specifically will benefit from the research, because they can pave the way to circular products and with it new business models. There might even be possibilities for Code Product Solutions to take on a new role within the loops of the circular economy as a remanufacturer or refurbisher. All stakeholders of the project and their interests are shown in figure 2.

space available for images / figures on next page

introduction (continued): space for images

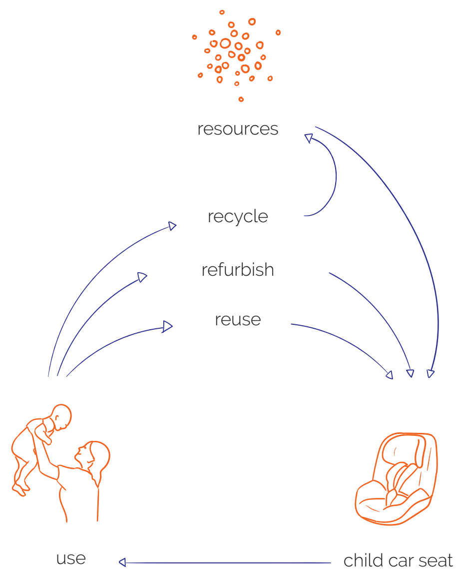


image / figure 1: A circular life cycle of child car seats

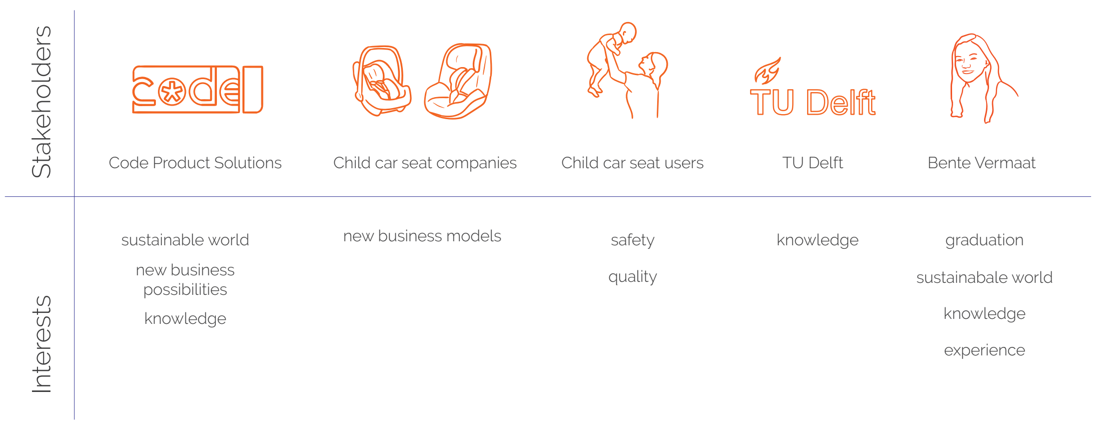


image / figure 2: Stakeholders and their interests in this graduation project

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

In recent years, research has been conducted regarding integrating products into circular business models, however, it is currently unknown how safety critical consumer products compare to the principles of the Circular Economy. The main question of this graduation project will be: "What are the challenges of integrating a safety critical consumer product into the repair and refurbish loops of the Circular Economy?"
This research question will be addressed by performing a case study of one type of safety critical consumer product, namely child car seats. Issues at hand will be finding out whether current child car systems can be integrated into the Circular Economy as is and if not, how they could be adjusted so that they can be integrated. Are there any obstacles regarding dis- and reassembly? What kind of checks need the products or parts surpass before being ready for the next customer? Are there any obstacles regarding material use?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The objective of this graduation project is to contribute to the development of circularly designed child car seats for the company Code Product Solutions.

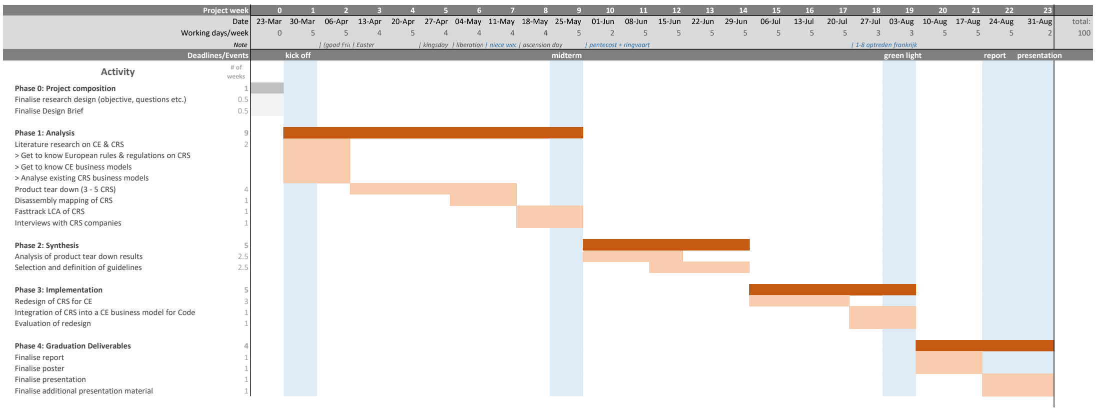
Firstly, existing child car seats will be evaluated regarding repairability and refurbishability, according to the principles of the Circular Economy. This will be achieved through a product tear down of several child car seats, based upon which a disassembly map (De Fazio, 2019) will be created. The existing child car seats and more specifically their Bill of Materials will be further evaluated by performing a fast track Life Cycle Assessment. Additionally, interviews with the brands of the assessed child car seats will be held.
Based on the analysis of the existing child car seats, a design guide will be developed incorporating recommendations on how to design child car seats according to the principles of the circular economy. These recommendations will vary from short-term adjustments to child car seats in order to make them fit a circular business model and to ensure their quality at the end of every use cycle, to long-term solutions ensuring closed loops. The recommendations of the design guide will be illustrated with a circular redesign of a child car seat.

De Fazio, F. (2019). Enhancing Consumer Product Repairability. [master thesis] Retrieved from http://resolver.tudelft.nl/uuid:810db9a6-9718-4451-8f8f-67ad0cdccad9

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and 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 activities.

start date 30 - 3 - 2020 | 31 - 8 - 2020 end date



Above is shown the Gantt Chart of this graduation project. In total, the duration of the project will be 23 weeks, due to holidays and some personal activities.

List of abbreviations:
CE: Circular Economy
CRS: Child Restraint System or child car seat

Events:
Kick off meeting: 30 March
Midterm evaluation: 25 May
Green light meeting: 27 July
Presentation & Graduation: 24 August

Initials & Name B.M. Vermaat Student number 4375998

Title of Project Improving circularity of Child Restraint Systems

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

My main motivation for this graduation project is bringing to practice my theoretical knowledge about circular design, as I have not performed any practical assignments on circular design before. I believe that circular design should be the norm in order to preserve the earth for future generations. I am curious to see how the theoretical ideals of the circular economy will hold up against economic and practical limitations and with that I am curious to experience the challenges of implementing circularity into the design practice.

During the analysis of existing child car seats, I hope to get acquainted with the complexity of finished products since the focus of the Industrial Design education of the TU Delft lies mostly on the design process itself. The reason for this is that I feel like there is a gap in my knowledge between the first development stages and the ready-for-market stage of products.

Lastly, I am looking forward to the challenge of taking care of all stakeholders and their interests involved in the project and I hope I can further improve my project management skills.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Appendix B

User research: interviews with parents currently using baby car seats

#1
Naam: Anne
Kinderen: 1 dochter, 1 jaar

1. Welke stoel/stoelen/base heb je?

Maxi Cosi, tweedehands via een vriendin, vanuit klimaatbewustzijn. Vaak wel de stoffen nieuw of iig heel heet wassen.

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

Milieu bewustzijn, wel overgekocht van een bekende vanwege veiligheid en hygiëne.

3. Wat vind je nu van de stoel?

Helemaal prima, wij hebben niet zo'n base eronder, dat kan wel. Wij gebruiken gewoon de riem en dat werkt helemaal prima en dat is makkelijk omdat we veel switchen van auto. Verder vind ik het heel onhandig, kijk dat stangetje (hendel) moet natuurlijk omhoog voor de veiligheid maar echt vervelend is het wel om die aan twee kanten in te moeten drukken, daar krijg ik rugpijn van. Ik vind het leuk dat het stofje een leuk printje heeft, maar die heb ik natuurlijk ook zelf uitgekozen. Ik vind hem niet zo zwaar. Ik laat de maxi cosi in de auto staan in principe.

4. Zijn er al dingen stuk of versleten? Wat?

Nee helemaal niks, terwijl het ding al wat ouder is nu ongeveer 3 jaar oud. Wat krasjes op de zijkanten van de hendel.

5. Wat zou je willen veranderen aan het product?

Naast die stang, vind ik het onhandig hoe de zonnekap vastzit. Zonnekap geeft een geborgen gevoel voor het hoofdje van mijn kind, ook in de winter, het voelt veilig. Het zit alleen aan de achterkant heel los en het springt snel af van de hendel. Ik zie dat liever als kliksysteem of zo.
Ik stap niet over naar een vooruitkijkende stoel, want ik weet van de veiligheid dat het beter is om het zo lang mogelijk achterstevoren te laten.
Ik zou heel graag de gordel om mijn kind heen willen vervangen, de gordel ervan vind ik wel echt vies. Want daar spugen ze altijd op.
Je kunt door het wiegsysteem aan de onderkant van de stoel de stoel iets meer rechtop of iets meer plat neerzetten in de auto.

#2
Naam: Daniel
Kinderen: 2 zoons, één van 1 maand en één van 2 jaar

1. Welke stoel/stoelen/base heb je?

Maxi Cosi met een base en twee kinderstoelen van maxi cosi

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

Eentje van de kinderstoelen is van de buren overgenomen en dat was wel lekker goedkoop en later nog een bijgekocht, omdat we twee auto's hebben. Toen hebben we een wat betere gekocht waar ons kind een aantal jaar mee kan. Daar zitten van die extra kussens in zodat ze er langer in passen, ik geloof tot 17 kilo ofzo. Babystoel ook nieuw gekocht, omdat we hadden gelezen dat het spul wat erin zit niet zo heel lang goed blijft.

3. Wat vind je nu van de stoel?

Babystoel is zo'n kinderdrager, iedereen noemt het Maxi Cosi toch? Makkelijk dat je die base gewoon in je auto kunt laten zitten en dat ding erop kunt zitten. Bij die grotere stoeltjes is het isofix systeem ideaal, je klikt de stoel er gewoon in en het zit goed vast. Hij heeft een ligstand. Sommige van die bases hebben zo'n draaisysteem, dat lijkt me wel fantastisch.

4. Zijn er al dingen stuk of versleten? Wat?

Echt versleten niet. Volgens mij zijn we een van die schouderdingetjes kwijt, die zat los. Je klikt hem vast en dan heb je zo'n touw om het aan te trekken, maar dat loopt heel stroef dus dat zal wel ergens klem zitten ofzo (over kinderstoel)

5. Wat zou je willen veranderen aan het product?

Ze zijn gewoon heel handig, ik denk niet dat je er iets aan kunt veranderen.

#3
Naam: Gerben
Kinderen: 1 dochter, 3 jaar

1. Welke stoel/stoelen/base heb je?

Een hele oude Maxi Cosi voor babies met zo'n handvat van familie overgenomen, zo een die verkeerdom in de auto moet. Die gebruiken we nu niet meer. Daarnaast een andere Maxi Cosi die staat in mijn auto. Nu hebben we een iets grotere, die kun je ook kantelen zodat ze kunt slapen die staat in de auto van mijn schoonmoeder. Ik weet het merk niet, ik denk ook Maxi Cosi en het heeft twee delen voor andere leeftijd met zo'n kussentje wat je eruit kunt halen. Heb hem alleen in de auto gezet, zelf nog niet gebruikt. Dit is een peuterstoel.

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

Ik heb bij het kopen wel opgelet of er een ISOfix systeem in mijn leaseauto zit, maar later niks mee gedaan.

3. Wat vind je nu van de stoel?

Mijn kind slaapt snel in de stoel, ik denk dat ze het chill vindt. Ik vind het hele logge dingen. Je botst standaard wel tegen deurposten oid aan. Als je hem niet nodig hebt, neemt hij wel veel plek in dat is echt onhandig. Bijvoorbeeld als je naar de ikea wilt. Als je een kleine auto hebt, neemt het echt veel plek in. Als ik hem niet in mijn eigen auto heb staan, dan voelt het echt leeg.
Het knopje waar je de gordel mee dicht doet, dat moet echt heel goed bedacht zijn zodat mijn kind het niet zelf open gaat maken. Ze is nu slim genoeg om het soms wel eens bijna los te maken.
In de huidige stoel als je de schoudergordels vast hebt gemaakt met dat lange lint, is dat na twee keer wiebelen wel weer los. Je wilt als ouder eigenlijk ook het liefst dat je dat kunt zien, dat het goed vastzit. Bijvoorbeeld op mijn Yepp kinderstoel op de fiets zie je dat (bevestiging van stoel op de fiets). Ouders zijn heel lui he en ze krijgen weinig slaap en het eerste wat je niet checkt is kijken of die gordeltjes nou goed zitten. Je mag best wel die ouders een beetje opvoeden hiervoor.
Je voelt je heel veilig in een auto en je hebt ondertussen al zo vaak je kind erin vervoert en je rijdt al zo lang en je rijdt toch netjes etc.

4. Zijn er al dingen stuk of versleten? Wat?

De oude stoel hebben we een extra hoes voor gekocht omdat die wel erg versleten was. Het zijn best oude stoeltjes zijn, ik denk ouder dan 10 jaar. Die stoel die je achterover kunt zetten, dat is echt fantastisch. Ik zie dat mijn kind dan echt zo wegdommeld.
De bekleding. Mechanisme lijkt me nog goed. Ik denk de gordels dus niet echt goed is omdat het redelijk snel los gaat zitten en ik denk dat dat niet zo hoort te zijn.

5. Wat zou je willen veranderen aan het product?

Gordel bevestiging. Alles wat echt goed vast moet zitten wat je manueel moet doen, daar moet extra aandacht aan besteed worden. Autostoeltjes staan er een beetje om bekend dat gebruiksgemak laag is met gordels eromheen doen enzo.
Plek in de auto is ook belangrijk, ik zou het superfijn vinden als mijn kind naast me zou kunnen zitten op net zo'n veilige manier als achter in de auto. Als we ver moeten reizen en je alleen met je kind bent, dan is het voor allebei echt heel saai. Je zit echt zo ver mogelijk als maar kan van elkaar vandaan en dan kun je gewoon geen contact hebben.

#4
Naam: Marjolijn

Kinderen: twee dochters, 2 jaar en 4 maanden

1. Welke stoel/stoelen/base heb je?

Maxi Cosi voor de jongste en voor de oudste een stoel met zo'n module voor de buik. Maxi Cosi 2,5 jaar oud en die andere dan 1,5 jaar oud. Tweede gekocht toen ze een maand of negen was.

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

Bij de babystoel dat Maxi Cosi het meest bekende merk is. Niet verdiept in welke types, maar deze was geloof ik in de aanbieding. Die kinderstoel was aangeraden door vrienden.

3. Wat vind je nu van de stoel?

Zijn allebei heel fijn. Superfijn dat de Maxi Cosi op een kinderwagen onderstel kan en we hebben daarvoor ook zo'n isofix base. Superfijn dat je je kindje niet steeds in en uit de stoel hoeft te halen. Kinderstoeltje zit ook vast aan de auto met ISOfix, met de gordel duw je dat ding tegen haar aan. Enige wat ik lastig vind is dat je goed moet opletten dat haar benen niet scheef zitten of dat ze te veel achterover hangt, want dan krijg je die module er niet goed tegenaan. Zeker toen ze nog wat kleiner was, hing ze nogal veel in de stoel.

4. Zijn er al dingen stuk of versleten? Wat?

Base gaat helemaal goed, die stop je 1 keer in je auto en daar kom je niet meer aan. Bij de Maxi Cosi zit zo'n binnenstukje in (schuim in een soort netje waarvan het netje al wel echt versleten is). Misschien ook wel doordat ik het in de wasmachine heb gestopt zonder het schuim er uit te halen.

5. Wat zou je willen veranderen aan het product?

De Maxi Cosi: het riempje om het vast te maken moet je vaak verstellen afhankelijk van of ze een dikke jas aan heeft, daardoor weet ik eigenlijk niet zo goed of het nou goed zit of niet.
Die andere stoel: de hoofdsteun kun je in hoogte verstellen maar dat gaat echt niet makkelijk. Volgens mij zou dat wel makkelijk moeten gaan, stapsgewijs per klikje.

#5
Naam: Nicolet
Kinderen: 1 dochter, 2,5 jaar

1. Welke stoel/stoelen/base heb je?

Babystoeltje gehad (was een Maxi Cosi Pebble) en nu een groep 1 stoel van prénatal.

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

We hebben die Maxi Cosi tweedehands gekocht, daar liepen we tegenaan omdat we een wandelwagen tweedehands kochten en deze erbij kregen. Hele praktische overweging dus. Hij was toen 3 jaar oud dus nu maximaal 6 jaar oud. We hebben hem gebruikt tot ze 1 jaar was. (Deze is nu door naar Julia & Bart.) We hadden ons van tevoren wel een beetje verdiept, we wisten dat het merk goed was maar de serie ofzo hebben we ons niet in verdiept. Via marktplaats van onbekenden.
Bij degene die we nu hebben was de prijs doorslaggevend.

3. Wat vind je nu van de stoel?

Die Maxi Cosi was echt wel heel fijn, die was heel praktisch. Die gebruikten we op alle manieren dat je hem kon gebruiken, ook op de wandelwagen bijvoorbeeld. Die prenatal stoel die is groter en laat je in je auto staan. Hij is wel moeilijker in je auto vast te maken, wij gebruiken geen ISOfix ofzo. Hij ziet er netjes uit en is wel makkelijk in gebruik.

4. Zijn er al dingen stuk of versleten? Wat?

Nee bij allebei niet. Zijn allebei in goede staat. Die hendel van de Maxi Cosi wordt echt veel gebruikt dus die moet echt soepel lopen.

5. Wat zou je willen veranderen aan het product?

Ik zou willen dat je geen rekening hoeft te houden met alle omstandigheden, die Maxi Cosi zou ik minder zwaar willen hebben. Die sjouw je gewoon echt veel heen en weer.
Je kunt er makkelijk een hoes ofzo omheen doen maar ik zou het uiterlijk zelf wel wat leuker maken, kindvriendelijker leuke kleurtjes enzo.

Als je kind een jaar is, dan weegt het hele ding wel echt zo'n 15 kilo en dan wordt tillen écht pittig. Ik zette hem dan altijd op mijn heup, ik zou het leuk vinden als daar een creatieve oplossing voor zou komen. Misschien iets van een schouderband die extra steun zou kunnen geven ofzo.

#6
Naam: Martijn + vriendin
Kinderen: 1 dochter, 14 maanden

1. Welke stoel/stoelen/base heb je?

Wij hebben een Maxi Cosi, de eerste was een Cabrio Fix en we vonden de Pebble als opvolger te duur en hebben nu de goedkoopste groep 1 van Maxi Cosi.

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

We hadden eerst een tweedehands Maxi Cosi, maar daar zakte onze dochter in weg en dat was niet prettig. Volgens mij kwam die stoel uit 2004, maar die hebben we echt maar heeeel kort gebruikt (maar iets van 5 keer). We wilden een stoeltje waar ze stevig en rechtop in kon zitten. Ze viel altijd in slaap en we wilden dat ze veel steun had. We hadden dus eerst een hele oude tweedehands Maxi Cosi gekregen maar die dus vervangen voor een eerstehands. Ook omdat we toen op vakantie gingen met de auto en ze er lang in moest gaan zitten. Bij die eerste stoel hadden we wel een ISOfix, maar bij de tweede stoel was dat heel duur en die stoel verplaats je toch niet. Bij die babystoel is dat superhandig dat je het erin kunt klikken.

3. Wat vind je nu van de stoel?

Wat ik gek vond aan die eerste stoel is dat ze tussen de driepuntsgordel door kon kruipen. Ze ging steeds binnen een seconde met haar hoofd uit die gordel. Ze was toen ongeveer een jaar oud en toen zijn we dus gewisseld van stoel.
Onze dochter zit graag rechtop dus dat hebben we heel erg meegenomen bij het kiezen van de kinderstoel. Hij zou nog wel nog meer rechterop mogen. Je kunt het instellen, je hebt bijvoorbeeld een loungestand maar die gebruiken wat minder vaak.

4. Zijn er al dingen stuk of versleten? Wat?

Nee niks! Ze zien er netjes uit. Het handvat van de Maxi Cosi was een beetje bekrast. We hebben die ook wel veel op het onderstel van de kinderwagen gehad. Op vakantie vooral.

5. Wat zou je willen veranderen aan het product?

Ik zou iets meer standardisatie wel chill vinden. Ieder model heeft nu zijn eigen base. Zou het fijn vinden als je onafhankelijk van de base elke stoel erop zou kunnen zetten. Ik vond dat nu wel echt doolhof met uitzoeken.
Iets meer mogelijkheden om in de auto speeltjes vast te zetten ofzo. Nu gooit ze het speeltje op de grond en dan gaat ze natuurlijk huilen. Iets van afleiding wat vast kan zitten aan de stoel. Tijdens het rijden kun je dan niks doen. Met de tweede stoel zit ze recht vooruit, dat is wel fijner.

#7
Naam: Julia + man
Kinderen: 1 dochter, 14 maanden

1. Welke stoel/stoelen/base heb je?

Stoel overgenomen van Nicolet, de Maxi Cosi Pebble. Volgens mij had zij hem ook van iemand anders via marktplaats. We zijn recent overgestapt, die Pebble hebben we een jaar gebruikt. Sinds vijf weken hebben een nieuwe Maxi Cosi Pearl. We hebben één base gekocht, de familyfix, waar beide stoeltjes op passen.

2. Wat waren je overwegingen bij het kiezen van een kinderautostoel?

Bij die Pebble ging dat gewoon natuurlijk omdat Nicolet hem over had en wij die gewoon over konden nemen. Ik had wel liever een nieuwe gehad maar mijn man vond dit prima en toen dacht ik ook ach het is wel gewoon goed. Bij het kopen van de Pearl pasten maar weinig stoelen op die familiyfix dus we waren beperkt in de keuze. Het merk Maxi Cosi vond ik veilig klinken en de pearl paste daar nog mooi op en hij was in de aanbieding. Die base is wel echt superprettig dat je niet hoeft te klooien met die gordel, je hoeft geen trucje uit te halen en het zit meteen vast.

3. Wat vind je nu van de stoel?

Die Pebble was gewoon normaal, geen dingen die heel erg uitsprongen qua noemenswaardigheid. Ik vond het fijn dat die hoofdverkleiner er bij zat, ons kindje was echt klein dus het was heel fijn om extra vulling te hebben bij haar hoofdje. Bij die pearl vind ik het heel prettig dat je schouderbandjes automatisch naar buiten buigen zodat je die bandjes niet aan de kant hoeft te houden.

4. Zijn er al dingen stuk of versleten? Wat?

Die Pebble is volgens mij nog helemaal heel, alleen de sticker met veiligheidsinstructies laat los. Verder is hij helemaal intact, wel een paar kleine krasjes. Hij ziet er netjes uit! Pearl is nog helemaal top natuurlijk!

Twee keer is de ruit ingetikt van de auto aan de kant van de stoel. Toen hebben we de hoes gewassen en geprobeerd alles op te zuigen, maar we zijn bang dat er nog wel wat splintertjes ergens zitten. Er zitten een paar mini openingetjes in de stoel en daar zijn wat scherfjes in gevallen die je nu kunt horen rammelen, die krijg je er dus ook niet meer uit.

5. Wat zou je willen veranderen aan het product?

Zo licht mogelijk zodat je hem makkelijker kunt tillen. Makkelijk te plaatsen in de base. Ik vind het zelf heel prettig als je makkelijk de hoes eraf kunt halen en kunt wassen. En qua veiligheid zou het top zijn als je een garantie zou kunnen hebben dat iets in orde en veilig is voor tweedehands. Daar ben ik echt voorstander van. Zou mooi zijn om te kijken naar de mogelijkheden om zulke producten met elkaar te kunnen hergebruiken. Goedkoop zou mooi zijn.

Het lijkt ons handig als je een stoeltje makkelijk kunt draaien als je even wat wilt veranderen bijvoorbeeld even vastklikken of voor het erin zetten (oh ik hoor net dat dat al bestaat).

Appendix C
Interview with Cyril Smals of Code Product Solutions

Interview met Cyril Smals – Tuesday 28th April 2020

Werkzaam bij Code Product Solutions, voorheen werkzaam bij zijn eigen circulair design bureau en hiervoor bij Dorel (maxi cosi).

In Delft afgestudeerd methodiek milieubewust ontwerpen. Vooral gericht op LCA. Er is al heel veel gebeurd in deze richting.

Over de integratie van kinderautostoeltjes in de Circulaire Economie?

- Tip: Beperk de scope tot alleen base en baby carrier.
- Alles valt en staat met de economie, er is geen wetgeving op dit moment die het aantrekkelijk maakt. Europese regels lijken alleen in te gaan op verpakking en ik acht de kans klein dat de EU regels gaat maken op consument product niveau.
- In de gaten houden: is het uiteindelijk economisch voordelig voor een bedrijf om duurzaam te ontwerpen? Ik denk dat het kan, van product aanbod naar dienst aanbod. Kijk bij medestudenten of zij conclusies hebben over economische haalbaarheid
- Het ontwerp wordt compleet anders als je recycling en hergebruik mee gaat nemen.
- Alles is nu gericht op kosten, alles is kunststof want staal is duur. Na tien jaar moet je een huidige ontwerp stoeltje niet meer willen gebruiken (o.a. door kunststof degradatie).
- De tweedehandsmarkt is de grootste concurrent van een PSS van stoeltjes, dus als je iets kunt bieden waarbij je beter bent dan zij, dan wordt het mogelijk het rendabel te maken.
- Over een CE systeem: De verkoop van stoeltjes gaat eigenlijk altijd via baby stores, waarom zou die vrachtwagen niet ook vol terugrijden met gebruikte stoeltjes?
- Ik ben ervan overtuigd dat wanneer een bedrijf dit echt gaat doen (pss) dat ze dan van scratch opnieuw moeten beginnen. Het hele ontwerp zal anders gaan.
    - Mijn antwoord: tijdschaal van korte tot lange termijn ontwikkelingen en design guide
    - Als je een visie hebt over die tijdschaal, kun je zeggen "ik beperk met tot fase 1" met scenario X. (…) Anders is het denk ik te veel. Vraag jezelf af "wat wil ik afleveren?", wil je iets tastbaars afleveren, dan moet je het afbakenen.
- Over reparatie: groot verschil bij verschillende fabrikanten. Wat doe je met producten waar krassen opzitten? Bij laptops hebben ze gewoon verschillende niveau's per hoeveel schade.

Bronnen:
- GE plastics recycling
- Milieubewust ontwerpen
- Milieugericht produktontwerpen (promis)

Wat zijn kritieke onderdelen bij refurbishment? Gebruiksslijtage?
Belangrijkste aspect bij refurbishing verwacht ik de stoffen (fabrics) en misschien ook het schuimgedeelte. Stel dat je EPP pakt ipv EPS, dan is het duurzamer (?). De overweging is vaker: stop ik er iets meer waarde in maar gaat het dan langer mee of is het betrouwbaarder? EPS is bros en EPP is flexibeler.

Zo’n base is, die van Swandoo iig, voornamelijk staal. Die buitenschalen doen helemaal niks, die zijn alleen mooi en kosten niet veel. Als je die heel makkelijk kunt vervangen en alle krassen zijn eraf en het binnendeel kun je opnieuw gebruiken dan is hij eigenlijk zo goed als nieuw. Zo’n buitenschaal zou best kunnen werken met recyclen, de vraag blijft weer: hoeveel gaat het dan kosten? De economische vraagstelling is erg belangrijk, alle fabrikanten willen dat weten. En daarnaast inderdaad wat is er gebeurd met het product. Misschien oplossen met een sensor, maar wat kost dat dan en hoe lang gaat dat dan mee?

Misschien wil je wel gaan vergelijken wat de milieuwinst gaat zijn tussen recycling en de huidige situatie. LCA is hiervoor geschikt. Denk bij LCA na over wat je eraan wilt hebben, het is bruikbaar voor vergelijken van verschillende scenario’s.

Appendix D

Interview with Adriaan Siewertsen of Shield Restraint Systems

Interview met Adriaan Siewertsen – Thursday 6th June 2020

- Adriaan kent Code enigszins maar heeft nooit met hen samengewerkt. Kent Cyril van DPI toen Adriaan bij Dorel werkte. Hij werkt nu bij Shield, een bedrijf die de gordels en buckles maakt. Dorel voor Maxi Cosi hebben met DPI gas injectie molding geintroduceerd.
- Zelf nog altijd ambitie om richting sustainable maken van bepaalde markten (product markt combinatie) ik weet ook dat er veel over nagedacht is. Bijvoorbeeld bij Dorel al een LCA laten doen. Ook nog blauwe maandag bij Philips in Drachten gezeten.

Wat voor schade komt vaak voor? Wat gaat vaak kapot?

- Ik denk dat je op een grote lijst schades kunt opstellen. Ik weet dat bedrijven in Engeland hier ook precies mee bezig zijn geweest: die hebben lokaal gekeken naar EoL recycling/refurbishing.
- Ik denk de gordelsystemen. Bekleding zelf is ook erg kwetsbaar. Over het algemeen staat een autostoel in een auto, maar als je het wel meeneemt naar buiten kan er natuurlijk wel vuil in komen etc. UV bestendigheid is ook belangrijk.
- ISOFix is minder cruciaal dan de sluiting. Maar bij een crash of hoge belasting gaat het natuurlijk wel achteruit.

Welke onderdelen zie jij als belangrijkst voor het veiligheidsacpect?

- Misschien moet je wel bij belangrijke onderdelen zeggen “ik zet er een heel nieuw gordelsysteem in”. Liability probleem. Je moet garanderen dat het doet wat het suggereert te doen. Product liability voor stoelen is 10 jaar. Of zeg je dan de tweede keer dat het nog 7 jaar oke is?
- Wij als leverancier [van buckles en gordels] zullen of kunnen nooit de garantie geven op een sluiting die al drie jaar heeft gefunctioneerd. Het is wel ontwikkeld voor dergelijk lang gebruik (kinderen die erop gaan staan, vuil erin), maar je moet de kwaliteit waarborgen. Wij doen dat bij productie door continu te meten of ze voldoen aan eisen. Tot het oneindige toe. We testen het product veel langer en harder dan nodig zou zijn om maar zeker te zijn dat het voldoet. Bij een productie run van 10.000 gaan er 10-20 naar het lab en als daar iets niet lekker is, wordt de productie geblokkeerd. Dat komt bij ons zelden voor omdat het al ‘mature’ producten zijn. Voorbeeld veertjes die 15.000 cycles mee moeten kunnen vanuit onze eigen eis. Bij tweede gebruik weet je niet wat je levert. Veer is een goed voorbeeld: veer verliest veerkracht. Dus na drie jaar gebruik voldoet deze veer vast niet meer aan onze eigen eis.
- Regelgeving EU: 5000 cycles voor isofix bevestiging en dan nog steeds voldoen aan eisen zoals ontkoppelkracht (bellcurve). Vraag: wat voor eisen worden er gesteld aan refurbished producten? Cruciaal om de haalbaarheid te halen. Niemand doet dat op dit moment, dus dit is onbekend.
- Probleem: ieder refurbished product is anders. Bijvoorbeeld ontwerp zo inrichten dat je veiligheidsonderdelen gewoon maar vervangt om zeker te zijn van de veiligheid.

Wat denk jij van de integratie van kinderautostoeltjes in de circulaire economie?

- Eigen gedachten/ambities: ik heb wel vaker nagedacht over je zou het eigenlijk helemaal moeten uitpluizen. Hoe zou een propositie eruit kunnen zien. Hoe kan het commercieel sterk zijn? Er ligt een duidelijke kans

- 1) omdat er in de industrie op dit moment weinig mee wordt gedaan (jaren 90 was het aan het opkomen met wetgeving, Maxi Cosi en Britax grote spelers, door de jaren heen is de kunststofontwikkeling steeds belangrijker geworden) (vuistregel destijds: vervang het staal door aluminium) (de huidige base is geoptimaliseerd om voor een oke prijs te fabriceren in NL; dit gaat hand in hand met sustainability want het verschepen van het gehele product vanuit China naar hier lijkt mij de verkeerde weg)
  - 2) en omdat de markt er gevoelig voor is.
- In heel veel van die stoelen zie je die rotatiesystemen en ik weet dat dat eigenlijk producten zijn die hebben dezelfde functie als een normale base (de Priori van maxi cosi was iets van 8 kilo een stoel van Britax is 15 kilo, vanuit materiaalgebruik is dat helemaal de verkeerde weg. Leuk dat het ding kan ronddraaien, maar niet met zoveel kilo's! Dit geeft ook een hoge kostprijs. Komt ook door de nieuwe normering door het i-size verhaal: mooi voor de veiligheid maar slecht voor het milieu, vanuit de historie van de LCA waaruit bleek dat iedere kilo die je erin stopt te veel is. (zelfde punt als Nine over het gewicht van de stoel tijdens het rijden in de auto impact). (BMW i3 als iconisch voorbeeld van een sustainable product)
- ADAC keuring is drijvende kracht in de markt. Alle merken kijken naar hun tests en daarop ontwikkelen ze hun stoelen. Gelukkig test ADAC ook usability en worden hele zware stoelen wel lager gescoord.
- Rear-facing stoelen zijn zwaarder denkt Adriaan.
- In Australie mogen stoelen niet meer dan 10 kilo wegen. Een ISOFix systeem bestaat dus niet zoals wij het kennen, want dat is veel te zwaar (bijvoorbeeld in America zo'n losse ISOFix gordel (latch), dat mag niet in de EU volgens R129 omdat het niet rigid is)
- De vraag is in hoeverre de markt er klaar voor is. Bart van de GreenTom buggy heeft gewoon op een gegeven moment bedacht "ik ga dit gewoon doen" en is in staat geweest om een buggy duurzaam te maken. Dat het vijf jaar mee kan zonder problemen. Alles is kunststof, er zitten alleen maar een paar schroeven in. En ook nog allemaal hetzelfde kunststof! Lastige punten bij buggy: wielophanging, plekken met weinig ruimte maar veel krachtoverbrenging. Assemblage is ook eenvoudig bij dit product.
- Ontwerpprincipes:
  1. weinig verschillende materialen
  2. weinig gewicht
  3. weinig assemblage
- In industrie zie je veel afval van onderdelen die 'obsolete' werden door vernieuwde modellen, bijvoorbeeld bekledingsstoffen. Oplossing zou zijn als je per order productie doet: de aankleding van de stoel pas doen als er een stoel besteld is.
- Ik zie een tegenontwikkeling waarvan ik denk jongens dit gaat verkeerd. Eerste booster seat voor Dorel inclusief hoofd en rugsteun was 5 kilo en nu zijn die dingen gigantisch. Het is gedaan om nou te voldoen aan de eisen en de normen maar het is onduidelijk hoeveel dat nou eigenlijk bijdraagt. Het verkoopt wel. Het is niet geoptimaliseerd voor milieu. Ik denk dat daar wel kansen liggen ja. Men wordt zich meer bewust, maar de vraag is: is dat de happy few of zijn dat er veel meer, bereikt het de grote groep? Het is aan de industrie om de switch te maken.
- Het lijkt bijna alsof mensen refurbishen als extraatje zien, je maakt nog wat extra winst met een tweede leven, maar je moet er vanaf het begin op inzetten. Idealiter moet de marge van een refurbished product gelijk zijn als wanneer je iemand een nieuw product geeft. Het hele scenario moet rendabel zijn.
- Lease systeem: ik denk dat het kan werken. Aankoop gedrag en aankoop moment zijn hierbij bepalend:
  - a) wanneer motiveer je iemand tot een lease contract?
  - b) is dat het goede moment?

Waarom leaset iemand een auto? Omdat je niet nu het bedrag op tafel wilt of kunt leggen. Bij een kinderautostoel is dit bedrag veel lager dus de incentive minder aanwezig. Je hoeft niet het leasen te introduceren als je wilt refurbishen en andersom, maar het helpt wel de logistieke stromen. Een lease systeem moet écht voordelen opleveren voor de consument, dit is wel een marketing verhaal. Faciliteren van flexibiliteit aan de consument kan hier aan bijdragen. (of je koopt een nieuwe auto waar de oude stoel niet in past en je moet nu een andere) De rol van de retail en van een autostoeltjes bedrijf wordt anders. Waardeketen anders.

- Hoe krijg je je producten weer terug? Ingewikkelde logistieke stroom. Misschien via bestaande winkels. Misschien kan ik refurbishen decentraal doen tot bepaalde niveaus, gelijk aan service-concept:
    - Service levels bij car seats:
        1. dit kan gedaan worden door de mensen thuis
        2. dit kan gedaan worden door de retailer
        3. dit kan gedaan worden door een servicepunt
- Consumentenbonden en ANWB enzo verzinnen wel elke keer iets nieuws, om het plat te zeggen. Die hebben zich tot doel gesteld om een soort (r)evolutie te ontketenen in de markt om de veiligheid steeds verder te verbeteren. Je krijgt dus generaties van producten die aan een steeds nieuwe set eisen voldoen of hier zelfs op vooruitlopen om zich te onderscheiden. Een oude generatie producten kun je dan niet echt meer verkopen. Misschien beperkt dit de refurbishment periode. Modulariteit zou dit kunnen oplossen.
- Er zijn producten die meegaan tot 12 jaar maar is meestal onzin hebben dan vaak maar 3 sterren (veiligheid). Maar zo'n product gaat dus wel lang mee. Misschien moet je deze uitdaging wel aangaan. (Staat tegenover Nine's idee van veel versimpeldere producten achter elkaar of dus 1 product voor lang.) Trend in markt nu is "multigroup seats", door R129 ontstaan maar ook door andere markten zoals China met andere gebruiken (amper babystoelen, ze sjouwen niet met babies).

Appendix E

Interview with Derrick Barker of JMDA

Background info on where JMDA is regarding circular CRS

- Started in 2017 to figure out disposal problem of CRS trying to salvage the value in the waste
- Trying to find a viable way to deal with end of life of CRS
  - Manually breaking down seats did not appear to be viable due to the complexity of how they are built in the first place. So many fasteners, so many materials. To many man hours to disassemble the products.
    - Fabrics are non-recoverable, foams as well
  - Finding a way to make the industry pay for the recovery of value of CRS
  - Shredding of seats like disposal of used cars did appear to be viable! All steel parts go one way, all the plastics another way and fabric foams etc. another. Industrial scaled operation.
    - Metals are easy
    - Plastics are separated in a different place and remade into pallets
    - The rest is incinerated
    - You can reuse about 90 percent of the seat this way, 10 percent is utilised to recover energy
  - Collecting the seats now appears to be the largest hurdle. Because the shredding companies are located far away from each other and from the consumers.
    - Partly, retailers can play a part for this
    - Local waste management sites are licensed operations (subcontractor to a waste management company) and would have to relicense to separately collect the seats
    - We would like to just dispose them in the metal bin! But often the metal companies just throw away the plastic.
  - There is a company that creates 'heat' from plastic (this actually just sounds like incinerating waste)
- We started with what we have instead of what could be as Code's approach is now. So we've got a solution of what to do with the product in the end, but this is a consequence of what the products currently are.
  - What does each component do, what do they add to safety etc.
  - We have built a roadmap/landscape of where the current challenges are.
  - In America, the more steel you put in a car seat, the safer they think it is.
- Trial with around 30 car seats to reprocess the seats. Trying to let the plastic and metal separating companies together.
- JMDA has designed more than 100 child car seats.
- Derrick is part of the regulation testing committee (?) so he would like to introduce regulations regarding sustainability such as x amount should be recycled materials.
- Biggest challenge with reusing the product is liability!
  - Nothing to do with physical aspects of seat itself
  - Within one family they will be used for a long time; there is a problem when you move from one to another family or when the seat is used longer than the material lifetime.
  - In the UK, it is illegal to resell car seats and when you dispose of them, you have to put them in the general bin.
  - In the UK, people will hang on to their seats, they will keep them in their garage because they know they can't sell them and they do not want them to end up in landfill (which is what will happen).

    - Warranty is only for the first customer. “Oh blimey I never realised there was a law for that!”
- Interesting for Derrick/JMDA:
    - Shared interest in the overall proposition in trying to improve the sustainability of car seats. In that context I think it would be good to cooperate. We [JMDA] are not trying to create a scheme, but we want to work together on this problem, we want to share.
    - Work together on one project. Trying to find out what we could do regarding materials for example. JMDA brings expertise in designing a whole seat and Code brings expertise in CA analysis.
        - Manufacturing challenges example: restricted by China production facilities
    - JMDA has crash testing facilities so we can actually crash stuff!
    - Beware of consumer reaction to recycled materials regarding safety products. You should be able to say this is as good or better than before.
- This would be a not for profit exercise. The income stream will come not from the project itself but from the value you bring later to your clients.
    - Rudimentary evaluation tools such as pieces of software for manufacturers; evaluation data you can sell
    - We see it as our responsibility to progress child car seats. We are limited partly by regulations, governments, and manufacturers.
- Recycled plastics are now more expensive than virgin because of processing costs and lack of volume (which affect each other).

There are so many different elements that affect the design of the product. For example, swapping metal for plastic brings costs of computer analysis and costs of moulds. Time pressure also plays a role.

Appendix F

Hotspot Mapping excelsheets filled in for the six products

HotSpot Mapping Datasheet

General project information

Brand name	Swandoo	Albert
Product category	Baby Carrier	
Authors	Bente Vermaat	
Date	01-May-20	
Location	Delft	at home

<-------- You can enter data in the light blue cells

Overall HotSpot Results

Total:		Average:		
- time to disassemble	696 sec	- force	2	[1=low .. 10=high]
- number of tasks	125	- accessibility	2	[1=clear .. 10=obstructed]
- number of steps	74	- positioning	2	[1=easy .. 10=difficult]
- number of tools	13			

General properties · Activity properties · Difficulty of Access · Functional sensitivity · Material properties · HotSpot Indicators

Step number	Name	Subassembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weight (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	shoulder pads	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Works without	Mixed materials mainly	42						fabric & filling
2	snap sticks	no	main assembly	Disconnect snap	Hands		2	4	light resistance	Clear	No/low precision										product manipulation
3	sun canopy elastic bands	no	main assembly	Remove	Hands		2	5	light resistance	Obstructed	High precision										
4	sun canopy	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Works without	Mixed materials mainly	87					⚑	fabric & foam
5	unbuckle	no	main assembly	Disconnect snap	Hands		1	3	moderate resistance	Clear	No/low precision										product manipulation
6	baby pillow from head pillow	no	main assembly	Remove	Hands		1	6	light resistance	Clear	No/low precision										
7	shoulder straps through baby pillow	no	main assembly	Other	Hands		2	5	light resistance	Clear	No/low precision										
8	baby pillow	yes	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision										
9	baby pillow velcro	no	baby pillow	Disconnect snap	Hands		2	3	light resistance	Clear	No/low precision										product manipulation
10	baby pillow foam	no	baby pillow	Remove	Hands		1	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	299			⚑	⚑	⚑	
11	baby pillow upholstery	no	baby pillow	Remove	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	56						
12	baby pillow spoon	no	baby pillow	Remove	Hands		1	3	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	17						
13	head pillow upholstery bottom	no	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision										
14	shoulder straps through head pillow upholstery	no	main assembly	Other	Hands		2	7	light resistance	Clear	No/low precision										
15	head pillow upholstery	no	main assembly	Remove	hands		1	3	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	58						fabric
16	head pillow screw	no	main assembly	Unscrew	Screwdriver	PH1	1	24	light resistance	Obstructed	Moderate precision					⚑					
17	shoulder straps through head pillow foam	no	main assembly	Other	Hands		2	10	light resistance	Obstructed	No/low precision										
18	head pillow	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	234			⚑	⚑	⚑	foam + PP glued
19	snap buttons	no	main assembly	Disconnect snap	Hands		4	4	light resistance	Clear	No/low precision										product manipulation
20	main upholstery elastic bands	no	main assembly	Remove	Hands		3	7	light resistance	Clear	Moderate precision										
21	main upholstery top part	no	main assembly	Remove	Hands		1	13	light resistance	Clear	No/low precision										product manipulation
22	shoulder straps through main upholstery	no	main assembly	other	Hands		2	3	light resistance	Clear	No/low precision										
23	buckle through main upholstery	no	main assembly	other	hands		1	7	moderate resistance	Clear	No/low precision										
24	elastic bands belt guides	no	main assembly	remove	hands		2	12	light resistance	Obstructed	No/low precision										
25	main upholstery	no	main assembly	Remove	Hands		1	13	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	533				⚑	⚑	fabric
26	foam EPP L+R	no	main assembly	Remove	Hands		2	20	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	325	⚑		⚑	⚑	⚑	product manipulation
27	belt guide screws	no	main assembly	Remove	Screwdriver	PH1	4	57	light resistance	Clear	No/low precision					⚑					
28	belt guide	yes	main assembly	Remove	Hands		2	1	light resistance	Clear	No/low precision										
29	belt guide opaque	no	belt guide	Remove	Hands		2	1	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	26						
30	belt guide transparent	no	belt guide	Remove	Hands		2	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	32			⚑			glow in the dark
31	handle	yes	main assembly	Unscrew	wrench	10	2	74	light resistance	Obstructed	No/low precision					⚑					
32	handle spacer (L+R)	no	handle	other	Hands		2	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	6			⚑			they fall out when you unscrew the handle
33	handle axes (L+R)	no	handle	Other	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	32			⚑			
34	handle dark grey bit (L+R)	no	handle	Unscrew	Screwdriver	PH1	4	48	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	28	⚑					
35	handle light grey bit (L+R)	no	handle	Disconnect snap	hands		4	12	moderate resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	32						
36	handle metal bit (L+R)	no	handle	Remove	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Works without	Steel	24						
37	handle white bit (L+R)	no	handle	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	24						
38	handle spring (L+R)	no	handle	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Works without	Steel	0						
39	handle	no	handle	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	480			⚑	⚑	⚑	
40	shell bottom	yes	main assembly	Unscrew	Screwdriver	PH1	8	94	light resistance	Obstructed	No/low precision					⚑					
41	shell bottom bracket	no	shell bottom	Unscrew	Screwdriver	PH1	2	19	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	7	⚑					
42	shell bottom handle	yes	shell bottom	Unscrew	Screwdriver	PH1	2	15	light resistance	Clear	No/low precision										
43	shell bottom handle opaque	no	shell bottom handle	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	14						
44	shell bottom handle transparent	no	shell bottom handle	Remove	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	24			⚑			glow in the dark
45	shell bottom	no	shell bottom	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	445				⚑	⚑	
46	snap sticks	no	main assembly	Remove	Hands		2	17	moderate resistance	Clear	No/low precision	part wears during use	Works without	Mixed materials mainly	50	⚑					
47	slider	yes	main assembly	Unscrew	Screwdriver		3	31	light resistance	Clear	No/low precision					⚑					
48	shoulder straps through main shell	no	main assembly	Other	Hands		2	6	light resistance	Clear	No/low precision										
49	shoulder straps	no	slider	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	192			⚑	⚑	⚑	strap fabric
50	slider axis	no	slider	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	45			⚑			
51	slider POM A	no	slider	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	21			⚑			
52	slider spring	no	slider	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	0			⚑			
53	slider POM B	no	slider	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	25			⚑			
54	slider guide	no	slider	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	68			⚑			
55	UM-top	yes	main assembly	Remove	Hands		1	12	heavy resistance	Clear	No/low precision										UM = unlocking mechanism
56	UM-top screws (L+R)	no	UM-top	Unscrew	Screwdriver	PH1	2	19	light resistance	Clear	No/low precision					⚑					
57	UM-top weird springs (L+R)	no	UM-top	Remove	Hands		2	4	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Steel	2						
58	UM-top hooks (L+R)	no	UM-top	Remove	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	40			⚑			
59	UM-top axes	no	UM-top	Remove	Hands		2	19	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	144	⚑		⚑	⚑		
60	UM-top black plastic	no	UM-top	Remove	Hands		2	5	moderate resistance	Clear	Moderate precision	part wears during use	Won't function without	Thermoplastic	27			⚑			
61	UM-top strings	no	UM-top	Remove	Hands		2	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	5			⚑			
62	UM-top black metal	no	UM-top	Remove	Hands		2	20	moderate resistance	Clear	High precision	part wears during use	Won't function without	Steel	106	⚑		⚑			
63	UM-top grey part	no	UM-top	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	74			⚑			
64	UM-bottom POM A	no	main assembly	Remove	Lever / Prybar		1	4	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	6			⚑			product manipulation
65	UM-bottom POM B	no	main assembly	Remove	Lever / Prybar		1	2	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	11			⚑			
66	UM-bottom springs	no	main assembly	Remove	Hands		2	1	moderate resistance	Clear	No/low precision										
67	UM-bottom screws (L+R)	no	main assembly	Unscrew	Screwdriver	PH1	2	22	light resistance	Clear	Moderate precision					⚑					
68	UM-bottom washer axes (L+R)	no	main assembly	Remove	Lever / Prybar		2	10	light resistance	Obstructed	Moderate precision	low maintenance part	Won't function without	steel	12						
69	UM-bottom leftover	yes	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision										
70	UM-bottom black	no	UM-bottom leftover	Remove	Hands		1	2	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	24						UM-top leftover does not show up as an option
71	UM-bottom axis	no	UM-bottom leftover	Remove	Hands		1	3	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Steel	13						
72	UM-bottom hooks	no	UM-bottom leftover	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	64			⚑			
73	UM-bottom sticks	no	UM-bottom leftover	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	22			⚑			
74	main shell remainder	no	main assembly	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	1311			⚑	⚑	⚑	

HotSpot Mapping Datasheet

General project information

Brand name	Swandoo	ISOfix base	<--------	You can enter data in the light blue cells
Product category				
Authors	Bente Vermaat			
Date	08/05/2020			
Location	Delft	home		

Overall HotSpot Results

Total:		**Average:**		
- time to disassemble	535 sec	**- force**	2	[1=low .. 10=high]
- number of tasks	75	**- accessibility**	2	[1=clear .. 10=obstructed]
- number of steps	42	**- positioning**	3	[1=easy .. 10=difficult]
- number of tools	16			

General properties				Activity properties					Difficulty of Access			Functional sensitivity		Material properties		HotSpot Indicators					
Step number	Name	Subasssembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weight (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	grip large	no	main assembly	Disconnect snap	Hands		1	7	moderate resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	22						
2	grip small	no	main assembly	Disconnect snap	Hands		1	5	moderate resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	18						
3	difficult axis	no	main assembly	Disconnect snap	Pliers		1	18	heavy resistance	Clear	High precision	part wears during use	Won't function without	Steel	33			⚐			
4	easy axis	no	main assembly	Disconnect snap	Hands		1	4	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	33			⚐			
5	bottom shell screws	no	main assembly	Unscrew	Screwdriver		15	130	light resistance	Clear	No/low precision					⚑					product manipulation
6	top shell	no	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	448				⚐	⚑	product manipulation
7	leg axis nut	no	main assembly	Unscrew	Wrench	10	1	50	light resistance	Clear	High precision					⚑					forgotten step: see bottom of sheet, should be performed before this step
8	leg axis nut spring	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision										
9	leg axis	no	main assembly	Remove	Hands		1	10	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	28			⚐			also frees up some washers
10	leg	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	1114			⚐	⚑	⚑	this is a subassembly removed from the main assembly, but I do not think it can be further disassembled because of rivets. How to account for the materials and weight?
11	tape bottom shell	no	main assembly	Remove	Hands		2	8	light resistance	Clear	No/low precision										
12	bottom shell	no	main assembly	Remove	Hands		1	6	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	393				⚐	⚐	
13	undo loop nuts	no	main assembly	Unscrew	Wrench	10	4	49	light resistance	Clear	No/low precision					⚑					product manipulation, also frees up some washers from front loop
14	loops	no	main assembly	Remove	Hands		2	3	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	102			⚐			
15	back indicator screw	no	main assembly	Unscrew	Screwdriver		2	36	light resistance	Clear	No/low precision					⚐					
16	back ABS part A	no	main assembly	Remove	Hands		1	4	light resistance	Clear	Moderate precision	low maintenance part	Won't function without	Thermoplastic	2						
17	back push button	no	main assembly	Remove	Hands		1	2	light resistance	Clear	Moderate precision	low maintenance part	Won't function without	Thermoplastic	8						
18	bowden cable A2 back push button + spring	no	main assembly	Remove	Hands		1	3	light resistance	Clear	High precision										other end still attached
19	back indicator	no	main assembly	Remove	Pliers		1	4	moderate resistance	Clear	Moderate precision	low maintenance part	Won't function without	Thermoplastic	4						
20	push back indicator spring	no	main assembly	Other	Lever / Prybar	small	2	20	moderate resistance	Obstructed	High precision					⚐					hold back to a certain point
21	Bowden cable B1 B2 metal	no	main assembly	Other	Pliers		2	6	moderate resistance	Clear	Moderate precision										unlock
22	Bowden cable B1 B2 droplet	no	main assembly	Other	Pliers		2	6	moderate resistance	Obstructed	High precision										unlock
23	white sliders	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	2						
24	back mount	no	main assembly	Remove	Hands		1	0	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	34						
25	front indicator spring	no	main assembly	Remove	Pliers	small	1	4	light resistance	Clear	Moderate precision										
26	front indicator	no	main assembly	Remove	Pliers	small	1	5	light resistance	Clear	Moderate precision	low maintenance part	Won't function without	Thermoplastic	5						
27	front push button spring	no	main assembly	Other	Pliers	small	1	2	light resistance	Obstructed	Moderate precision										hold back to a certain point
28	Bowden cable A1 droplet	no	main assembly	Other	Hands		1	5	light resistance	Obstructed	High precision										unlock
29	front push button	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	1			⚐			
30	Bowden cables A1 A2	no	main assembly	Disconnect snap	Hands		2	5	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	19			⚐			
31	front mount	no	main assembly	Remove	Hands		1	0	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	65						
32	screws between yellow and slider	no	main assembly	Unscrew	Screwdriver	PH2	2	14	light resistance	Clear	No/low precision										product manipulation
33	slider female + springs	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	27			⚐			product manipulation
34	tape axes	no	main assembly	Remove	Hands		2	3	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Steel	14						
35	slide metal frame from yellow frame	no	main assembly	Remove	Hands		1	4	light resistance	Clear	Moderate precision	low maintenance part	Won't function without	Steel	1432				⚑	⚐	
36	bolt 13	no	main assembly	Unscrew	Wrench		2	46	light resistance	Obstructed	No/low precision	low maintenance part	Won't function without	Steel	18	⚑					
37	bolt 13 torsion spring	no	main assembly	Remove	Hands		2	2	light resistance	Clear	No/low precision										
38	bolted hook	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	46			⚐			
39	white greasy bits	no	main assembly	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	4			⚐			also frees up springs
40	yellow frame + bowden cables B + slider male	no	main assembly	Remove	Hands		1	0				part wears during use	Won't function without	Mixed materials mainly	1450			⚐	⚑	⚑	this is what is left at the end of disassembly
41	*forgotten step 1:	no	main assembly	Unscrew	Screwdriver	PH2	2	22	light resistance	Clear	No/low precision					⚐					
42	*forgotten step 2:	no	main assembly	Unscrew	Screwdriver	PH2	2	32	light resistance	Obstructed	Moderate precision					⚐					

HotSpot Mapping Datasheet

General project information

Brand name	Cybex	Cloud Z
Product category	Baby Carrier	
Authors	Bente Vermaat	
Date	07-May-20	
Location	Delft	at home

<--------- You can enter data in the light blue cells

Overall HotSpot Results

Total:		**Average:**		
- time to disassemble	1149 sec	**- force**	2	[1=low .. 10=high]
- number of tasks	136	**- accessibility**	2	[1=clear .. 10=obstructed]
- number of steps	63	**- positioning**	2	[1=easy .. 10=difficult]
- number of tools	14			

General properties				Activity properties					Difficulty of Access			Functional sensitivity		Material properties		HotSpot Indicators					
Step number	Name	Subassembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weight (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	unbuckle	no	main assembly	Disconnect snap	Hands		1	3	moderate resistance	Clear	No/low precision										
2	shoulder pads	no	main assembly	Remove	Hands		2	3	light resistance	Clear	No/low precision	part wears during use	Works without	Mixed materials mainly	32						
3	shoulder straps through newborn inlay	no	main assembly	Other	Hands		2	4	light resistance	Clear	No/low precision										
4	newborn inlay	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Works without	Mixed materials mainly	165				⚑		
5	snap button headrest and backrest	no	main assembly	Disconnect snap	Hands		2	4	light resistance	Clear	No/low precision										
6	shoulder straps through headrest	no	main assembly	Other	Hands		2	5	light resistance	Clear	No/low precision										
7	headrest cover	no	main assembly	Remove	Hands		1	9	light resistance	Clear	Moderate precision	part wears during use	Aesthetically important	Mixed materials mainly	155						
8	snap button leg support cover	no	main assembly	Disconnect snap	Hands		2	8	light resistance	Clear	No/low precision										
9	manipulation put into reclined position	no	main assembly	Other	Hands		1	4	moderate resistance	Clear	No/low precision										
10	leg support cover	no	main assembly	Remove	Hands		1	25	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Mixed materials mainly	206				⚑	⚑	
11	snap buttons backrest cover to seating	no	main assembly	Disconnect snap	Hands		2	6	light resistance	Clear	No/low precision										
12	partly remove backrest cover from sides	no	main assembly	Other	Hands		2	6	light resistance	Clear	No/low precision										
13	fold out sun canopy	no	main assembly	Other	Hands		1	2	light resistance	Clear	No/low precision										
14	snap buttons backrest cover under sun canopy	no	main assembly	Disconnect snap	Hands		2	8	moderate resistance	Clear	No/low precision										
15	snap buttons backrest cover back	no	main assembly	Disconnect snap	Hands		3	3	light resistance	Clear	No/low precision										
16	fold back sun canopy	no	main assembly	other	Hands		1	3	light resistance	Clear	No/low precision										
17	backrest cover	no	main assembly	Remove	Hands		1	57	moderate resistance	Clear	Moderate precision	part wears during use	Aesthetically important	Mixed materials mainly	292	⚑			⚑	⚑	product manipulation
18	reclined position handle screws	no	main assembly	Unscrew	Screwdriver	torx T2	2	16	light resistance	Clear	No/low precision										
19	reclined position handle	no	main assembly	Remove	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Fibre Reinforced Plastic	17						
20	screws at the back	no	main assembly	Unscrew	Screwdriver	torx T2	6	54	light resistance	Clear	No/low precision					⚑					product manipulation
21	back belt guide assembly	yes	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision										
22	back belt guide screws	no	back belt guide assen	Unscrew	Screwdriver	torx T2	3	23	light resistance	Clear	No/low precision										
23	belt guide back plate	no	back belt guide assen	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	93						
24	belt guide grip	no	back belt guide assen	Remove	Hands		1	2	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	38						
25	belt guide blue bit	no	back belt guide assen	Remove	Hands		1	3	moderate resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	9						
26	belt guide black bit	no	back belt guide assen	Remove	Hands		1	0	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	32						last part of subassembly
27	slider screws	no	main assembly	Unscrew	Screwdriver	torx T2	4	45	light resistance	Clear	No/low precision					⚑					product manipulation
28	slider backplate	no	main assembly	Remove	Hands		1	11	light resistance	Clear	Moderate precision	part wears during use	Won't function without	Thermoplastic	92			⚑			
29	slider lever	no	main assembly	Remove	Hands		1	3	light resistance	Clear	Moderate precision	part wears during use	Won't function without	Thermoplastic	8			⚑			
30	shoulder straps through back	no	main assembly	Other	Hands		2	4	light resistance	Clear	No/low precision										
31	slider subassembly	no	main assembly	Remove	Hands		1	5	heavy resistance	Obstructed	Moderate precision	part wears during use	Won't function without	Mixed materials mainly	104		⚑	⚑			it cannot be disassembled further
32	tape part 1	no	main assembly	Remove	hands		4	32	light resistance	Clear	No/low precision					⚑					
33	fold sun canopy	no	main assembly	Other	Hands		1	3	light resistance	Clear	No/low precision										this step is not necessary when sun canopy is removed earlier in the process
34	tape part 2	no	main assembly	Remove	hands		4	37	light resistance	Clear	No/low precision					⚑					
35	EPS head central	no	main assembly	Remove	Hands		1	3	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	10			⚑			
36	EPS head L+R	no	main assembly	Remove	Lever / Prybar		2	360	heavy resistance	Clear	Moderate precision	part wears during use	Won't function without	Foam	54	⚑		⚑		⚑	
37	EPS legs L+R	no	main assembly	Remove	Hands		2	14	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	32			⚑			
38	side impact screws L+R	no	main assembly	Unscrew	Screwdriver	torx T2	8	78	light resistance	Clear	No/low precision					⚑					
39	side impact silver L+R	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	low maintenance part	Aesthetically important	Thermoplastic	11						
40	side impact sub L+R	yes	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision										
41	side impact sub screws L+R	no	side impact sub L+R	Unscrew	Screwdriver	PH1	8	60	light resistance	Clear	Moderate precision					⚑					
42	side impact screw-on L+R	no	side impact sub L+R	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	24			⚑			side impact protection
43	side impact rest L+R	no	side impact sub L+R	Remove	Hands		2	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	61			⚑			side impact protection
44	leg ISOfix screws	no	main assembly	Unscrew	Screwdriver	torx T2	4	30	light resistance	Obstructed	Moderate precision					⚑					
45	shell to cradle screws L+R	no	main assembly	Unscrew	Screwdriver	torx T2	2	28	light resistance	Clear	No/low precision					⚑					
46	shell from cradle pivot points	no	main assembly	Remove	Hands		2	4	moderate resistance	Obstructed	No/low precision										
47	pull reclined position system	no	main assembly	Other	Hands		1	2	moderate resistance	Clear	No/low precision										
48	shell to cradle springs	no	main assembly	Other	Hands		2	6	moderate resistance	Clear	Moderate precision										
49	shell subassembly	yes	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision										
50	leg ISOFix axis	no	shell subassembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	54			⚑			
51	shell leg and back	no	shell subassembly	Remove	Lever / Prybar		2	25	moderate resistance	Clear	Moderate precision										
52	shell leg part	no	shell subassembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	538			⚑	⚑	⚑	
53	reclined position system screws (L+R)	no	shell subassembly	Unscrew	Screwdriver	torx T1	2	22	light resistance	Clear	Moderate precision										
54	reclined position system (L+R)	no	shell subassembly	Remove	Hands		2	2	light resistance	Clear	No/low precision										consisting of washers, axes, springs
55	sun canopy	no	shell subassembly	Disconnect snap	Hands		2	5	moderate resistance	Obstructed	No/low precision										
56	sun canopy hard plastic	no	shell subassembly	Disconnect snap	Hands		5	5	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	135						
57	sun canopy fabric (L+R)	no	shell subassembly	Disconnect snap	Pliers		8	22	moderate resistance	Clear	Moderate precision	part wears during use	Works without	Thermoplastic	109						fabric
58	booklet holder screws	no	main assembly	Unscrew	Screwdriver	torx T2	4	37	light resistance	Clear	No/low precision					⚑					
59	booklet holder	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	56						
60	back ISOfix screws	no	main assembly	Unscrew	Screwdriver		4	36	light resistance	Clear	No/low precision					⚑					
61	back ISOfix axis	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	54			⚑			
62	remainder cradle subassembly	no	main assembly	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	1511			⚑	⚑	⚑	
63	remainder shell back part	no	shell subassembly	Remove	Hands		0	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	919			⚑	⚑	⚑	

HotSpot Mapping Datasheet

General project information

Brand name	Cybex	Z base	<-------- You can enter data in the light blue cells
Product category	ISOfix base		
Authors	Bente Vermaat		
Date	23-May-20		
Location	Delft	at home	

Overall HotSpot Results

Total:		**Average:**		
- time to disassemble	1120 sec	**- force**	3	[1=low .. 10=high]
- number of tasks	115	**- accessibility**	2	[1=clear .. 10=obstructed]
- number of steps	48	**- positioning**	3	[1=easy .. 10=difficult]
- number of tools	15			

General properties				Activity properties					Difficulty of Access			Functional sensitivity		Material properties		HotSpot Indicators					
Step number	Name	Subassembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weight (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	unscrew bottom shell	no	main assembly	Unscrew	Screwdriver	TX20	12	144	light resistance	Clear	No/low precision					⚑					
2	undo snap fits shells	no	main assembly	Disconnect snap	Lever / Prybar		22	93	moderate resistance	Obstructed	Moderate precision					⚑					product manipulation
3	drill out release button rivet	no	main assembly	Other	Uncommon too	3.5	2	54	moderate resistance	Clear	High precision					⚑					drill, positioning is really awkward because of the leg, the product will not lay flat or stay in any sort of fixed position
4	grey and green release button	no	main assembly	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	10						ergonomically important
5	top shell	no	main assembly	Remove	Hands		1	10	light resistance	Clear	Moderate precision	part wears during use	Aesthetically important	Thermoplastic	500				⚑	⚑	
6	leg axes clips	no	main assembly	Disconnect snap	Lever / Prybar	small	2	8	heavy resistance	Clear	High precision										
7	leg axes	no	main assembly	Remove	Hands		2	4	light resistance	Clear	Moderate precision										
8	support leg	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	595			⚑	⚑	⚑	
9	finger protector	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	15						
10	rotation guide hooks	no	main assembly	Unscrew	Screwdriver	TX20	4	40	light resistance	Clear	No/low precision					⚑					
11	rotation guide hooks	no	main assembly	Remove	Hands		4	4	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	20						
12	rotation shell	no	main assembly	Unscrew	Screwdriver	tx20	3	20	light resistance	Clear	No/low precision										product manipulation
13	rotation shell back	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	60						
14	rotation shell buttons	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Works without	Fibre Reinforced Plastic	51					⚑	
15	rotation shell main	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Mixed materials mainly	329				⚑		
16	installation indicators	no	main assembly	Disconnect snap	Hands		2	10	light resistance	Clear	Moderate precision	low maintenance part	Won't function without	Thermoplastic	0						
17	bowden cables front attachment	no	main assembly	other	Hands		2	2	moderate resistance	Clear	No/low precision										take ends from sockets
18	spring one end	no	main assembly	Other	Hands		1	3	moderate resistance	Clear	High precision										
19	nut front attachment	no	main assembly	Unscrew	Wrench	10	1	15	light resistance	Clear	No/low precision										
20	front attachment female metal	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	11			⚑			
21	bowden cable male metal	no	main assembly	other	Hands		1	10	moderate resistance	Obstructed	High precision										remove one end from socket
22	front attachment male metal	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	32			⚑			
23	front attachment plastic	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	9						
24	drill out rivets back	no	main assembly	Other	Uncommon too	4	6	270	heavy resistance	Clear	Moderate precision					⚑					product manipulation
25	drill out rivets bottom	no	main assembly	Other	Uncommon too	4	2	90	heavy resistance	Clear	Moderate precision					⚑					product manipulation
26	drill out rivets side	no	main assembly	Other	Uncommon too	4	2	90	heavy resistance	Clear	Moderate precision					⚑					product manipulation
27	drill out rivets bottom	no	main assembly	other	Uncommon too	4	2	90	heavy resistance	Clear	Moderate precision					⚑					product manipulation
28	booklet holder	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	21						product manipulation
29	ISOfix slider buttons	no	main assembly	Remove	Lever / Prybar		2	10	heavy resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	26						ergonomically important
30	free all Bowden cables	no	main assembly	Other	Hands		3	50	light resistance	Obstructed	High precision					⚑					unloop, unhook, and free from glue
31	lock ISOfix sliders and slide inside main assembly	no	main assembly	Other	Hands		2	8	moderate resistance	Clear	No/low precision										
32	lid bottom shell	no	main assembly	Remove	Lever / Prybar	small	1	3	light resistance	Clear	Moderate precision	low maintenance part	Works without	Thermoplastic	2						product manipulation
33	unloop bowden cable	no	main assembly	Other	Hands		1	5	light resistance	Clear	Moderate precision										product manipulation
34	bottom shell	yes	main assembly	Remove	Hands		1	20	moderate resistance	Clear	Moderate precision										
35	frame middle screw	no	main assembly	Unscrew	Screwdriver	TX20	1	8	light resistance	Clear	No/low precision										
36	unhook long plastic hooks	no	main assembly	Other	Hands		2	6	heavy resistance	Clear	No/low precision										
37	unhook small plastic hook	no	main assembly	Other	Hands		1	3	heavy resistance	Clear	No/low precision										
38	rotating mechanism	yes	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision										
39	small plastic hook	no	rotating mechanism	Remove	Hands		1	2	light resistance	Clear	Moderate precision	low maintenance part	Won't function without	Fibre Reinforced Plastic	2						
40	cylinder	no	rotating mechanism	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Fibre Reinforced Plastic	10						
41	rotating mechanism main	no	rotating mechanism	Remove	Hands		1	0	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Fibre Reinforced Plastic	33						
42	wheels	no	bottom shell	Remove	Hands		8	12	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	16						
43	metal bits	no	bottom shell	Remove	Hands		2	8	moderate resistance	Clear	No/low precision	low maintenance part	Works without	Steel	14						
44	white lever	no	bottom shell	Remove	Hands		1	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	3			⚑			
45	black lever	no	bottom shell	Unscrew	Screwdriver	TX20	1	8	light resistance	Clear	No/low precision										
46	black lever	no	bottom shell	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	6			⚑			
47	bottom shell	no	bottom shell	Remove	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	1100				⚑	⚑	
48	frame	no	main assembly	Other	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Steel	4800			⚑	⚑	⚑	this is what is left after disassembly

HotSpot Mapping Datasheet

General project information

Brand name	Maxi Cosi	Pebble Pro
Product category	baby carrier	
Authors	Bente Vermaat	
Date	05-Jun-20	
Location	Delft	at home

<-------- You can enter data in the light blue cells

Overall HotSpot Results

Total:		**Average:**		
- time to disassemble	424 sec	**- force**	2	[1=low .. 10=high]
- number of tasks	62	**- accessibility**	1	[1=clear .. 10=obstructed]
- number of steps	34	**- positioning**	2	[1=easy .. 10=difficult]
- number of tools	5			

General properties				Activity properties						Difficulty of Access		Functional sensitivity		Material properties		HotSpot Indicators					
Step number	Name	Subassembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weight (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	unbuckle	no	main assembly	Disconnect snap	Hands		1	3	moderate resistance	Clear	No/low precision										
2	head pillow	no	main assembly	Remove	Hands		1	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	66			⚑			
3	infant inlay	no	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	236			⚑	⚑		
4	free buckle from upholstery	no	main assembly	Other	Hands		1	2	light resistance	Clear	No/low precision										
5	unfold flexible plastic	no	main assembly	Other	Hands		1	3	light resistance	Clear	No/low precision										
6	elastic bands L+R	no	main assembly	Other	Hands		2	10	moderate resistance	Clear	Moderate precision										
7	upholstery around buckle area	no	main assembly	Other	Hands		1	12	moderate resistance	Clear	No/low precision					⚑					
8	upholstery around buttons L+R	no	main assembly	Other	Hands		2	9	light resistance	Clear	Moderate precision										
9	upholstery	no	main assembly	Remove	Hands		1	5	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Mixed materials mainly	437				⚑	⚑	
10	sun canopy	no	main assembly	Other	Hands		2	5	light resistance	Clear	Moderate precision	part wears during use	Works without	Mixed materials mainly	54						
11	shoulder pad holders	no	main assembly	Disconnect snap	Hands		2	9	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	18						
12	shoulder pads	no	main assembly	Disconnect snap	Hands		2	8	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Mixed materials mainly	84						
13	flexible cover	no	main assembly	Disconnect snap	Hands		9	184	moderate resistance	Clear	Moderate precision	part wears during use	Aesthetically important	Thermoplastic	338	⚑			⚑		product manipulation
14	foam legs	no	main assembly	Remove	Hands		1	4	light resistance	Clear	No/low precision	low maintenance part	Works without	Foam	8						
15	foam head (L+R)	no	main assembly	Remove	Hands		2	2	light resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	130			⚑		⚑	
16	foam holder (L+R)	no	main assembly	Disconnect snap	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	124			⚑		⚑	
17	foam sides (L+R)	no	main assembly	Peel off	Hands		2	8	moderate resistance	Clear	Moderate precision	part wears during use	Won't function without	Foam	40			⚑			
18	foam back	no	main assembly	Peel off	Hands		2	12	moderate resistance	Clear	Moderate precision					⚑					remove tape
19	foam back	no	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision	part wears during use	Won't function without	Foam	49			⚑			shoulder straps through holes
20	back belt guide	no	main assembly	Unscrew	Screwdriver	TX20	1	12	light resistance	Clear	No/low precision					⚑					
21	back belt guide	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	30			⚑			
22	strap height adjuster	no	main assembly	Unscrew	Screwdriver	TX20	2	18	light resistance	Clear	No/low precision					⚑					
23	strap height adjuster front	no	main assembly	Disconnect snap	Hands		4	3	light resistance	Clear	No/low precision	part wears during use	Works without	Fibre Reinforced Plastic	53					⚑	
24	strap height adjuster back	yes	main assembly	Disconnect snap	Hands		2	5	light resistance	Clear	No/low precision										
25	strap height adjuster knobs (L+R)	no	strap height adjuster	Remove	Hands		2	10	moderate resistance	Clear	Moderate precision	part wears during use	Works without	Fibre Reinforced Plastic	18						
26	strap height adjuster back	no	strap height adjuster	Other	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Works without	Thermoplastic	52						is what is left of the subassembly
27	handle cover (L+R)	no	main assembly	Disconnect snap	Lever / Prybar	small	2	16	moderate resistance	Clear	Moderate precision	low maintenance part	Aesthetically important	Thermoplastic	16	⚑					
28	handle screws	no	main assembly	Unscrew	Screwdriver	TX20	2	40	moderate resistance	Clear	No/low precision					⚑					
29	handle	yes	main assembly	Remove	Hands		1	3	light resistance	Clear	No/low precision										
30	handle button (L+R)	no	handle	Remove	Hands		2	10	moderate resistance	Clear	Moderate precision	part wears during use	Won't function without	Fibre Reinforced Plastic	34			⚑			
31	handle	no	handle	Other	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	400			⚑	⚑		
32	side belt guide black (L+R)	no	main assembly	Disconnect snap	Lever / Prybar		2	12	moderate resistance	Clear	Moderate precision	part wears during use	Won't function without	Thermoplastic	30	⚑		⚑			
33	side belt guide blue (L+R)	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Thermoplastic	14			⚑			
34	shell + buckle + axes + straps	no	main assembly	Other	Hands		1	0	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	2200			⚑	⚑	⚑	is what is left after disassembly

HotSpot Mapping Datasheet

General project information

Brand name	Maxi Cosi	3wayfix
Product category	ISOfix base	
Authors	Bente Vermaat	
Date	03-Jun-20	
Location	Delft	at home

<-------- You can enter data in the light blue cells

Overall HotSpot Results

Total:		**Average:**		
- time to disassemble	1269 sec	**- force**	3	[1=low .. 10=high]
- number of tasks	93	**- accessibility**	1	[1=clear .. 10=obstructed]
- number of steps	40	**- positioning**	2	[1=easy .. 10=difficult]
- number of tools	13			

General properties				Activity properties						Difficulty of Access		Functional sensitivity		Material properties		HotSpot Indicators					
Step number	Name	Subassembly	Part of ...	Activity	Required tool	Tool size	Task frequency	Time to disconnect (sec)	Force	Accessibility	Positioning	Maintenance	Functionality	Material group	Weight (g)	Time	Activity	Priority part	Environmental	Economic	Notes
1	ARB	no	main assembly	Disconnect snap	Hands		1	10	moderate resistance	Clear	No/low precision										
2	battery lid	no	main assembly	Unscrew	Screwdriver	PH2	1	10	light resistance	Clear	No/low precision										product manipulation
3	battery lid	no	main assembly	Remove	Lever / Prybar	small	1	2	light resistance	Clear	Moderate precision	low maintenance part	Works without	Thermoplastic	15						
4	batteries	no	main assembly	Remove	Lever / Prybar		2	10	moderate resistance	Clear	No/low precision										
5	ARB	no	main assembly	Unscrew	Screwdriver	TX10	6	40	light resistance	Clear	No/low precision					⚑					product manipulation
6	ARB	no	main assembly	Disconnect snap	Hands		4	14	moderate resistance	Clear	No/low precision										
7	ARB back	no	main assembly	Remove	Hands		1	2	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	165						
8	ARB rods	no	main assembly	Remove	Hands		1	4	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Steel	262						
9	ARB front	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	172						
10	top shell	no	main assembly	Unscrew	Screwdriver	TX20	10	140	moderate resistance	Clear	Moderate precision					⚑					product manipulation
11	top shell	no	main assembly	Remove	Hands		1	5	light resistance	Clear	No/low precision	low maintenance part	Aesthetically important	Thermoplastic	570				⚑		product manipulation
12	ARB tongue	no	main assembly	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	14						
13	leg cover	no	main assembly	Disconnect snap	Lever / Prybar		4	6	moderate resistance	Clear	Moderate precision	low maintenance part	Works without	Thermoplastic	44						
14	support leg	no	main assembly	Unscrew	Screwdriver	TX20	4	58	moderate resistance	Clear	No/low precision					⚑					
15	PCB & cables	no	main assembly	Disconnect snap	Hands		5	5	light resistance	Clear	Moderate precision										
16	PCB	no	main assembly	Disconnect snap	Hands		5	25	moderate resistance	Clear	High precision	low maintenance part	Won't function without	PCB	6					⚑	aluminium profile + PAGF
17	support leg	no	main assembly	Remove	Hands		1	6	moderate resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	1320			⚑	⚑	⚑	product manipulation
18	ISOFix slider buttons (L+R)	no	main assembly	Remove	Lever / Prybar		2	33	heavy resistance	Clear	Moderate precision	part wears during use	Aesthetically important	Thermoplastic	24	⚑					
19	ISOFix slider shell (L+R)	no	main assembly	Disconnect snap	Lever / Prybar		2	32	moderate resistance	Clear	Moderate precision	low maintenance part	Works without	Thermoplastic	76						
20	pins (L+R)	no	main assembly	Remove	Uncommon tool		2	720	heavy resistance	Clear	Moderate precision	low maintenance part	Won't function without	Steel	60	⚑					
21	ISOFix sliders (L+R)	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	part wears during use	Won't function without	Mixed materials mainly	1072			⚑	⚑	⚑	product manipulation, subassembly
22	ARB angle system (L+R)	yes	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision										product manipulation
23	main axis	no	main assembly	Remove	Hands		1	8	moderate resistance	Clear	No/low precision	low maintenance part	Won't function without	Steel	126						
24	front axis cover (L+R)	no	main assembly	Unscrew	Screwdriver	TX20	4	46	moderate resistance	Clear	No/low precision					⚑					
25	front axis cover (L+R)	no	main assembly	Remove	Hands		2	4	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Thermoplastic	44						
26	lock mechanism	yes	main assembly	Remove	Hands		1	8	light resistance	Clear	No/low precision										
27	middle connector	no	lock mechanism	Remove	Hands		1	1	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Fibre Reinforced Plastic	82						
28	release button (L+R)	yes	lock mechanism	Remove	Hands		2	4	light resistance	Clear	No/low precision										
29	front axis(L+R)	no	lock mechanism	Remove	Hands		2	2	light resistance	Clear	No/low precision	low maintenance part	Won't function without	Steel	116						
30	release button (L+R)	no	release button (L+R)	Unscrew	Screwdriver	TX8	4	40	light resistance	Clear	High precision					⚑					
31	release button slider (L+R)	no	release button (L+R)	Remove	Hands		2	0	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Thermoplastic	6						
32	release button main (L+R)	no	release button (L+R)	Remove	Hands		2	0	light resistance	Clear	No/low precision	part wears during use	Aesthetically important	Fibre Reinforced Plastic	30						
33	release button connector (L+R)	no	release button (L+R)	Remove	Hands		2	0	light resistance	Clear	No/low precision	low maintenance part	Works without	Thermoplastic	8						
34	unscrew (L+R)	no	ARB angle system (L+	Unscrew	Screwdriver	TX20	4	20	light resistance	Clear	No/low precision										
35	ARB angle system cover (L+R)	no	ARB angle system (L+	Remove	Hands		2	0	light resistance	Clear	No/low precision	low maintenance part	Works without	Fibre Reinforced Plastic	78						
36	ARB angle system wheel (L+R)	no	ARB angle system (L+	Remove	Hands		2	0	light resistance	Clear	No/low precision	low maintenance part	Works without	Fibre Reinforced Plastic	68						
37	ARB angle system main (L+R)	no	ARB angle system (L+	Remove	Hands		2	0	light resistance	Clear	No/low precision	low maintenance part	Works without	Fibre Reinforced Plastic	138				⚑	⚑	
38	battery holder	no	main assembly	Disconnect snap	Hands		1	4	moderate resistance	Clear	Moderate precision	low maintenance part	Won't function without	Mixed materials mainly	7						
39	locking parts	no	lock mechanism	Other			0	0				part wears during use	Won't function without	Mixed materials mainly	1248			⚑	⚑	⚑	subassembly left after disassembly
40	bottom shell	no	main assembly	Other			0	0				part wears during use	Won't function without	Thermoplastic	1603			⚑	⚑	⚑	last part after disassembly

Appendix G
Disassembly diaries of the six products

Disassembly diary
Swandoo Albert

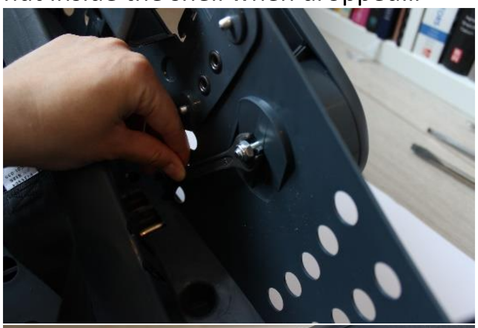
Weight: 5.1 kg
Dimensions: 58 x 44 x 67 cm
ADAC safety score: […]
Price: €259

1. **Shoulder pads:** The shoulder pads seem a bit too big to be used in combination with the baby pillow.
2. **Snap sticks:** snap them to open up the 'pocket' of the sun canopy
3. **Sun canopy elastic bands:** Remove elastic bands from hooks, then remove sun canopy. Elastic bands are small, and the hooks are only visible if you bring your eyes to the same height.
4. **Sun canopy** removed
5. **Unbuckle**
6. **Remove baby pillow from head pillow** partial removal of the head pillow by removing the fabric of the baby pillow from the head pillow
7. **Fidget shoulder straps through holes of baby pillow**
8. **Baby pillow assy** removal
9. **Baby pillow Velcro 2x:** removing Velcro makes it possible to take out the foam from the upholstery
10. **Baby pillow foam:** taking out the foam of the upholstery immediately frees up the upholstery as well so for upholstery 0 seconds is filled in
11. **Baby pillow upholstery** see 10
12. **Baby pillow spoon:** removal from pocket inside the baby pillow upholstery
13. **Head pillow upholstery bottom:** partially take off the upholstery from the bottom of the head pillow foam
14. **Fidget shoulder straps through holes of head pillow upholstery**
15. **Remove head pillow upholstery**
16. **Unscrew head pillow screw:** while holding the flaps of the head pillow; you definitely need two hands
17. **Shoulder straps through head pillow foam**
18. **Remove head pillow**

19. **Snap buttons** a little bit hidden, since they are between the fabric and the shell
20. **Upholstery elastic bands** unhook 3 elastic bands from hooks in the shell of the baby carrier
21. **Main upholstery top part** removing the part of the upholstery around the baby's head to be able to remove the whole; fold it over and underneath to the front of the carrier
22. **Shoulder straps through main upholstery**
23. **Buckle through main upholstery**
24. **Elastic bands belt guide:** remove them; if you have larger hands/fingers, this might prove difficult. However, I am not sure whether they are really necessary in the product. I would leave them out.
25. **Main upholstery:** removing the rest of the upholstery from the shell frees up the whole upholstery
26. **Remove foam:** both left and right, starting with left. It took significantly less time to take them both out compared to the first tries of disassembling the foam, this might be

because of elasticity or just becoming better at it.

27. **Belt guide screws:** duration of screwing is long. The screws are long and are self-tapping
28. **Belt guide:** consists of two parts, see below. Transparent part is part where car seat belt would loop around if no ISOfix base is used. This part is therefore crucial. The opaque part is mainly jus there for aesthetics.
29. Belt guide opaque
30. **Belt guide transparent**
31. **Handle assembly**: unscrew nuts with a wrench. There is a risk of losing your nut inside the shell when dropped…



32. **Handle spacers** fall out of the handle assembly when nut is unscrewed (do not lose them)
33. **Handle axes** are metal and plastic (with the logo on it)
34. **Handle dark grey bit** unscrew 2x PH1
35. **Handle light grey bit** unsnap 2x
36. **Handle metal bit** just take it out
37. **Handle white bit** same
38. **Handle spring** same
39. **Handle** is what is left, quite difficult to weigh, since it does not stand upright, and it does not fit on a scale
40. **Shell bottom assembly:** I do not think a power tool could be used for these screws, since there is too little space. Maybe when elongated. Do not lose the screws; a magnet is handy for removing the screws from their holes, otherwise you need to turn the whole thing upside down. Main shell can be lifted off the bottom shell.
41. **Shell bottom bracket** unscrew 2x
42. **Shell bottom handle assembly** unscrew 2x
43. **Shell bottom handle opaque**
44. **Shell bottom handle transparent:** glows in the dark; functional when the seat is installed without an isofix base
45. **Shell bottom:** is what is left and weighs quite a lot; it does not seem to have a function other than protecting some of the stuff inside the shell. It seems to be more aesthetically functional, just so users do not see the inside of the seat
46. **Snap sticks:** remove from main shell by pulling them out; quite some force is needed
47. **Slider assembly:** unscrew 3 screws

48. **Shoulder straps through main shell:**
49. **Shoulder straps:** remove from axis
50. **Slider axis: remove axis and this will free up both POM parts and the spring**
51. **Slider POM A:**
52. **Slider spring:** do not lose it
53. **Slider POM B:**
54. **Slider guide** is what is left after disassembling this subassembly
55. **UM-top assembly** remove by removing the axes of this assembly from their sockets in the main shell, it works, but might not be the official

way of removing this…

56. **UM-top screws** both left and right, symmetrical, unscrew
57. **UM-top weird springs** both left and right, symmetrical, slide from axes
58. **UM-top hooks** both left and right, symmetrical, slide from axes
59. **UM-top axes** two axes, slide from holes in the following parts one after the other
60. **UM-top black plastic:** remove strings from black plastic part to free it; the strings are put into sockets similar to how guitar strings work
61. **UM-top strings:** the strings will fall out when you flip over the subassembly
62. **UM-top black metal:** remove the hooks of the springs from the holes in the black metal parts; symmetrical L+R; I should have used pliers for this instead of my nails
63. **UM-top grey part:** is what is left after disassembling this subassembly
64. **UM-bottom POM A:** (product manipulation) use prybar to remove from main assembly

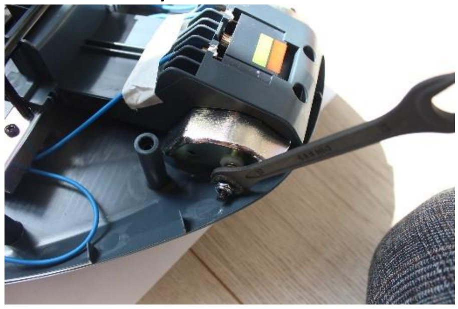
65. **UM-bottom POM B:** use prybar to remove from main assembly, springs will get lose as well
66. **UM-Bottom springs**: remove from assembly with hands
67. **UM-bottom screws**: unscrew 2x PH1
68. **UM**-bottom washer axes: remove by putting a prybar/screwdriver/something pointy in the hole and push the washer axes out. Remove them further with your hands
69. **UM-bottom leftover:** remove this from main assembly by pulling the axis out; this will probably cause everything that is left in this subassembly to fall apart by sliding from the axes
70. **UM-bottom black:** remove from axis
71. **UM-bottom axis:** remove from sticks and hooks
72. **UM-bottom hooks:** remove from inbetween the sticks
73. **UM-bottom sticks:** this is what is left over from this subassembly
74. **Main shell including buckle:** this is what is left after a complete disassembly. The buckle cannot be removed from the main shell without cutting the strap. Other parts that are still attached to the main shell are the supports for the belts (so that the EPP foam does not get scratches or dents) which are rivetted in place and also the sun canopy pocket attachment is riveted in place.

Swandoo ISOfix base

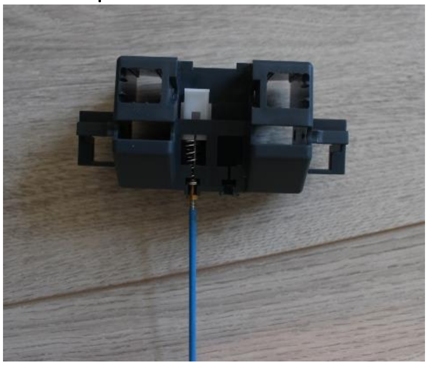
Weight: 5.4 kg
Dimensions: 60 x 33 x 15 cm
Price: €199

1. **Grip large:** remove the grey grip with your hands, a bit of prying might be necessary.
2. **Grip small:** once the large grip is removed, the small grip is easy to access and to remove
3. **Difficult axis:** a lot of force is needed to remove this axis from the plastic hole, so I used a plier. It is difficult to position the plier, since you have to reach inside the blue plastic shell.
4. **Easy axis:** you can just use your hands to remove this from the main assembly. The easy and difficult axis are interchangeable.
5. **Bottom shell screws:** (first turn the product upside down) there are 15 of these screws and you could probably not reach them with a standard power tool bit since they are quite deep. It takes really long to remove all of them.
6. **top shell:** when all 15 of the screws on the bottom shell are removed and the product is turned the right side up, the top shell can be taken off

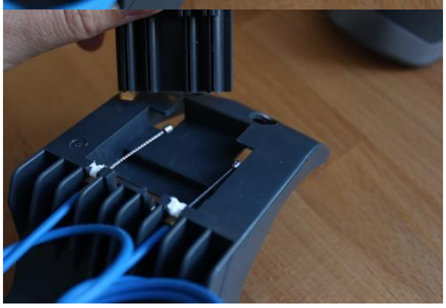
   *Forgotten step in spreadsheet: unscrew 2x2 screws attaching the frame to the bottom shell

7. **leg axis nut:** unscrew the nut that attaches the leg axis and thus the leg itself to the main assembly. A socket or ratchet wrench would have worked better than the open-end wrench which I used (because I have nothing else), since the movement is obstructed by the bottom shell.
   
8. **Leg axis nut spring**: is released when removing nut
9. **leg axis:** remove by pushing with hands
10. **support leg:** is then freed from main assembly
11. **tape bottom shell**
12. **bottom shell:** slide the construction from the bottom shell
13. **undo loop nuts:** turn the assembly upside down to reach the bolts
14. **loops:** the black loops can be removed when the assembly is turned right side up again (or fall out) after unscrewing the bolts
15. **back indicator screw:** unscrew 2x
16. **back ABS part A:** is now freed and can be taken out from its hole, while also removing it from Bowden cable A2
17. **back push button:** can be removed in order to take out Bowden cable A2
18. **Bowden cable A2 + spring:** remove from push button by sliding out, the other end is still attached to the front indicator. Also frees up spring.
19. **Back indicator:** remove with pliers, it rotates because of its own moulded plastic axis
20. **Back indicator spring:** use pliers/prybar to push them past the

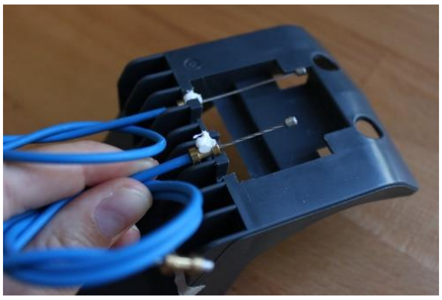
narrow point



21. **Bowden cable B1 metal bit:** take out the metal bit of Bowden cable B1 from its holder with pliers (now the spring is free to move around the whole length of the Bowden cable, instead of just the bit inside the plastic part)
22. **Bowden cable B1 droplet:** take out the droplet of Bowden cable B1 from the white sliding part, the cable is now free from the back indicator assembly (but still attached to the yellow frame at the other end)
23. **White sliders:** take out of mount
    REPEAT STEP 20 TO 23 FOR BOWDEN CABLE B2
24. **Back mount:** is now freed from any connections to other parts
25. **Front indicator spring:** remove from its place with plyers
26. **Front indicator:** take out from its mount with plyers, while removing attached Bowden A1 and A2 cable droplets from their gutters



27. **Front push button spring:** hold back with pliers
28. **Bowden cable A1 droplet:** unlock from socket
29. **Front push button:** remove
30. **Bowden cables A1 and A2 from front mount:** just take them out, the white glue is for show or against rotation (?); the cables are now free at both ends



31. **Front mount:** is now freed from any connections
32. **Screws holding yellow and slider female together**: turn assembly upside down, then unscrew 2x
33. **Slider female**: turn assembly right side up, slider female is now freed and can be removed (+ springs between slider female and male)
34. **Tape axes:** remove tape and axes
35. **Yellow & metal**: slide metal frame from yellow frame
36. **Bolt 13**: unscrew 2x (symmetrical)
37. **Bolt 13 torsion spring:** remove 2x (symmetrical)
38. **Bolted hook**: remove 2x (symmetrical)
39. **White greasy bits**: just take them out, also frees up spring, 2x (symmetrical)
40. **Yellow frame + slider male + Bowden cables B1 B2**: this is what is left after disassembly. The rest is riveted in place.

Cybex Cloud Z

Weight: 4.8 kg
Dimensions: […]
Price: €259

1. **Unbuckle:**
2. **Shoulder pads:** remove the shoulder pads from the shoulder belts by sliding them down. I have seen other models of this seat and there the pads have snap buttons
3. **Shoulder straps through newborn inlay**
4. **Newborn inlay:** after freeing the inlay from the shoulder straps, you can just take it out
5. **Snap button headrest and backrest:** undo the snap buttons 2x that fasten the headrest and backrest to each other
6. **Shoulder straps through headrest cover**:
7. **Headrest cover**: remove from main assembly by pulling it from the plastic parts that it fits around while fiddling the lever through the hole
8. **Snapbutton leg support cover**: undo the snap buttons that attach the leg support cover to the plastic of the main assembly 2x
9. **Manipulation put into reclined position:** to take off the leg support cover, the whole seat should be put into reclined position by simultaneously pulling the lever behind the head part and by pushing on the leg part of the seat.
10. **Leg support cover:** now the leg support cover can be taken off. The fabric needs to be loosened around the buckle and the strap area.
11. **Snap buttons backrest cover to seating:** 2x
12. **Partly remove backrest cover from sides**
13. **Fold out sun canopy:** to reach the following two snap buttons
14. **Snap buttons backrest cover under sun canopy:** 2x
15. **Snap buttons backrest cover back:** 3x
16. **Fold back sun canopy**
17. **Backrest cover:** remove while folding around several parts at the back of the seat, this requires some force

18. **Reclined position handle screws:** unscrew 2x torx
19. **Reclined position handle**: remove
20. **Screws at the back:** unscrew 6x torx
21. **Back belt guide assembly:** remove
22. **Back belt guide screws:** unscrew 3x torx
23. **Belt guide backplate:** remove
24. **Belt guide grip:** remove
25. **Belt guide blue bit:** remove
26. **Belt guide black bit:** is what is left of this subassembly
27. **Slider screws:** unscrew 4x torx screws which attach the sliding mechanism to the rest of the seat
28. **Slider backplate:** slide out
29. **Slider lever:** from backplate, slide up and take out
30. **Shoulder straps through back:**
31. **Slider subassembly:** push the axes of the slider subassembly upwards with your thumbs, while holding the strip

of plastic from the shell that is in the way towards your body, so your thumbs fit. Pushing the slider assembly axes will remove the axes from their holes/rails.

32. **Tape:** remove the tape from the EPS parts, 4x

33. ~~**Fold sun canopy:** to reach the other half of the tape, fold the sun canopy~~
34. **Tape part 2:** remove tape, 4x (alternative: cut through tape right between the two parts which it is holding together, this would be faster, but might not work because of the foam)
35. **Remove EPS head central:** the EPS parts are glued to the shell but can be pulled off.
36. **Remove EPS head L+R:** some prying is necessary with a sharp flatheaded screwdriver to 'cut' through the glue and the foam.

37. **Remove EPS leg L+R:**
38. **Side impact screws L+R:** unscrew 8x at the inside of the shell, both L+R (2x4 L+R symmetrical)
39. **Side impact silver L+R:** remove (2x L+R symmetrical)
40. **Side impact subassembly L+R:** remove (2x L+R symmetrical)

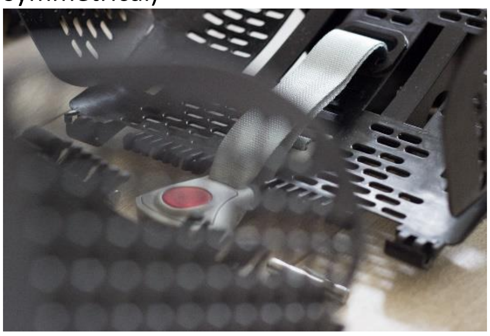
41. **Side impact sub screws L+R:** unscrew 8x PH1, small screws (2x4 L+R symmetrical)
42. **Side impact screw-on L+R:** remove (2x L+R symmetrical)
43. **Side impact rest L+R:** is what you are left with: two separate plastic parts held together by a riveted axis and a spring
44. **Leg ISOfix screws:** unscrew 4x also frees up washers
45. **Shell to cradle screws L+R**: unscrew (2x L+R symmetrical)
46. **Shell from cradle:** undo shell from cradle pivot points where you just unscrewed them

47. **Pull reclined position system:** pull on the reclined position system to take out the axes from their locked positions and now you are able to partly remove the shell from the cradle (reassembly is quite difficult!)

48. **Shell to cradle springs:** remove the springs attached to the shell

49. **Shell subassembly:** remove from cradle

50. **Leg ISOfix axis:** remove from shell subassembly
51. **Shell leg and back parts:** remove axes holding the shell leg and back parts together. These axes functions as a rotation point as well. (L+R symmetrical)



52. **Shell leg part:** remove
53. **Reclined position system screws:** unscrew (2x L+R symmetrical)
54. **Reclined position system:** remove axis, washer, and spring (they may fall out or the spring may launch them) (2x L+R symmetrical)
55. **Sun canopy:** disconnect snapjoint (2x2 L+R symmetrical)
56. **Sun canopy hard plastic:** disconnect snapjoints 5x
57. **Sun canopy fabric:** disconnect snapjoints 2x4 (L+R symmetrical)
58. **Booklet holder screws:** unscrew 4x
59. **Booklet holder:** remove
60. **Back ISOfix screws:** unscrew 4x also frees up washers (2x2 L+R symmetrical)
61. **Back ISOfix axis:** remove

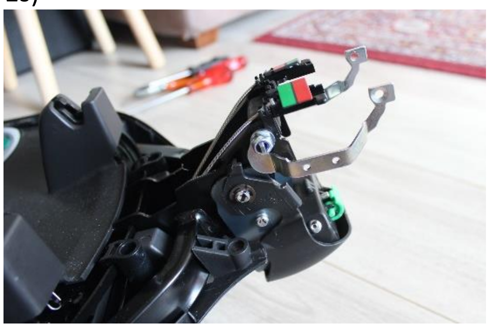
You are left with the cradle subassembly consisting of the handle, front belt guides, a part of the reclined position system, and several PP shells together forming the cradle. Quite some screws are visible at this point on the inside of the cradle, but after unscrewing, the subassembly can still not be taken apart. It appears that the hooks which fasten onto a stroller are in the way to reach two main screws of the handle. These two screws seem to be the last things keeping the whole cradle together. Unfortunately, the stroller hooks seem forever stuck in their place and after prying for half an hour, I conclude they are immoveable.

Cybex Z base

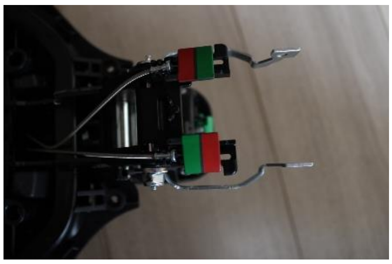
Weight: 7.7 kg
Dimensions: 67 x 41 x 37 cm
Price: €219

1. **Unscrew bottom shell screws:** 12x TX20, half of these screws are positioned too deep to reach with a bit-set screwdriver, which means you need a dedicated torx screwdriver with a long shaft for this.
2. **Undo snap fits shells:** with spudger or flathead screwdriver and hands; these snap fits are all around the edge of the shells. 6x + 5x with metal insert per side = 22 in total
3. **Drill out rivet release button:** 2x, on both sides; it is probably easier to do this first, but I did not since I first wanted to unscrew and not damage the product for good. After unscrewing, it became clear that this rivet definitely needed to be drilled out. (around 2x27 s, a bit slow because we were careful); non-reusable fastener

4. **Remove grey and green release button:** after drilling the rivets, the grey and green parts of the lever can be removed (also frees up a small axis)
5. **Remove top shell**: lift from the main assembly, maybe the rotating shell is in the way, you can remove the top shell while rotating the rotation shell through it.
6. **Undo leg axes clips:** with a tiny flathead screwdriver the clips 2x holding the axes attaching the leg to the main structure can be pushed from their position. (I do not know the correct name for these clips and supposedly there are tools for this)
7. **Remove axes:** from the leg by pushing with a prybar or screwdriver (2s)
8. **Remove leg:**
9. **Remove finger protector:** friction fit around leg
10. **Unscrew rotation guide hooks:** 4x
11. **Remove rotation guide hooks:** 4x
12. **Unscrew 3x TX20 rotation shell:** product manipulation
13. **Remove Anti Rebound Bar back**
14. **Remove Anti Rebound Bar buttons**
15. **Remove Anti Rebound Bar main**
16. **Installation indicators:** remove snapfit and unlock Bowden cable (2x 1s)



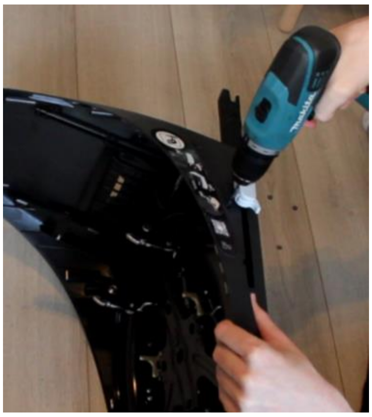
17. **Bowden cables:** take ends from sockets



18. **Spring:** remove one end

19. **unscrew nut from front attachment:** size 10, (10s)
20. **remove female metal part**
21. **remove Bowden cable from male metal part:** Remove Bowden cable from socket in metal part, high precision, it helps when you remove tension from system
22. **remove male metal part**
23. **remove front attachment plastic**
24. **drill out rivets back:** 6x, diameter 4, 45s per rivet; non-reusable fastener

25. **drill out rivets bottom:** awkward positioning of product, it wobbles when it is upside down. 2x at the front around where the leg attachment was
26. **drill out rivets side:** again, awkward positioning of product, both L+R of product. Rivets are positioned next to ISOfix sliders



27. **drill out rivets bottom:** wobbly. 2x in the middle of the bottom (this step is not necessary for the removal of the shell, but is needed to free up the small metal parts attached to the bottom shell, step 43)

28. **Remove booklet holder:** you can just take it out from between the bottom shell and the frame at the back
29. **Remove ISOFix slider buttons:** you can either pull really hard or use a prybar to wedge the white knobs from the main assembly
30. **Free all Bowden cables from loops and glue:** there are three cables and they are hooked to the bottom shell on several places. It is not possible to take picture of these since they are hidden beneath the frame.
31. **Put ISOFix hooks in locked position and slide the sliders entirely inside the shell:** push the hooks in locked position with your fingers, so that the sliders are free to slide. This also makes sure that the two axes on each side have the right width from each other to move upwards through the shell.
32. **Open lid at bottom of shell to remove Bowden cable:**
33. **Loop the Bowden cable:** loop the Bowden cable all the way through this hole which was shielded by the small lid. (product manipulation)
34. **Remove bottom shell from frame:** you have to pull the frame upwards and to the front to position the frame correctly to free the ISOfix sliders
35. **Unscrew middle screw frame**
36. **Unhook long plastic hooks:** turn frame upside down for this 2x hooks, you need quite some force for this
37. **Unhook small black hook:** you need some force for this or use a screwdriver as a lever

38. **Remove rotating mechanism**
39. **Remove small hook from rotating mechanism:** (you can also remove the Bowden cable)
40. **Remove cylinder from rotating mechanism**
41. **The main part of the rotating mechanism is what is left**
42. **Remove wheels from bottom shell:** 8x (it is possible that these already fell out before this step)
43. **Remove metal bits from bottom shell**
44. **Remove white lever from bottom shell:** remove spring and take out lever
45. **Unscrew black lever:** 1x tx20
46. **Remove black lever from bottom shell:** remove spring and take out lever

What is left is the frame of the base consisting of a stationary and a rotating part. All left over components are riveted in place or are welded together. This frame takes up 4,8 kg of the total of 7,7 kg.

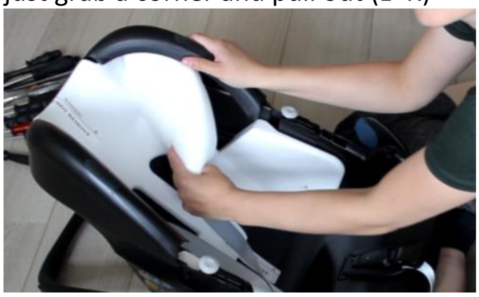
Maxi Cosi Pebble Pro

Weight: 4.55 kg
Dimensions:
Price:

1. **Unbuckle**
2. **Remove head pillow:** pull the head pillow and free the straps
3. **Baby inlay:** pull and free from the straps
4. **Free buckle from upholstery**
5. **Unfold flexible plastic:** to be able to reach the upholstery at the front of the seat
6. **Remove elastic bands from belt guides:** by pulling them around the belt guides at the sides of the seat 2x
7. **Remove upholstery around buckle area**
8. **Remove upholstery around buttons:** 2x, these buttons are flexible
9. **Remove upholstery:** pull the upholstery free from the seat and free from the straps in one movement

10. **Sun canopy:** remove by unhooking two elastic bands
11. **Remove shoulder pad holders:** by pulling them upwards and away from the seat to undo their snap fits (L+R)
12. **Remove shoulder pads:** they were held in place by the holders and two additional snap fits and slide them from the shoulder straps (L+R)
13. **Remove flexible cover:** disconnect the 9 snap joints all around the product which connect the flexible cover to the shell (product manipulation) *I think disconnecting takes way longer than connecting the flexible cover to the shell because these snap joints as a whole can be inserted like a nail into the shell including the cover in one movement.*

14. **Remove foam legs:** EPS, pull out
15. **Remove foam head:** memory foam, just grab a corner and pull out (L+R)

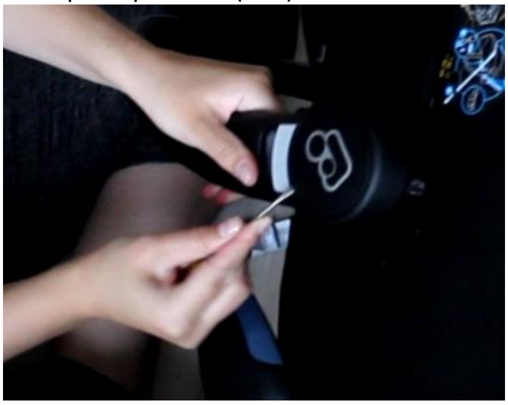


16. **Foam holder:** *(I do not know how to call these parts, but they keep the memory foam part in place and also give stiffness to the upholstery around it*) first remove the two snap fits at the back of the head area, then the second pair of snap fits at the side can be disconnected while removing the

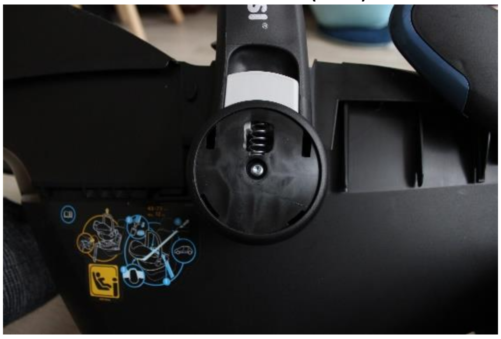
whole part. (L+R)

17. **Remove foam sides:** remove the 'do not remove' tape functioning as an extra connection between the foam parts and the shell and while doing this you can take out the foam
18. **Remove foam back tapes:** remove the two pieces of tape connecting the foam to the shell
19. **Remove foam back:** pull out of the shell while also putting the shoulder straps through the holes.

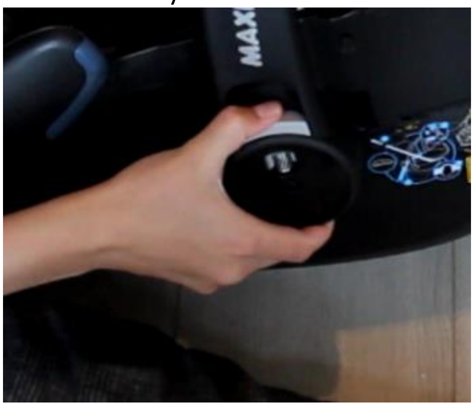
20. **Unscrew back belt guide:** 1xTX20
21. **Remove back belt guide**
22. **Unscrew strap height adjuster:** 2xTX20
23. **Remove strap height adjuster front:** by undoing snap fits (4x) and pull away from straps
24. **Remove strap height adjuster back:** by undoing snap fits (2x) and pull away from straps
25. **Remove strap height adjuster knobs:** from subassembly strap height adjuster back by pulling outwards and upwards to free from the spring (L+R)
26. **Strap height adjuster back:** is what is left of this subassembly (also a two springs)
27. **Remove handle cover:** by using a prybar/small screwdriver to undo the 2 snap fits per side (L+R)



28. **Unscrew handle:** 2xTX20 (L+R)



29. **Remove handle:** push handle button on both sides of the handle while simultaneously pulling the handle sides outwards to remove from the main assembly



30. **Remove handle button:** remove handle button out of the handle by pulling it free from the spring
31. **Handle:** is what is left of this subassembly
32. **Remove side belt guide black part:** by using a prybar/small screwdriver to undo the snap fits
33. **Remove side belt guide blue part:** by sliding it out of the part that is moulded as one with the shell

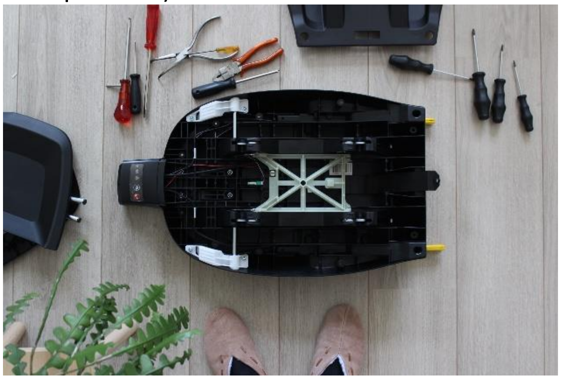
What is left is the shell of the product including the buckle and buckle locking system as well as the axes fitting the ISOfix system on the base. The shoulder straps cannot be removed from the product either, because of the buckle system still being attached to the shell.

Maxi Cosi 3wayfix

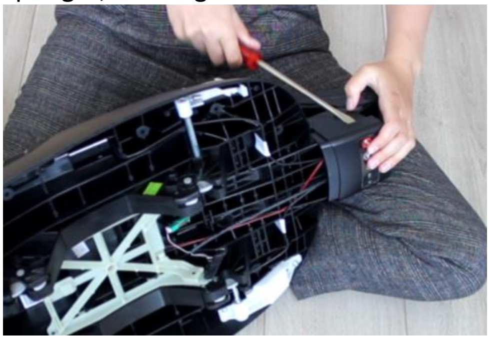
Weight: 6.35 > actual weight 7.35
Dimensions: 37.5 x 38 x 70 cm
Price: €219

1. **Release Anti Rebound Bar:** push the big snap fit at the back of the base and pull the ARB upwards to release from the base. Quite some force is needed.
2. **Unscrew battery lid:** 1x PH2 (product manipulation)
3. **Remove battery lid:** use spudger
4. **Remove batteries:** 2x AA
5. **Unscrew ARB:** 6x TX10 (product manipulation)
6. **Undo snap fits:** 4x
7. **Remove ARB back**
8. **Remove ARB rods**
9. **Undo friction fit & remove ARB front**
10. **Unscrew top shell screws:** 10x TX20 at the underside of the base, quite some force necessary (product manipulation)

11. **Remove top shell:** (product manipulation)



12. **Remove ARB tongue**
13. **Undo snap fits leg cover: 4x** use spudger, now leg cover is free



14. **Unscrew support leg:** 4x TX20
15. **Undo friction fit PCB & cables:** remove the PCB and the cables from their position in the top of the support leg, they are still attached to other components on the other end of the cables.
16. **Remove cables from PCB:** the PCB is now free, high precision
17. **Remove support leg:** slide the support leg out of the bottom shell of the base
18. **Remove ISOFix slider buttons:** use a spudger to wedge the buttons free from their axes (product manipulation, L+R symmetrical)

19. **Undo ISOfix slider shell snap fits:** use spudger, now they are free (product manipulation; L+R symmetrical)
20. **Remove pins**: you need a lot of force for this. These pins were definitely not made to be disassembled. I used pincers to be able to get a grip behind the head of the pins. (product manipulation, L+R symmetrical)

21. **Remove ISOfix sliders:** pull them out of the base, they probably fall out from the bottom already. (product manipulation, L+R symmetrical)
22. **Remove ARB angle system:** pull them upwards out of the base (L+R symmetrical)
23. **Push/pull main axis through the bottom shell:** this axis was kept in place by the two pins previously removed and its removal is key to the dismantling of the whole product

24. **Unscrew front axis cover:** 4x (L+R symmetrical)
25. **Remove front axis cover:** 2x (L+R symmetrical)
26. **Remove lock mechanism from bottom shell:** by pulling the whole subassembly upwards out of the shell

27. **Remove middle connector:** from the two parts with the locking hooks, it could also already fall out while pulling out the whole subassembly
28. **Remove release button:** from parts with locking hooks (L+R symmetrical)
29. **Remove front axis:** from parts with locking hooks (L+R symmetrical)
30. **Unscrew release button:** 4x TX8
31. **Release button slider, main & connector:** are now separated from each other (L+R symmetrical)
32. **Unscrew ARB angle system:** 4x TX20 (L+R symmetrical)
33. **Remove ARB angle system cover**
34. **Remove ARB angle system wheel**
35. **ARB angle system main:** is what is left of this subassembly (L+R symmetrical)
36. **Undo snap fit battery holder:** to remove the battery holder from the bottom shell

You are left with an empty bottom shell. Almost the whole product is disassembled now, except for the support leg, the ISOfix slider/anchors, and the **two parts with the locking hooks**. These are still subassemblies with parts riveted together, but these are also subassemblies that you would probably replace as a whole.

Appendix H
Bill of Materials of the six products

Bill of materials

Swandoo Albert
weight: 5.1 kg

#	Name	Material	weight [g]	amount	total [g]
1	shoulder pads	mixed	21	2	42
2	sun canopy	mixed	87	1	87
3	baby pillow foam	polyurethan	299	1	299
4	baby pillow upholstery	polyester	56	1	56
5	baby pillow spoon	PP	17	1	17
6	head pillow	mixed	234	1	234
7	head pillow upholstery	polyester	58	1	58
8	upholstery	polyester	533	1	533
9	foam left	EPP	164	1	164
10	foam right	EPP	161	1	161
11	belt guide opaque	PP	13	2	26
12	belt guide transparent	PP	16	2	32
13	handle	PP	480	1	480
14	handle axes	mixed	16	2	32
15	handle spacer	metal	3	2	6
16	handle light grey bit	PA	16	2	32
17	handle dark grey bit	PP	14	2	28
18	handle white bit	POM	12	2	24
19	handle metal bit	metal	12	2	24
20	handle spring	metal	0	2	0
21	shell bottom	PP	445	1	445
22	shell bottom handle transparant	PP	24	1	24
23	shell bottom handle opaque	PP	14	1	14
24	shell bottom bracket	PP	7	1	7
25	snap stick	mixed	25	2	50
26	Unlocking Mechanism top axes	metal	72	2	144
27	UM-top hooks	mixed	20	2	40
28	UM-top black metal	metal	53	2	106
29	UM-top black plastic	PA	27	1	27
30	UM-top strings	metal	2.5	2	5
31	UM-top torsion springs	metal	1	2	2
32	UM-top grey part	PP	74	1	74
33	UM-bottom hooks	mixed	32	2	64
34	UM-bottom POM A	POM	6	1	6
35	UM-bottom POM B	POM	11	1	11
36	UM-bottom black	PA	24	1	24
37	UM-bottom axis	metal	13	1	13
38	UM-bottom sticks	PP	11	2	22
39	UM-bottom washer axes	metal	6	2	12
40	Slider axis	metal	45	1	45
41	Slider POM A	POM	21	1	21
42	Slider POM B	POM	25	1	25
43	Slider spring	metal	0	1	0
44	Slider guide	PP	68	1	68
45	shoulder straps	mixed	96	2	192
46	shell main including buckle and belt surface	mixed	1311	1	1311
	total weight				**5087**

Bill of materials

Swandoo ISOfix base

weight: 5.4

#	Name	Material	weight [g]	amount	total [g]
1	grip large	PA	22	1	22
2	grip small	PA	18	1	18
3	axes	metal	33	2	66
4	top shell	PP	448	1	448
5	bottom shell	PP	393	1	393
6	leg axis	metal	28	1	28
7	loops	metal	51	2	102
8	back indicator	ABS	4	1	4
9	back ABS part A	ABS	2	1	2
10	back push button	ABS	8	1	8
11	back white sliders	POM	1	2	2
12	back mount	PP	34	1	34
13	front indicator	ABS	5	1	5
14	front push button	ABS	1	1	1
15	front mount	PP	65	1	65
16	Bowden cable A1	mixed	6	1	6
17	Bowden cable A2	mixed	13	1	13
18	tape axes	metal	7	2	14
19	bolt 13	metal	9	2	18
20	bolted hook	metal	23	2	46
21	slider female	PA GF30	27	1	27
22	small white sliders	POM	2	2	4
23	metal frame	steel	1432	1	1432
24	yellow frame + slider male	mixed	1450	1	1450
25	Bowden cable B1	mixed	0	1	0
26	Bowden cable B2	mixed	0	1	0
27	support leg	mixed	1114	1	1114
	total weight				**5322**

Bill of materials

Cybex Cloud Z

weight: 4.8 kg

#	Name	Material	weight [g]	amount	total [g]
1	shoulder pads	mixed	16	2	32
2	newborn inlay	mixed	165	1	165
3	headrest cover	mixed	155	1	155
4	backrest cover	mixed	292	1	292
5	leg support cover	mixed	206	1	206
6	reclined position handle	PA+GF	17	1	17
7	belt guide backplate	PP	93	1	93
8	belt guide grip	PP	38	1	38
9	belt guide blue bit	PP	9	1	9
10	belt guide black bit	PP	32	1	32
11	slider backplate	PP	92	1	92
12	slider lever	PP	8	1	8
13	slider subassembly	mixed	104	1	104
14	Side impact silver	unknown	11	1	11
15	Side impact screw on	PP	24	1	24
16	side impact rest assembly	mixed	61	1	61
17	ISOfix axes	steel	54	2	108
18	booklet holder	PP	56	1	56
19	EPS head center	EPS	10	1	10
20	EPS head L+R	EPS	27	2	54
21	EPS legs L+R	EPS	16	2	32
22	shell leg part	mixed	538	1	538
23	shell back part	mixed	919	1	919
24	sun canopy hard plastic	PP	135	1	135
25	sun canopy fabric	unknown	109	1	109
26	cradle subassembly	mixed	1511	1	1511
	total weight				**4811**

Bill of materials

Cybex Z Base

weight: 7.7 kg

#	Name	Material	weight [g]	amount	total [g]
1	support leg	mixed	595	1	595
2	finger protector	PP	15	1	15
3	top shell	PP	500	1	500
4	release button green part	PP	2	1	2
5	release button grey part	PA6	8	1	8
6	rotation guide hooks	thermoplastic	5	4	20
7	Anti Rebound Bar main	PP	329	1	329
8	Anti Rebound Bar back	PP	60	1	60
9	Anti Rebound Bar buttons	PAGF	51	1	51
10	installation indicators	POM	0	2	0
11	front attachment plastic	PP	9	1	9
12	front attachment metal male	steel	32	1	32
13	front attachment metal female	steel	11	1	11
14	wheel	thermoplastic	2	8	16
15	ISOfix slider buttons	PP	13	2	26
16	booklet holder	PP	21	1	21
17	rotating mechanism main	PAGF	33	1	33
18	rotating mechanism cylinder	PAGF	10	1	10
19	rotating mechanism small hook	PAGF	2	1	2
20	bottom shell metal bits	steel	7	2	14
21	bottom shell white lever	POM	3	1	3
22	bottom shell black lever	PAGF	6	1	6
23	bottom shell	PP	1100	1	1100
24	bottom shell lid	PP	2	1	2
25	frame	mixed	4800	1	4800
	total weight				**7665**

Bill of materials

Maxi Cosi Pebble Pro

weight: 4.55 kg

#	Name	Material	weight [g]	amount	total [g]
1	head pillow	mixed	66	1	66
2	infant inlay	mixed	236	1	236
3	upholstery	mixed	437	1	437
4	sun canopy	mixed	54	1	54
5	flexible cover	unknown	338	1	338
6	shoulder pads	mixed	42	2	84
7	shoulder pad holder	PP	9	2	18
8	foam legs	EPS	8	1	8
9	foam sides	EPS	20	2	40
10	foam back	EPS	49	1	49
11	foam head	memory foam	65	2	130
12	back belt guide	PP	30	1	30
13	foam holder	unknown	62	2	124
14	strap height adjuster front	PPTF	53	1	53
15	strap height adjuster back	PP	52	1	52
16	strap height adjuster knob	PPTF	9	2	18
17	side belt guides black	PP	15	2	30
18	side belt guides blue	PP	7	2	14
19	handle cover	PP	8	2	16
20	handle button	PAGF	17	2	34
21	handle	PP	400	1	400
22	shell + buckle + straps + axes	mixed	2200	1	2200
	total weight				**4431**

Bill of materials

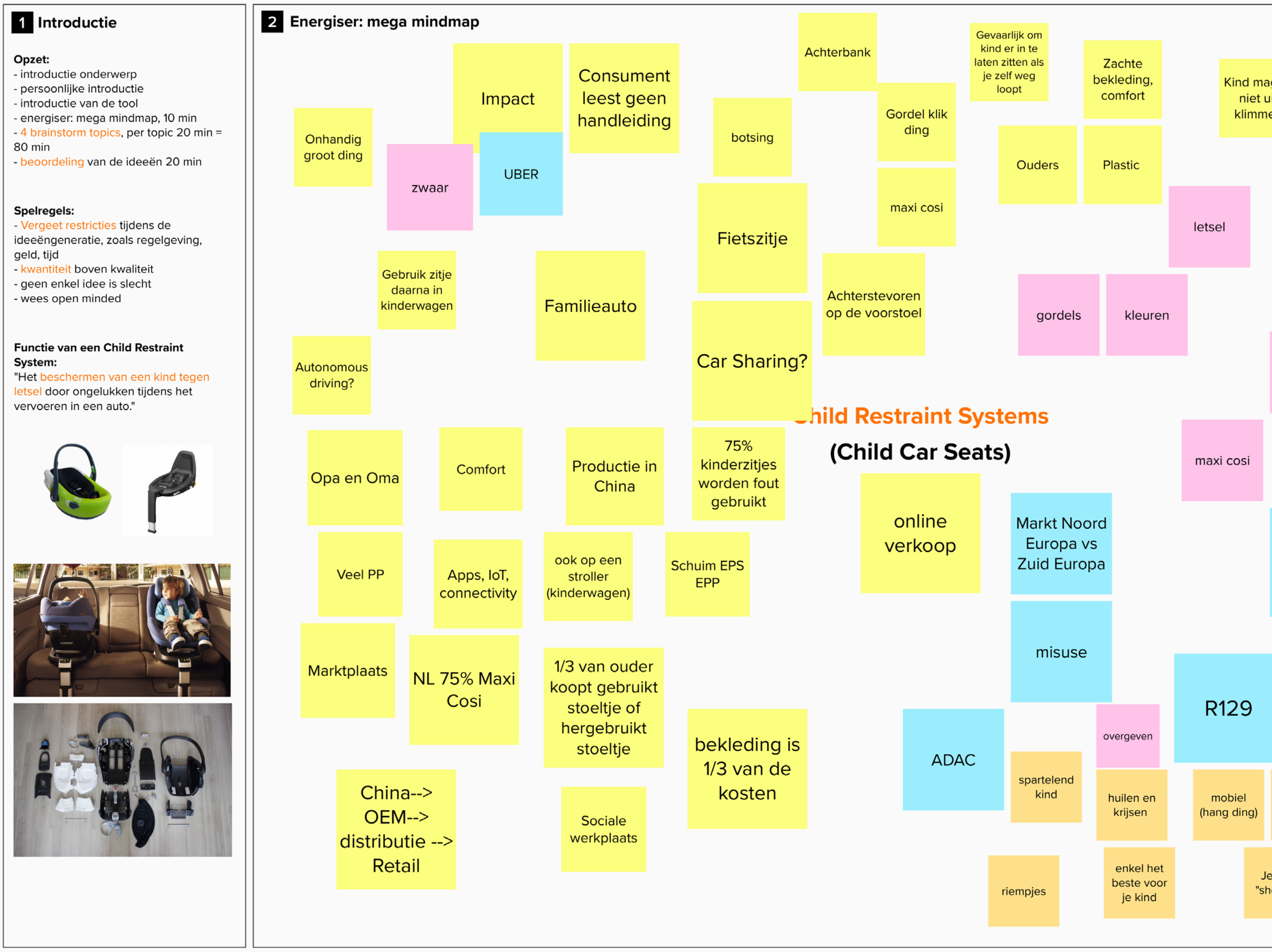
Maxi Cosi 3wayfix

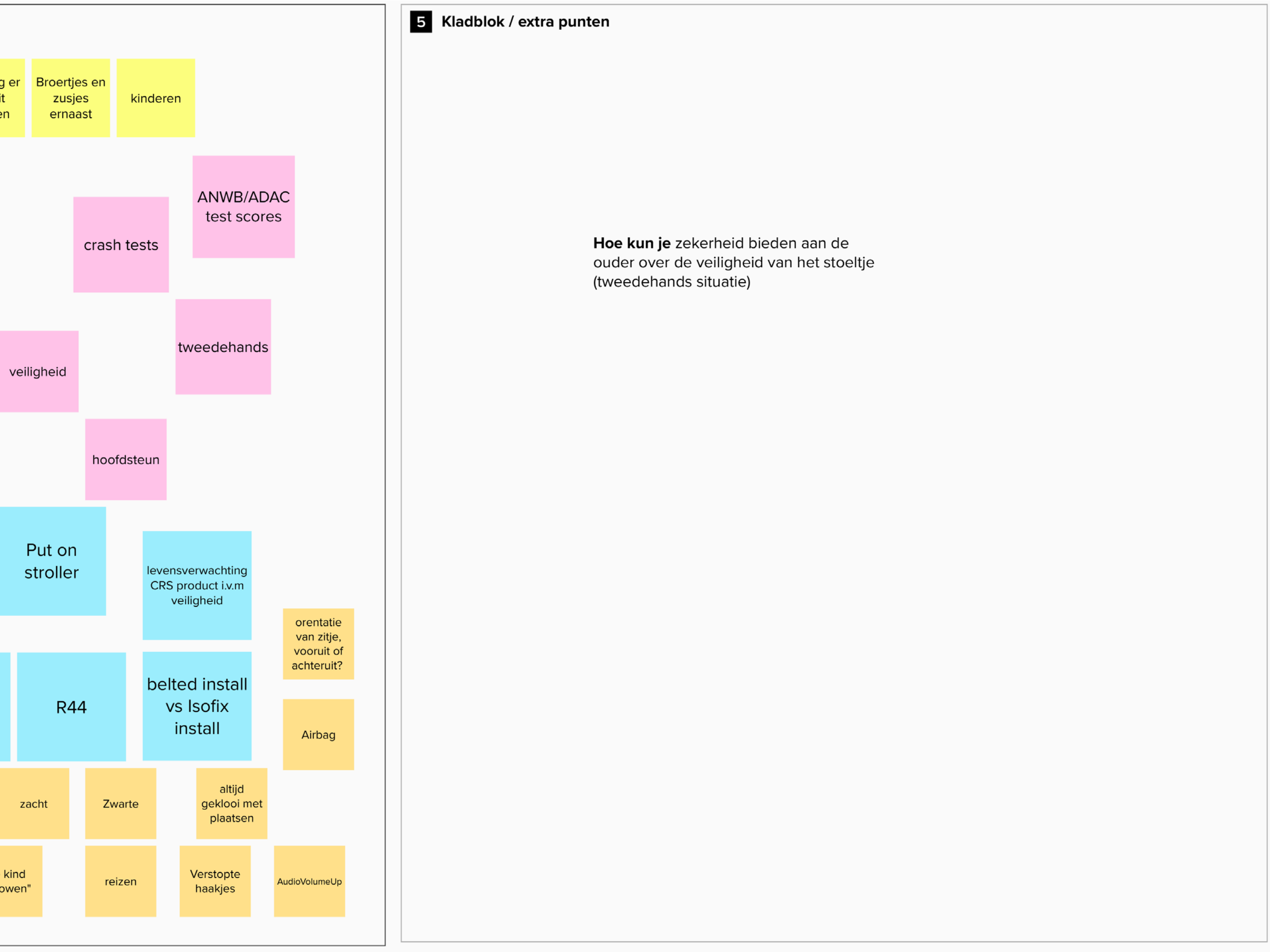
weight: 6.35 kg

#	Name	Material	weight [g]	amount	total [g]
1	battery lid	ABS	15	1	15
2	ARB front	PP	172	1	172
3	ARB back	PP	165	1	165
4	ARB rods	steel	131	2	262
5	ARB tongue	PP	14	1	14
6	top shell	PP	570	1	570
7	leg cover	PC/ABS	44	1	44
8	support leg	mixed	1320	1	1320
9	PCB	electronics	6	1	6
10	battery holder	electronics	7	1	7
11	ISOfix slider button	unknown therı	12	2	24
12	ISOfix slider shell	PP	38	2	76
13	pin	steel	30	2	60
14	main axis	steel	126	1	126
15	ARB angle system wheel	PA-GF	34	2	68
16	ARB angle system cover	PA-GF	39	2	78
17	ARB angle system main	PA-GF	69	2	138
18	front axis cover	POM	22	2	44
19	front axis	steel	58	2	116
20	release button slider	POM	3	2	6
21	release button main	PA+GF	15	2	30
22	release button connector	POM	4	2	8
23	ISOfix slider	mixed	536	2	1072
24	middle connector	PA-GF	82	1	82
25	locks	mixed	624	2	1248
26	bottom shell	PP	1603	1	1603
	total weight				**7354**

Appendix I:

Brainstorm for the redesigns with Cyril Smals, Harold van Aken, Romy Zwetsloot and Jerry de Vos





Broertjes en zusjes ernaast
kinderen
ANWB/ADAC test scores
crash tests
tweedehands
veiligheid
hoofdsteun
Put on stroller
levensverwachting CRS product i.v.m veiligheid
orentatie van zitje, vooruit of achteruit?
R44
belted install vs Isofix install
Airbag
zacht
Zwarte
altijd geklooi met plaatsen
reizen
Verstopte haakjes
AudioVolumeUp
5 Kladblok / extra punten
Hoe kun je zekerheid bieden aan de ouder over de veiligheid van het stoeltje (tweedehands situatie)

3 Brainstorm

zitje in een looping plaatsen, zodat die die energie ergens kwijt kan

in een vloeistof plaatsen met veel wrijving

honingraat bumper

Materiaal dat veel indeukt maar wel weerstand geefft

Airbag springkussen

opblaasbal zoals met dat gekke voetbalspel

Van top tot teen intapen aan de auto stoel vast

FixStop OK Stootblok trein

Hoe kun je impact (versnelling/vertraging) beperken voor het kind?

Stoeltje in elastieken hangen

Bungee jump

richting van de impact veranderen naar zijwaards

veel ruimte

cocooning

Niet te hard rijden

shockabsorber

Gewoon een gordel om doen

kracht verdelen over een groter oppervlakte

transformer stoeltje --> past exact op postuur kind

zweven

EPS-EPP-EPE

Gordel die als bergsport vertragings 'acht' werkt

Springstoel

Kind laten zweven

omzetten naar andere energie, warmte, geluid

abstandsgewebe van PP

Paardenhaar

Lucht Demper

Richting verandering tijden crash

shock indicator sticker

Crush zones honingraad mee gespuitgeit

crash sensor

Vangnet

Airbags

explosief gordel aantrekken bij crash

desinfectie bolletjes in materiaal verwerken

opblaasbaar kinderstoeltje wat in de wasmachine kan.

nieuwe onderdelen verkopen

testkit aanbieden

Officieel schoon laten maken door producent/retailer

autow... voor de... st...

Voorlichting

Laag kunnen "afpellen"

certificaat over dat het schoongemaakt is

sticker eroverheen plakken

beschermende laag kunnen toevoegen

Hoe kun je twijfels over hygiene voorkomen bij de ouder?

materiaal gebruiken wat geen viesigheid kan openemen

self healing materials

Stoffen die water en vuil afstotend zijn

onderhouds boekje

stoffering opdelen in verschillende stukken om verspilling te voorkomen bij vervanging

Gewoon recyclen van de stoffen/ padding

gebruik neppleer / makkelijk af te wassen

Gras ipv stof

Slijtage is probleem en kleurverlies voor wassen...

binnenste buiten kunnen keren van de bekleding

Hangmat van maken

verstelbaarheid van stoel

korte ritjes maken

Massage stoel van maken

Stoelverwarming /koeling

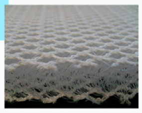
Particle foam uit hernieuwbare grondstof PLA

ganzeveren

Luchtbed

opgespannen stof of draadmateriaal over frame

EVA schuim



Afleiding creeren

metaal veren

POM matrasje met gespuitgeiete uitstulpingen en verende werking

Abstandsgewebe

Vloeistof tussen materiaal, soort waterbed

zen muziek

waterbed stoeltje

pyjama aantrekken voor reis

elastieken spannen

opblaas onderdelen

Kind geen comfort bieden

Wat is de minimale hoeveelheid ondersteuning die nodig is?

kind laten draaien tijdens de reis

Met een lolly zijn ze al snel blij

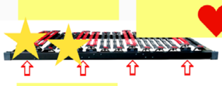
Maak een gipse mal van je kind

PP net zoals bureaustoel

Hoe kun je zitcomfort bieden aan het kind?

veel discrete ondersteuningen uit TPE/PP

Lie flat



3d scan van je kind

Vorm van het stoeltje veranderd mee met de vorm van het kind

Als ouder kan je de vorm van het stoeltje aanpassen aan de vorm van het kind, met warmte (materiaal met lage maximum service temerature)

vullen van hoes met grasachtig materiaal

slaapzak

Memoryfoam

comfort uit de vorm

Opblaas stoeltje

Actief luchtbed --> ook veiligheid

AR

display met grafiek van kwaliteit over tijd.

ouders flexibiliteit van kind laten ervaren

verfbom bij fout gebruik

selftest bij vertrek

Kracht sensor

self tying shoes

achtba... beug... syste...

gyroscopisch gestabiliseerd zitje

duidelijke use-cues

Voorlichtings campagnes

Installatie App

VR simualtie instructie

Hoe kun je zekerheid bieden aan de ouder over het installeren van het de stoel?

Onderdeel van je rijbewijs en theorie examen

vision systeem in de auto die problemen herkend

Safety advocates zoals in de US

Bij registratie van geboorte --> verplicht examen

Augmented reality app --> scan van je kind in het stoeltje

geen multi-groep stoel toelaten in de regelgeving

Meer handhaving en hogere boetes

stoeltje in de achterbank integreren

Connectivity met de auto --> niet rijden bij fout

leas... -... va... me...


asstraat
e gehele
oel
geen stoffering
Gaat het om geur? Nieuw geurtje er aan geven
Zorg dat elk onderdeel individueel schoon gemaal kan worden
Onderdelen los bestellen
Material die grondig schoon gemaakt kunnen worden
Schoonmaak handleiding
stomerij service
Dingen die in de wasmachine kunne
Hoge drukspuit er op
Business model waarin het zitje gel rd word
Zitje kan dan helemaal schoon gemaakt worden door het bedrijf
gordel en bekleding laten reinigen bij de Appie of IKEA
Materiaal dat uit zichzelf schoon wordt. Zoek in de natuur naar een soortgelijk mechanisme. Biomimicry
Voorkomen at het vies wordt. Kotsbakje aan de baby vastmaken
gordel laten vervangen bij de retailer met speciaal gereedschap
Kots camouflage patroon
zelf bekleding wassen
disposable bekleding
Matrassen worden bijna nooit tweede hands gekocht denk ik...
<--Auping
hoes
3d scan gebaseerd harnas
Afstandssensoren die afstand tot omgeving zoals voorstoel bepaalt
Stoel waar je mee kan praten en die aan jou opdrachten geeft met lampjes op de stoel waar je moet zijn
an
el
em
kleurcodering op de schouderbandjes
Usecues
Virtual reality app voor installatie
Grote kooi met afmeting van de R129 VSF box met daarin opgehangen het stoeltje
Kleurcode aangeven
Stap voor stap handleiding in een app
de
t kind in
Verschillende 'maten'. Aan de hand van de lengte van het kind
Kind aanpassen aan het stoeltje. Bv dikkere jas aan doen
Zorgen dat het stoeltje mee vormt met het kind
1 keer op de juiste manier instellen (duurt lang), Daarna alleen nog maar met kliksystemen snel je kind v ast zette.
Als regel stellen dat je kind een bepaalde houding aan moet nemen. Als hij dat nog kan zit hij niet goed vast.
Korte handleiding die visueel en snel gelezen kan worden
Waarschuwing usecue op de plekken waar het vaak fout gaat.
Handleiding filmpje. Is leuker dan tekst
se concept -
> meer en
ker contact
t de ouders
4 Beoordeling
Per brainstormtopic per beoordelingscategorie één idee die goed scoort.
Wenselijk voor de gebruiker (desirability)
Is haalbaar (feasibility)
Is rendabel (viability)
Draagt bij aan de duurzaamheid van het product
Eervolle vermelding / wildcard