GREENTOM GO

Designing a circular and sustainable hand cart

Graduation Thesis
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GREYHOUND

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Word list

This list contains terms that are used throughout the report, together with their definitions and background information.

Polymer

A large molecule made of linked, repeating strings of smaller molecules called monomers. Materials formed by polymers depend on the type of molecules and the type of bond. Examples of natural polymers are natural rubber, wood, and even proteins. Examples of synthetic polymers are synthetic rubbers, plastics, and glass. (Bradford, A., 2017)

Plastics are often called polymers, since they are synthetically made of polymers. The polymers that plastics are made of are often petroleum-based. (American Chemistry Council, 2019)

Plastics

There are two types of plastics: thermoplastics and thermosets.

Thermoplastics can be heated and remelted into the same material, thus recycled. Thermosets will burn when being heated and cannot be remelted, and are therefore difficult to recycle. (American Chemistry Council, 2019)

Some plastics can be flexible and stretchable, and are called elastomers (which are often thermosets). (CES, EduPack, 2018) Think of rubber bands or shoe soles. Other plastics can be foamed by adding foaming agents to the material or trapping gas in the liquid. Think of styrofoam, PU, or EVA. (CES, Edupack 2018)

Post-consumer waste

Opposed to post-industrial waste (re-processable waste produced after the production of parts before sale, such as trimmings or rejects), post-consumer waste is what users discard as waste after use. This waste can be physically separated into categories of waste, such as glass, paper, PMD, or organic, and collected as source for use for recycling, composting, or energy recovery for incineration. (Hickman, 2019)

Circular Economy

A circular economy is a model that provides business and economic opportunities as well as environmental and societal benefits by transforming linear make-to-waste systems into circular ones that regenerate living systems and/or recover product components or materials for new cycles, ultimately eliminating the generation of waste and reliance on finite resources. This can be done on small, local scale, or large, multi-organisational scale. (Ellen MacArthur Foundation, 2017)

Collection

No sustainable end-of-life can be implemented without collection of product parts or materials. To realize this, three possible methods of collection after use, as proposed by Kumar & Putnam (2008) are:

1. Product collection by the manufacturer without involvement of the retailer.
2. Product collection by the retailer, with the manufacturer buying back from the latter.
3. Product collection by a third party, with the manufacturer buying back from the third party.

End-of-Life

The End-of-Life (EoL) refers to what happens to a product after a user decides to discard it at the end of the product life cycle. There are several discarding methods, such as municipal waste incineration or landfill. However, there are also more sustainable scenarios, such as prolonging a product's life cycle by means of repairing or maintenance, or scenarios suitable for a circular system that give produced parts or materials a 'second life' such as refurbishing, remanufacturing, and recycling. (Shelley, 2010)

Maintenance
Strictly spoken, maintenance is not an end-of-life process, but rather prolongs the product life by repairing faulty components. (Ideal&Co, 2016)

Refurbishing
Refurbishing can be defined as the "process of returning [a product] to satisfactory working condition [...] [by] repairing or replacing the major components. (Ideal&Co, 2016) Refurbished products are often aesthetic in nature and working but are often not comparable with new or remanufactured products. (Circular Economy Practitioner Guide, 2018)

Both 'refurbished' products and 'remanufactured' products are products that have been tested by either the original manufacturer or a 3rd party before being sold. Furthermore, 'Refurbished' products, as well as 'remanufactured' products, include a warranty, which make these types of products more desirable than 2nd hand product not having this warranty. (Jung. B., n.d.)

Remanufacturing
As defined by (Ideal&Co, 2016) "remanufacturing denotes the process of disassembly of products into components, testing and recombining the components into products of at least the original performance. The resultant is a product that is 'as new'". According to this definition, no repair is needed for the specific part, and the best working parts are combined to a remanufactured product.

Remanufacturing is usually done by the original manufacturer instead of a 3rd party since they have better access to the original engineering or electronic schematics as well as replacement parts. Furthermore, compared to refurbishment, remanufactured products might also include extensive testing. However, it should be kept in mind that the definition of refurbishment or remanufacturing differs per company. (Jung. B., n.d.)

Recycling
"Recycling is the process of recovering materials from a product at the end of a life cycle [...] [in which] materials recovered feed back into the feedstock for the original [closed loop] or other [open loop] purposes." (Ideal&Co, 2016)

Materials that are recycled should have properties equivalent to those of the original material to make them suitable as material in closed-loop cycles. (de Pauw, I., 2015) McDonough and Braungart call this type of recycling 'upcycling' (Eschner, 2017), while other sources misuse the term 'upcycling' to describe the reuse of parts in a crafty manner to create new products the parts were not created for, however prolonging the part life. (NS, n.d.)

Downcycling
Opposed to 'recycled' materials, downcycled materials are recycled materials that have worsened material properties than that of the original material, often due to contaminants or mixing materials with different properties. Think of recycling printer paper into toilet paper. (Eschner, 2017)

Bio-based
Bio-based material is non-food related material that is produced from biomass, often from (residual) sources of the food and agricultural industry, substituting sources from fossil fuels. (RVO, n.d)

A misconception is that bio-based materials are also biodegradable. However, the terms are not synonymous and not all bio-based materials are biodegradable or recyclable. (van den Oever et al., 2017)

Biodegradable

A material is biodegradable when the material degrades in a relatively shorter time than the non-biodegradable variant of the material. However, this still could take up to 5 years (Lewis Thomas, N., n.d.), which could not be considered 'short', and which is only useful if the material is accidentaly lost in nature or sea (such as fishing lines). (Bos, et al., 2017)

If a material biodegrades in less than six months, it can be considered compostable (for industrial composting).

Compostable

Compastable material is material that biodegrades in less than six months, which is suitable for industrial composting at a specialized facility. Not all materials are also suitable for home composting, which is a less controlled environment with lower temperatures than at the industrial composting facility. Whether or not a material is suitable for home composting or for industrial composting is often noted on the material itself. (InnProBio, n.d.)

PMD

Is an abbreviation for the collection of Plastic packaging, Metal packaging and Drink cartons, which will each be more easily separated into their own category after collection. (Avalex, 2019a)

PP

Is an abbreviation for Polypropylene, a thermoplastic which is recyclable. It is a commonly used material for simple plastic products (CES, Edupack 2018)

rPP

Is an abbreviation for recycled PP which is made from remelted PP as source material, and which is also recyclable. (CES, Edupack 2018)

PET

Is an abbreviation for polyethylene terephthalate, a thermoplast which is recyclable and a common material for plastic bottles. (CES, Edupack 2018)

rPET

Is an abbreviation for recycled PET which is made from remelted PET as source material, and which is also recyclable. (CES, Edupack 2018)

EVA

Is an abbreviation for ethylene-vinyl-acetate, an elastomer which can be foamed and is often used as sole material in running shoes. (Bos, et al., 2017)

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APPENDIX

Preface

Ask yourself the following question: Do you care for the planet you're living in? I am sure that at least a small part of you says yes. You may separate paper and glass for recycling. What about plastics? And did your parents tell you to finish your plate to not waste food? Or were food scraps thrown away, or perhaps composted? Is throwing a can of soda in the bushes okay if you can't find a bin? Do you bike instead of taking the car when having the opportunity? Do you buy the biological, local, free-range eggs rather than the cheaper eggs? Do you bring your own bag or cup to the store or find one-use plastic bags, cups, or trays more convenient? What matters for you, and what does not?

Making the 'right' decision can depend on several aspects, such as available information, effort, or costs, apart from the value of wanting to be environmentally friendly. The same counts for designing and developing products. In our lives, the word 'sustainability' often gets mentioned. What it really implies, I got to learn over the course of my studies. A product isn't sustainable by placing a sticker or made-up certification on the product with this claim, though many companies do this to attract users (also called greenwashing). A product is not necessarily sustainable by being made of bio-material. In fact, developing a truly sustainable product is something a little more complex, in which not only environmental aspects have to be taken into account (what impact does it have on the planet?), but also the social aspects (is it produced in a fair way?), as well as the income and outgoings (is it viable?).

Learning about all different aspects of how a product can be made environmentally friendly, and how certain decisions to do so impact the product and system around it in complex ways, have always fascinated me. Some solutions can be ingenious, truly sustainable, beautiful, and well competitive as well. Such a well designed product, doing good for both the user, company, and environment, is something I think can be appreciated by many, and learning to design a product as such is something I think matters and I can get enthusiastic about.

Therefore, when the company Greentom presented their stroller during one of our lectures at the faculty, I became well enthusiastic about their company. Not only was the Greentom stroller beautiful looking and made of 97% recycled material, but Greentom was also able to have a structurally sound product from the recycled material, claimed the design to have production costs no higher than if the product were made of virgin material, and went so far as to have their material provider achieve white post-consumer plastic granulate for the manufacturing of their parts, which makes them one of the first companies to achieve this. This company is set on a path of becoming a circular brand, and their impressive design solutions showed that this was possible by genuinely wanting to achieve this goal. This was the moment that my mind was set on doing a graduation project for Greentom.

In the end, Greentom shows a great example of a company delivering beautiful, well-designed, affordable, competitive, and sustainable products. Yet, few companies seem to follow their footsteps to produce equally sustainable products. Of course, this may not be one of the values of a company, but if with some effort a product of a company can be designed equally beautiful, functional, and profitable (if not even more so), then there are few reasons not to do so. Learning the ways to do this, and mastering them to be able to show the ability of having a positive and sustainable outcome, is something I hope to achieve during my graduation project as well as in any future projects to better be able to show what the 'right' decisions could be for a sustainable world.

Abstract

Hand carts are small carts that can be pushed or pulled by hand, and are typically used to conveniently transport both belongings and small children on a day out. As there are currently no known highly sustainable hand carts on the market, Greentom aims to add a sustainable hand cart to their portfolio on their path of becoming a circular lifestyle brand.

The main objective of this graduation was to design a sustainable hand cart product concept for young families in the Netherlands, which is simple in its design, easy to use, and affordably priced. The hand cart should furthermore be suitable for up to three children to sit in and suitable to transport goods.

Research was done on current hand carts on the market, on users' experiences with them, and on the current sustainability and circularity of Greentom's currently produced product. This research resulted in a list of users' needs and wishes in a hand cart, including the ideal dimensions, needed safety norms, needed requirements for it to be easy to use, and the selling price preferred to be under €250. Furthermore, the research concluded that rPP and rPET are the most suitable and sustainable materials to be used in the hand cart chassis and textile respectively, and that an end-of-life scenario where new Greentom products are sent back and refurbished into 2nd-life products would result in hand carts with 62% lower eco-costs and 71%€ value capture compared to the product with a linear incineration end-of-life. By using these concluded required elements of a hand cart, and by defining the Greentom form family and future hand cart style, several ideas were developed after which five product ideas were proposed.

The five ideas showed promising iterations on the basic frame structure, folding principle, push/pull bar design, and bottom design. By detailing their ergonomic and constructional aspects, which concluded the exact dimensions, necessary wheel types, push/pull bar positioning, weight-support beam construction, and necessary folding structure iterations, the ideas were concretized into three concepts: 'Horizontals', 'Twofold', and 'Diagonal'.

The concepts were evaluated based on three main criteria from the list of requirements, after which the 'Diagonal' was concluded to be the most promising concept to be further developed into detail. Detailing the concept was done by defining the to-be-improved points with a structural mock-up model, and by defining and further developing satisfier and exciter attributes to ensure a high degree of customer satisfaction using the KANO model. Lastly, after building a 1:1 functional prototype of the improved final concept, the prototype was evaluated by means of a user test, and showed to successfully satisfy all users' needs and wishes with positive reactions on all attributes.

The final design, the 'Greentom Go' concludes to be 1) *simple* in its design since it complies with Greentom's form family style while also expressing its own Hand Cart style, 2) *easy to use* as it is easily (un)foldable, enables children to independently step in and out of the hand cart, allows attachment of Greentom accessories and a baby car seat, and is well manoeuvrable by having large wheels, a pushable handlebar, and by being lightweight (7.57kg), and 3) *affordable* since the reuse of existing and future moulds as well as the refurbishment end-of-life scenario allows for lower total costs enabling a selling price of €220. Therefore, the stated design goal is concluded to be successfully achieved by the Greentom Go.

01

DESCRIBE

In this chapter

Any design project should be thought-out well before starting, to effectively execute the design project and successfully reach the desired goal.

This section describes the context, focus, and design goal of the graduation project, and how it will be approached.

1.1 Introduction

On a day out, hand carts are ideal for young families. For children, it is fun to be pulled along, and parents can conveniently transport their belongings and the children, and do not have to worry that their children might get tired from walking, if they already can walk (See Figure 1). Greentom wants to develop a sustainable hand cart to add to their portfolio, and is a company that currently designs, develops, and produces sustainable strollers (Greentom, 2018a).

Figure 1 - A typical hand cart in use (Ourlittlephotodiary, 2017)

Greentom positions its current strollers, as seen in Figure 2, as “the greenest stroller on planet earth” (Greentom, 2018b). The strollers are made out of 97% recycled materials and can be recycled after use. The frame is made out of (white) recycled PP, the fabric is made out of recycled PET bottles, and the mattress is made from 100% natural wool combined with organic cotton. The design is made in such a way that it can be quickly (dis) assembled, and uses as little different kinds of materials and different parts as possible. These solutions make it possible to easily change individual worn parts to increase the lifespan of products, or to process parts of returned products into re-recycled mono-materials for new product cycles, eliminating the need of using finite virgin material. These design decisions help improving the sustainability and ultimately the circularity of Greentoms products. (CuddleCo, 2013; Red-dot-21, 2016; Greentom 2018c; Greentom, 2017)

At this moment, however, there are no known hand carts on the market with similar performance in sustainability. Product that are created with the use of finite material resources, harmful production methods (use of additives, glue, lack of design for disassembly, non-recyclable materials), and an incineration or landfill end-of-life will ultimately lead to worsened environmental, social, and economic conditions, due to the release of toxic emissions and material depletion, for future generations to live in (Umwelt Bundesamt, 2019).

To counter this, recent EU policy strives for the development of sustainable products that allow for a circular economy, targetting the transition from the current linear, make-to-sell mindset to a circular and sustainable one. (European Commission, 2014) This is exactly where the graduation project of developing a Hand Cart for Greentom could make a difference.

Figure 2 - The Greentom strollers - From left to right: Greentom reversible, Greentom carrycot, Greentom classic

1.2 Project Brief

1.2.1 Project focus

Greentom's vision is to "become a circular lifestyle brand that grows with the life stage of the consumer" (Gemeente Maastricht, 2018) Thus, expanding their portfolio with the addition of a sustainable hand cart for young families would be a valuable addition for environmentally conscious families as well as for Greentom's vision.

The focus of the project will, therefore, be on sustainability, thus designing a product that benefits the social (People), ecological (Planet), and economic (Profit) aspect of a sustainable system (de Pauw, I., 2015), specifically focussing on the latter two as the project aims more attention at developing a physical product rather than on developing the system it lies in, while also focussing on circular design, allowing materials and parts to be used anew at the end of their life.

1.2.2 Design goal

The challenge is to design a hand cart that, like the Greentom stroller, is affordably priced but also would be able to fit a circular economy, while complying with Greentom's mission, which is "to create smart, functional and sustainable products [...] to colour the world and [future generation] greener." (Greentom, 2018a)

Therefore, my design project goal is as follows:

To design a sustainable Hand Cart product concept for young families in the Netherlands which is simple in its design (smart), easy to use (functional), and affordably priced.

The hand cart should be suitable for two to three children (from 0 to 5 years old) to sit in and suitable to transport goods.

See Appendix A0 for the detailed project brief.

1.3 Approach

The design goal is approached by splitting the project into four phases: research, ideation, conceptualization, and concept detailing.

As can be seen in Figure 3, each phase is started with a goal and closed with the conclusions regarding that goal. Each of these phases' conclusions help further develop the final concept design of the Greentom Hand Cart.

The research phase will be concluded with a list of requirements and wishes which can be used as a guideline during the ideation phase. The ideation phase will be concluded with a selection of most promising idea directions, which will be used as a starting point for the conceptualization phase. The conceptualization phase will be concluded with the selection of the most promising concept which will be further developed in detail during the concept detailing phase. Finally, the concept detailing will be concluded with the final concept design of the Greentom Hand cart, having synthesised all phases into the final design.
Each phase is shaped as a diamond, inspired by Double Diamond model by the Design Council (2019), only expanded to fit all design phases. The main idea is that the phases diverge to find information related to the phase goal, and converge to conclude the phase with relevant conclusions as a starting point for the next phase.

Inside each phase, several other design methods are used, and will be discussed as they appear in each chapter. Furthermore, it should be noted that during the divergence and convergence of phases as well as between phases, there are constant iterations of solutions and taken pathways by changing or improving them, to reach the final conclusions that best solve the design challenges. However, for the sake of overview and readability, the design process will be described linearly.

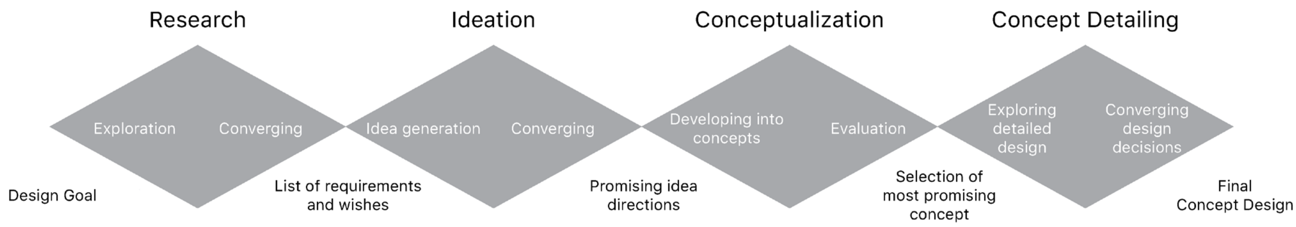


Figure 3 - Visualization of the design approach used to reach the design goal

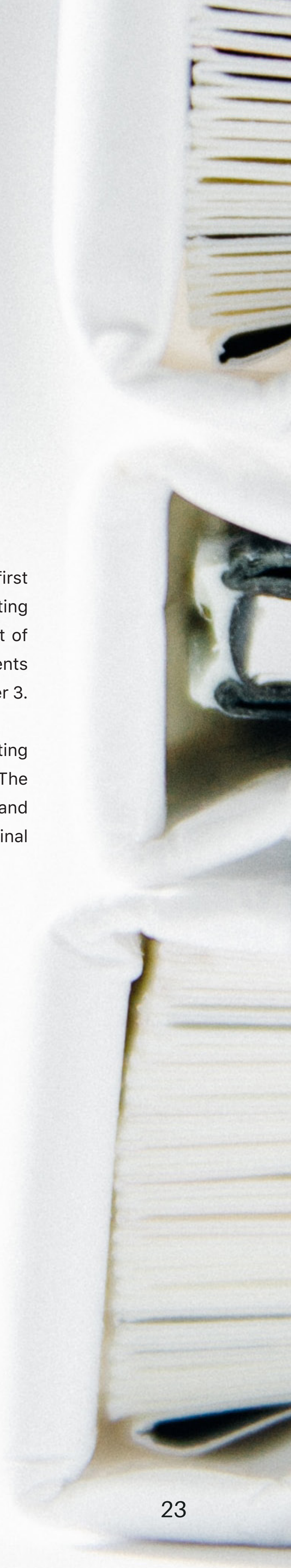
02

RESEARCH

In this c hapter

To be able to design the Greentom Hand Cart that best reaches the assignment goals, it is first necessary to gain insights by means of research into topics regarding sustainability, existing hand carts, and its users. The goal of the research is to use these insights to create a list of requirements and wishes to ensure that design goals are best reached. This list of requirements and wishes will then help as a guideline during the development of hand cart ideas, in Chapter 3.

The research chapter is split into four parts: The first part involves the analysis of competing hand carts. The second part revolves around the analysis of user's experiences and wishes. The third part presents the analysis of the environmental impact of current Greentom products and how the future Greentom Hand Cart could be made more sustainable based on that. The final part will discuss the conclusions and insights made from these analyses.



2.1 Competing hand carts

The goal of this section is to explore what competing hand carts are out there, what their positive and negative aspects are, and to see where the Greentom Hand Cart could make a difference to compete regarding these findings.

To do so, existing hand carts are analysed by means of a desk research (Section 2.1.1.1), by physically trying them out (Section 2.1.1.2), and via exploring (online) users' and retailers' opinions (Section 2.2.1 and 2.2.2). Next, the hand carts are compared by means of a perceptual map (Section 2.1.2). The conclusions of this section will be combined with the conclusions of the Field research (Section 2.2) in Section 2.2.3.

2.1.1 Hand cart analysis

What is a hand cart? Hand carts traditionally used to be wooden carts on four wheels meant to transport produce from farmers to growing cities in the 19th century, comparable to the one in Figure 4. (Lavigne, 2015) It can be seen in the German word for hand cart, 'Bollerwagen', that the word originally consists of the word "bollern" which means to rumble (likely the sound the wheels made on cobblestones), and "wagen" which means cart. (Langenscheidt, 2018ab) Still, the hand cart is most popular in Germany, where hand carts are traditionally used on Father's day to transport drinks for fathers to celebrate. (Porter, E., 2019)

Nowadays, hand carts are becoming increasingly known also in countries not used to the concept of hand carts, having changed from traditional wooden hand carts to more convenient, foldable, compact, and hip carts. By creating a hand cart that competes well with existing hand carts, the Greentom Hand Cart could become a good product to users still less familiar with the concept. (Information from interview with retailer in Appendix A9)

Figure 4 - An old german hand cart (Haider, D., 2019)

2.1.1.1 Desk research

As Greentom has no experience with hand carts, first, properties are explored by analysing existing hand carts sold on retailers' websites. Properties of 30 competing hand carts are documented (see Appendix A2) to be used as the basis for comparing hand cart properties with a Perceptual Map (Section 2.1.2). Differences between hand carts are aspects such as their style, folding mechanisms, (un)folded dimensions, weight, prices, capacity, and attributes.

One specific find is that 20% of the analysed hand carts can be pushed as well as pulled.

Secondly, norms for hand carts are analysed, to which Appendix A3 shows the detailed norm analysis. Looking at the different hand carts and their norms, it is concluded that it is common that the addition of a push bar in a hand cart is accompanied with the additional safety norm EN 1888, requiring a hand brake or foot brake and safety straps in a pushable carriage for children

Thirdly, several online forums, videos, and blogs are consulted. The online users most commonly indicated needing the hand cart to have big wheels to better ride in sand, to let it have enough inner volume to fit 'enough belongings', and to have a compact hand cart when folded to take along. Common wishes are the ability to have a roof/umbrella, the ability to attach a baby car seat inside the hand cart, and to have breaks to use the cart on slopes. (ANWB, 2015; Forum Viva, 2012; Forum Viva, 2018; Zwangerschapspagina, 2017abc; GrootGezin, n.d.).

These first indications of needs and wishes are later compared to the user's needs and wishes resulting from the Questionnaire (Section 2.2.2), and interviews (Section 2.2.3). Appendix A4 shows the detailed findings regarding online users' preferences.

Additional insights are that users also indicated that pulling a hand cart on long walks might be more difficult than pushing the cart. Another user indicated finding it unpleasant not to be able to see the children when pulling them behind in the city. Thus, the difference in experience between pushing and pulling a hand cart is interesting to also explore.

2.1.1.2 Trying out hand carts

To gain hands-on experience with hand carts and find insights that desk research cannot easily provide, physical competing hand carts properties are analysed, after which the hand cart manoeuvrability is tried out.

Physical competing hand cart properties

Negative and positive aspects of existing hand carts, selected on the basis of an initial list of product requirements, are analysed by exploring multiple, physical hand carts first-hand to help better define appropriate requirements for the Greentom Hand Cart.

In terms of *manoeuvrability*, it is found that heavier hand carts and hand carts with small, hard wheels are more difficult to manoeuvre than light, big-wheeled hand carts. Furthermore, hand carts with wheels that move together with the pull bar (Figure 5) are better to manoeuvre than those with wheels moving independently from the pull bar (Figure 6).

Regarding *foldability*, hand carts which require the disassembly of parts during (un)folding (Figure 7) are more inconvenient since they require more steps and attention than those without the need of loose parts during (un)folding. Furthermore, when folding, some hand carts are less intuitive than others. The UlfBo for example (Figure 8), does not indicate well how it can be folded. Lastly, few hand carts are able to stand upright when folded, such as the Beachtrekker Life (Figure 9), while many have to be laid down after folding, occupying more space.

In terms of *comfort*, many of the insides of the hand carts did not feel comfortable by touch (Figure 10). In some hand carts this is solved by adding plastic boards on top of the beams (Figure 15), in others a soft cushion is integrated or placed on top of the support structure (Figure 11).

Regarding *safety*, the Beachtrekker Life shows to be an example of a hand cart with a dangerously unstable wheelbase structure, tipping over when the wheels and handlebar are turned and the weight (of a child) being in the front corner, thus shifting the centre of gravity beyond the tipping point (Figure 11 and Figure 12).


Figure 5 - Handlebar moving wheels


Figure 6 - Small independent wheels


Figure 7 - (Un)folding requires loose beams


Figure 8 - Folded hand cart unable to stand


Figure 9 - Folded hand cart standing


Figure 10 - Uncomfortable support structure


Figure 11 - Hand cart being seemingly stable


Figure 12 - Little force makes cart tip over


Figure 13 - Plates added to support structure

Push/pull bar manoeuvrability

Few hand carts can be pushed, and additional norms are required if a hand cart has a push bar (see previous section). However, are there also clear benefits of being able to push a hand cart compared to pulling that weigh up to these additional norms? To find out hands-on, a bent tube acting as a push bar is installed on top of an existing pullable hand cart -since no hand cart with a push bar is available- to compare the experience when pushing and when pulling the cart (See Figure 14).

For the try-out, a MacWagon hand cart is used, filled with a 60kg box to simulate the weight of three P50 five-year-old children (DINED, 2017a).

It is concluded that the hand cart moved to the side when being pulled and there is no vision on the contents (Figure 15). When pushing the hand cart, the concluded benefits of a push bar are that the cart remains in the middle, pushing requires less force and seems to be comfortable for the posture, and there is view on the content/children (Figure 17).

Regarding the wheels, it is concluded that steering felt more comfortable when pushing at the side of the added push bar (Figure 14) opposed to pushing at the side of the pull bar (Figure 17). Thus, having the swivel wheels on the far side and the stationary wheels on the near side of the user manoeuvred better when pushing. This is possibly due to the turning point being closer to the user allowing for tighter turns. The opposite orientation of these wheel types manoeuvred more easily when pulling, possibly since the swivel wheels could then immediately follow a change of direction. Further research on the most comfortable wheel type configuration can be found in Section 4.1.1.2.

Lastly, it is found that the subject's weight in Figure 16, equal to the weight of three children, could be too much for a textile without any beams underneath to support the weight (unless the textile supports heavy weights as Cordura textile does, utilized in UlfBo hand carts).

Figure 14 - The MacWagon with an added improvised push bar

Figure 15 - Pulling the hand cart

Figure 16 - Trying out the sitting comfort

Figure 17 - Pushing the hand cart

2.1.2 Perceptual map

Introducing a new product into a market segment with few close competitors would make the product stand out and possibly lead to a successful introduction. Therefore, the goal of the perceptual map is to visually compare existing hand carts to see where a possible market gap could be for successfully introducing the Greentom Hand Cart.

The perceptual map, as seen in Figure 18 and Figure 19, is created by plotting the price of the hand cart against the perceived style, since users buy hand carts that fit within their preferred price range, and since hand cart aesthetics matter the most when looking for a hand cart if all functionalities hypothetically would be equal between competing hand carts.

The prices are gathered using the created list in Appendix A2, whereas the hand cart styles are subjectively rated on a scale of 0 to 10, with 0 being the most common in design and conservative, and 10 being the most unique and innovative in style.

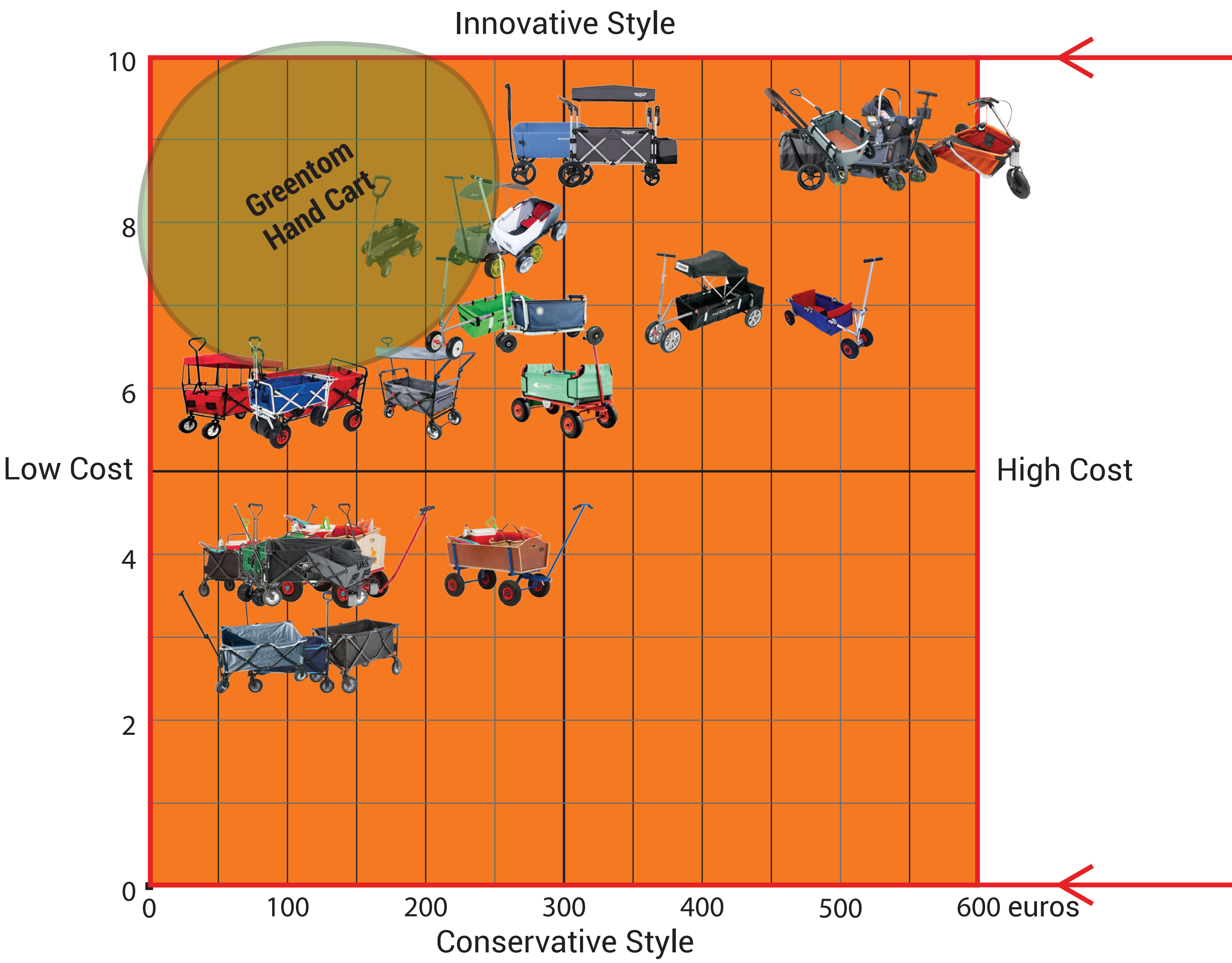


Figure 18 - Perceptual map, positioning hand carts based on their cost and perceived aesthetics - Zoomed-in area from Figure 19

Examples conservative-style features are: cheap, fragile, or uncomfortable looking structures, and unfoldable wooden structures. Examples of innovative-style features are: hand carts with rounded, uncommon (not box-like) shapes, or those with uncommon features such as roofs, push bars, added pouches, or car seat attachments.

It is assumed that hand carts appearing the most unique and innovative are perceived as the most aesthetically pleasing, however, future research regarding users' hand cart style preferences could be done to confirm this.

It is concluded that a possible market gap for hand carts that are innovative in style and and have a price up to €250, of which the empty area containing few competitors can be seen in the top-left corner of Figure 18, assuming that users find hand carts with an innovative style (top) more aesthetically pleasing than those with a conservative style, and that users prefer more affordable hand carts (left) over expensive ones.

Naturally, this competitive advantage will only remain strong if also all users' most needed attributes in a hand cart are present. Keeping the price low while also living up to all wished attributes is a challenge, for which solutions are discussed in-depth in Section 3.3.

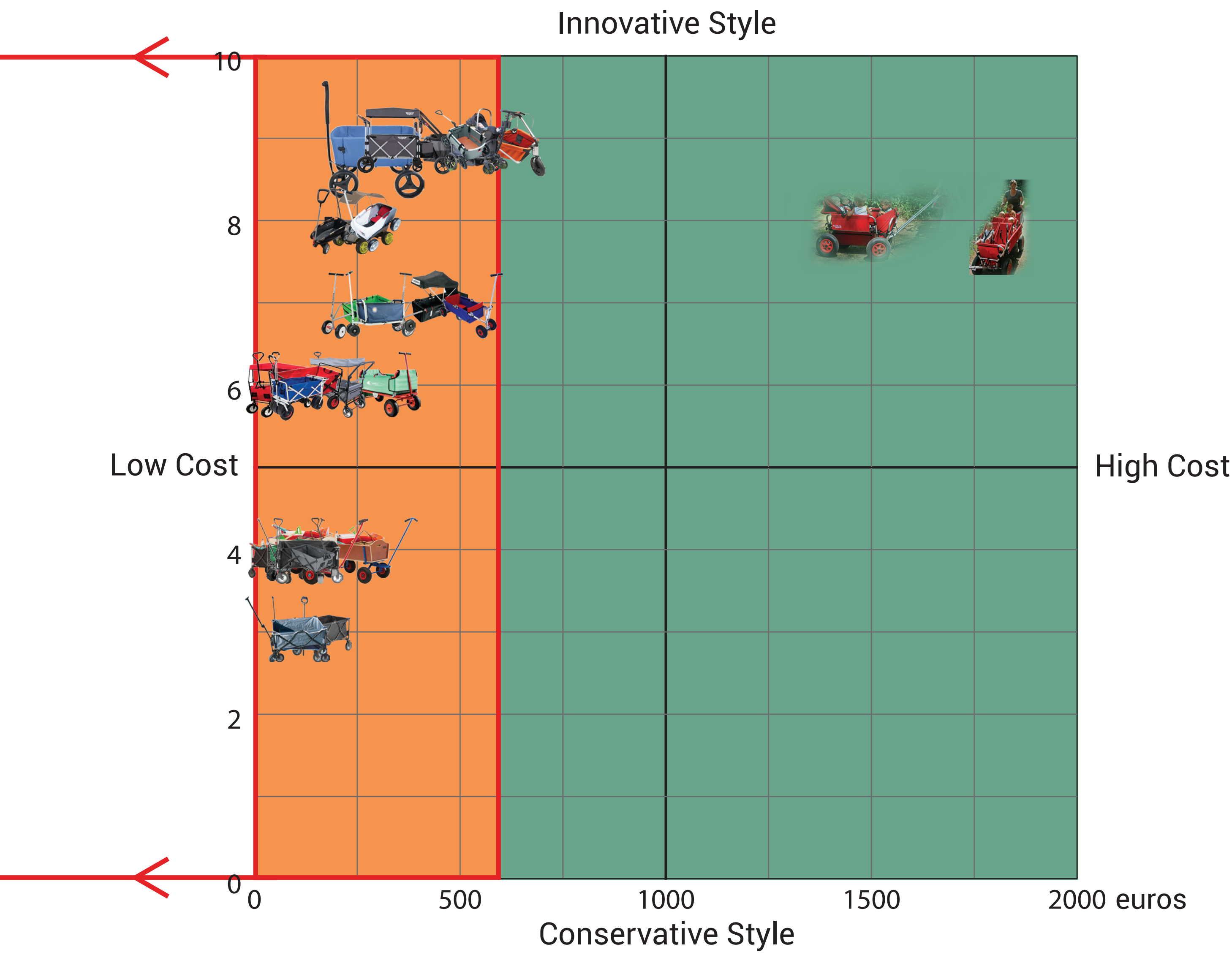


Figure 19 - Perceptual map, positioning hand carts based on their cost and perceived aesthetics.

2.2 Field Research

The previous section gave insights into possible needs and issues in hand carts. However, validation of these insights is essential. Therefore, the goal of this section is to find the users' needs and wishes, both to validate the findings of the competing hand cart analysis (Section 2.1.1) and to create an additional set of requirements and wishes for the Greentom Hand Cart.

To find these needs and wishes, a questionnaire is sent out to hand cart users (Section 2.2.2), and interviews are conducted with a hand cart user (Section 2.2.3.1) and a hand cart seller (Section 2.2.3.2). Lastly, the main conclusions of Section 2.1 and this section are discussed in Section 2.2.3.

2.2.1 Methods

The questionnaire (Section 2.2.2) is set with the goal of finding the overall users' preferences within existing hand carts and mainly consists of quantitative questions (meaning to generate data usable to analyse statistically).

The questionnaire is distributed by using several Dutch and German online forums for parents with small children, by using social media platforms such as LinkedIn and Facebook, and by inviting people having a hand cart on the streets to participate. Users that do not own a hand cart are excluded from the questionnaire since they would not have enough insights or experience with hand carts. Appendix A5 shows a list of all the questions that are asked in the questionnaire.

Both the user interview (Section 2.2.3.1) and retailer interview (Section 2.2.3.2) are conducted to find out the underlaying reasons behind users' preferences, consisting of only qualitative questions (meaning to exploratively research underlying reasons). Regarding the retailer interview, in addition to this goal, underlaying reasons are sought for regarding why some hand carts sell better than others.

Regarding the user interview, a user is invited to be interviewed, and to show how their own hand cart is being used with her children of 3 and 5 years old after the interview. Colouring books and toy cars are available during the half-hour interview to entertain the children, and a mobile device is used to record the entire interview after permission is asked. Appendix A8 shows a list of questions and answers of the user interview.

Regarding the retailer interview, the owner of Active Kids / bolderkar-shop.nl is interviewed who apart from selling hand carts online, also has the largest showroom of hand carts in the Netherlands in Breda. Since retailers are in daily direct contact with the user, an interview can provide their valuable insights on user's preferences and problems while being able to well compare competing hand carts according to those.

The open-end questions asked to the retailer are in regards to users' common preferences, comparing attributes between competing hand carts, and the retailer's suggestions for improvements in hand carts after years of experience selling hand carts from different producers to users. A mobile device is used during the interview to record the entire interview after permission is asked. Appendix A9 shows a list of questions and answers of the retailer interview.

2.2.2 Questionnaire

After having distributed the questionnaire, 16 people of Dutch nationality and 4 people of German nationality had filled in the questionnaire. The relevant results, categorized into sections, are presented in this section.

Target group

95% of the respondents have children as shown in Figure 20. The figure also shows that 70% of all hand cart users have more than 1 child. 74% of users with children also indicated that some of their children ride along inside the hand cart (See Appendix A6).

When asking users how old the children are that ride along inside the cart, users mention the oldest children are up to 5/6/7 years old, and the youngest are 1 year old (See Appendix A6). One user even indicated: *"From the moment they can sit independently"*, which is around 7 months (BabyCentre Staff, 2019), *"until their 5th/6th year"*.

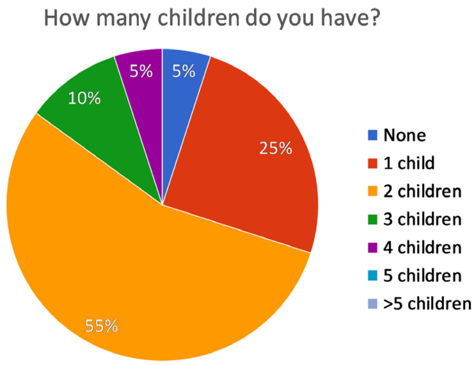


Figure 20 - Number of children per hand cart user

Owned Hand Carts Prices

When comparing owned hand cart types (see Appendix A6) with hand cart prices in Appendix A2, 50% of the hand cart users that filled in the questionnaire are owners of cheap, foldable hand carts that cost up to €100, and 70% of all users owned a hand cart under €200, indicating that the price range for the future hand cart can be close to this range.

Primary Use of Hand Carts

Figure 21 shows that hand carts are mostly both used for transporting belongings and children.

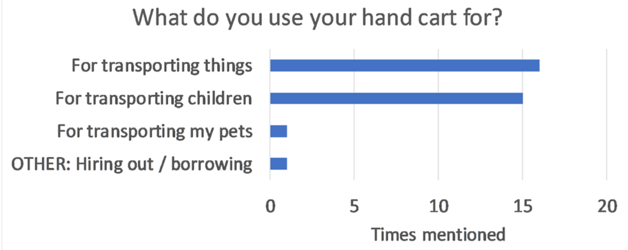


Figure 21 - Type of use per hand cart

Context

As seen in Figure 25, hand carts are mostly used on the beach, at the zoo, at the camping, or at the amusement park.

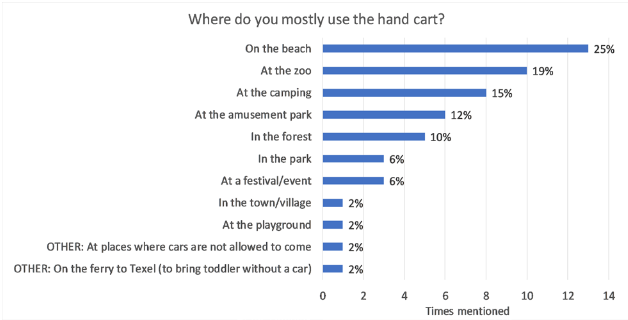


Figure 22 - Locations of use

Needs and wishes

The aspects users find most important when buying a hand cart (only being able to choose a maximum of 4 aspects out of the list) are shown in Figure 23. These are Compactness when folded, Manoeuvrability (how well it steers), Weight, Comfort for passengers, and Inner Volume. Being able to choose your own colour/pattern is mentioned once as a priority, and environmental friendliness, or appearance are not mentioned to be an attribute users found to be first priority when buying a hand cart. Appendix A6 shows that users have mixed feelings about the importance of attractiveness and environmentally friendliness, and value personalizability the least.

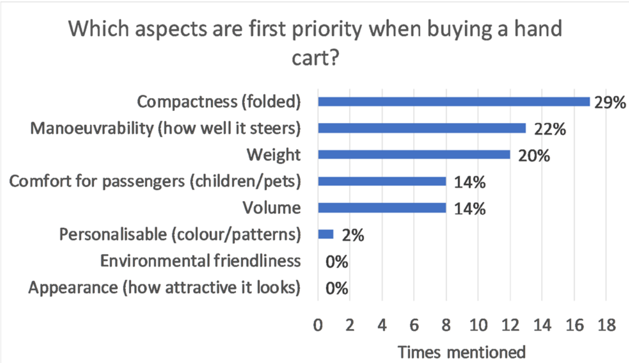


Figure 23 - Users' most valued attributes

When asking which other unmentioned aspects would be on first place, users mentioned sturdiness, sun protection, child safety, wheel types, broad wheels for the beach, and extra storing compartments.

Most users would like their ideal hand cart to cost up to €100. 15% would pay 100 - 200 euros, 10% would pay 200 - 300 euros, and 10% would pay 300 - 400 euros, as shown in Figure 24. A slight shift in frequency distribution towards higher prices can be seen for ideal hand carts compared to prices of user's currently owned hand carts.

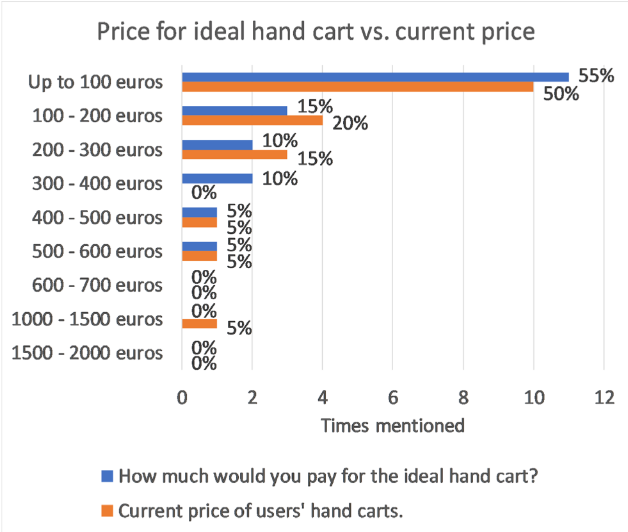
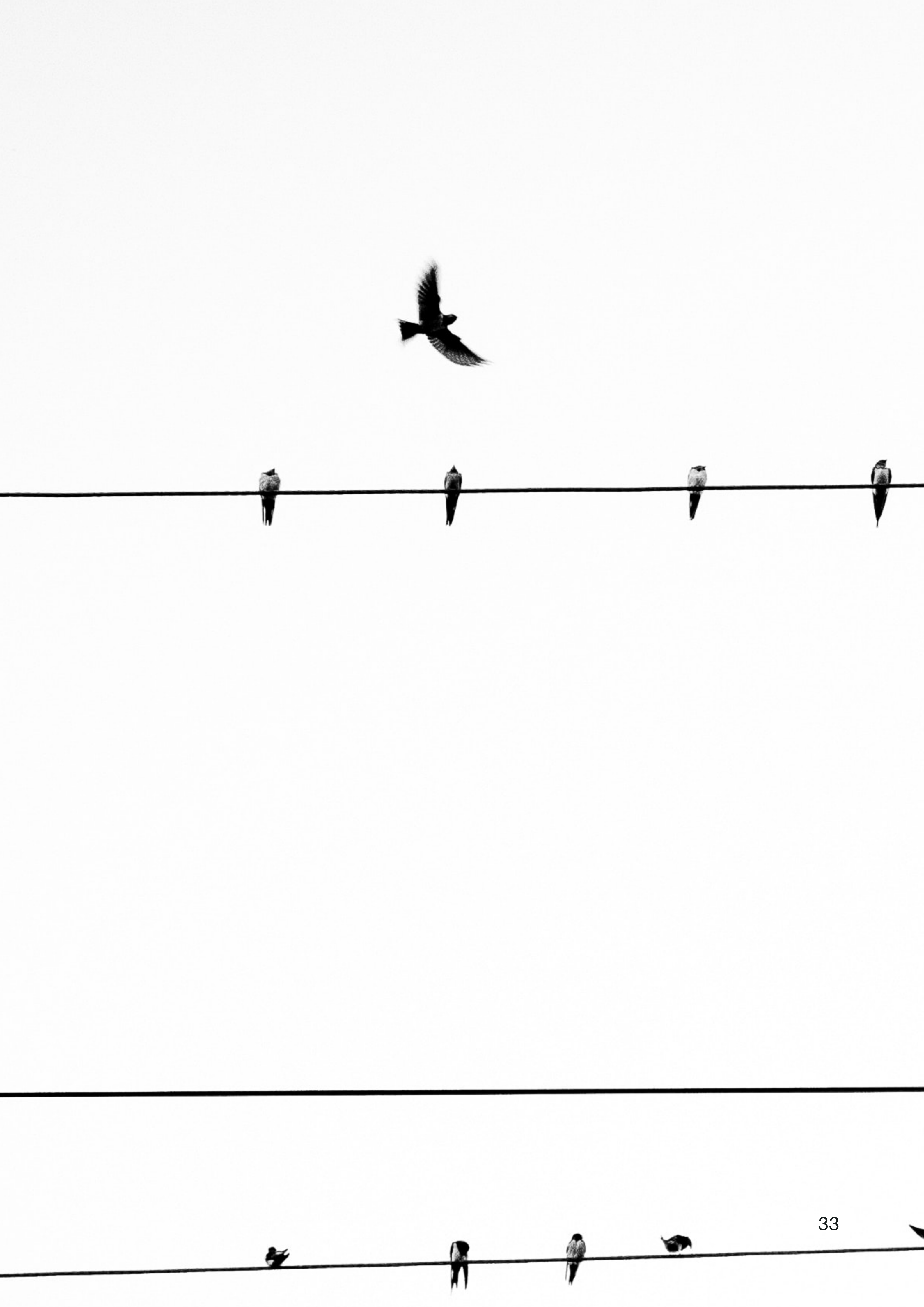


Figure 24 - Users' price for an ideal hand cart vs their current price



2.2.3 Interviews

2.2.3.1 User interview

Target group

The user indicated the reason to use their hand cart -a MacWagon- is because the hand cart is nice to have during a day out or during a holiday, since it fits both children as well as more belongings, opposed to a single stroller.

For her children, the user thinks the hand cart is suitable until the child does not find in the cart anymore, and from the moment a child can sit independently without being strapped in. This is because children can move freely by themselves without straps being available, which might be dangerous if they cannot sit well by themselves properly, and is especially dangerous if children decide to stand up by themselves suddenly. However, the use also mentions that freedom to move is nice for the children, but having them strapped to the seat is more practical. A combination would be preferred. Also, the possibility of putting a children's car seat is preferred, for when the children are younger, to make it possible to use the hand cart with them too.

Context and use

The user does not use the hand cart in the city, because it is difficult to manoeuvre with it in a crowded place, and she accidentally rides the hand cart over people's feet when pulling due to not having a good vision of the cart behind her. The user mentioned a push bar would be handy, due to being able to check on the children, and being able to watch out not accidentally riding over people's toes. Also, it might be easier to push the cart when riding on uneven surfaces, which the user currently does not do but would if it easier to walk with the hand cart that way. The user did mention finding it difficult to pull along two children in the hand cart.

As Figure 25 shows, young children are lifted by the parent into or out of the hand cart. This could prove to be more difficult if the parent is pregnant, has back problems, or any disabilities. Figure 26 shows that older children can step into the hand cart themselves, but that higher cart sides would make this more difficult to do.

Figure 25 - The user lifting up her 3 year old out of the cart.

Figure 26 - The eldest 5 year old child climbing out by herself.

Needs and wishes

The most important aspects that the user prefers in an ideal hand cart, in descending order of importance, are:

1. **Manoeuvrability:** That it is easy to pull along.
2. **Foldable and compact:** To save space at home.
3. **Personalizability:** Being able to choose own style or covers. "Hand carts are very ugly".

Furthermore, the user indicated to be interested in environmentally friendly hand carts, and says to prefers unattractive hand carts that fold up compactly compared to attractive hand carts with bigger frames and wheels. Regarding costs, the user indicated to be willing to pay €200 for an ideal hand cart.

Other wishes the user indicated are:

- **Upright when folded**: Having the hand cart stand by itself when folded.
- **Detachable textile**: Being able to remove the textile from the frame to be able to easily clean it.
- **Sun/rain cover possibility**: During bad weather, the user uses a stroller with a rain cover instead of her hand cart which does not have a rain cover.
- **Car seat**: Ability to fit a car seat


Drive
Drive

2.2.3.2 Retailer interview

Target group and context

According to the retailer, the main reason for families to use the hand cart, is because once they have 2 or more children, the stroller becomes unhandy; transporting goods and children on days out is more handy with a compact hand cart than with two strollers for the children (or one stroller with an add-on platform) and additional bags for goods. The sent-out questionnaire (Section 2.2.2) confirms this, showing that 70% of users who own a hand cart have 2 children or more. Also, the interviewed user confirmed this when asking about the reason of using a hand cart. Thus, hand cart customers can be directly linked to customers of strollers with two or more small children.

Furthermore, the retailer said that in his experience, children up to five years old use the hand cart to sit in. The questionnaire confirms this, showing children up to 7 years old using the hand cart. The interviewed user indicated letting her children use the hand cart until they lose interest or are too big to fit.

Customer's hand cart preferences

According to the retailer, customers find the following aspects important in order from most to less important:

1. **Big wheels:** *"Big wheels are needed for comfort when using the hand cart more often, and to be used at the beach. The bigger the wheels, the better they ride on the beach. However, big wheels might also make the hand cart less compact when it is folded".*
2. **Large volume:** *"Customers want everything to fit in a hand cart (for example 2 to 3 children). Typically, hand carts are 1 meter wide (to fit in a car)."*
3. **Compactness:** *"80% of hand carts sold nowadays are foldable. They should have a simple folding system which uses as less loose parts as possible to prevent any parts from breaking or losing." Furthermore, according to the retailer,* the cheapest hand carts are bought the most. Regarding category of hand carts not considered cheap (>€200), customers tend to want to buy the Beach Wagon Lite (see Figure 27), due to its relatively low price within this category of €290, big wheels, large volume, great manoeuvrability, and attractive and user-friendly design (such as soft sides and the spring-elevated handlebar). However, since the base cannot be folded, the Beach Wagon will stay large after folding. Thus customers tend to buy the Beachtrekker Life instead (Figure 28), which is similar in price (€289). This proves that foldability is more important than aesthetics.
4. **Aesthetics:** *"The way the hand cart looks can lead to a customer's 'WOW!' feeling. The hand cart should be available in multiple colours which are flashy and hip. However, a price exceeding the customer's expectations leads to the customer not buying the product it loved so much. Thus, the price has to match the customer's expectations and should not be higher than €300."*

Figure 27 - Beach Wagon Lite

Figure 28 - Beachtrekker Life

Additional requirements

In addition to the above-mentioned user's preferences, Mr Hofte said that a hand cart should be:

- **Comfortable**: "Users, even those buying the cheapest hand carts tend to also buy all available accessories (such as mattresses, tent roofs, etc.) for the hand cart to make the hand cart comfortable and safe for their children."
- **Safe**: Especially the more expensive are found to have safety features such as straps or breaks. However, *"hand carts are considered to be toys and do not need to have these safety features since they*

are officially not meant for the transport of children. However, as soon as the hand carts can be pushed, they are considered as push prams, which involve safety norms", according to the retailer.

- **Well manoeuvrable:** Making the hand cart light is one way to make the hand cart easier to transport and to manoeuvre. However, making the hand cart light *"proves to be difficult for manufacturers"*, according to Mr Hofte.
- **(Feeling) Sturdy**: *"A main difference between the cheap hand carts and the more expensive hand carts is that the cheap ones tend to break soon. [...] If good materials are used, and a sound structure, then the hand cart will also feel more 'premium' during use."*

Common wishes

- **Children's car seat**: According to Mr Hofte, many users ask if there is the possibility to attach a children's car seat onto the hand cart.
- **Extra pouches**: Furthermore, Mr Hofte, as well as users, praise extra pouches in (or outside) the hand cart to fit belongings more comfortably.

2.2.3 Conclusion Field Research

Table 1 shows which needs are concluded in each section of both the hand cart analysis section and the field research section.

The table shows that aesthetics is not a top priority attribute. However, it can be assumed that high aesthetics is the decision-maker when all priority attributes are present. When it does, the price of the hand cart is best not to exceed the price the user would expect based on the attractiveness of the hand cart.

The need for a push bar is not mentioned explicitly in the questionnaire and retailer interview. However, it is concluded to be a present need based on the following:

- It is concluded that a push bar would benefit the user by enabling seeing the children in front of the user in the cart, and keeping the hand cart riding in the middle preventing it from bumping into people in crowded areas. The user interview shows that the lack of these benefits when pulling is why the user does not use the hand cart in the city and possibly why the questionnaire shows the hand cart being less used at a festival/even and least used in the town/village.
- It is concluded that a push bar would benefit the user by requiring less force and a more comfortable posture compared to pulling. As the questionnaire concludes that the hand cart is currently used less in the forest or the park, it is assumed that the mentioned benefits could make the hand cart more likely to be used on rougher terrain (in combination with suitable wheels as mentioned before).

Regarding the set design goal in Section 1.2, the questionnaire confirms that the hand cart is primarily and equally used to transport both belongings and children, concludes that the hand cart can be best made suitable for children up to 6 years old instead of 5 years old as was initially stated, and confirms that the hand cart can best be suitable to fit at least 2 children, up to 3 children, as findings are that the largest group of hand cart users has two children (55%), the second-largest group has 1 child (25%), and the third-largest group has 3 children (10%).

Table 1 - Mentioned needs and wishes per section

Concluded needs	**User questionnaire**	**User interview**	**Retailer interview**	**Hand cart analysis**
Priority attributes:				
Compactness (when folded)	✔ - 29% mentioned as priority	✔	✔	✔
Manoeuvrability (how well it steers)	✔ - 22% mentioned as priority	✔	✔	✔
Weight	✔ - 20% mentioned as priority	✘	✔	✔
Comfort for passengers	✔ - 14% mentioned as priority	✘	✔	✔
Volume	✔ - 14% mentioned as priority	✔	✔	✔
Other valued attribues:				
Big, broad wheels suitable for the beach	✔ - Hand carts most used at beach	✔	✔	✔
Aesthetics	✔	✔	✔	✔
Safety	✔	✔	✔	✔
A price no higher than €300	✔	✔	✔	✔
A push bar apart from a pull bar	✘	✔	✘	✔
A collapsable front entry	✘	✔	✘	✘
Wishes:				
Baby car seat	✔	✔	✔	✔
Sun/rain protection	✔	✔	✔	✔
Cart standing upright when folded	✔	✔	✔	✔
Extra storing compartments	✔	✘	✔	✘
Detachable textile	✔	✔	✔	✘


FIELD
NOTES

2.3 Sustainability

Apart from a research that ensures that the product will comply with all users' needs and wishes as was done in Section 2.1 and 2.2, Greentom is also set to create products that also do good to nature.

Therefore, the goal of this section is to define the requirements that ensure that the Greentom Hand Cart will have a low environmental impact in a future circular economy. This is done by first doing a research on how to further reduce the future environmental impact of and within the product life cycle of the Greentom Hand Cart, and secondly, based on these outcomes, by defining the materials of the Greentom Hand Cart that fit a sustainable product life cycle and will also be suitable to implement in Greentom's future circular economy.

2.3.1 Method

The requirements regarding the environmental impact are found by using the following approach: First, the current Greentom product life cycle (PLC) and the system it lies in is analysed to then calculate the product's current material flow in terms of circularity and value capture based on the product's current end-of-life scenario (Section 2.3.2). Next, by using the ResCom Circularity Calculator tool by Ideal & Co, a future better alternative end-of-life scenario is defined (Section 2.3.3). In Section 2.3.4, the current environmental burden of each of the phases of the PLC is analysed by means of a Fast-track Life Cycle Analysis (from now referred to as LCA). Data will be processed with the help of a list of environmental impact data called the Industrial Design & Engineering MATerials database (Idemat in short) which act as the multiplication factors for the to-be-defined variables. Based on the LCA results of the current Greentom product, the current environmental impact will be compared with the Greentom Hand Cart's future environmental impact in its alternative end-of-life scenario and PLC (Section 2.3.5), and a material selection with a reduced environmental impact will be made for the future product (Section 2.3.6). Finally, Section 2.3.7 will give an overview of the defined main requirements based on these analyses.

2.3.2 Current PLC and circularity

First, the current product system of a Greentom product is visualized. In the current system of a Greentom Classic (Figure 29) all stakeholders the product currently interacts with can be seen, their role and locations, the type of transport used as well as the distance between these stakeholders for the product (materials), and the path that product materials or parts take. See Confidential Appendix CA1 for the interview with Greentom on which this analysis is based.

What can be concluded from the analysis, is that only 2% of the customers in Europe send their product back for recycling after use. It is assumed that this is due to the lack of incentive to send back the product. Incentives to return a product after use are looked into further in the next section. Furthermore, of those products that are sent back, the rPP parts of the Chassis are currently bought by a 3rd party and shredded into recycled flakes for general use recycling, and the rPET textile of the Classic Seat is being collected until a suitable stakeholder is found to chemically recycle the textile. (From interview in CA1) Thus, currently, 98% of produced Greentom products are in a cradle-to-grave system. This linear end-of-life is best to be changed into a circular one to fit a sustainable, circular economy.

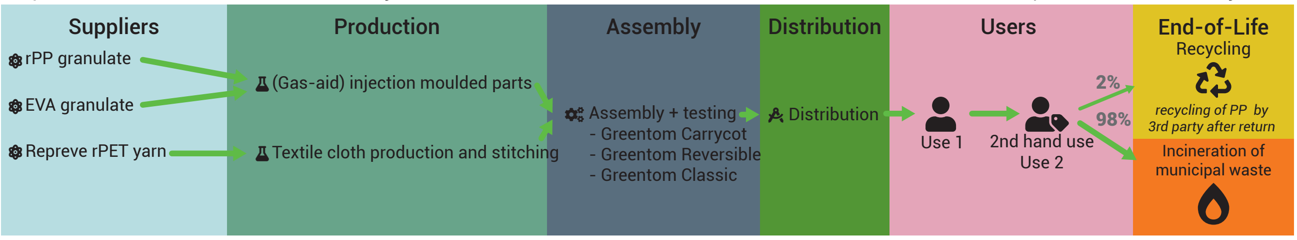


Figure 29 - System/contact between stakeholders (where stakeholder names, location, and transport distance are left out due to confidentiality)

In order to find out which end-of-life scenario for the hand cart holds the best potential in terms of costs, material, and environmental impact for Greentom, the current end-of-life scenario is explored, as well as the collection and four alternative end-of-life scenarios that are suggested for circular economy scenarios, namely: 1) maintenance, 2) refurbishing, 3) remanufacturing, and 4) recycling. These possible alternative scenarios are evaluated by using the ResCom Circularity Calculator by Ideal & Co.

Since the hand cart could have similar attributes to the Greentom Classic, such as a plastic frame and an inside textile, a conclusion of the best end-of-life scenario for the Greentom Classic could also serve as the best end-of-life scenario for the Greentom Hand Cart. The analysis is done on the Chassis as well as on the Classic Seat, which includes the canopy, the seat itself, and the textile basket as seen in Figure 30. The recycled percentage of the rPP lies between 80 and 100% (see technical data sheet provided by Greentom in Confidential Appendix CA3), and the Classic Seat consists of more parts and materials than only rPET textile. However, for simplification of the calculations, the Chassis is assumed to be made out of 97% rPP (KVKinnovatietop100, 2017) and the Classic Seat is assumed to be entirely made of 100% rPET.

Figure 31 shows the combined Circularity Calculator results of the current product, in which the material flow in weight percentage and costs in percentage of the total product costs (not sales costs(!)) can be seen per product life cycle stage, which currently ensures a circularity of 50% and a value capture of 1%.

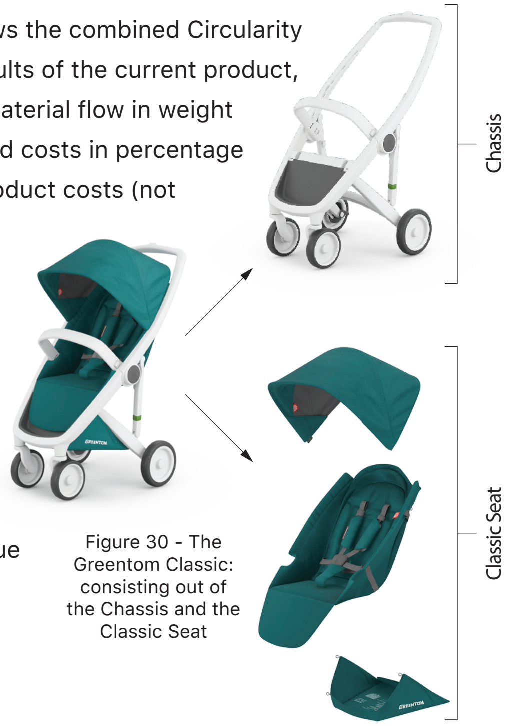


Figure 30 - The Greentom Classic: consisting out of the Chassis and the Classic Seat

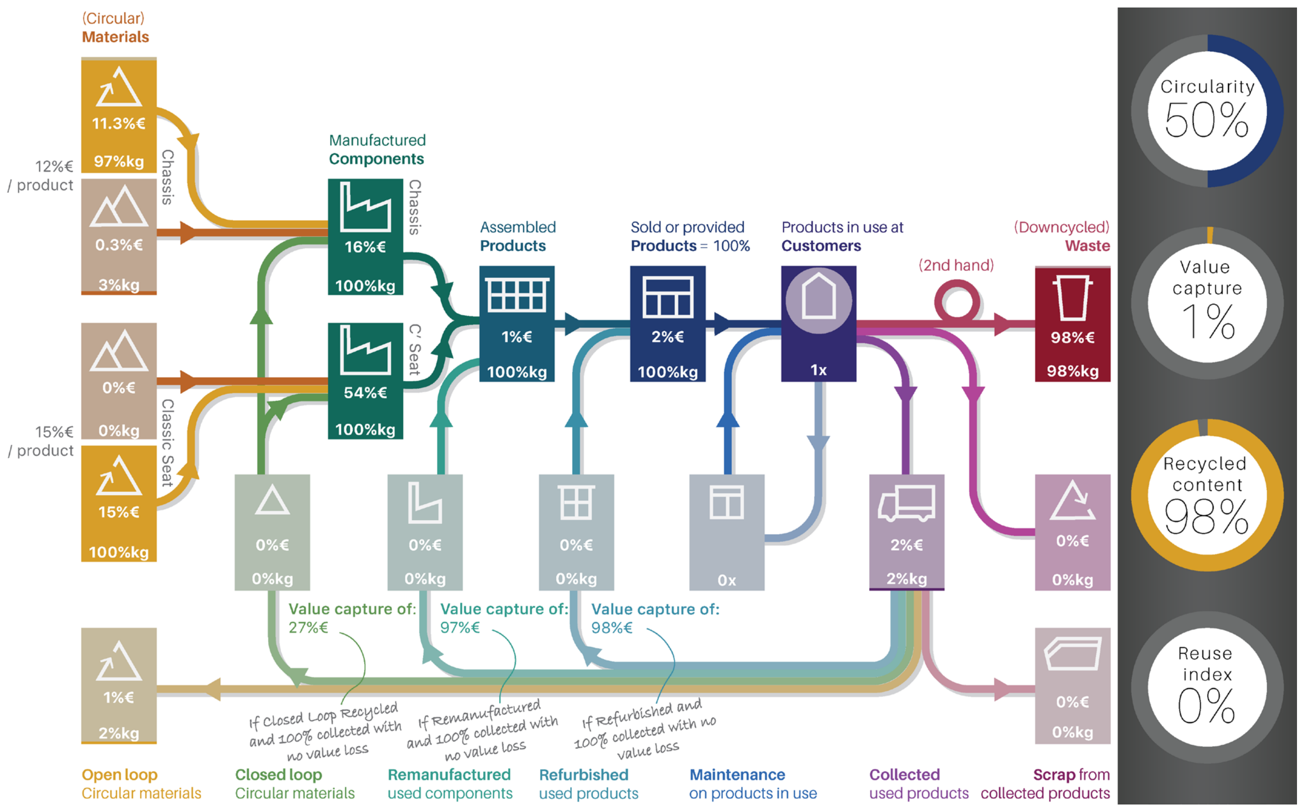


Figure 31 - Potential circularity and value capture of the current product life cycle

2.3.3 Future PLC and circularity

The first step to realizing an alternative, circular end-of-life scenario, is to ensure a larger percentage of collection of the products at their end-of-life. Brito, *et al.* (2011) describe eight different types of incentives to return a product after use, of which six relevant to the current situation are discussed:

1. **Deposit fee:** Returned fee after product is returned.
2. **Take back:** Collecting the product for free, or for a lower fee than normally would have to be paid.
3. **Fee/compensation:** Buying back the product.
4. **Trade-in:** Trading the old product for a new product.
5. **Easy and simple method of supply:** Either picking up the product or have drop off locations in place.
6. **Environmental responsibility**: Appealing to the environmental consciousness of people.

A possible incentive to send back the Greentom Hand Cart could, therefore, be a compensation for every sent back product, as well as offering the possibility to send back the product per post service free-of-charge. This can be done by integrating the reward fee and the return shipping fee into the selling price of the hand cart.
Next, with the information from Figure 31, the potential future value capture per new life cycle stage is calculated: Would 100% of all products be returned, a value capture of 27%€ (12% € Chassis, and 15% € Classic Seat) could be achieved if the materials of a product would be fully recycled in a closed loop, 97%%€ if the products could be fully remanufactured into a new product, or 98%€ if the products would be fully refurbished, of which the latter is shown in Figure 32.

Thus, it can be concluded that remanufacturing and/or refurbishing the Greentom Hand Cart are the preferred end-of-life scenarios, holding the most value capture in terms of costs and material saving compared to the current situation for the Greentom Classic. Comparing this to a possible best-case scenario in which 90% is collected and 80% is refurbished the value capture would be 71%€ (or 75%€ including the recycled end-of-life of unrefurbished parts), as seen in Appendix A7. The percentage depends on the percentage of products returned, and the percentage of the parts of those products that are suitable for the intended end-of-life-scenario (thus, not being functionally worn). See Confidential Appendix CA4 for the detailed CC results and used data.

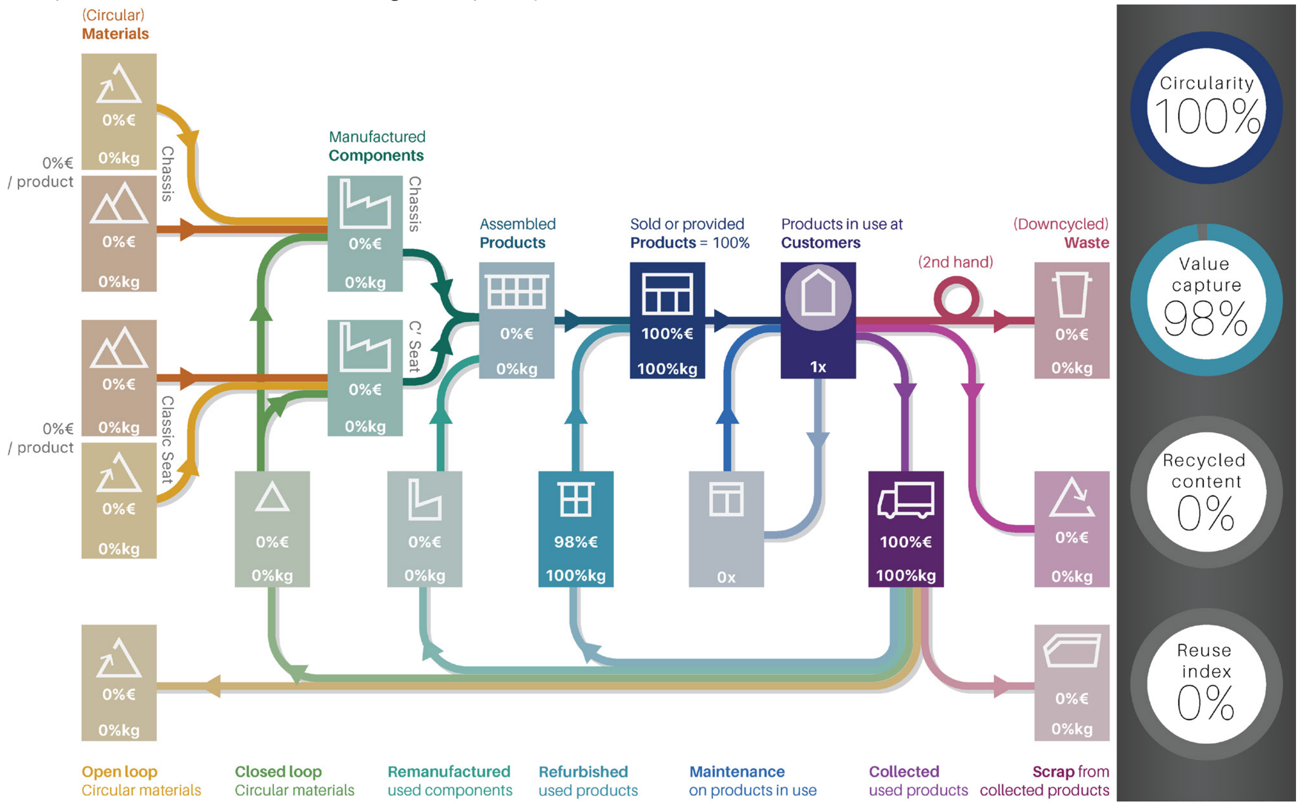


Figure 32 - Potential circularity and value capture of the future product life cycle

Implications for product design

As is concluded from Figure 31, remanufacturing and/or refurbishing the Greentom Hand Cart is preferred to make new circular products. However, depending on the condition or type of use of the parts or, in some situations, different end-of-life scenarios are better to be taken. This section further explores and determines which end-of-life scenarios the hand cart chassis and textile could best follow.

According to Keijsers, K (2013), users define three types of issues that users dislike when being offered to use a children' carriage as 2nd hand:

- *Emotional*: Rather than having visual wear, this reason often is based on the reason of hygiene when a second use cycle is initiated.
- *Visual wear or dirt*: Does not interfere with the functioning of the product, but applies to its looks. When initiating a second use cycle with a new user, these worsened aesthetics might be of an issue.
- *Functional break and wear*: These issues interfere with the proper working of the product and decrease the product life span.

Thus, after collection, as also mentioned by Kin *et al.* (2014), the hand cart is to be disassembled, cleaned, and inspected per part to determine if the part is suitable for refurbishing and/or remanufacturing. After, the parts reassembled into the end product which is then tested.

Chassis

Refurbishing/Remanufacturing:

The chassis is expected to only show visual wear, meaning the parts can be reconditioned to look as-new during refurbishment, and then reassembled. If no visual wear is present, the parts can be directly reassembled as remanufactured parts or reassembled in combination with refurbished parts.

Closed-loop recycling:

Chassis parts that show functional wear or break are unsuitable for refurbishing/remanufacturing but can, therefore, instead be recycled into new chassis parts. To minimize material value loss, the chassis should have as few different materials as possible and a density difference of at least 0,03 [g/cm^3] between different materials to ensure the best material differentiability after shredding for closed loop recycling. (Bogue, 2007)

Furthermore, the hand cart tyres are assumed to be too functionally worn to be refurbished/remanufactured, and is, therefore, to be recycled instead.

Textile

Refurbishing/Remanufacturing:

Textile showing minor, repairable flaws, with no signs of wear may be reconditioned into refurbished textile. Its achievability has been proven by The Renewal Workshop, a company that "takes discarded apparel and textiles and turns them into Renewed Apparel, upcycled materials or recycling feedstock" guaranteeing no signs of "stains, pilling, fading, fabric fatigue or overall signs of exterior wear." (The renewal workshop, 2018). To be able to refurbish the textile, it should be detachable, washable and separatable from any other inner parts.

Closed/Open-loop recycling:

Textile that is not refurbishable is best to be recycled, preferably into new yarn for the hand cart.

There are two types of textile recycling: 'mechanical recycling' and 'chemical recycling'. Both types of recycling have its pros and cons and their suitability also depends on the type of textile material. (See Appendix A11 for more information on plastic and textile recycling).

Furthermore, it is assumed that a possible cushion inside the hand cart textile cannot be refurbished/remanufactured due to emotional reasons and reasons of hygiene, and is, therefore, to be recycled.

In conclusion, the defined end-of-life scenarios for the chassis and textile provide promising results and can ensure the best value capture. However, apart from this, also the materials should be defined that can best achieve these scenarios. Therefore, Section 2.3.2 further explores and defines the hand cart materials, while taking into account the defined scenarios.

2.3.4 Current environmental impact

Defining the best end-of-life scenario for the future Greentom Hand Cart is not enough to make the product count as sustainable. To know how sustainable a product truly is, the environmental impact of all aspects of the product is interesting to analyse: from the materials used, up to production, transport, product use, and finally end-of-life. The stages of a product are part of a cycle called the product life cycle (PLC), as shown in Figure 33. The current environmental impact of each stage of the Greentom Classic (see Figure 35) is therefore analysed by means of a Fast-track Life Cycle Analysis (LCA) after which the results are used as a benchmark to be improved or strived for when designing the Greentom Hand Cart. Next, the current impact is compared with the impact in the future system in Section 2.3.5. Confidential Appendix CA2.2 shows the full Excel sheet of the used data and results of the Fast-track LCA.

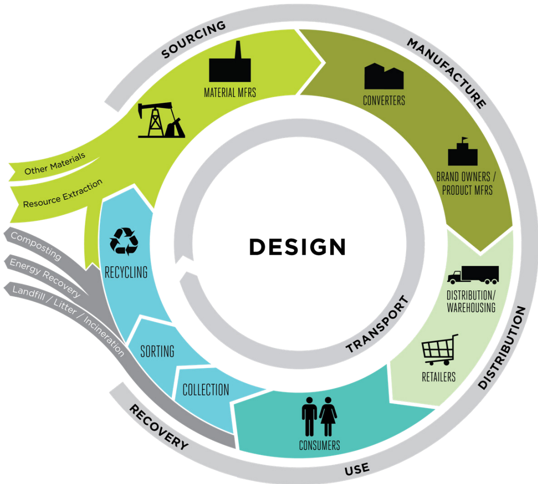


Figure 33 - A Product Life Cycle (Greenblue, n.d)

2.3.4.1 Fast-track LCA

1. System boundaries

Part of the LCA, it to first communicate what (sub) stages of the PLC are exactly included, and what is left out. This is done by defining the system boundaries of the Greentom Classic.

As can be seen in the system tree diagram of the Greentom Classic (Figure 34), the boundaries of the system are indicated with a broken line, with boxes marked in grey laying outside the system boundary. The packaging of the product as well as the use phase of the system is not included since focussing on reducing a user's cleaning behaviour or improving the product packaging lies outside the scope for designing the future Greentom product.

2. Functional Unit

A functional unit is "a quantified description of the performance requirements that the product system fulfils". (Consequential-LCA, 2015) The functional unit in the case of the Greentom Classic is defined as: "Transporting a child up to six years old in Europe, three times a week, with an estimated product life span of for five years."

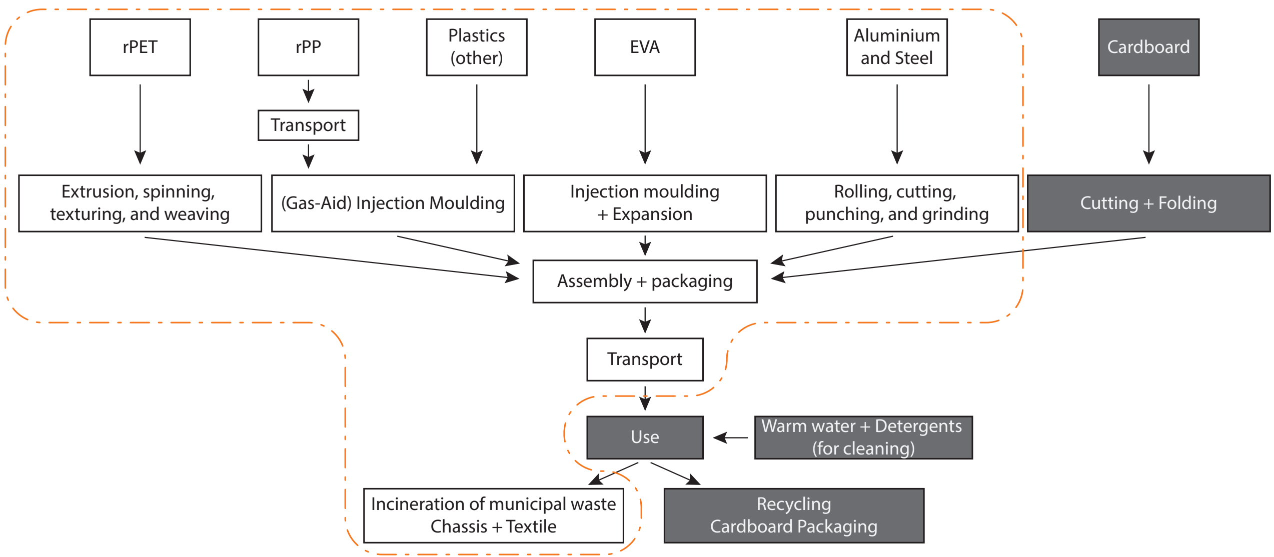


Figure 34 - System tree diagram with indicated boundary for the Greentom Classic LCA

3. Quantification

Regarding transport, the distance of the transported material and parts is calculated based on the data from the product life cycle system regarding the location of different stakeholders (see Section 2.3.2).

Regarding the parts of the Greentom Classic, the product is split into its Chassis and Classic Seat for part identification. Each part of the Chassis is identified using part data sheets provided by Greentom (called the bill of materials, in short BOM). Since no BOM is available for the Classic Seat, an old design of the Classic Seat is taken apart for part identification. After identifying all parts, the parts are numbered and named. See Confidential Appendix CA2.1 for the BOM for both the Chassis and the Classic Seat.

Furthermore, the weight of the parts is defined. For the Chassis parts, an Excel sheet provided by Greentom is consulted. Since no weight data on the Classic Seat is available, all its identified parts are weighed.

Finally, the type of material per identified part is defined. For the Chassis, the previously mentioned sheet is consulted. Since no data on the part material of the Classic Seat is available, except for the outer rPET textile, each part is analysed with material determination methods to define the material (see Confidential Appendix CA2.4).

Figure 35 - The Greentom Classic

4. Environmental impact indicators

The LCA can display a product's environmental burden with different 'indicators', depending on which burden(s) one wants to assess. Two types of indicators and their benefits are highlighted below:

Carbon footprint

The global warming based indicator called "*carbon footprint*" is expressed in kg CO_2 equivalent per kilogram material. The word equivalent indicates that this number is also taking other greenhouse gasses into account such as methane (Vogtländer, 2010). This indicator is good to use if only the carbon footprint of a product life cycle is wished to be highlighted. However, it is less suitable for products in a circular economy since it does not take into account the impact of material depletion that recycled materials - seemingly having a higher carbon footprint due to the carbon footprint of recycling - help to reduce.

Eco-costs

The prevention-based indicator called "*eco-costs*" is expressed in terms of euros per kg material: hidden obligations or "costs that should be made to reduce the [caused] environmental pollution and depletion" (Ecocostsvalue, n.d. (a)). The total eco-costs consist of the summation of eco-costs of human health (sum of carcinogens, summer smog, fine dust), eco-costs of ecosystems (sum of acidification, eutrophication, ecotoxicity), eco-costs of resource depletion (sum of abiotic depletion, land-use, water, and land-fill), and eco-costs of global warming (sum of CO_2 and other greenhouse gases). (Ecocostsvalue, n.d. (a))

Thus, eco-costs not only take into account the carbon footprint of a product but also other equally-important burdens a product life cycle might cause. Furthermore, the environmental impact is expressed in euros that could be invested to reduce the caused environmental impact, which is a better conceivable value than kg CO_2 equivalent. Therefore, eco-costs are chosen to be used to express the results in the LCA.

2.3.4.2 Results Fast-track LCA

Based on the results from the Fast-track LCA, the following can be concluded:

Impact per stage

Figure 36 shows that the largest product life cycle stage impact in percentage of the Greentom Classic it that of the Material stage and the Production stage, rather than the Transport or End-of-Life. Therefore, it is wise to focus on reducing the impact of especially those two stages.

However, it should be noted that the End-of-Life stage cannot be disregarded, even though the impact of the End-of-Life stage seems to be low. The reason for the seemingly low impact is because the LCA excludes recycled materials from the End-of-Life stage in its analysis, to avoid an unjust 'double-positive' effect when a recycled material would again be recycled is evaded. However this would be logical for a cradle-to-grave product, it means that the LCA is not well suitable for analysing the impact of circular systems, but that it is important to do take the End-of-Life scenario of recycled materials into account to ensure a sustainable product.

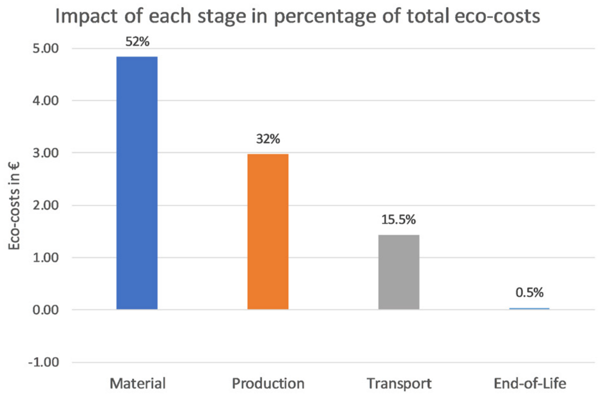


Figure 36 - Impact of each product life cycle stage

Material stage impact

Regarding the material stage impact, Figure 37 shows that rPP (91% of the Chassis weight being the main material) and rPET (55% of the Classic Seat weight being the main material) have the same relatively low impact per kg material compared to the other used materials in the Greentom Classic. Furthermore, the figure shows that many materials have a higher impact per kg material than rPP and rPET whilst also significantly contributing as impactful Chassis material (as shown in Figure 38) or impactful Classic Seat material (as shown in Figure 39).

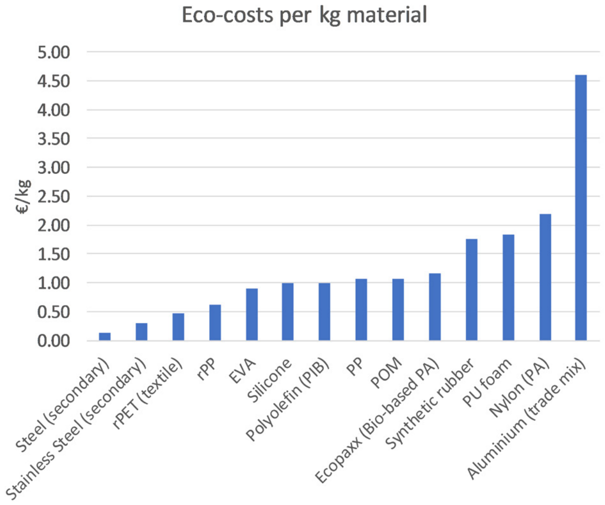


Figure 37 - Impact per kg material used in the Greentom Classic

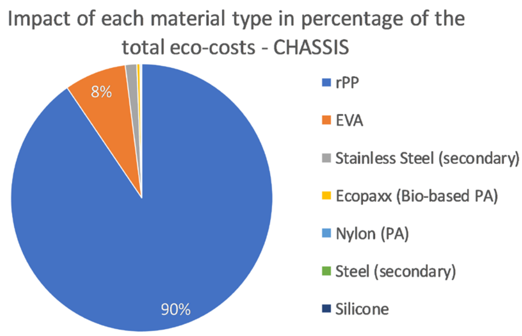


Figure 38 - Impact of each material in the Chassis

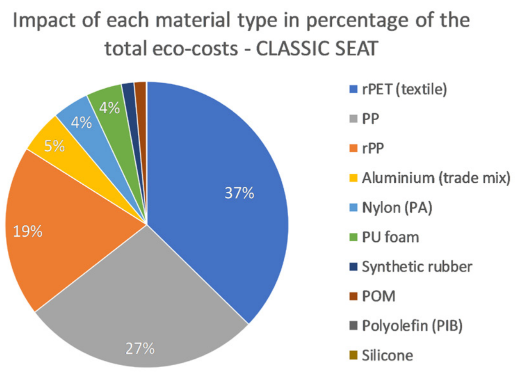


Figure 39 - Impact of each material in the Classic Seat

These materials that have a higher impact per kg material than the main materials rPP and rPET could be substituted for a less impactful, recyclable material from a recycled source. Therefore, it is concluded that EVA which is used as the tyre material (8% of the total Chassis eco-costs), PP which is used in parts of the Classic Seat (27% of the total Classic Seat eco-costs), Aluminium which is used inside the recline lock (5% of the total Classic Seat eco-costs), Nylon which is the material of the velcro (4% of the total Classic Seat eco-costs), and PU foam which is used as the cushioning material (4% of the total Classic Seat eco-costs) can be substituted for a different, more sustainable material if possible.

Lastly, it is concluded that materials to look into as possible suitable materials are Steel (secondary) and Stainless Steel (secondary). Figure 37 shows that Steel (secondary) as well as Stainless Steel (secondary) have the lowest relative environmental impact per kg. Even if secondary steel might not be available as a material for production, then the average market mix steel still has a relatively low impact per kg, being 0.68 €/kg (Vogtländer, 2015), making it a possible suitable material.

It should be noted the price and material properties are to be taken into account when considering alternative materials. Therefore, Section 2.3.6 further compares possible suitable materials based on these results.

Production stage impact

Regarding production stage impact, Figure 40 shows that spinning, texturing, and weaving the textile has a relatively large impact per kg produced material which is almost twice as high compared to the impact per kg produced material for injection moulding, whilst both production processes also account for the largest percentage of total production impact as seen in Figure 41. Since zinc plating accounts for less than 0.05% of the production impact of the Greentom Classic, it can be concluded that the amount of needed textile may be kept to a minimum when designing for it, whilst not compensating for functionality.

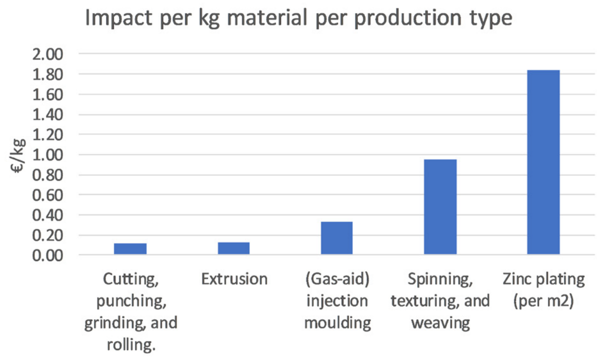


Figure 40 - Impact per kg produced material per production type

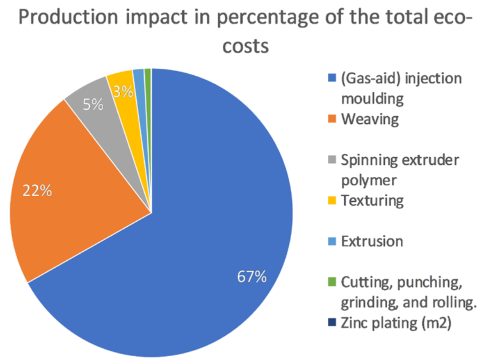


Figure 41 - Impact of each production process in the Greentom Classic

Transportation stage impact

Regarding the transportation stage, it can be concluded that a Truck + container (28 tons) has a higher impact per tkm than a container ship (see Confidential Appendix CA2.3). Therefore, when trucks are needed for transportation, the Hand Cart can best be designed in such a way that it occupies as less space to fit more products per truck.

It should be noted that a different end-of-life scenario with a take-back system instead of cradle-to-grave scenario will also mean that the transportation impact will be built up differently.

End-of-Life stage impact

Even though a small percentage of the Greentom Classic materials are from a non-recycled source, the environmental burden of the materials could be further reduced by substituting virgin materials with those that are recyclable, of a recycled source, and have eco-costs equal or lower than that the substituted material.

The future take-back system is promising when it ensures that materials can be reused instead of incinerated. Even though metals are recovered after municipal incineration for recycling, this percentage is only 20% in the case of aluminium. (Biganzoli & Grosso, 2013) Therefore, it is assumed that all material recovery, including metal, will be higher with a right take-back system in place than after incineration with municipal waste.

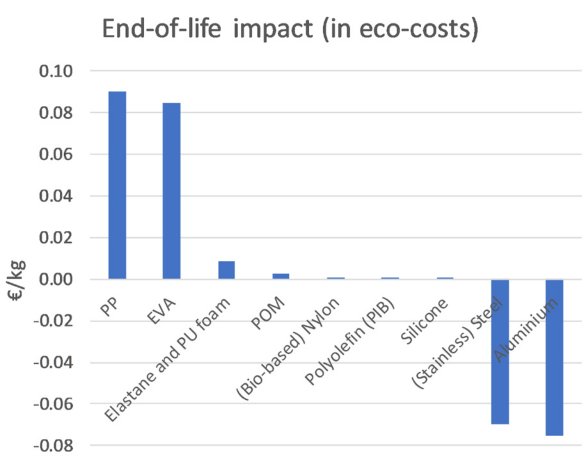


Figure 42 - End-of-Life impact of virgin materials

2.3.5 Future environmental impact

A future take-back and remanufacturing/refurbishment system having higher eco-costs (for example due to increased transportation and/or production impact) than the current linear, cradle-to-incineration system would of course not be desirable for Greentom or the environment. Therefore, to see if the future take-back system is environmentally beneficial compared to the current system, the product's life cycle impact of the current and future system is compared in terms of eco-costs. To do so, the calculated eco-costs of the current situation (Confidential Appendix CA2.2) are used as a base for calculating the future impact of the product in a refurbishment end-of-life scenario (not yet with alternative materials implemented, as these are selected in the next section(!)). The results of the comparison are used as an indication for the probable reduction of environmental impact in a refurbishment end-of-life scenario of a similar product, the Greentom Hand Cart.

The future refurbishment scenario is defined as three possible situations.

1. Best-case scenario: 90% of products get returned and both the textiles and chassis get 80% refurbished. 20% gets (chemically) recycled.
2. 90% of products get returned and 80% of the chassis get refurbished. 100% of the textiles gets incinerated and 20% of the chassis get recycled.
3. Worst-case scenario: 50% of products get returned and 50% of the chassis get refurbished. 100% of the textiles get incinerated and 50% of the chassis get recycled.

For the calculation of the impact in future scenarios, it is assumed that:

- Since refurbished parts are sourced from collected products, the percentage refurbished rPP and/or rPET expressed in kg material is subtracted from the material, production, and transport stage impact.
- Production methods for refurbishment are added to the LCA with their impact, being the application of heat with a heat gun to aesthetically damaged parts.
- The transport from customers to Greentom is

added to the LCA with the impact of 350 km (return scenario in the Netherlands) with a truck + trailer.

- The end-of-life scenarios for other materials than virgin materials is not taken into account due to the limitations of the LCA for circular scenarios.

Figure 43 shows the impact of the product life cycle stages for the current scenario and for the future refurbishment scenario. The figure concludes that the future system with a refurbished Greentom Classic has a 50% lower impact on average than the current scenario. Figure 44 shows that the worst-case scenario also has a lower environmental impact than the current scenario. Thus, the new, future system is attractive for Greentom, if costs to implement the system are lower than the gained costs in a refurbishment system (calculated in Confidential Appendix CA7). Confidential Appendix CA2.3 shows the calculation method and the LCA of the Greentom Classic in this future scenario.

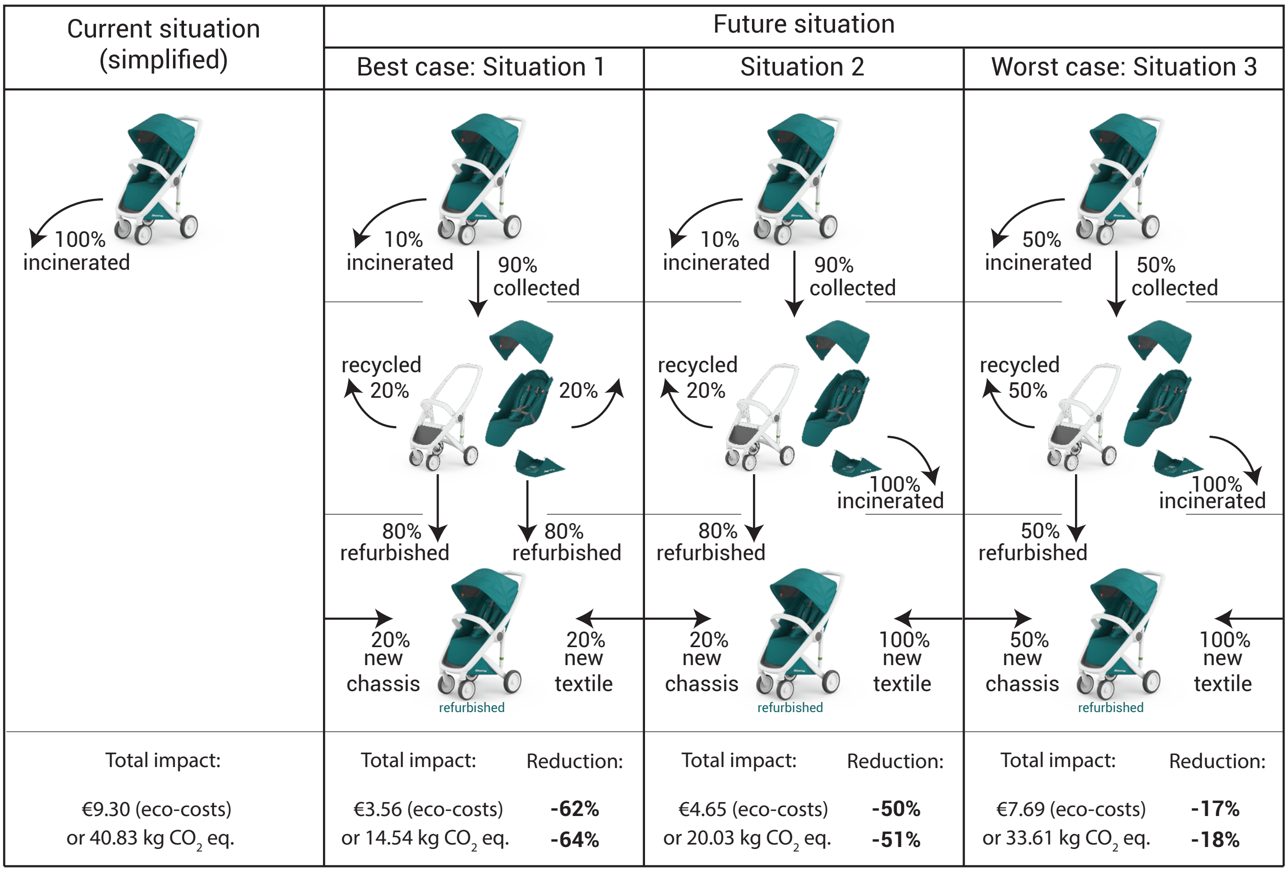


Figure 43 - Environmental impact in eco-costs of the Greentom Classic in its current system and in the defined future system

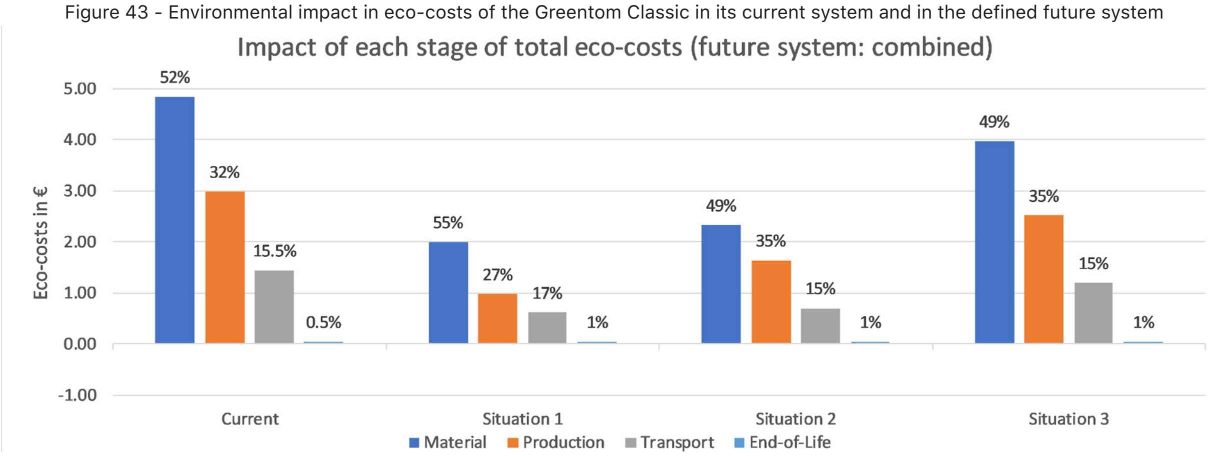


Figure 44 - Eco-costs of Greentom Classic in current system

2.3.6 Material Selection

In the previous section, a new, future, environmentally beneficial take-back system with a suitable end-of-life for the rigid chassis parts and the textile part of the Greentom Hand Cart is established. Furthermore, it is concluded in Section 2.3.4.2 which materials may be substituted for a different, more sustainable material if possible. This section compares possibly suitable materials based to use in the Greentom Hand Cart.

2.3.6.1 Greentom's current rPP supplier

Most plastics are downcycled, making plastic granulate from a downcycled source less attractive due to their worsened properties and aesthetics.

However, Quality Circular Polymers (QCP), Greentom's partner for its rPP plastic granulate produces plastic granulates that, on the contrary, can be used in high-end application. This is possible since they claim to use "the latest technological and in-house innovation in the field of [plastic grade] recipe development, extrusion, and purification technology", making their material an attractive recycled alternative for high-end applications to virgin plastics. (QCPolymers, n.d.)

Currently, QCP produces r(HD)PE and rPP granulates from sorted post-consumer waste provided by SUEZ, the Rotterdam-based plastic sorting and resource management company. Not only is QCP able to produce recycled granulate suitable for high-end applications, but, they can tweak the granulate recipe to company specification. Regarding aesthetics, QCP is able to make fully white recycled granulate without compromising on the recycled content by selecting white only sorted post-consumer plastic flakes, on the initiative of Greentom. (QCPolymers, n.d. b; Sittardgeleen, 2018)

This makes their recycled plastic granulate both a suitable, aesthetically pleasing, and sustainable recycled source material, possible for Greentom carts transporting children.

2.3.6.2 Chassis

It is concluded in Section 2.3.4.2 that EVA, PP, Aluminium, Nylon, and PU foam are best to be substituted for those materials suitable for the same application that are recyclable, of a recycled source, and having the same or lower environmental impact as rPP and rPET to serve as a better example of possible materials for the Greentom Hand Cart.

In the case of the Chassis of the Hand Cart, it can thus be evaluated for which materials those with a higher environmental impact such as EVA (for the tyres) may be substituted, yet also whether the currently used rPP is the best suitable material, and whether materials that have a lower or equal environmental impact such as Stainless Steel (sec.) and Steel (average trade mix) could be suitable alternative main materials. (See Section 2.3.6.4 for an indication of alternatives for EVA).

To do so, a list of possible suitable materials is made with the help of the material and process database software CES EduPack. A comparison is done by plotting the materials' yield strength and costs against each other on a grid. 'Yield strength', since the material should ensure resisting an equal or greater amount of stress for the same thickness compared to the currently used rPP grade before the material would plastically deform. 'Costs', since the material should preferably cost less than the currently used rPP grade in order to stay true to one of the product requirements being that the product "should be affordable" (see Section 2.4).

Next, the materials are narrowed down by eliminating those not fitting further criteria. Further criteria that the materials should comply with are that the material should be recyclable. The material should be suitable to use in (fresh) water, the material should be suitable to use in soil (clay), and the could not be brittle (glass) which would all not be suitable for applications in a hand cart used outside. This resulted in the plot as shown in Figure 45 which shows a narrowed down selection of possibly suitable materials for the chassis, excluding materials such as low alloy steel, starch-based thermoplastics (TPS), Cellulose polymers (CA), and Polylactide (PLA). Appendix A12 gives a detailed description of the material elimination process.

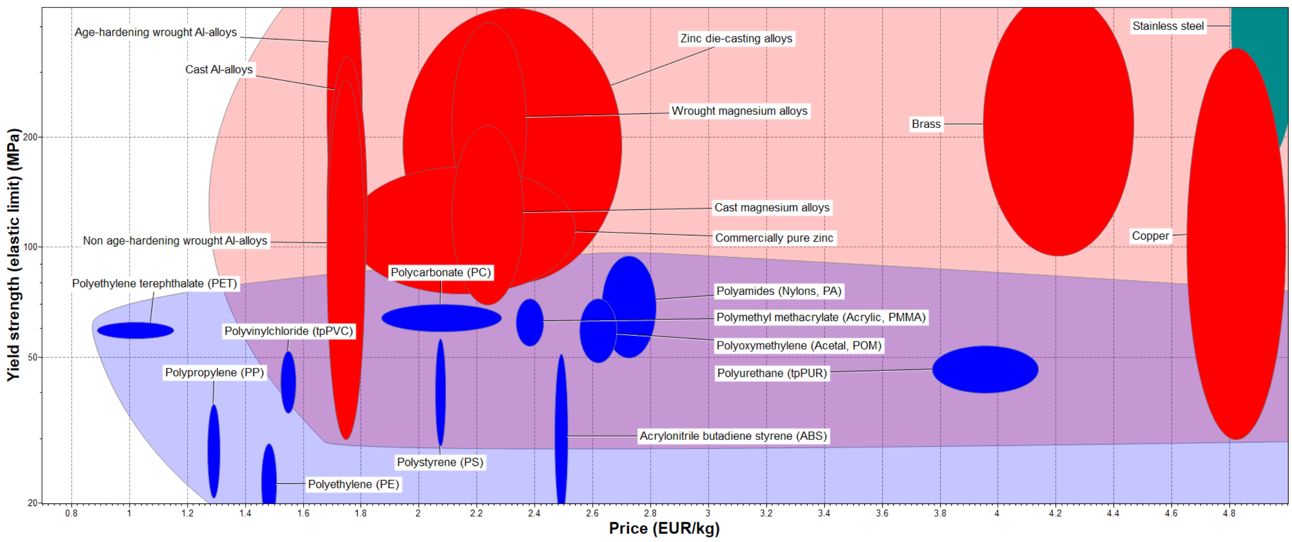


Figure 45 - Global comparison materials for Chassis after added criteria. CES EduPack (2018)

Next, this selection is further narrowed down by defining unsuitable materials, discussed in detail in Appendix A12.1. Only recycled variants are shown, since it is concluded in Section 2.3.4.2 that the materials should not only be recyclable but also from a recycled source to have a reduced environmental impact. The narrowed down selection of materials are each evaluated on their eco-costs (Figure 46), density (Figure 47), and price (Figure 48).

It can be concluded from Figure 46 and Figure 47 that all indicated materials with lower eco-costs than rPP also have higher densities. Furthermore, all material types except for ABS, PS, and PE also have higher yield strengths than rPP (as shown in Figure 45), which means that, in combination with a high Young's modulus yet relatively low density, they could achieve the same strength as rPP but with a thinner wall thickness, reducing weight and costs of that material.

Regarding stainless steel and magnesium, extruding these materials as tubes with a thinner wall-thickness could make the structure light, inexpensive, and have lower eco-costs compared to rPP. However, since this would also result in a product with an entire different distinctive form family, and casting the metals in more organic forms is a much more complex and time-intensive than the current chassis blow-mould plastic injection process, it is concluded that these materials would not be suitable for the chassis of the Greentom Hand Cart.

It is concluded that rPP remains the best material for the chassis of the Greentom Hand Cart due to having the lowest costs (as shown in Figure 48), lowest density (as shown in Figure 47), although highest eco-costs compared to the other materials (as shown in Figure 46). Furthermore, straight stainless steel or magnesium tubes would not fit the Greentom form family, rPET -although the least expensive material as shown in Figure 48- is not suitable for structural beam applications as it is typically used as film, fittings, tapes, containers, or ovenproof cookwares, assumingly due to cheaper producibility related to a lower needed melting temperature (CES 2019), and other materials with lower eco-costs but higher yield strength as in the case of POM, PMMA, Nylon (PA) and PC would have a higher weight and costs if they would not achieve a significantly thinner wall thickness compared to rPP beams. Furthermore, it should be kept in mind that the collaboration with QCP shows many benefits such as achieving white recycled material colour, local materials, and material to specification, that other recycled granulate providers might not have.

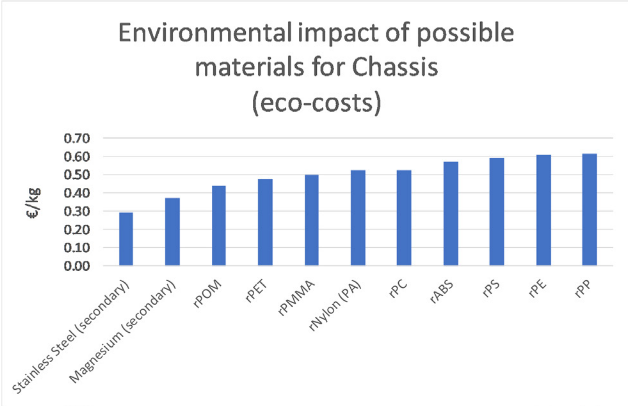


Figure 46 - Carbon footprint of selected Chassis materials (Idemat, 2015)

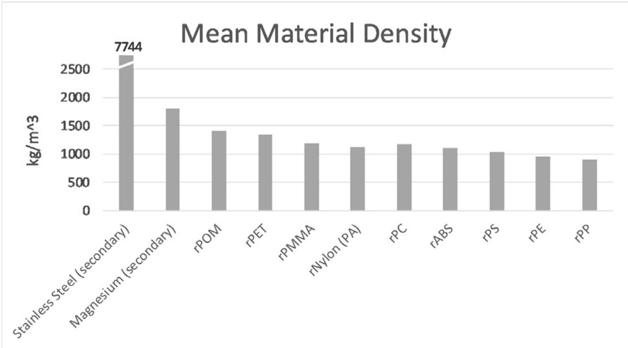


Figure 47 - Mean material density of selected Chassis materials (CES EduPack, 2018)

Figure 48 - Mean material price of selected Chassis materials (CES EduPack, 2018)

2.3.6.3 Textiles

In the case of the Textile of the Hand Cart, it can be evaluated for which materials those with a higher environmental impact such as PU (for the cushioning) could be substituted that are also recyclable, of a recycled source, and have the same or lower environmental impact than rPET, but also whether the currently used rPET is the best suitable material compared to other possibly suitable materials. (See Section 2.3.6.4 for an indication of an alternative for PU.)

Suitable alternatives to rPET textile would best be from a recycled or renewable source, and could be recyclable or alternatively compostable (which is better than incineration although loses potential value capture compared to recycling (Dr. ir. Bouwhuis, personal communication, 2019). Since mechanical recycling of textile results in low-quality textile, unless mixed with 80% virgin fibre (Payne, A, 2015), chemically recycled textile is concluded to be more suitable for woven textile applications due to being able to achieve a quality close to its original feed properties opposed to mechanical recycling. (Shen, Worrell, & Patel, 2010. Even though chemical recycling has a twice as big carbon footprint compared to mechanical recycling (see Appendix A11.2), it is assumed that it has lower eco-costs due to eliminating material depletion.

Therefore, possible materials that are compared with rPET textile (recyclable and sourced from recycled post-consumer PET bottles) are: Tencel Austria textile (a biodegradable and compostable textile made out of dissolved pulp from cellulose from certified renewable forests while managing a closed-loop recycling of the used chemicals during production (Lenzing, 2019; Tencel, 2018; Lenzing AG, n.d.; Lenzing Group, 2019 [VIDEO])), and SaXcell textile (a chemically recyclable material made out of chemically recycled post-consumer cotton (Huijerman, A.,2018; Boer group recycling solutions, 2019; Oelerig, J., 2016; Dr. ir. Bouwhuis, personal communication, 2019. See Appendix A11.2 for further details regarding these selected materials and their processing.

Environmental Impact

Based on the combined results as discussed in Appendix A12.2 regarding Tencel Austria, rPET, and SaXcell, Figure 49 is created showing their carbon footprint and eco-costs. Apart from these materials, added materials in the comparison to act as a reference are rCA (cellulose acetate which like Tencel Austria and Lenzing Viscose Asia is a cellulose-based material), virgin BioCotton (since this is the base of SaXcell material), and Lenzing Viscose Asia (which SaXcell CEO and textile technology expert Dr. ir. Gerrit Bouwman assumingly weighed SaXcell up against.

It is important to note that these numbers show the carbon footprint of the materials up to fibre, but not up to textile. The carbon footprint of rCA, rPET, and BioCotton is that of the recycled material itself before being turned into fibre.

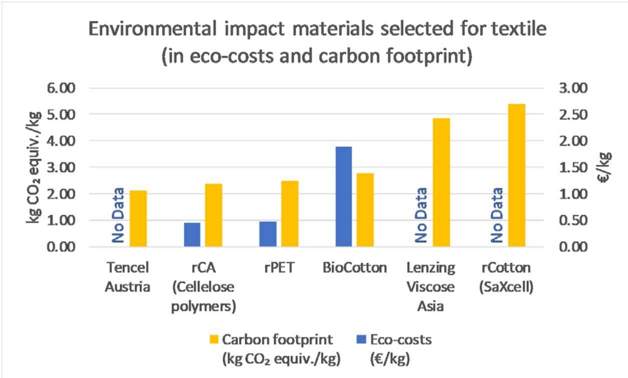


Figure 49 - Environmental impact of selected material and reference

It is concluded, based on Figure 49, that no good estimation could be made on which type of material, be it Tencel Austria or SaXcell, would be best for the environment compared to rPET. This is due to having only data regarding the carbon footprint being available. However, for a true indication of the environmental impact of the materials data regarding their eco-costs are needed to show the entire burden of the material in terms of impact on human health, ecosystems, resource depletion, and global warming of which the carbon footprint in kg CO_2 equ./kg is part of.

To still be able to well compare the materials, other different properties are compared, including water absorption and costs.

Water absorption

An important material property that is taken into account in the comparison of the materials is the water absorption of the rPET (Polyester), SaXcell (rCotton), and Tencel (Austria). Figure 50 shows a graph referenced by (Lorpen, 2019) and (Lenzing fibres, 2005). The figure shows that Tencel absorbs 12 times as much water as polyester, and cotton absorbs 3 times as much water as polyester (rPET).

Figure 50 - Increase of moisture in a textile when the textile is moved from a relative humidity of 65% to a relative humidity of 100%. The moisture refers to the weight of the dry textile.(Lorpen, 2019) (Lenzing fibres, 2005)

It is concluded from Figure 50 that Tencel (Austria) shows to be unsuitable for applications of the hand cart in a moist environment or under rain, since the material would have to dry 12 times longer than polyester (rPET). Cotton (SaXcell) would have to dry 3 times as long as polyester, making it also less suitable for the hand cart than rPET textile.

Costs

Since no partnership had thus far been found by Greentom to chemically recycle rPET textile after use (when refurbishing is not possible), SaXcell textile could be a good alternative since a local and circular partnership is possible. Whether the benefit of this partnership weighs up to the material drying three times as long as rPET textile could be evaluated by comparing the costs of the materials.

According to Dr. ir. Bouwhuis, SaXcell textile has similar costs to Tencel (assumed to be Lenzing Viscose Asia (Figure 49), as mentioned in Appendix A12.2). Virgin cotton has half the price of SaXcell or Tencel. The relative costs of rPET textile to these materials could not be defined since rPET prices differ heavily per producer.

It should be noted that chemically recycling textile suitable for the process into re-usable fibres would only be cost-effective starting at 10.000 tonnes of the same material (Dr. ir. Bouwhuis, personal communication, 2019), which is an unachievable amount of textile to produce for Greentom individually. Therefore, a local chemical recycling partner producing and chemically recycling the same type of textile is best to be consulted to do so cost-effectively. (Greenblue, 2017)

It is concluded that, since the price ration between rPET and SaXcell is unknown, no conclusion could be made on whether SaXcell would be a better alternative to rPET textile regarding its costs. Therefore, since both SaXcell textile and rPET material would have to be chemically recycled, but SaXcell absorbs three times as much water as rPET, it is wise to keep rPET as the textile material and to continue searching for local chemical recycling partners to recycle the rPET with into new rPET fibre.

2.3.6.4 Indications - Tyres and cushioning

Tyre material

As indicated in Section 2.3.4.2, the materials that are best to be substituted due to having higher eco-costs than rPP is EVA foam, used as the material for the tyres.

EVA foam can be recycled into new foam, but is essentially downcycled, comprised of multiple shredded foam parts (such as is also done with PU foam as seen in Figure 51), rather than recycled into a uniform foam usable for the same original application as a tyre (Intcorecycling, 2015). As also is concluded that a Greentom tyre cannot be refurbished after functional degradation (Section 2.3.3), a material for the tyres may be used from a recycled source which can be recycled into a part with the same functionality, which is important to be researched further.

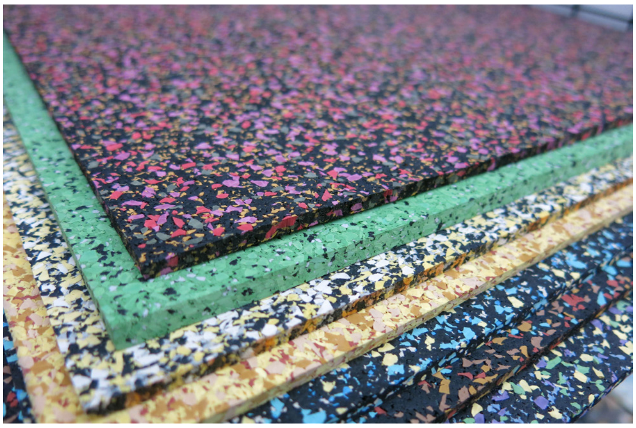


Figure 51 - Downcycled PU foam (Contractoptions, n.d.)

Figure 52 - Biodegradable 'Growfoam' used to cultivate seedlings (Agro-chemie, 2019)

Figure 53 - Plusfoam - recyclable foam (Aroyan, 2014)

Cushioning

As indicated in Section 2.3.4.2, the material that is best to be substituted due to having higher eco-costs than rPET is PU foam, used as the cushioning in the seat.

Since the cushioning cannot be refurbished due to emotional and hygienic reasons (Section 2.3.3), the cushioning can best be recycled. Thermoplastic PUs can be recycled, thermosetting PUs cannot. (CES EduPack, 2018) Thermoset PU foam is the most commonly encountered foam (Ebnesajjad, S., 2014), and assumed to be used in the Classic Seat. Therefore, the material is not recyclable and may be substituted for a material which is recyclable, from a recycled source, and has similar or lower eco-costs to rPET.

Possible alternatives to PU foam are compostable foams such as 'Growfoam' made of Polyhydroxyalkanoate (PHA) natural foam by Foamplant produced in the Netherlands (Figure 52) (Foamplant, 2018), and 100% recyclable foam such as 'Plusfoam' produced in Germany (Figure 53), which is a petrochemical based classified foam (Aroyan, 2014). However, in order to conclude whether these materials have favourable eco-costs and attractive costs compared to PU foam, further research on these indications is important to do.

2.3.7 Conclusion Sustainability

It is concluded from Greentom's current linear system, in which 98% of its products get incinerated as household waste, that it is wise to change this system into a circular one, incentifying the return after use by offering a compensation for sending back the product free-of-charge.

After subjecting the Greentom Classic -similar in its build to the future Greentom Hand Cart- to the Circularity Calculator tool, it is concluded that the preferred end-of-lives for the Greentom Hand Cart parts are: 1) refurbishment/remanufacturing for the Chassis and the Textile where only aesthetic wear is present (Figure 54), 2) closed-loop recycling for the Chassis where refurbishment is not possible due to functional break or wear (Figure 54), 3) chemical recycling for the Textile where refurbishment is not possible due to irreparable signs of exterior wear, 4) closed-loop recycling for the tyres since they are assumed to be too functionally worn after use to be refurbished/remanufactured, and 5) recycling or composting for the cushioning inside the textile since it is assumed not to be suitable for refurbishment/remanufacturing after use due to emotional reasons and reasons of hygiene.

In the best-case scenario in which 90% of the products are collected and 80% of the chassis and textile is refurbished, it is calculated that a product with this circular system for a second product life cycle results in 62% lower eco-costs and 64% lower carbon footprint and a value capture of 71%€, or respectively 50% and 51% if only 80% of the chassis and not the textile gets refurbished. Furthermore, in terms of economic costs, it is calculated that 97% of the total product value could potentially be captured with this circular system. However, further research in the additional economic costs of the new investments for the circular system is important to do.

The Fast-track Life Cycle Analysis on the Greentom Classic concludes that rPP and rPET are one of the least impactful materials inside the product apart from Stainless Steel (secondary) and Steel (average market mix). After a thorough comparison of suitable main materials for the Chassis and the Textile, it is concluded that rPP remains the best suitable material for the Chassis of the Greentom Hand Cart and rPET textile remains the best suitable material for the textile. Alternative, more sustainable materials for the tyres, cushioning, and velcro may be defined with additional research, but shows that possible closed-loop recyclable or compostable materials are available.

Figure 54 - A refurbishable part showing scratches as aesthetic wear (Keijsers, 2013)

Figure 55 - A part unsuitable for refurbishment, showing functional breakage (ProvideYourOwn, n.d.)

2.4 Conclusions - Research

Based on the conclusions of each of the research topics (Section 2.1, 2.2, and 2.3), the following combined list of requirements and wishes is created. This list will serve as a checklist for concepts to comply to and to evaluate concepts with. See Appendix A13 for the full list of requirements and wishes.

Design Requirements

The product should be suitable for parents with up to three children:

- The product should be compact (when folded).
  - Fitting the trunk of an average car.
- The product should have a large inner volume to fit up to three 6-year-old children.
- The product should be comfortable for passengers.
  - The product should have an integrated plate or cushioning to make the support structure more comfortable.
- The product should be safe.
  - The product should comply with safety norm EN 1888-parts 1 and 2 if a push bar would be added, requiring safety straps, a hand brake or foot brake.
  - The product should have a support structure underneath the textile to support the weight of the content/children.
  - The product should not be able to tip over during use by placing four wheels outside the border where external forces could act on.

The product should be easy to use:

- The product should steer well/be well manoeuvrable
  - The product should have big, broad wheels to be suitable for the beach, comparable in size to the largest existing hand cart wheels of competing, foldable hand carts.
  - The product should have a push bar.
    - This requires less force than a pull bar, allows a view on the content/children, is better for the posture, and enables the cart to stay in the middle instead of on the side of the user. Due to these reasons, another benefit is that users might also use the hand cart in more crowded areas such as the town/village, or at a festival, or on rougher terrain such as the forest or park.
  - The product should have its stationary wheels at the near side of the user when pushing and on the far side when pulling.
  - The product should be able to be lifted by a user with average strength for transport.
- The product should not contain any small loose parts to prevent users from losing them.
- The product's (un)folding steps should be understandable for the user and executed without problem after explaining the steps once.

The product should be sustainable:

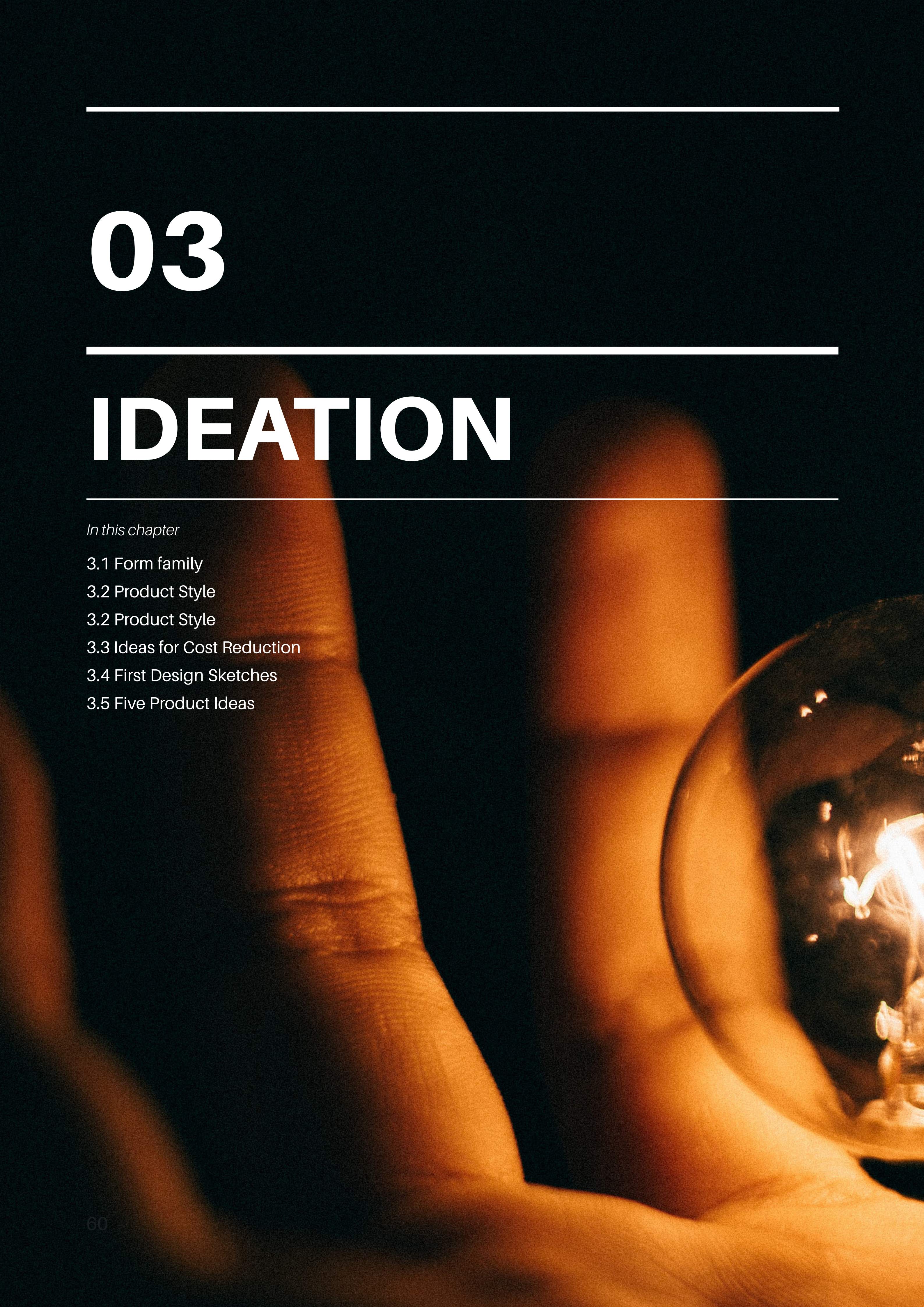
- The product should encourage customers to send it back to Greentom at its end-of-life to let it re-enter a circular product flow.
- The product should, at its end-of-life be suitable for remanufactured/refurbished, and (closed-loop) recycled where refurbishment is not anymore possible.

- The product chassis should be made out of high quality, >80% recycled PP. The product textile should be made out of rPET. The remaining parts should be made out of materials from a recycled source which are also (closed-loop) recyclable.

The product should be affordable:
- The product should have a selling price of up to €250.

The product should be attractive/aesthetically pleasing:
- The product should be innovative in style.

Wishes
- The product could have the possibility to attach a car seat.
- The product could have extra storing compartments.
- The product could have detachable textile (for easy cleaning).
- The product could have breaks to use the hand cart on slopes.
- The product could have the possibility to attach sun/rain protection.
- The product could be able to stand by itself when folded (to save occupied space).
- The product could have wheels that move together with a pull bar.



03

IDEATION

In this chapter

During the ideation phase, my goal is to select promising ideas. These ideas will then be further developed and evaluated during the conceptualization phase (Chapter 4).

This chapter describes the desired form family, product style, ideas to reduce costs, first product sketches, and five clear product ideas.

3.1 Form family

To make the Greentom Hand Cart a distinctive Greentom product, it may comply with the recognizable form of the Greentom brand, consequently triggering the same intended emotional experience the form family conveys (Core Jr., 2009). Therefore, the form characteristics of the current Greentom products as seen in Figure 56 are analysed after which a form family collage is made, as seen in Figure 57, to communicate the interpreted form family characteristics.

The collage in Figure 57 shows product forms with straight lines, soft bendings where needed for function, and a recognizable circular element its bottom half exposed at the joint. The form is kept simple with a form-follows-function attitude and looks spotless and clean. The colours are simple, soft, and not superfluous. The chassis distinguishes itself as a sturdy and safe frame protecting the soft textile it surrounds. Keywords derived from the form family collage are: *simple/no-nonsense, kind/caring/environmental friendly,* and *safe*.

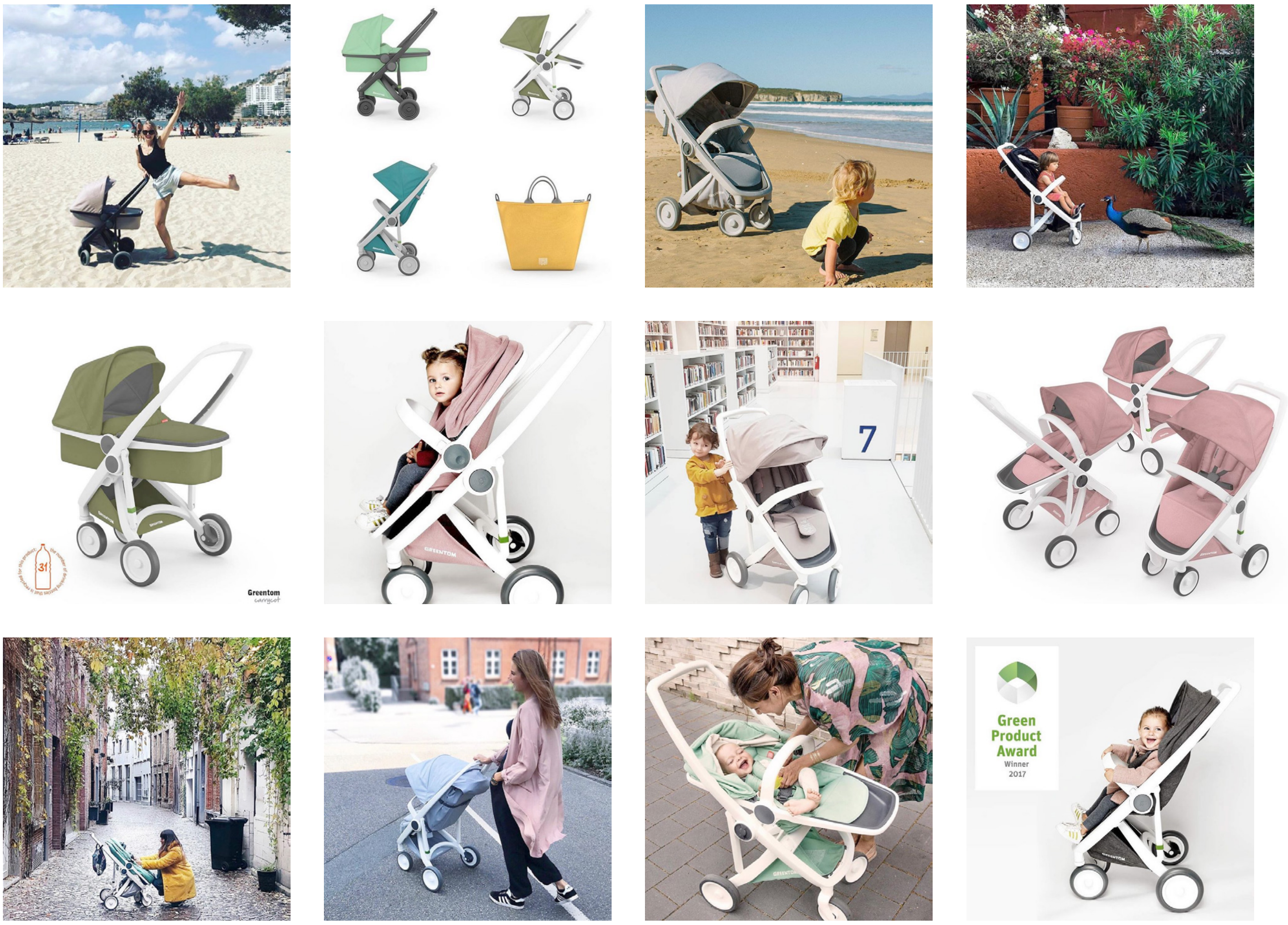


Figure 56 - Greentom products

Figure 57 - Form family collage

Furthermore, just like with the Greentom Classic, the Greentom Hand Cart may also enable users to attach existing Greentom accessories onto the hand cart, such as the Greentom Reversible, Greentom Car Seat, and the Greentom Carrycot (see Figure 58) to make it easy for users to use these accessories in both the Greentom hand cart and the Greentom strollers. Therefore, if the Greentom Hand Cart fits the defined Greentom form family, it will ensure that the accessories will visually fit the Greentom Hand Cart as well.

Figure 58 - Greentom interchangeable accessories: the Greentom Car Seat, the Greentom Carrycot, and the Greentom Reversible

3.2 Product Style

Apart from being part of the Greentom form family, the hand cart can also have its own, individual style within this form family to help it stand out attractively from other hand carts. Therefore, the individual Greentom Hand Cart style is defined in this section.

The individual hand cart style is defined by creating distinctive product-style keywords for the hand cart which also fit the Greentom form family characteristics (see previous section). These keywords are then expressed in collages to 1) set a basis for the symbolic form which can be translated in additional form characteristics within the product, and 2) express the emotion they contain which should be evoked within users by means of these form characteristics while keeping the form family characteristics in mind.

Four individual Greentom Hand Cart style keywords are defined, which are the following:

Care

Care, which is the same keyword as used in the form family, expresses a form that provides a safe environment, protecting passengers for rest and relaxation. (See Figure 59)

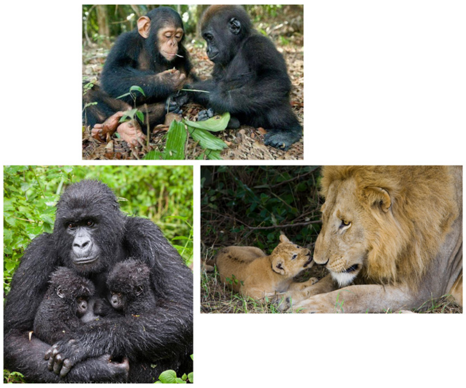


Figure 59 - Collage expressing care

Strength

Strength, which fits the form family keyword 'safety', is expressed as a robust (chassis) functioning trustworthingly, calmly, and without doubt: immovable when the breaks are engaged, and moving as soon as it is desired. (See Figure 61)

Figure 61 - Collage expressing strength

Proudness

Proudness, which fits the form family keyword 'simple/ no-nonsense' and 'environmentally friendly', expresses a 'chest-forward and head-up' like form which can be expressed in the chassis form: a hand cart to-be-seen. (See Figure 60)

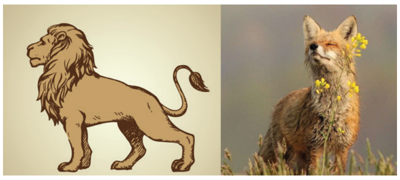


Figure 60 - Collage expressing proudness

Controlled playfulness

Controlled playfulness, which fits the form family keyword 'kind' and 'safety', expresses an environment which can be safely explored: enabling children to safely peek out of the hand cart and interact with the parents, other children, and the environment. (See Figure 62)

Figure 62 - Collage expressing playfulness in a controlled manner

3.3 Ideas for Cost Reduction

It is concluded in Section 2.1.2 that the Greentom Hand Cart should have a selling price between 100 and 250 euros. To ensure a production cost as low as possible, there are three ways this could be done:

1. **Using as few moulds as needed**: By designing the product in such a way that it needs the least different parts and the least complex parts, not only less (expensive) moulds are needed for the production of those parts, but (dis)assembly time would also be reduced. Therefore, designing a hand cart which is simple in its design yet functional (easy to use), -characteristics which are part of Greentom's mission (Section 1.2.2)-, this consequently means not only the reduction of tooling costs but also of labour costs.
2. **Using existing moulds**: By reusing moulds that are used for the Greentom Classic, such as the moulds for the tyres, rims, fasteners, swivels, and caps, the same produced parts can be used for the Greentom Hand Cart, eliminating the need for producing multiple new moulds. However, it is important to ensure that these parts used in the Greentom Classic are suitable for the Greentom Hand Cart. Research on the suitability of the Greentom Classic wheel sizes is done in Section 5.2.2.1.
3. **Refurbishment/remanufacturing existing parts**: As concluded in Section 2.3.3, remanufacturing the chassis as well as the textile of products returned after use could lead to 97% of the total product value (and therefore costs) potentially being captured in an ideal hypothetical scenario, since no new materials nor new production of the parts are needed when producing the refurbished/remanufactured product. The 3% of the captured value that is lost lies in the assembly stage: the product should be disassembled, cleaned, refurbished, and reassembled again for testing before being sold again. To ensure that the labour costs for doing so remain low, the product is best to be designed in such a way that (dis)assembly can be done easily and quickly. (Read more about design for (dis)assembly in Appendix A11.1).

3.4 First Design Sketches

With the defined form family, hand cart style, and cost reduction solutions in mind, multiple first hand cart ideas are generated in this section.

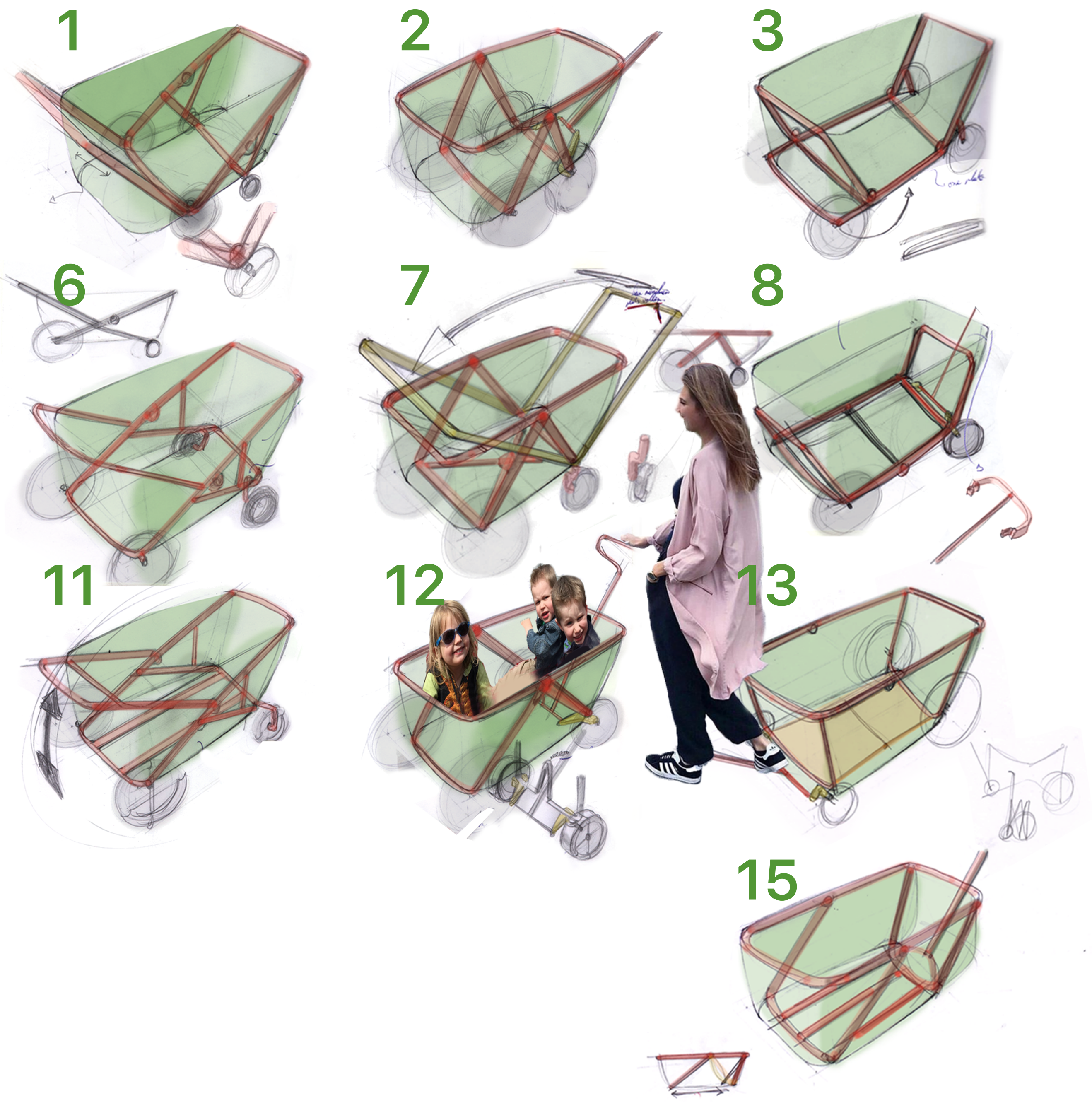
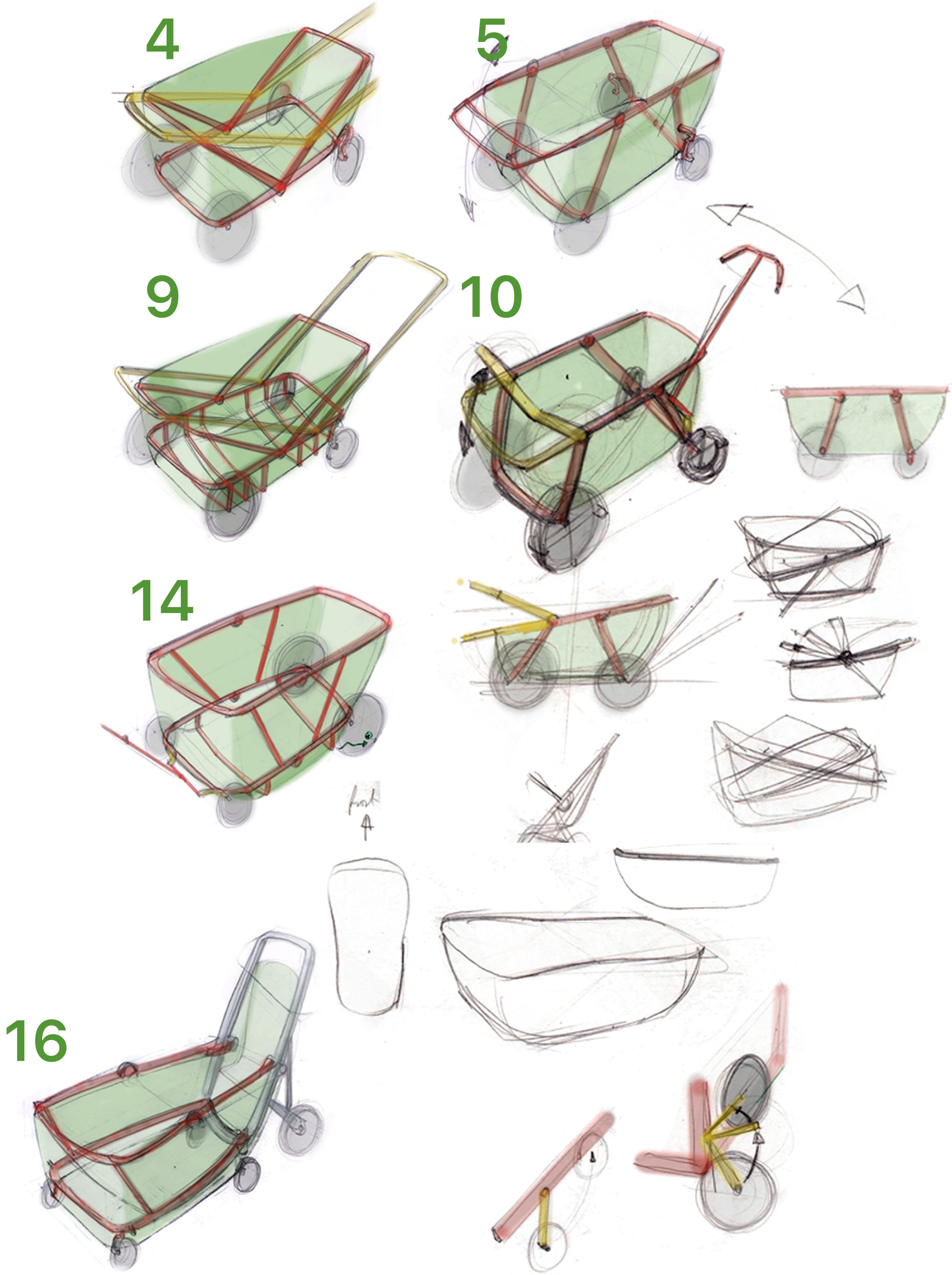


Figure 63 - Idea directions

The hand cart ideas are generated by means of several creative methods including brainwriting, PMI Method (Plus, Minus, Interesting), image-associative brainstorming, and structure model making (See Appendix A14). Figure 63 shows several of these ideas, sketched in detail, with the textile in green, and the chassis in red or yellow.

The ideas show iterations on the basic frame structure, folding principle, push/pull bar design, and bottom design. Those hand cart ideas that came out to be the most promising idea directions based on these aspects are concluded to be: idea number 10, 11, 12 (with the handlebar idea from 7), 14, and 16. The next section describes the benefits of these five idea directions.



3.5 Five Product Ideas

Five idea directions are worked out into product ideas. These five idea directions are: The 'Threefold' (Figure 64), 'Horizontals' (Figure 65), the 'Twofold' (Figure 66), the 'Diagonal' (Figure 67), and the 'Combiner' (Figure 68).

Figure 64 with idea direction 'Threefold' shows a hand cart that can be folded in three, which means that it could be folded up more compactly than other hand carts. Furthermore, the hand cart has an integrated push bar also acting as a frame when not in use which decreases the total amount of parts (and thus material use and costs).

2. Figure 65 with idea direction 'Horizontals' shows a hand cart with two horizontal frames, both folding in the middle. This not only ensures that the hand cart remains standing upright when folded as the wheels act as the support base, but also that the bottom of the textile has a rigid border around it to be attached to securely, better supporting the weight of the belongings.

3. Figure 66 with idea direction 'Twofold' shows a hand cart similar to 'Threefold', only folding in two, while also having one push bar that switches over into a pull bar when flipped. This two-in-one push bar decreases the total amount of parts. Furthermore, by having one joint instead of several for the beams to pivot around, folding is more simple as it requires fewer steps.

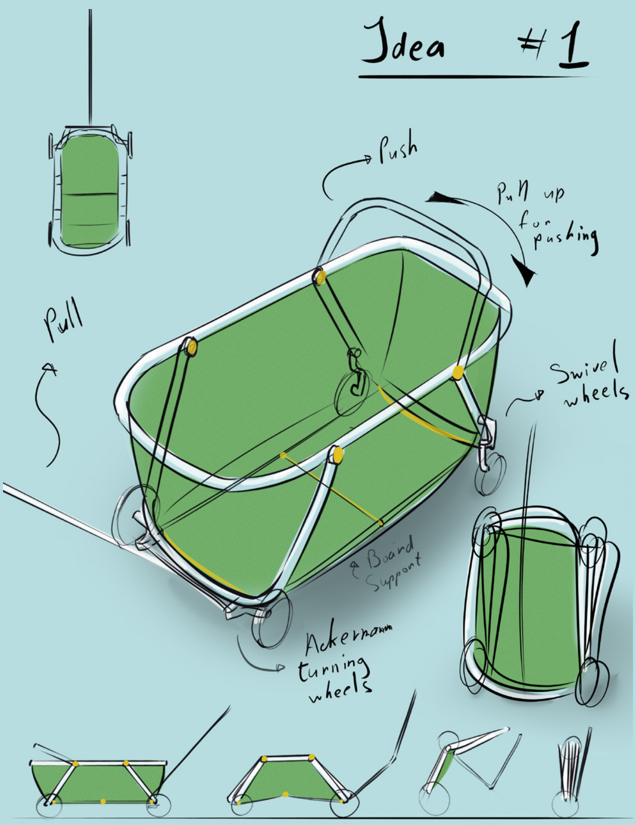


Figure 64 - Idea direction 1: "Threefold"

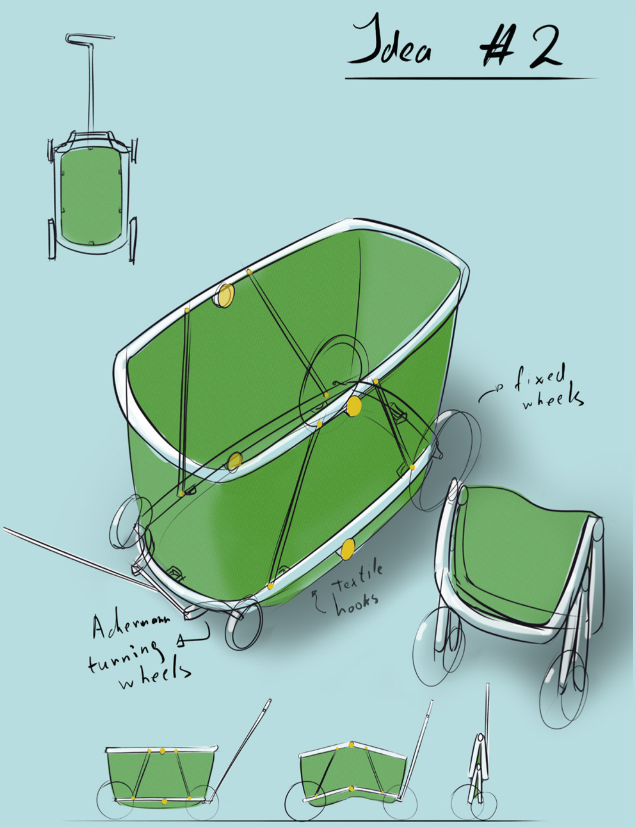


Figure 65 - Idea direction 2: "Horizontals"

4. Figure 67 with idea direction 'Diagonal' shows a hand cart with a diagonal frame and a front that can be lowered for easy entry of small children, eliminating the need for parents to lift their child(ren) in and out of the hand cart. Furthermore, the push bar integrated in the front beam decreases the total amount of parts. Additionally, the diagonal frame is supported by two side rods which automatically are put in place after (un)folding, increasing the rigidity of the folding structure and ease of (un)folding.

5. Figure 68 with idea direction 'Combiner' shows a hand cart that functions as an attachment to the Greentom Classic, being able to fold together with the folded Greentom Classic. This is a unique way to integrate the extra space that the hand cart provides in the Greentom Classic for existing customers. As the existing Greentom Classic stroller as a push bar, the need for a push bar is eliminated, decreasing the total amount of needed parts.

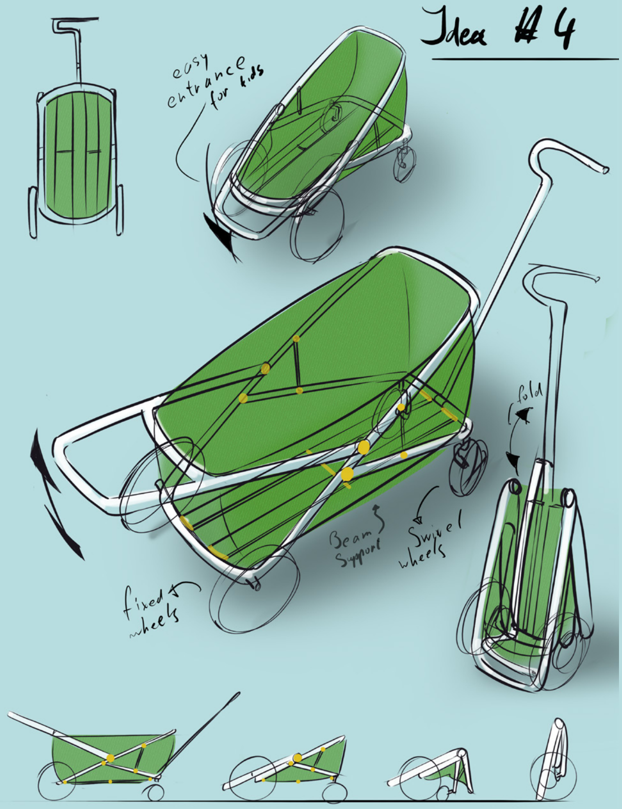


Figure 67 - Idea direction 4: "Diagonal"

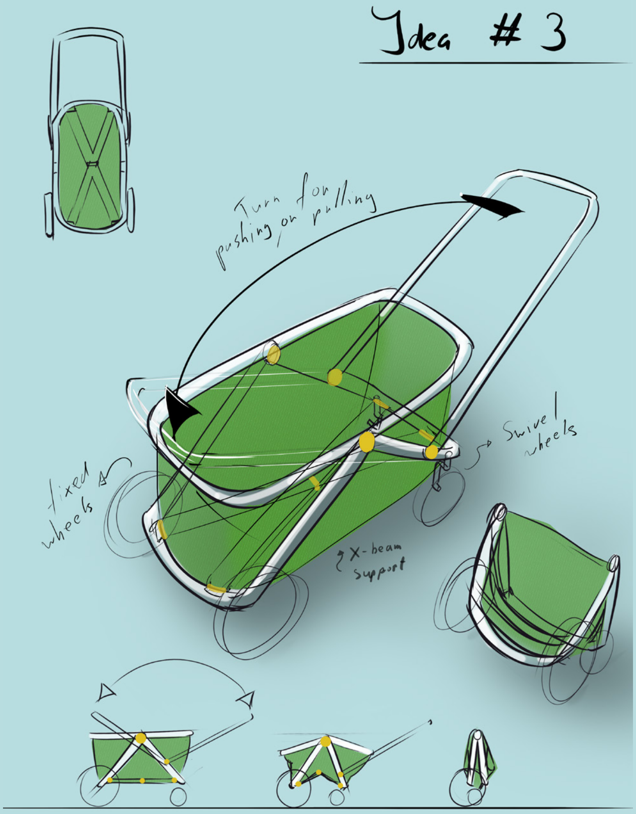


Figure 66 - Idea direction 3: "Twofold"

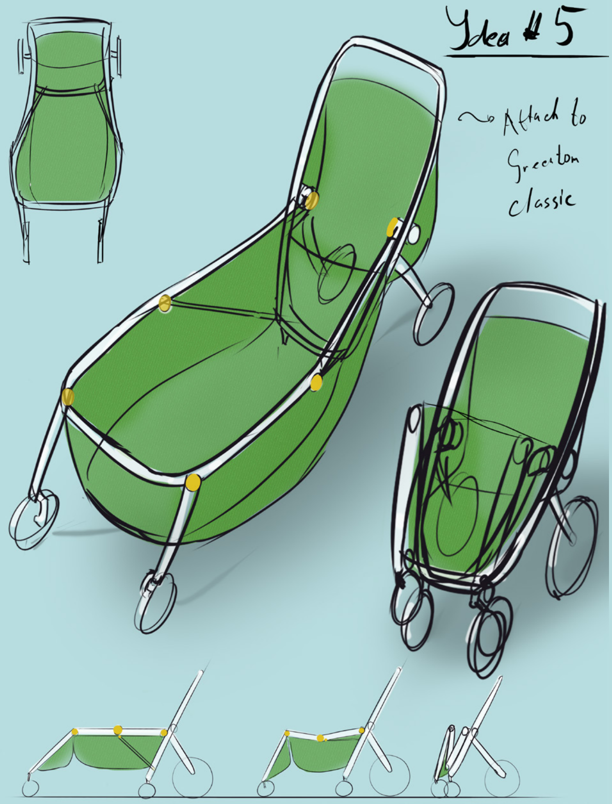


Figure 68 - Idea direction 5: "Combiner"

04

CONCEPTING

In this chapter

In this chapter, the five hand cart idea directions which have been developed during the Ideation phase will be further explored in detail by concretizing two aspects, namely 1) the hand cart ergonomics: including its volume, dimensions, wheel type configuration, and push/pull bar positioning, and 2) the hand cart construction: including the bottom support structure, and the foldability and stability. These outcomes are used to create promising concepts. Finally, these concepts will be evaluated against the selected requirements after which the most promising concept is selected to continue with as the Greentom Hand Cart concept.

4.1 Ergonomics & Construction

In this section, the main characteristics of the ideas within each idea direction have explored and concretized. The aspects that will be further explored in detail within this section are the ergonomics of the hand cart -including the dimensions, wheel configurations, and the positioning of the push/pull bar-, and the construction of the hand cart -including the weight supporting bottom beams, and folding mechanisms. Conclusions regarding these aspects will help develop detailed, comparable concepts.

4.1.1 Ergonomics

4.1.1.1 Volume and dimensions

To define the appropriate dimensions suitable for families with up to three children, the anthropometric database DINED is consulted.

By using the anthropometric data of children, the dimensions is calculated for the hand cart, as visualized in Figure 69. These dimensions ensure that up to three up to six years old (of the 90th percentile in their dimensions (P90)) can sit inside the hand cart: one in the front and two in the back (see Figure 71). How much room there is left for bags, depends on the number of children and the size of the children. Therefore, two six-year-old children inside the hand cart freely leave enough room for bags, whereas three six-year-old children tightly leave room for belongings. Appendix A15 shows the exact calculations of these dimensions and DINED anthropometric data used.

Since users prefer a hand cart with a large volume (see Section 2.4), the hand cart volume based on the dimensions is compared to that of competing hand carts, seen in Figure 70. (See Appendix A2 for the list of competing hand carts) Based on this comparison, it is concluded that the Greentom Hand Cart's inner volume of 186 litres is relatively large and 1.5 times as large as those of most competing hand carts, thus complying with the users' needs.

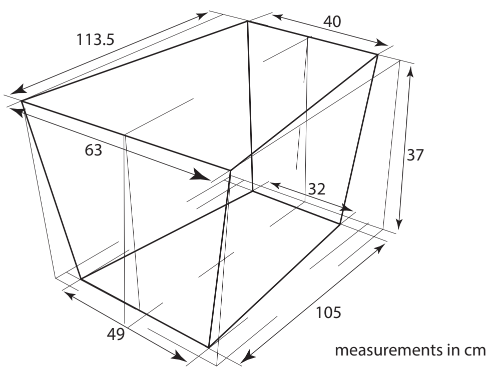


Figure 69 - Concluded Greentom Hand Cart dimensions

	Inner Dimensions (in cm)			Inner Volume (in m^3)	Inner Volume (in liters)
	(Mean) Length	(Mean) Width	Height	l*w*h	
Greentom Hand Cart	109	46	37	0.19	186
Competing hand carts:					
Beach Wagon Lite	85	50	32	0.14	136
Beachtrekker Life	75	52	32	0.12	125
MacWagon	80	42	25	0.08	84
Ulfbo	90	40	25	0.09	90
Eckla Bollerwagen	85	45	25	0.10	96
Coocarooc Breeze	110	57	33	0.21	207
Berger	94	50	27	0.13	127
Leggero Gogo	90	42	37	0.14	140
Keenz - Stroller Wagon	65	49	36	0.11	115
Travel & Co	90	47	34	0.14	144
Mean dimensions competitors	**86**	**47**	**31**	**0.13**	**126**
% Greentom Hand Cart to mean dimensions competitors	**126%**	**97%**	**121%**	**147%**	**147%**

Figure 70 - Hand cart inner volume comparison

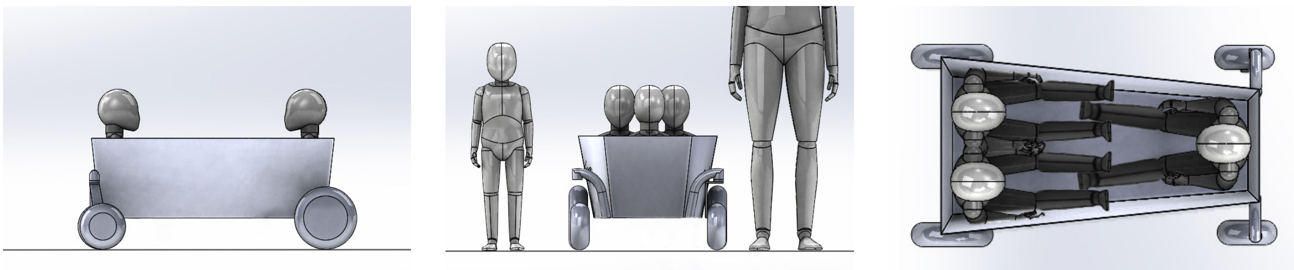


Figure 71 - Three-year-old P95 children sitting inside the dimensioned hand cart. From left to right: side view, front view, top view.

4.1.1.2 Manoeuvrability - wheel configuration

As concluded in Section 2.4, users prefer a hand cart that manoeuvres well. Not only the wheel type, but also the wheel positioning, wheel type combination when pushing or pulling, and the diameter of the wheels could affect how well the cart manoeuvres (Al-eisawi et al., 1999). Therefore, these factors are looked further into.

Several different wheel types are tried out using different hand carts with 75kg inside to simulate the weight of three P50 six-year-old children (DINED, 2017a). The wheel types included: 1) 'swivel wheels' (Figure 72) which turn independently from each other, 2) 'turning wheels' (Figure 73) which move in the direction of the pull bar, and 3) 'Ackermann' wheels (Figure 74) which move in the direction of the pull bar but also have an Ackermann-principle linkage between the wheels to make them turn around the same point of rotation to reduce tyre slippage (DataGenetics, 2016). Figure 75 shows a simplified illustration of the hand carts.

Figure 72 - Hand cart with swivel wheels: the Active-Outdoor Wagon

Figure 73 - Hand cart with turning wheels: the Beachtrekker Life

Figure 74 - Hand cart with Ackermann wheels: the Beachwagon Lite

Based on the try-out results as visualised in Table 2, it can be concluded that swivel wheels are the best front wheel types to use in a hand cart because they can take sharper corners than other wheel types, and because they allow for the hand cart to be both pushed and pulled, which concludes to have multiple benefits in Section 2.4.

Additionally, the retailer of the hand carts mentioned swivel wheels can swing a bit restlessly during use and can have difficulty in the case that a direction is changed rapidly in certain positions, compared to those wheel types that move together with the pull bar. (Retailer interview as in A9) However, since swivel wheels are even used with hand carts meant to support larger weights of those of five children or more (Bolderkar-shop, 2019), swivel wheels prove to be robust and comfortable to push even with these twice larger weights, and therefore having neglectable drawbacks for their benefits.

Lastly, it is confirmed that the Greentom hand cart wheels are best to have a large diameter to allow for better manoeuvrability. This is based on (Al-eisawi *et al.*, 1999) who state that the bigger the wheel size is, the less force is needed to move the cart. The exact size of these hand carts is researched in Section 5.2.2.1.

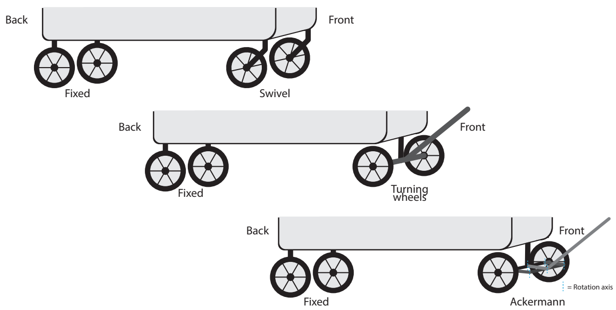


Figure 75 - Comfortable wheel positionings and wheel types

Table 2 - Results when manoeuvring hand carts with fixed back wheels and different front wheel types (such as in Figure 75)

Front wheel type	Can be pushed		Can be pulled		Corner
	from A	from B	from A	from B	radius
Swivel wheels	✓	~*	~*	✓	✓ ✓**
Turning wheels	✗	~*	✗	✓	✓ ✓**
Ackermann wheels	✗	~*	✗	✓	✓

* requires large side motion

** sharp turns possible

4.1.1.3 Manoeuvrability - Push/pull bar

Section 2.4 shows that a push bar has many benefits compared to a pull bar. But how could it be attached to the hand cart? To find out, the position of the attachment point and angle of the push/pull bar will be determined, after which the length of the push/pull bar is determined in Section 5.2.3.1, to ensure the best manoeuvrability.

The most favourable handlebar angles and attachment point are those at which the least (vertical) normal force (Nc) is generated during use -ensuring horizontal movement of the hand cart with the least amount of force applied. Calculations are done on two simplified situations of the hand cart (as seen in Figure 76 and Figure 77), in which the hand cart is represented as a box with a gravitational force of the object (Fz), an opposing force called the normal force (Nc), a friction force (F), an applied force from the handlebar (P), the handlebar angle (α), and dimensions: width (b) and height (h).

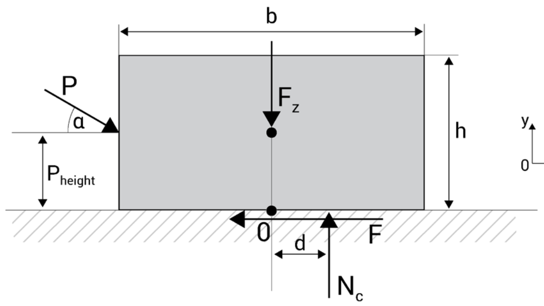


Figure 76 - Free body diagram of a "hand cart" pushed with force P

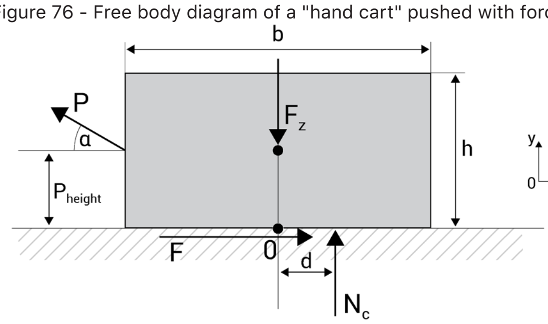


Figure 77 - Free body diagram of a "hand cart" pulled with force P

The main formulas used in the calculations are:

$$F = P * \cos(\alpha)$$

$$Fmax = \mu s * Nc$$

$$Nc = Fz - P * \sin(\alpha) = m * g - P * \sin(\alpha)$$

Thus, $Fmax = \mu s * (m * g - P * \sin(\alpha)) = P * \cos(\alpha)$

As seen in the formulas (where μs is static friction coefficient), the height of the force under a same angle does not influence the magnitude of friction force (F).

However, when pushing, the friction force (Fmax) of the object is lower if the angle of the pushing force acts more horizontally on the object, which will make it easier to push the object forward. This can be seen in Figure 78. Therefore, a high attachment point on the hand cart is preferred to ensure a smaller handlebar angle when pushing the hand cart. Appendix A16 shows the used calculations in full.

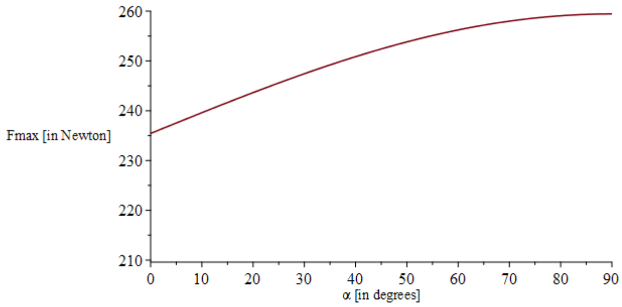


Figure 78 - Fmax during pushing dependent on alpha

Furthermore, it is concluded that, when pulling, the maximum friction force (Fmax) of the object is lower if the angle of the pushing force acts more vertically on the object, which will make it easier to pull the object forward. This is because the vertical force component of P (Py) helps reduce Nc. This can be seen in Figure 79. Therefore, an angle close to but under 45° is preferred to ensure a larger horizontal than vertical applied force when pulling the hand cart.

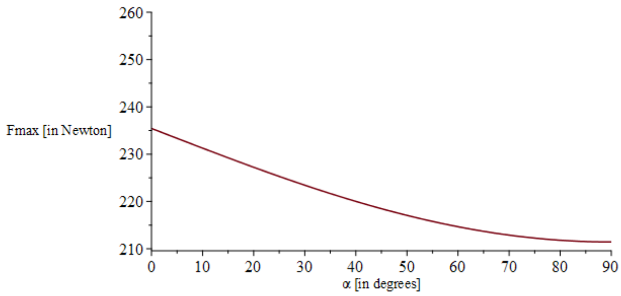


Figure 79 - Fmax during pulling dependent on alpha

Lastly, when comparing Fmax between Figure 78 and Figure 79, it can be seen that if only one hand is used both during pushing and pulling, then pulling will require slightly less force. However, pushing the hand cart will be easier than pulling the hand cart, based on the assumption that users will likely pull the hand cart with one hand, but push the hand cart with two (reducing the needed force per hand by half).

4.1.2 Construction

4.1.2.1 Stiffness and deflection

The weight support beams underneath the structure should be able to support the weight three children up to six years old (a requirement as concluded in Section 2.4). Even though boards will be placed on top of the beams for extra comfort (Section 2.4), the preferred structure of these support beams is therefore calculated to ensure that the weight is best supported.

To determine the preferred type of structure, two structures are compared with each other, as seen in Figure 80: one with the beams across the length, named 'Situation 1', and one with beams across the width, named 'Situation 2'. To simplify the calculations, a rectangular cross-section is defined (height h and width b), whereas the Greentom Classic has varying wall thicknesses due to its parts being gas-aid injection moulded.

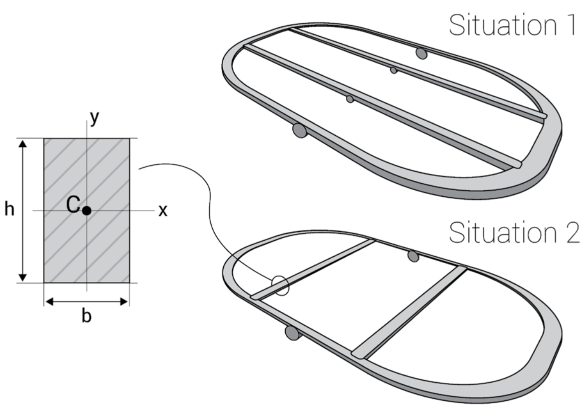


Figure 80 - Cross-section with two support beam types to be compared

The calculations are done on a simplified situation (as seen in Figure 81), in which the beam (both 'Situation 1', and 'Situation 2') has an equally distributed weight (*w*), running along length (l), and an opposing force called normal force (Fn) at joint A and B. The force acting on the beams is set to be equal to the weight of three six-year-olds (P50) with a safety factor of 1.5, resulting in a load of 103.5kg.

The main formulas used in the calculations are:

$$v = \frac{\iint M}{E * I}$$

Where $M = (Fn - w) * x$ and where $w = \frac{P}{L} * x$

Therefore, as seen in the formulas (where v is vertical deflection), the deflection is largest where M is the largest, which is in the middle of the beam.

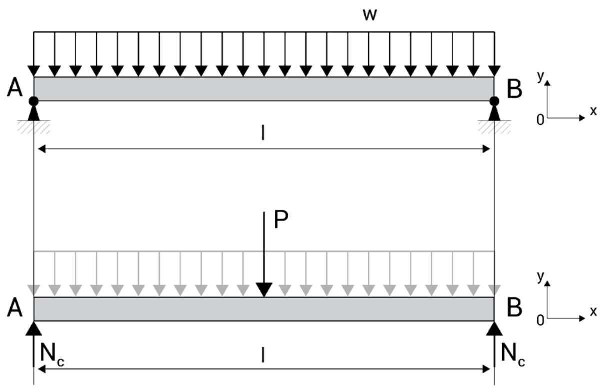


Figure 81 - Free body diagram of a support beam

Based on these calculations which can be found in full in Confidential Appendix CA5, it is concluded that with a cross-section of 2 (b) by 3 (h) cm, the beams in 'situation 1' have a maximum deflection of 29cm whereas the beams in 'situation 2' have a maximum deflection of 1.5 cm. Therefore, it is concluded that shorter beams in the design are preferred to support the same load since a deflection smaller than around 4 cm is preferred to ensure the passengers' comfort as well as avoid belongings to slide to the middle of the hand cart.

4.1.2.2 Foldability and Stability

To evaluate the foldability and stability of the hand carts of all selected idea directions and to improve those aspects from these insights, 1:1-scale foldable structure models are made of the chassis from each idea direction.

Each structure model is created as a quick model out of PVC tubes to evaluate the volume of the hand cart when folded (compactness), structural stability when unfolded (support), push/pull design and folding mechanism (ease of use), and overall design. Figure 82 to Figure 86 show the selected idea direction made into these quick structure models. Table 3 shows a summary of the evaluated aspects per structure model.

Regarding *compactness*, idea 1 - 'Threefold' (Figure 82) is the most compact, being {1 x 63 x 46}cm instead of {1 x 63 x 68}cm. If the three-fold folding system works with the weight support beams and wheels included, this folding system will be of great benefit for compactness.

Regarding *structural stability*, idea 4 - 'Diagonal' (Figure 85) is the most structurally stable. This is due to the side rod unfolding as support under the back top beam of the structure. Furthermore, 'Diagonal' also has the support bottom beams integrated into the structure, which show drastic improvement in the structural stability and ease of (un)folding, thus, proving the support beams to indeed be a valuable addition to all hand carts to improve their structural stability.

Regarding *folding principles*, 'Diagonal' shows that the side rod for supporting the back top beam to have another benefit: it automatically unfolds into a supporting position, requiring no extra (un)folding steps. Thus, opposed to placing supporting structures in place by hand, solutions which automatically (un)fold into place could be good to implement to improve the ease of (un)folding. Furthermore, the addition of weight support beams show an additional benefit: increasing the ease of (un)folding as the structure automatically folds when the beams are pulled upwards, and making it

Figure 82 - The structure model of idea direction 1 - the 'Threefold'

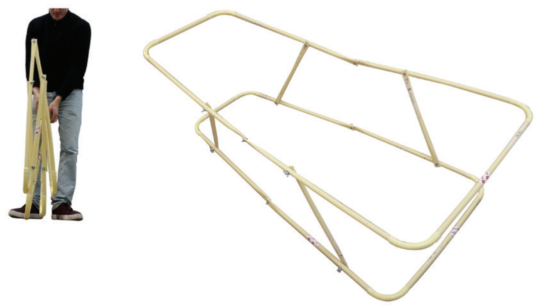


Figure 83 - The structure model of idea direction 2 - the 'Horizontals'

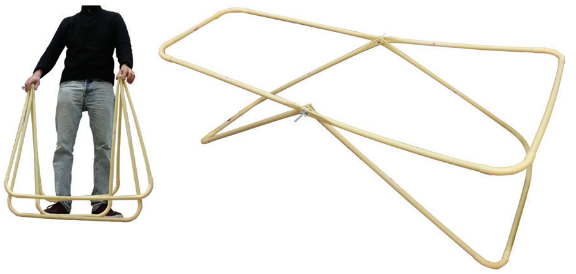


Figure 84 - The structure model of idea direction 3 - the 'Twofold'

Figure 85 - The structure model of idea direction 4 - the 'Diagonal'

easy to understand the unfolding steps.

In conclusion, regarding *overall design*, the following is concluded: The support bottom beams and side bars that automatically unfold into position to support top beams is favourable to implement to increase the hand cart's structural stability and ease of (un)folding (reducing folding steps and increasing the understandability of the folding steps). Furthermore, promising results are seen in the compactness of idea direction 1 - 'Threefold', the collapsible entry of idea direction 4 - 'Diagonal', and the folding mechanisms that let hand carts stand by themselves after folding due to the wheels moving together after folding to form the standing base. Lastly, since integrated push/pull beams in the frame are too short when folded upwards, it is concluded that a separate push/pull bar can best be used in the future concept, instead of integrating it as part of the chassis beams.

Figure 86 - The structure model of idea direction 5 - the 'Combiner'

See Appendix A17 for the detailed insights from each structure model.

Table 3 - Summary of evaluated aspects per structure model

	Compactness	Support	Push/pull	Folding	Design
Idea 1 - 'Threefold'	✓ ✓	✗ *1	✗ *5,6	✗ *8,9	✓ *12,13
Idea 2 - 'Horizontals'	✓	✗ *1,2	_ *6	✓ *10	~ *13,14
Idea 3 - 'Twofold'	✓	✗ *1	_ *6	✓ *10	~ *13,14
Idea 4 - 'Diagonal'	✓	~ *3,4	_ *6	✓ *10	~ *13,14,15,16
Idea 5 - 'Combiner'	✓	~ *1,4	_ * 6,7	✗ *9,11	✗ *17

*1 Needs extra beam support and bottom structure for weight support.
*2 Side rods to be improved to prevent top and bottom beams from moving.
*3 Weight support structure in the bottom makes structure feel sturdy.
*4 Side rod supports beam well. (Additionally, however, for idea 4 extra beam support is needed for the front top beam.)
*5 Back beam serving as a push bar is too low when folded upwards, and makes legs touch the bottom beam: a separate push/pull bar is needed.
*6 Pushing the hand carts from the narrow side feels more unnatural than pushing the hand cart from the wider side.
*7 Will likely only be pushed.
*8 Folding steps might be confusing.
*9 Would not be able to stand on its own when folded.
*10 Able to stand by itself when folded, due to the folding structure folding in half with the wheel locations supporting the structure at the bottom.
*11 Attachments are spiky, and bottom bars would rest against toddler when folded.
*12 Very compact.
*13 Push/pull bar may be added.
*14 Stands on its own when folded.
*15 Folding front beam down for easy entering looks promising
*16 Middle of the chassis sides are low, and let the textile above it hang loose.
*17 Pointy beams sticking out are dangerous and difficult to handle. Hand cart could be made both independent and dependant from the stroller.

4.2 Concepts

By combining the conclusions from the research phase (Section 2.4), with the concluded form family, hand cart style, and selected idea directions (Chapter 3), as well as with the newly gained insights regarding several aspects regarding the hand carts within these idea directions (Section 4.1), three Greentom Hand Cart concepts are created. During the course of this project, an intermediate step is performed between the concept phase and the ideation phase. Appendix A18 shows these concepts and the selection of the concepts presented here. This section presents and evaluates the concepts to conclude which Greentom Hand Cart concept will be further developed.

All three Greentom Hand Cart concepts can be folded in two at their middle which allow the hand carts to stand upright when folded, and have fixed back wheels and front swivel wheels allowing the hand cart to be both pushed and pulled comfortably. Furthermore, the concepts allow a push/pull bar to be attached to the front of the hand cart at the swivel wheels for pulling or to be fixed in the back of the hand cart at the fixed wheels for pushing. Lastly, the insides of the top joints of the hand carts also function as the position to insert other Greentom interchangeable accessories, such as the Greentom reversible, Greentom carrycot, or a (Greentom) car seat.

The following sections (Section 4.2.1, 4.2.2, and 4.2.3) present the unique aspects of each Hand Cart concept.

4.2.1 Concept 1 - 'Horizontals'

Concept 'Horizontals' (Figure 87), shows a hand cart with horizontal top beams as well as horizontal bottom beams, providing the bottom of the textile with a rigid border around it to be attached to securely. Furthermore, contrary to the other two concepts, the horizontal bottom beams allow the concept to have a weight support structure consisting out of four short beams, ensuring a bottom that deflects the least and thus will support any weight well.

It is, however, the only concept that has to remain symmetric in its construction for the folding mechanism -which includes four identical diagonal side rods- to work, limiting the aesthetic and stylistic possibilities. To ensure structural stability, the front and back of the hand cart include two plates that can be pushed into position after unfolding.

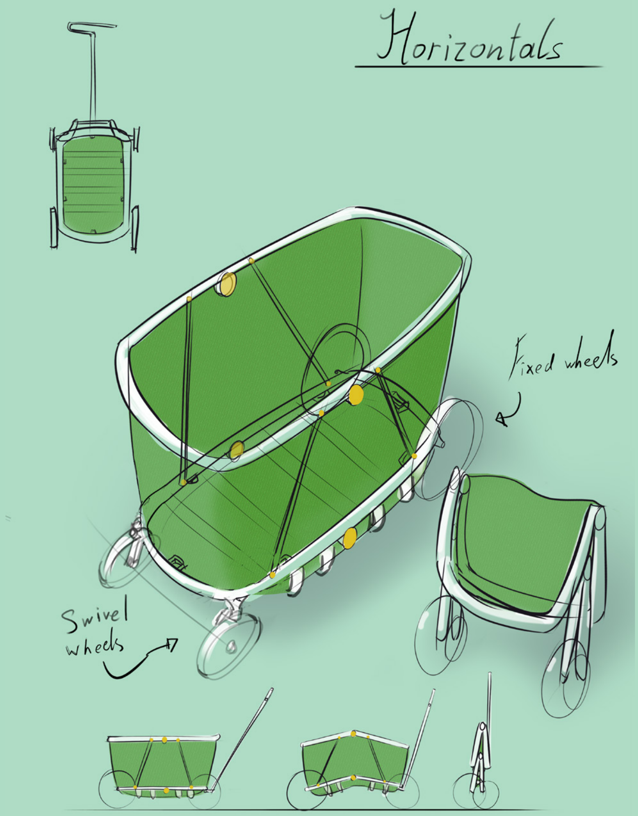


Figure 87 - Concept 'Horizontals'

4.2.2 Concept 2 - 'Twofold'

Concept 'Twofold' (Figure 88), shows a hand cart one joint for the beams to pivot around opposed to concept 1 which has two, allowing for a more simple and understandable folding of the hand cart.

Furthermore, two side plates can be seen in the front and back of the hand cart, which each fold in half and click into position after unfolding to support the top beams at each side. The weight support structure consists of two longer bottom beams that fold in one direction in the middle.

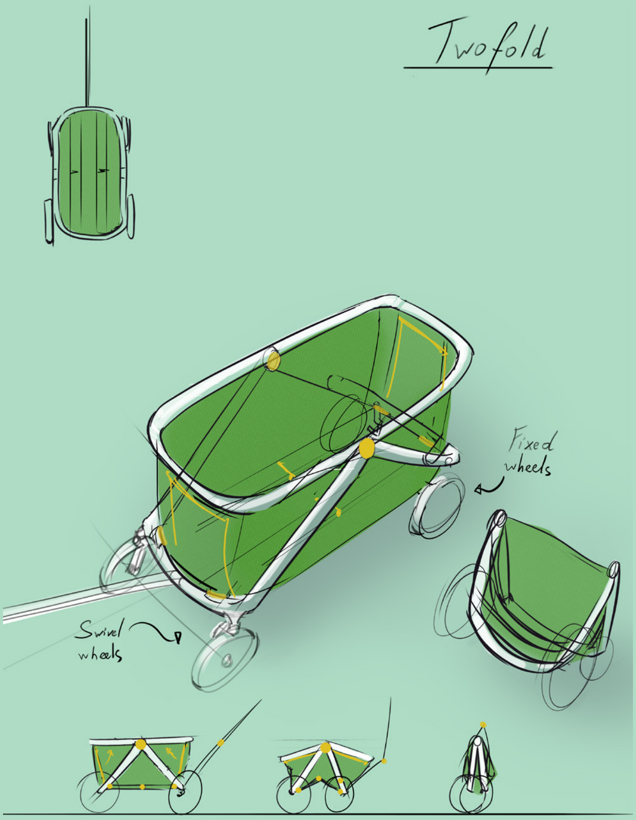


Figure 88 - Concept 'Twofold'

4.2.3 Concept 3 - 'Diagonal'

Concept 'Diagonal' (Figure 89), shows a hand cart with a front top beam that can be lowered for easy entry of small children and which can be locked into position when moved back up, eliminating the need for parents to lift their child(ren) in and out of the hand cart. The beam is supported by a front plate that folds in half and clicks into position after unfolding.

Additionally, the back top beam is supported by two side rods which automatically move into place after (un) folding, increasing the rigidity of the folding structure and ease of (un)folding.

Like the other concepts, the insides of the front top beam are used to insert other Greentom interchangeable accessories. However, since the beam slopes downwards to the middle, the accessories lie lower inside the hand cart after inserting them in position, leaving less space than the other concepts inside the hand cart. The weight support structure is identical to that of concept 2.

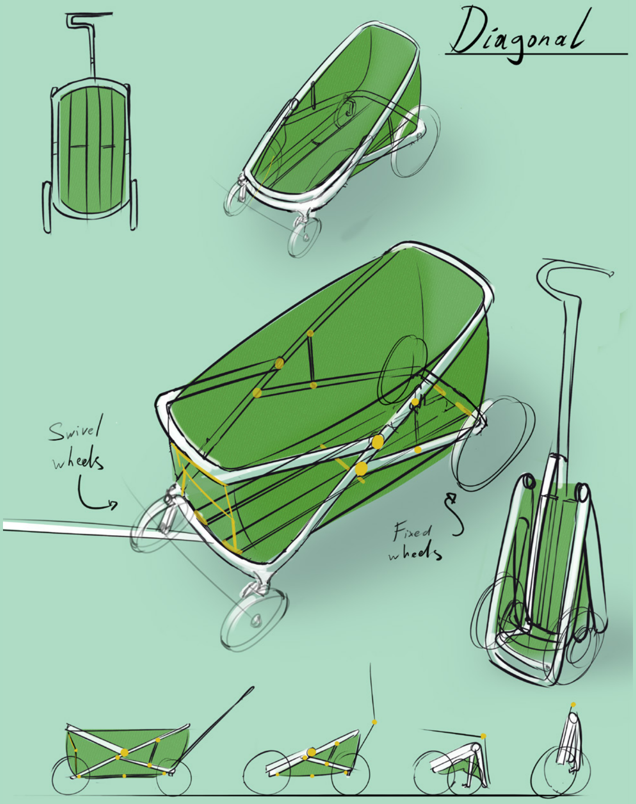


Figure 89 - Concept 'Diagonal'

4.3 Concept evaluation

In order to choose which Greentom Hand Cart will be further developed, the concepts are evaluated by the degree with which they comply with the requirements as defined in Section 2.4. By using a Harris profile, the relative strengths and weaknesses of each concept are visually compared, and the concept scoring the best is chosen.

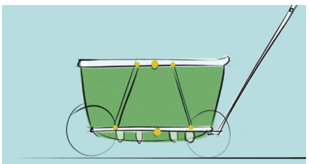
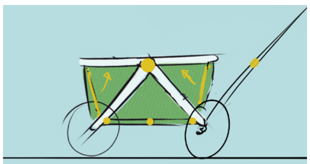
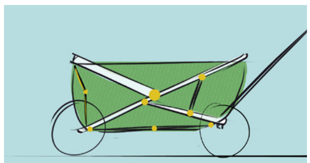
Two out of the main five requirements as defined in Section 2.4 are equally complied with to the same degree by the concepts. Therefore, since these requirements would not impact the score of the concepts, they are left out of the comparison, being: *"The product should be suitable for parents with up to three children"*, and *"The product should be sustainable"*.

The three out of five requirements to which the concepts each comply with in different degrees, therefore suitable as criteria for comparing the concepts, are the following:

1. *"The product should be easy to use."*
2. *"The product should be affordable."*
3. *"The product should be attractive/aesthetically pleasing."*

To better evaluate each concept's degree of compliance per requirement, two of these requirements are split up into multiple measurable factors (shown in grey in Figure 90). Each of the criteria as seen in the figure is given a score, for which the score of the latter two is calculated by taking the mean score of the factors appropriate to their criterion. '++' indicates that the concept complies excellently with the requirement/factor, and '+-' indicates that the concept complies, however, relatively poorly with the criterion or factor.

An overview of how these scores are calculated per criterion can be found in Table 4. Appendix A19 gives additional information on how the number of moulds and parts are calculated.

Criteria	***Concept 1 - 'Horizontals'***				***Concept 2 - 'Twofold'***				***Concept 3 - 'Diagonal'***			
	+-	**+**	**++**	**+++**	**+-**	**+**	**++**	**+++**	**+-**	**+**	**++**	**+++**
1. Easy to use [Low # of folding steps]			■				■				■	■
2a. Affordable [Low part complexity]		■					■	■			■	■
2b. Affordable [Small part size]			■				■				■	
2c. Affordable [Low number of moulds]			■	■			■				■	
3a. Aesthetically pleasing [Simple design]			■	■			■	■			■	
3b. Aesthetically pleasing [Complying cart style]		■					■	■			■	■
3c. Aesthetically pleasing [Unique design]			■		■	■					■	■

Figure 90 - Harris profile showing three criteria out of which two are split up into multiple factors (shown in grey)

By taking the mean score of the factors that together form criterion 2 and 3, which is done assigning a number to each score (score 1 to +-, score 2 to +, score 3 to ++, and score 4 to +++) and dividing the additions by three, the scores per requirement could be calculated and visualised in the Harris profile in Figure 91.

The Harris profile shows that the concept with the most coloured green blocks to the right is concluded to be concept 3 - 'Diagonal'. This concept is concluded to 1) be the easiest to use as it requires the least folding steps due to the supporting side rods automatically folding into position, 2) be equally affordable compared to the other concepts, requiring 10 non-complex, medium-sized moulds for 11 parts, and 3) be the most aesthetically pleasing design due to it looking relatively simple, very unique compared to existing hand carts and concepts, and the promising form freedom to be shaped to the Greentom form family and defined hand cart style. Thus, 'Diagonal' is chosen to be further developed.

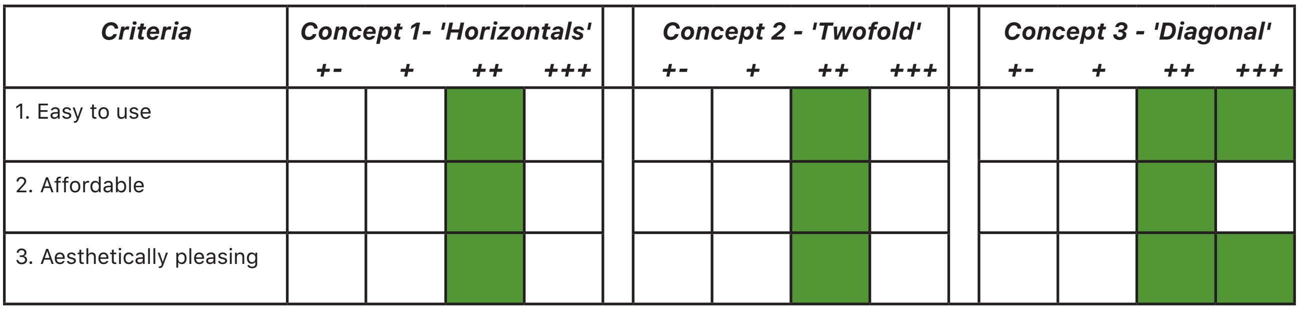


Figure 91 - Harris profile showing three criteria with results that are combined from the factors from Figure 90

Table 4 - Overview of score calculation per creterion

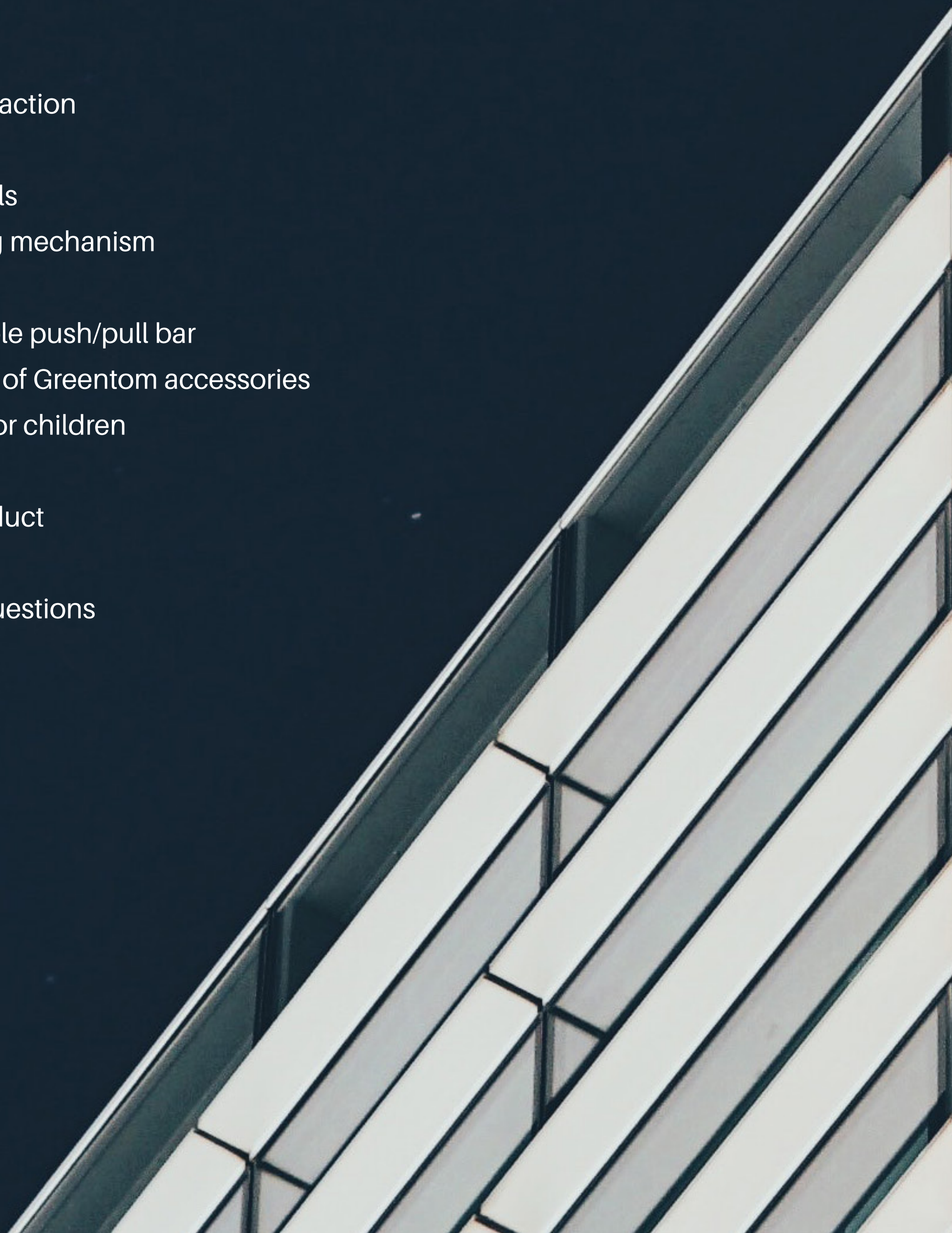
	Concept 1 - 'Horizontals'	Concept 2 - 'Twofold'	Concept 3 - 'Diagonal'
1. Low # of folding steps	++ 3 steps *1	++ 3 steps *2	+++ 2 steps *3
2a. Low part complexity	+ Relatively complex *4	+++ Not complex *5	+++ Not complex *5
2b. Small part size	++ Medium *6	++ Medium *6	++ Medium *6
2c. Low number of moulds	+++ 9 moulds *7	++ 10 moulds *8	++ 10 moulds *9
3a. Simple design	+++ Simple *10	+++ Simple *10	++ Medium *11
3b. Complying hand cart style	+ Little form freedom *12	+++ Promising *13	+++ Promising *13
3c. Unique design	++ Unique *14	+- Not unique at first glance *15	+++ Very Unique *16

*1) 1. The two top parts are unlocked. 2. The two bottom parts are unlocked. 3. While the bottom is pulled upwards, the beams fold in half.
*2) 1. The left top bar is pulled down. 2. Then the right top par is pulled down. 3. While the bottom is pulled upwards, the beams fold in half.
*3) 1. The left top part is unlocked. 2. While the bottom is pulled upwards, the bottom parts slide inwards by pressing down the top right beam.
*4) Concept 1 has relatively complex as the cross-directional bottom beams are integrated into the beams. Furthermore, the beams have small hoops, to attach the textile to, integrated as well.
*5) Concept 2 and 3 do not show any parts with many details or complex forms.
*6) All three concepts have beams of the same size as all concepts fold in half.
*7) Number of unique parts (excl wheels): 10 parts. Number of moulds: 9 moulds
*8) Number of unique parts (excl wheels): 10 parts. Number of moulds: 10 moulds
*9) Number of unique parts (excl wheels): 11 parts. Number of moulds: 10 moulds
*10) The concepts look simple in its design without unneeded extra details.
*11) Concept 3 looks a bit complex at first glance due to its unusual diagonal structure. However, for existing Greentom customers, the working structure might look similar, and thus more understandable, to that of the Greentom stroller.
*12) The design of concept 1 (inclinations, curves, etc.) cannot be changed well to fit future style keywords, since the folding principle requires the shape to stay symmetrical. This gives little form freedom to let the concept fit the Greentom form family and defined hand cart style.
*13) The design of the hand carts (inclinations, curves, etc.) can be changed to fit the Greentom form family style and defined hand cart style.
*14) None of the competing hand carts has a comparable design to concept 1, which makes this concept look unique.
*15) The design is similar to that of the Coocarooc Breeze and the NPK walking wagon even though the structural shape is hidden beneath a cloth in the two latter hand carts.
*16) Compared to the other concepts and other analysed hand carts in the market, this concept is the only concept using non-horizontal or vertical lines, apart from the cheap scissor-model hand carts.

05

DETAILING

In this chapter



The goal of this chapter is to improve the design of the selected concept and then to evaluate the improved concept with the target group.

The concept is first improved by making a 1:1-scale structure model to quickly pinpoint points of improvement. Next, the concept's attributes are divided into 'satisfiers' and 'exciters' based on theory regarding customer satisfaction, called the KANO theory, and further developed to ensure the customers' product satisfaction. Lastly, the improved concept is built as a 1:1 functional prototype and tested with the target group to verify the concept design with the target group.

5.1 Mock-up chosen concept

A 1:1-scale structure model is made to quickly pinpoint any points of improvement in the current concept by testing out this model. These points of improvement are then being solved, resulting in a rapidly improved concept.

To pinpoint any points of improvement, a foldable 1:1-scale structure model is made with connected PVC tubes as the chassis, masking tape for the textile, and shaped foam attached with metal wire as wheels to quickly simulate the concept.

When folding and unfolding the structure model, several points of improvements are found, being the following:

1. Unequal bottom lengths
2. Textile triangle does not fold
3. Bottom textile not stretching around bottom beams
4. Uneven wheel height after folding
5. Side textile shears in the corner
6. Textile getting stuck in joints
7. Support beam sticking through textile
8. Side board unhandy
9. Wheels pushed aside
10. Difficult to transport when folded


Figure 92 - Bottom moves out of vertical plane due to unequal diagonal bottom lengths (left). Wheels folding at unequal height due to unequal diagonal beam lengths (right).


Figure 93 - Textile preventing model from folding

Firstly, it is found that the bottom beams stick out when the structure model is being folded due to their unequal lengths, which also prevents the hand cart wheels from aligning in folded position, and the textile in the bottom of the cart to fold around the bottom beams (see Figure 92). Furthermore, when adding the triangular part of the textile at the top of the model, the connected textile prevented the chassis to be folded at all (see Figure 93).

These points of improvement are solved by eliminating the restraining triangular shape of the textile between the chassis beams, and by making the bottom beams equal in length to each other, as seen in the new structure shape in Figure 94 (solving points 1, 2, 3, and 4).

Secondly, in the newly defined structure shape (as seen in Figure 94c and recreated in Figure 95a), the textile in the joint corners prevent the back of the structure from

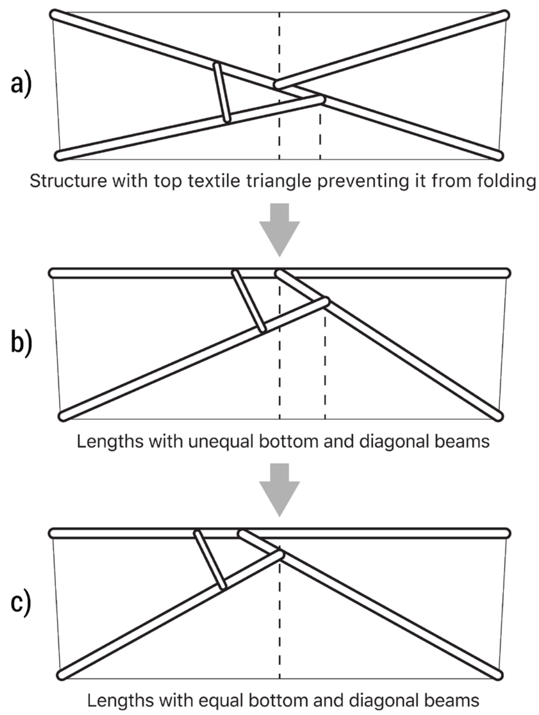


Figure 94 - Creating a structure with equal bottom and diagonal beams

folding. This is due to the beams moving slightly parallel away from each other during folding, and therefore pulling the textile in two directions, creating a strain inside the textile (as seen in Figure 95b). Furthermore, the textile gets stuck in the joints which rip the textile, and the small support beams are attached in such a way that they leave an unaesthetic looking hole in the textile.

a) Newly defined structure shape

b) Textile showing stress during folding (left), and ripping (right)

Figure 95 - Model with stress starting in top right corner, continueing down diagonally

These point of improvement are solved by attaching the textile only to the top beams and the horizontal parts of the diagonal beams instead of to all the beams sides, as indicated in Figure 96, and by leaving a small space between the joints and the textile (solving points 5, 6, and 7).

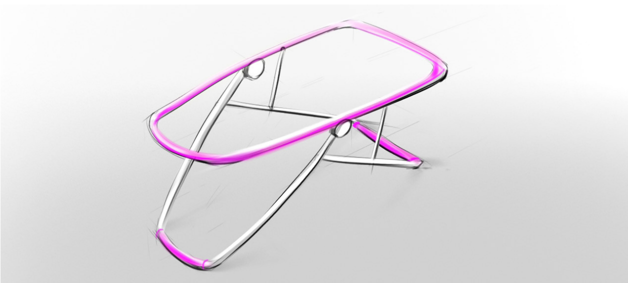


Figure 96 - Textile attached to the beam sides indicated with purple

Lastly, several points of improvements are found regarding the front board, wheels, and transport of the hand cart in folded position. The board moves freely in the front of the hand cart around the beam when not clicked into position, making it difficult to handle during (un)folding (as seen in Figure 97). Regarding the wheels, the top beam unintentionally pushes the wheels aside during folding as the wheels stand too close to the beam. Lastly, the hand cart is difficult to transport when folded due to the lack of any attachments to make this possible.

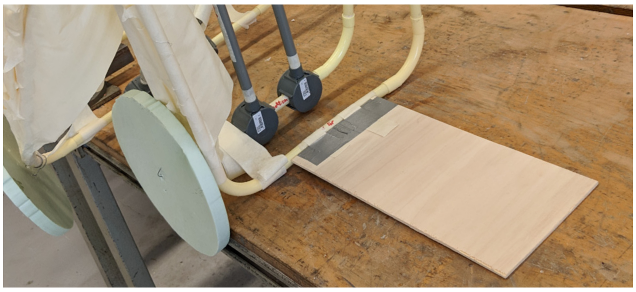


Figure 97 - Front board unintentionally moving freely around beam

These points are solved by ensuring that the front board is attached to the beams at all times and folds in place by itself when (un)folding (as seen in Figure 98), by creating a space between the wheels and the beams, and by implementing a shoulder strap for transporting the folded hand cart (solving points 8, 9, and 10).

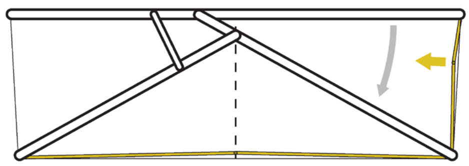


Figure 98 - Front board (indicated in yellow on the right) folding in two

5.2 Attribute development

Several aspects of the Greentom Hand Cart concept, also called product attributes, are designed to satisfy the (future) users' needs and wishes by complying with the defined program of requirements and wishes (as concluded in Section 2.4). To define which attributes are most important to focus on to ensure the customers' product satisfaction, these product attributes are divided into 'satisfiers' and 'exciters' on the basis of theory regarding customer satisfaction, called the KANO theory, after which they are further developed.

5.2.1 KANO model of satisfaction

The KANO model differentiates between customer needs to pinpoint which bring customer satisfaction. It classifies product attributes into four categories: Threshold attributes, performance attributes (also called satisfiers), excitement attributes (also called exciters), and indifferent attributes.

Threshold attributes are attributes that are considered to be self-evident. Without these attributes, the product would become useless, making the lack of this attribute become a dissatisfier. In a hand cart, these attributes would be: being able to transport belongings and/or children, having wheels, to be pulled by a handlebar.

Satisfiers are attributes that linearly lead to increased customer satisfaction, and are closely linked to the price users are willing to pay for the product. The more satisfiers and the better their fulfilment, the larger the customer satisfaction is. However, poor fulfilment of the satisfier would lead to customer dissatisfaction.

Exciters are attributes that are unexpected by users, but when present would give customers high satisfaction, and would lead to a competitive advantage. The absence of these attributes would not result in dissatisfaction.

Indifferent attributes are those with little or no importance. In a hand cart, it would be for example the placing of text. (Mind Tools Content Team, n.d.; Shyam Prasad, S., n.d.)

As can be seen in Figure 99, especially the satisfiers and exciters may be explored in the further detailing of the hand cart concept since "an ideal product should have all [Threshold attributes], maximize the performance attributes and incorporate as many "excitement" attributes as possible at a price that is affordable." (Shyam Prasad, S., n.d.)

To achieve this, the hand cart's physical attributes, separated into satisfiers and exciters, are further developed in this section. These attributes, derived from the set of requirements (Section 2.4) are the following:

1. Suitable for parents with up to three small children
   - A compact chassis when folded **[satisfier]**
   - A large-volume chassis when unfolded **[satisfier]**
2. Easy to use
   - An easy (un)folding mechanism **[satisfier]**
   - A collapsible front entry for children **[exciter]**
   - Attachable (Greentom) accessories **[exciter]**
   - Well manoeuvrable
     - Large wheels (beach suitable) **[satisfier]**
     - A re-attachable push/pull handlebar **[exciter]**
3. Sustainable
4. Affordable

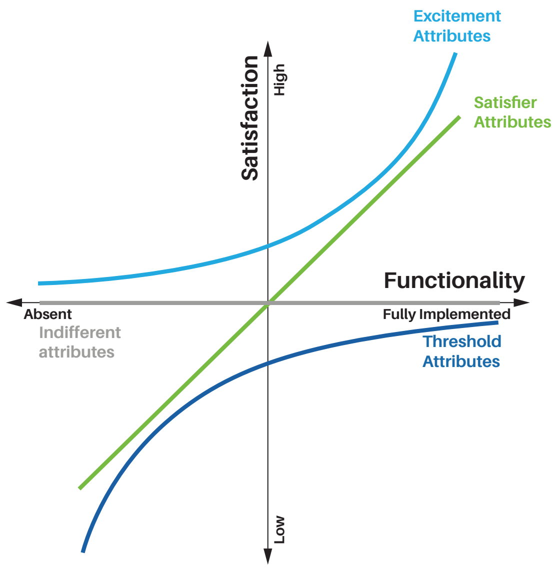


Figure 99 - KANO Model (based on (Mind Tools Content Team, n.d.) and (Shyam Prasad, S., n.d.))

5.2.2 Satisfiers

5.2.2.1 Large wheels

To find out how large wheels can be attached to the hand cart in a way that also ensures the hand cart to be folded compactly, further research is done regarding the diameters and positioning of the front and back wheels.

Height

It is concluded that by placing the wheels on the side of the hand cart instead of underneath, children can step more easily into the collapsible front entry (see Section 5.2.3.3) due to the bottom of the front entry falling below the children's knees making it easier to step in independently, as seen in Figure 100 and Figure 101.

For the illustration, anthropometric models created by 3DHumanModel (2019) are used of a standing 5-year-old (P50) and a 20-to-60-year-old female (P50), as well as two seated 5-year-olds (P90) inside of the hand cart.

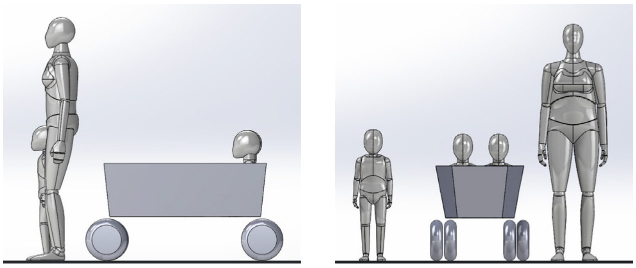


Figure 100 - Wheels placed underneath the hand cart

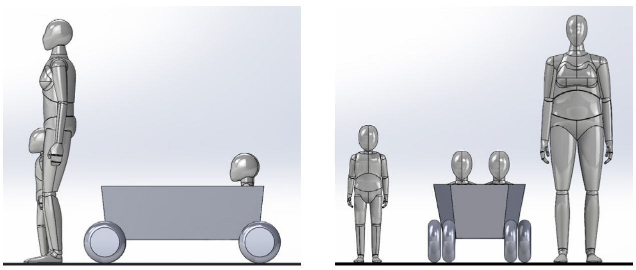


Figure 101 - Wheels placed on the side of the hand cart

Radius

Since the action radius of the swivel wheel is larger than the radius of the swivel wheel itself due to the vertical axis of rotation being slightly off-centre to function, the swivel wheel attachment point has to be placed at a distance >3/4th of the wheel diameter from the chassis for the swivel wheel to be able to turn 360°, as can be seen in Figure 102.

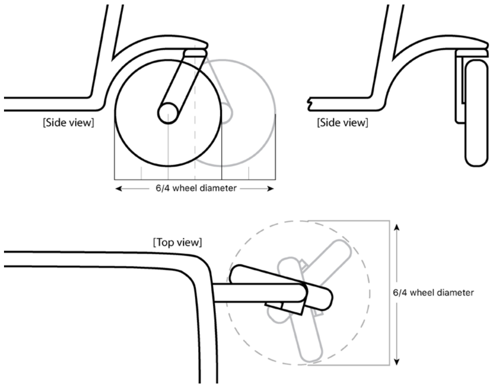


Figure 102 - Action radius of the swivel wheel

Compactness

To ensure that the hand cart remains compact when folded, the wheels are best to stick out as less as is possible while maintaining a large size.

Therefore, for the front swivel wheels, this compactness is achieved by guiding the connecting beam of the front wheels closely to the outer edge of the wheel, and by making the front wheels foldable against the textile. It is concluded that wheels with Ø<250mm -chosen to be Ø215mm of which the benefits are mentioned in Confidential Appendix CA6- can best be used with a pivoting connecting beam attached to a point in the front of the hand cart to achieve this, as seen in Figure 103.

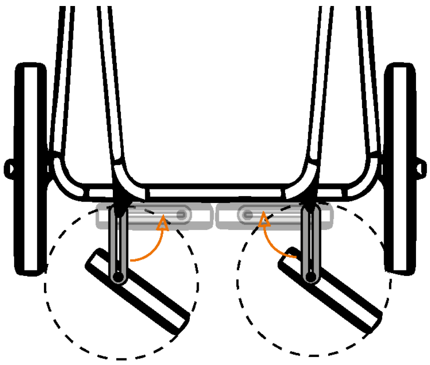


Figure 103 - Swivel wheel folding against folded chassis

The diameter for the back wheels are chosen to be Ø300mm -of which the benefits are mentioned in Confidential Appendix CA6-, which is similar to the wheel diameter of the hand carts with the largest wheel sizes being Ø290mm for the Beach Wagon Lite and Ø289mm for the Beachtrekker Life (as seen in Appendix A2).

5.2.2.2 Easy folding mechanism

The folding mechanism is made to have a large volume when it is unfolded and to be compact when folded. The folding mechanism of the hand cart is created in such a way that it is also easy to (un)fold: As seen in Figure 104, top front beam BC of the hand cart -which also functions as the entry gate for children- can be collapsed by pulling the vertical supporting beams inwards (indicated in yellow), after which the bottom of the hand cart can be pulled upwards (also indicated in yellow) to finish folding the hand cart. Side rod GH automatically folds and unfolds the back top in position, either unfolded (as seen in Figure 104), or folded parallel to the other beams (Figure 105). However, to ensure that side rod GH acts as intended, its length as well as joint positions on AB and DF need to be determined.

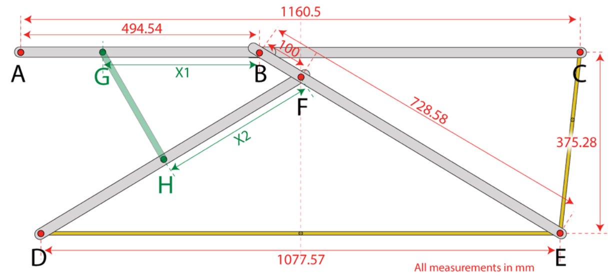


Figure 104 - Hand cart chassis in unfolded position, with point G and H at distance x1 and x2 from B and F respectively

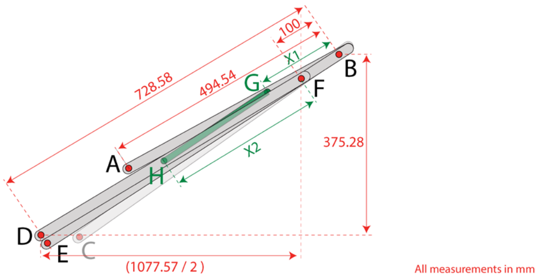


Figure 105 - Hand cart chassis in folded position, with point G and H at distance x1 and x2 from B and F respectively

The length and joint locations of the side rod are determined by means of calculations instead of trial and error since high accuracy is needed and the chance of error is best to be eliminated when drilling the joint holes in the future prototype.

By setting up the formula for side rod length GH in unfolded situation as well as in folded situation expressed in the two unknowns x1 and x2, and solving these two formulas to each other, the values x1, and x2 could be determined (and therefore also length GH) which comply with the two situations. These possible positions on the chassis are visualised in Figure 106. See Appendix A20 for the full calculations.

It is concluded that the best suitable position would be that of GH with x1 = 200mm, x2 = 314 mm, and therefore lengthGH = 214 mm, since this position would support the forces subjected onto beam AB the best as the side rod GH stands almost perpendicular to it, yet staying compact due to the shorter length since standing in a slight angle towards beam DF, as seen in Figure 106.

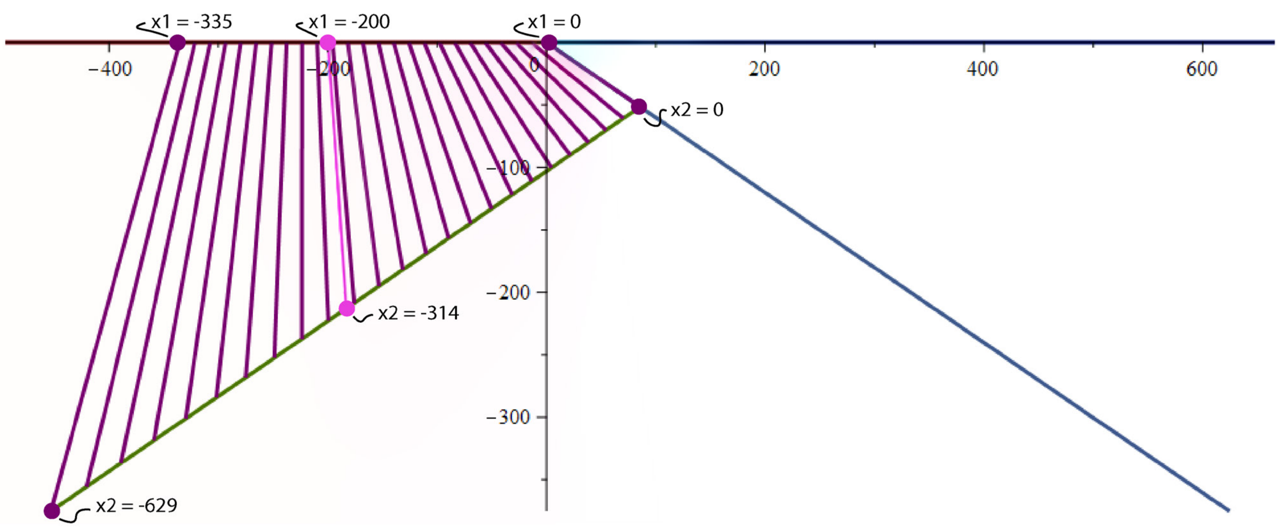


Figure 106 - Possible positions of side rod GH indicated in purple which allow folding and unfolding of the chassis into desired position

5.2.3 Exciters

5.2.3.1 Re-attachable push/pull bar

Different forms

To ensure a handlebar that is suitable for both one and two hands, suitable to be pulled and pushed, re-attachable, and foldable, further research is done regarding the form, attachment design, and length of the handlebar.

Four different forms (as seen in Figure 107) are evaluated in Table 5. From Table 5, it can be concluded that form D is the most suitable form for the handlebar.

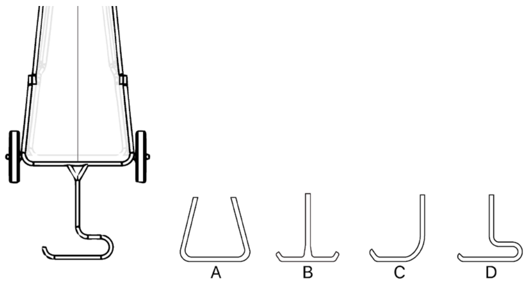


Figure 107 - Hand cart with four different proposed handlebar forms

Table 5 - Form evaluation per form type

	A	B	C	D
Suitable for both one and two hands	✓	✗*1	✓	✓
Compact in size	✗*2	✓	✗*2	✓

*1) Cannot be held in the middle with one hand
*2) Occupies a large width along the bar length (one or both sides)

Attachment design

To ensure that the handlebar can conveniently be used both for pushing and for pulling, the handlebar should be re-attachable and able to rotate around the front beam axis when pulling, but snapping fixed in place in the back where the cart will be pushed only. Therefore, a spring-loaded attachment gripper is designed that opens when its button is pressed (see Figure 108). Two triangular dents inside the gripper fit two triangular embossed forms in the back beam to snap fixed in place. This way, the handlebar is still able to rotate around the smooth front beam when being pulled. Furthermore, the handlebar is formed in such a way that the end is split into two attachment grippers in order to better withstand forces applied to the sides of the bar than one attachment point due to tension and compression forces acting on the two beams, as seen in Figure 108.

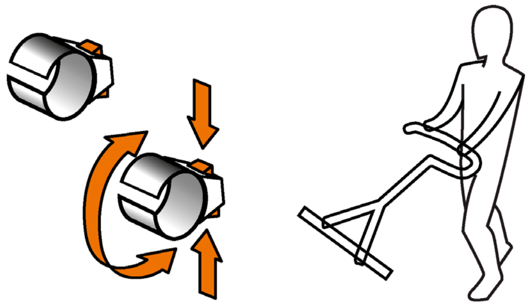


Figure 108 - Design of the handlebar attachment

Handlebar length

To ensure both a hand cart that well manoeuvrable in an ergonomically sound way, and a hand cart that can fold up compactly, further research is done on the needed handlebar length for this.

It is concluded that the height that the handlebar has to reach when pushing the hand cart is 1097mm, which is the mean elbow heigh for 20-30-year-olds (P50, mixed) (DINED, 2017b). When pulling, this height is 995mm, which is the mean hip height for 20-30-year-old (P90) (DINED, 2017b). To prevent the heels or toes of a person to touch the chassis when pulling or pushing, the average step distance is measured by hand, which serves as an indicator of the needed horizontal distance from the pulling hand to the hand cart, being 50cm.

Taking into account these optimal distances and the knowledge that the handlebar needs to be smaller than the largest beam in the chassis plus the back wheel radius, being <87.4cm (Appendix A21), for it to fold compactly with the hand cart, it is concluded that the length of the handlebar needs to be 77cm (see handlebar length calculations in Appendix A21).

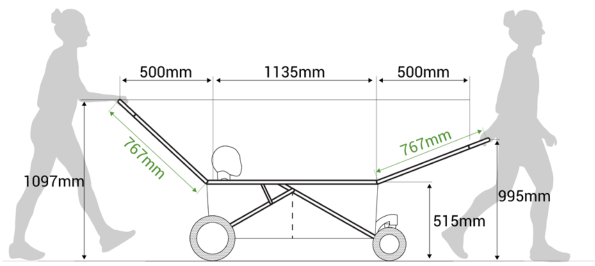


Figure 109 - Defined handlebar dimensions

5.2.3.2 Attachment of Greentom accessories

In order to ensure that the interchangeable accessories (see Figure 112), including the Greentom Car Seat (as well as several regular car seats with the help of Greentom's car seat adaptors), the Greentom Carrycot, and the Greentom Reversible, can conveniently be attached to the top beam of the hand cart when desired, it will be determined what the optimum locations are of the attachment points.

It is concluded that the best position on the top beam is at x = 395mm, as seen in Figure 110. At this location, all Greentom accessories would fit conveniently and safely inside the hand cart while ensuring enough space is left to fit at least two children in the back of the hand cart.

The retractable stumps on which the accessories can be fitted at that position are created in such a way that they can be pulled out of the chassis when needed, and pushed back inside when they are not needed to save space inside the cart, as seen in Figure 111. When pulled out, the attachment pins of each accessory with an outer width of 37cm can be inserted in the stumps which would then be 98 mm in length. (See Appendix A22 for the calculations of the position calculations of the attachment points.)

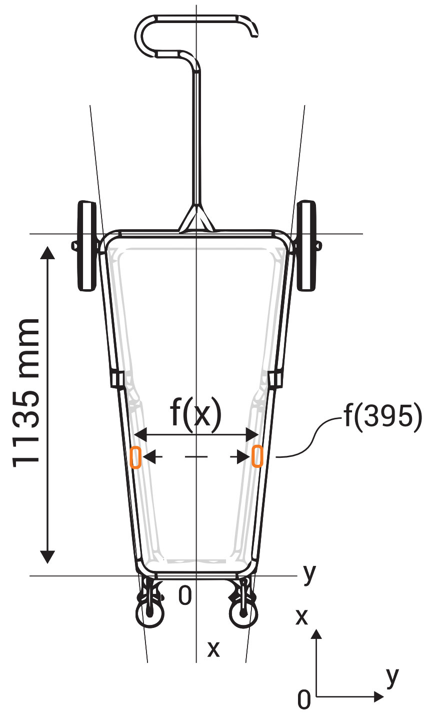


Figure 110 - Defined position of the retractable stumps to enable attachment of accessories

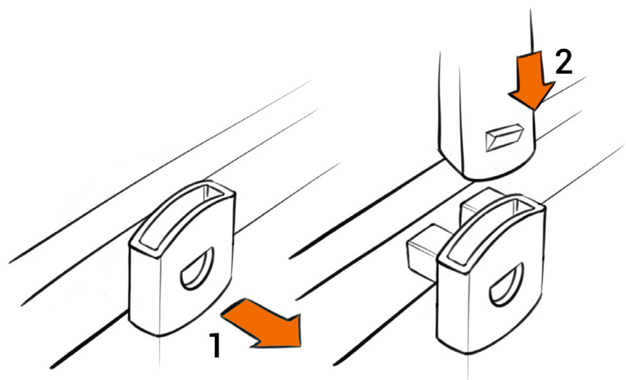


Figure 111 - Workings of the retractable stump at point f(395) for accessory attachment

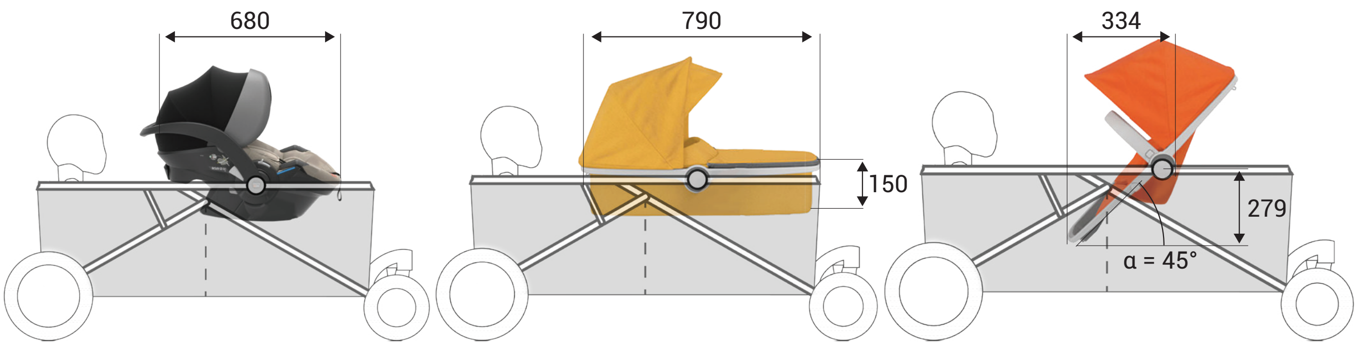


Figure 112 - Greentom accessory dimensions in mm. From left to right: Greentom Car Seat, Greentom Carrycot, Greentom Reversible.

5.2.3.3 Entry gate for children

The collapsible entry gate for children in the front of the hand cart makes it possible for its little passengers to easily climb into and out of the hand cart, as shown in Figure 113. This eliminates the need for parents to repeatedly carry the children into and out of the hand cart -as smaller children are not able to climb over the tall ridge independently-, which is especially alleviating for pregnant women, users with back pain, or any disabilities.

Like in the Greentom Classic, the two middle pivot points of the hand cart will be comprised of a pushable button on one side and a turnable button on the other side (see Figure 113). When both buttons are activated, the entire hand cart can be folded. When only the turnable button is activated while also pulling the entry gate inwards, the entry gate can be collapsed downwards.

Since collapsing the gate requires two actions, this will only be possible to do by the parent for added safety. When pulling the gate up, the system will lock back into place, which can be done by the children as well, adding playfulness to the interaction.

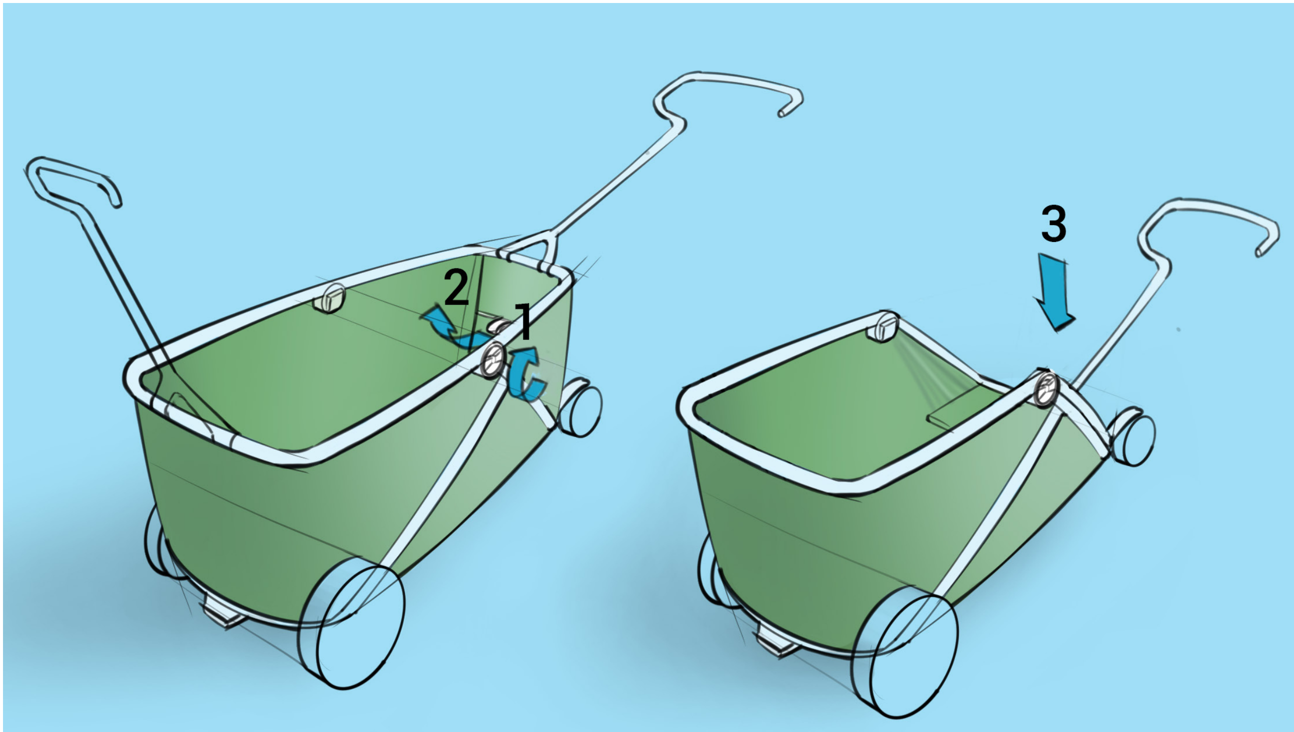


Figure 113 - The working principle of the children' entry gate

5.3 Prototype evaluation

The Greentom Hand Cart Concept now includes developed satisfiers and exciters which should comply with the target group's needs and wishes (as stated in Section 2.4). But do they indeed do so? To find out, a user test with current hand cart users is conducted. To let the users evaluate the dimensions and attributes of the Hand Cart design, a functional and foldable 1:1 Minimum Viable Product (MVP) is created of the Greentom Hand Cart concept in which also the to-be-evaluated attributes are integrated.

5.3.1 Minimum Viable Product

A Minimum Viable Product (MVP) is a functional prototype with the minimum required functionalities integrated to evaluate the user value of the concept in its most basic form. (Fagerholm et al., 2013)

The designed prototype as seen in Figure 114 will, therefore, have the main characteristics and attributes of the end concept design: 1:1 dimensions including a re-attachable textile, with satisfier attributes being a stiff yet easily foldable chassis and large-sized functional wheels, and exciter attributes being a collapsible entry gate for children and a re-attachable push/pull bar.

Aluminium tubes, which are more rigid and therefore more suitable for a functional prototype than the PVC tubes used in previous structure models, are cut and bent to technical drawing specifications (see Figure 115). Weldings ensure the handlebar to get its desired shape, after which it is attached to the chassis with wing-screws for easy (re)attachment via plates that ensure that the handlebar can rotate in the front but stays fixed when attached in the back (see Figure 116).

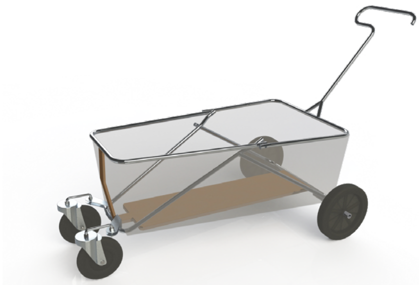


Figure 114 - 3D model of the desired prototype design

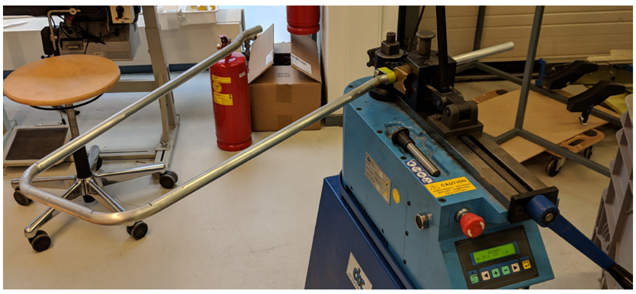


Figure 115 - An aluminum tube gets bent by a tube bending machine

Figure 116 - Bent plates that hold the handlebar put into position before fixing them with aluminum welding

The front and back wheels are of Ø200mm and Ø300mm respectfully, which are close to the intended wheel sizes of Ø215mm and Ø300mm. Special attachments made of sheet metal with wood in between are created to provide the attachment points to fold the swivel wheels against the textile when the hand cart is being folded (see Figure 117 and Figure 118).

Figure 117 - Cut and bent sheet metal being metal glued to the frame

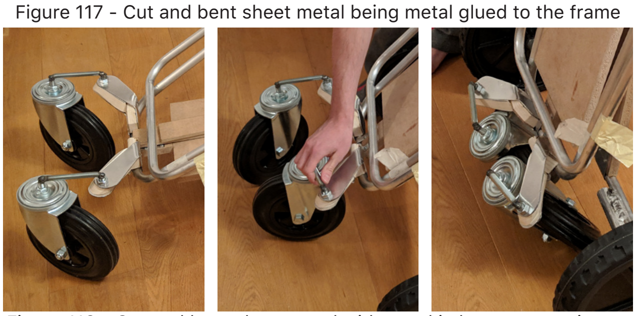


Figure 118 - Cut and bent sheet metal with wood in between serving as attachment points for the pivoting wheel Attachments

Hinged wooden boards are used in the bottom and in the collapsible front entry. The boards in the front entry get locked with an added part placed on top of the hinge (see Figure 119).

Figure 119 - The pivoting front boards with a 'lock' keeping the hinge in place to simulate the locking and unlocking of the front gate.

Lastly, the textile is cut, sewn, and equipped with velcro for easy (re)attachment (see Figure 120).

Figure 120 - The cut textile being sewn with black velcro attached

Stumps to enable attachment of Greentom accessories are not integrated, but will rather be asked about during the user test since asking about the users' opinion regarding the possibility to attach these extra accessories would be more efficient and important than to add retractable stumps to enable this action.

As seen in Figure 121 and Figure 122, finally an aesthetically pleasing, functional, (un)foldable, and manoeuvrable 1:1 scale prototype is created, with all satisfier attributes and near-all exciter attributes integrated, ready to be evaluated with the target group during a user test.

Figure 121 - The Greentom hand cart prototype - folded

Figure 122 - The Greentom hand cart prototype - unfolded

5.3.2 User Test

The user test is conducted to verify if the satisfier and exciter attributes satisfy the earlier set user's needs and wishes. These to-be-tested attributes (of which the physical ones are stated in Section 5.2.1), derived from the set of requirements (Section 2.4), are the following:

1. Suitable for parents with up to three small children
    - A compact chassis when folded **[satisfier]**
    - A large-volume chassis when unfolded **[satisfier]**
2. Easy to use
    - An easy (un)folding mechanism **[satisfier]**
    - A collapsible front entry for children **[exciter]**
    - Attachable (Greentom) accessories **[exciter]**
    - Well manoeuvrable
        - Large wheels (beach suitable) **[satisfier]**
        - A re-attachable push/pull handlebar **[exciter]**
3. Sustainable
4. Affordable
    - A selling price that does not exceed the users' price expectations based on the hand cart's physical attributes **[satisfier]**

Since the sustainability cannot be tested with any attributes available in the MVP, no questions are asked about this requirement during the user test.

5.3.2.1 Research questions

To find out the user's perceived value of the above-mentioned attributes, research questions are set-up. The main research questions which the user test will aim to answer are the following:

1. Is the hand cart deemed to be suitable for parents up to three children based on its folded and unfolded dimensions in the 1:1 MVP model?
2. Is the hand cart easy to use, based on the satisfier and exciter attributes in the 1:1 MVP model?
3. Is the hand cart well manoeuvrable (part of 'easy to use' requirement) based on the satisfier and exciter attributes in the 1:1 MVP model?
4. Is the hand cart affordable based on the user's price indication of how much they are willing to spend on the hand cart compared to other hand carts?

5.3.2.2 Method

The user test which is conducted by the mother accompanied by the eldest child (four years old) from a family of four, of which the father participated during the third part of the test as well.

The user test split into three parts: *The first part* introduces the user to the topic, goal, and proceedings of the user test. *During the second part*, the user is asked questions regarding the dimensions and attributes of the hand cart and is asked to perform certain actions with the MVP before each question, as seen in Figure 123. *During the third part*, non-physical properties are asked about including the possibility of attaching a car seat (without a physical car seat being present), as well as regarding the price that users would be willing to pay for the hand cart by providing a graph with all hand carts with their prices to help the users evaluate a suiting price for the MVP.

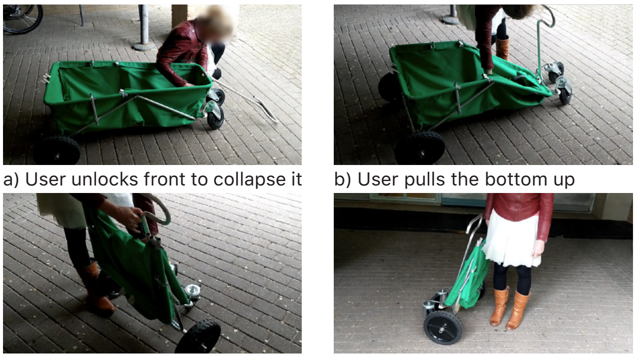
Figure 123 - User pulls the hand cart before being asked about the interaction

A list of the exact questions asked during each part of the user test, as well as the asked actions and provided price chart of competing hand carts can be found in Appendix A23.

Figure 124 - Front wheel connections slowly failing, yet functioning

5.3.2.3 Results

The results, as visualized in Figure 126, show that the user reacted positively on all exciter attributes. The user also reacted positively on all satisfier attributes with only minor suggestions. An example of a successful satisfier is that the user is able to intuitively (un)fold the hand cart without any problems in the first try, as seen in Figure 125.



a) User unlocks front to collapse it b) User pulls the bottom up

c) User holds wheel while folding d) The hand cart is folded

Figure 125 - User folding the hand cart successfully in the first try

The user test has shown that the satisfiers and exciters are well received by the target group and therefore make the hand cart easy to use, suitable for young families, and likely to be perceived as affordable in the future.

5.3.2.4 Discussion

The suggestions include being able to lock the folded cart in place, having something that makes the hand cart easy to transport, and having pockets inside the textile. Fortunately, these suggestions are already implemented in the concept design. However, the possibility to detach the back wheels, fix the pull bar upright when not in use, and having a water-repellant textile are suggestions that could be looked into as future recommendation.

During the test, the front wheel attachments slowly started failing, as seen in Figure 124. However, the wheels remained functional, the slow failing of the attachments could have influenced the user's attitude towards them. It also shows that a future recommendation might be to redesign the connections, possibly attaching them to the bottom of the hand cart while ensuring the children can still climb into the collapsed front gate.

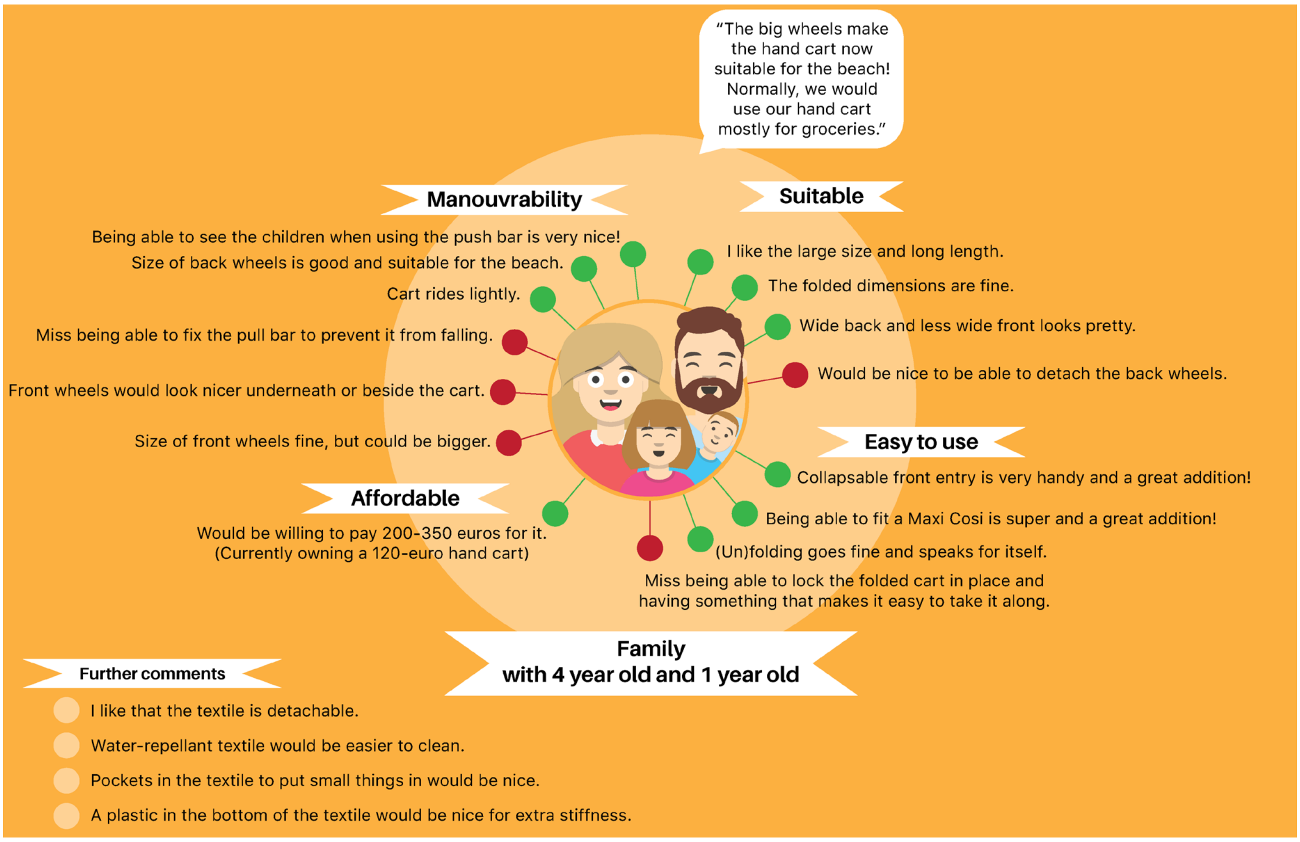


Figure 126 - Summary of results from user test

06

EVALUATION

In this chapter

In this chapter, the end result is discussed and evaluated based on the set design goal and defined requirements. Additionally to this, recommendations for future development of the final concept will be given, as well as a reflection on the graduation project as a whole.

6.1 Greentom Go

A summary of the Greentom Hand Cart, its properties, and what exactly it is that makes the Greentom Go comply with this design goal is summarized in this section.

The developed Greentom Go concept is a sustainable hand cart that is simple in its design, easy to use, suitable to fit 2 to 3 children up to six years old, and affordably priced.

The Greentom Go is a sustainable product that fits with Greentom's vision of becoming a circular brand. It not only uses recycled and recyclable rPP chassis material and rPET textile material for production, but it also has an incentivized take-back system which encourages users to send back their used Greentom Go free-of-charge in return for a compensation at the end-of-life of the product.

By designing the product in such a way that it can easily be (dis)assembled, the collected parts can then easily get remanufactured/refurbished into 2nd-life Greentom Gos. This remanufactured/refurbished closed-loop circular system, which enables parts to get a second life, results in a product with 62% lower eco-costs, or 64% lower carbon footprint, and 71%€ value capture compared to a product with a linear end-of-life after which products get incinerated, or respectively 50% and 51% in the scenario where only 80% of the chassis and not the textile gets refurbished/remanufactured.

Those parts that cannot be refurbished/remanufactured due to functional damage can be shredded and reproduced into new granulate for Greentom parts with QCP as partner (regarding the Chassis), or chemically recycled into new rPET textile (regarding the textile), making closed-loop cradle-to-cradle possible with little to no material property loss.

The Greentom Go is simple in its design since it complies with Greentom's no-nonsense, form-follows-function look, which excludes any superfluous details, while also expressing its own Hand Cart style.

The Greentom Hand Cart is easy to use since it can easily and intuitively be folded and unfolded without the need of loose parts. Secondly, it is easy to use since it is well manoeuvrable: done by having large wheels that make it suitable for difficult terrain such as the beach, by having a handlebar that can be pulled in the front or pushed from the back decreasing the needed applied force and improving body ergonomics, and by being 7.57kg which is light-weight compared to the average hand cart weight 13.85kg (calculations in Appendix A24).

Thirdly, the product is easy to use since small children can easily and independently step through the collapsible front entry after which the parents can close the entry, eliminating the need for parents to repeatedly carry the children into and out of the hand cart. Lastly, the Hand Cart is easy to use since all Greentom accessories as well as car seats (a much mentioned wish) can be attached to the Hand Cart by using the retractable attachment points, making it possible for parents to also safely transport their baby apart from older children and to use the Greentom accessories both in the Greentom stroller and in the Greentom Hand Cart. Additionally, the textile has extra pouches acting as storing compartments, and is detachable for easy cleaning.

The hand cart is suitable for young families as it has the perfect dimensions: having a large inner volume of 186 litres when unfolded, fitting two children in the back and one child in the front as well as belongings to bring along, which is 1.5 times as large as those of competing hand carts, while staying compact when folded with dimensions of {29 x 63 x 81.5}cm, comparable to the average competing hand cart, fitting an average car trunk. Secondly, it is suitable for young families as it is comfortable for passengers, having a soft cushion on top of flat bottom plates as well as in the front and back of the hand cart for back cushioning. Lastly, it is suitable for young families as it is safe: complying with the EN 1888-1 and 2 wheeled-child-conveyances safety norm, as the hand cart includes a foot brake, and three pairs of children' safety straps.

Finally, by using the same hinge button moulds, rear wheel moulds, and swivel wheel moulds as those for existing or possible future Greentom projects, and by implementing the refurbishing/remanufacturing system which has great value capture potential compared to merely reproducing parts from reshredded cradle-to-cradle granulates, the Greentom Hand Cart can be manufactured for lower costs. Reusing existing moulds saves 32% in mould investment costs, or 19% in total investment costs, making it possible to have a selling cost of €244.25 instead of €301.75 per product, returning 500% of investment over five years. If 1/4th of the total produced hand carts over that period of time would also be refurbished and/or remanufactured, then an additional 12% of the total investment costs would be saved, making it possible to have even lower selling cost of €215.20 instead of €244.25 per product.

Both latter cost estimation remain under the upper limit of €250, making the Greentom Hand Cart affordable for users. (see Confidential Appendix CA7 for the calculations of the cost estimation)

In conclusion, the Greentom Go successfully satisfies all requirements and several wishes from the list of requirements and wishes (Section 2.4), and successfully satisfies the stated design goal (Section 1.2.2).

6.2 Evaluation

In conclusion, the Greentom Go is a concept design for Greentom that is desirable, feasible, and viable.

Desirable
For Greentom, the product is desirable as the product is both simple in its design, and fits a sustainable, circular economy. This fits Greentom's form family and complies with Greentom's vision: becoming a circular lifestyle brand.

For users, it is desirable as it satisfies all their needs:

1. Being suitable for young families by having a large volume which fits belongings as well as all children up to six years old for 95% of users, being compact when folded, comfortable for its passengers, and safe as it includes a foot brake and children straps.
2. Being easy to use, as it has an easy (un)folding mechanism, a collapsible front entry for children, the possibility to attach (Greentom) accessories, and being well manoeuvrable as it has large wheels (suitable for the beach) and a re-attachable push and pull handlebar.
3. Being affordable, with a selling price of €220.

Feasible
The product is feasible due to the following reasons:

1. 74% of Greentom's existing customers, which is the percentage of users in the Netherlands with two children or more, are potential users of the Greentom Hand Cart, as families with two or more children tend to buy a hand cart next to their stroller for trips where both children and belongings have to be transported, and where having only one stroller becomes unpractical.
2. Multiple attributes (exciters) of the Greentom Hand Cart are unique compared to existing hand carts, and are concluded to be desirable by users. These exciters include a collapsible front entry, the possibility to attach a car seat and interchangeable Greentom accessories, and a re-attachable handlebar that can be pulled in the front or pushed in the back of the hand cart.
3. Being able to reuse existing moulds (or moulds for future projects), as well as by implementing a circular scheme for refurbishment/remanufacturing, make it possible to produce the hand cart for 31% reduced investment costs if 1/4th of all products get remanufactured/refurbished.
4. It can benefit from existing material company partnerships, as the product consists out the main materials rPP and rPET already used in Greentom strollers.
5. Provided that the style of the Greentom Hand cart would be perceived as aesthetically pleasing, the relatively low price of the hand cart would make it a well-competing product with few competitors.

Viable
The product is viable, as it is estimated to return five times its investment price in five years, providing that the return-shipment costs (to embedded in the selling price), and costs of remanufacturing/refurbishing equipment and workers is lower than the 12% economic benefit it creates (apart from the ecologic benefit).

6.3 Recommendation

The final concept design of the Greentom Go serves as a starting point of a possible new product design to add to Greentom's portfolio. However, any concept design should be further iterated and prototyped until it will be ready to produce. Therefore, this section highlights recommendations of which points to best address of the Greentom Go during its further future development.

The Greentom Go satisfies four wishes, as stated in Section 2.4: being able to attach a car seat, having extra storing compartments, having a detachable textile, and having breaks. However, since having the possibility to attach a sun/rain protection on the hand cart is also an often mentioned wish by users, Greentom should separately sell these attachments for their hand carts, proposed to consist of two foldable canopies on both sides of the hand cart -comparable to those in the Greentom strollers- which can be attached in the middle with an unfolding textile to act as a roof against sun and rain. Another often mentioned wish is that the hand cart to be able to stand by itself when folded to reduce occupied space. Being able to implement this in an improved design of the Greentom Go would further increase user satisfaction.

Research regarding the Greentom Go design was done only with a functional prototype, but not with the intended visual design of the final concept. Therefore, future research should be done to indicate users' perception of the hand cart in terms of aesthetics to verify that the concept design complies with the requirement of being aesthetically pleasing.

The prototype experienced that the front swivel wheels fixtures are prone to breakage, assumingly due to the large moment acting on the fixtures. Therefore, an alternative design should be considered in which the swivel wheels are attached underneath the hand cart instead of in the front, reducing this moment. The possible elevation of the hand cart bottom (making it difficult for smaller children to step into the hand cart through the collapsed gate), and folding challenges should be taken into account when doing so. Furthermore, the interviewed hand cart seller recommends ball bearings instead of rolling bearings inside of the hand cart wheels.

The pull/push handlebar length can be smaller than was calculated for the prototype, reducing needed material. During the length calculation in Section 5.2.3.1, the distance between the legs to the back of the hand cart (when pushing) had been set to the same distance as from the legs to the front of the hand cart (when pulling), while the needed stepping distance when pushing might be lower, which also reduce the needed length of the handlebar. Furthermore, the user test results indicate the user to wish for the possibility to fix the pull bar in the upright position when not in use. This is a wish that should be looked into for implementation since many existing hand carts do have the possibility to fix pulling bars in upright position, for which the Beach Wagon Lite even has a pull bar which automatically springs in upright position when not held.

Lastly, the selling price of €220 of a Greentom Go is a rough estimation based on the calculated total product costs in a system in which existing moulds (and future moulds for future projects) from other Greentom products are reused and in which 1/4th of the production is returned to Greentom for refurbishment. However, to verify that the 12% economic benefit of the refurbishing end-of-life scenario weighs up to the costs of implementing this scenario, a detailed cost estimation should be done in which the possible lower selling price for refurbished products is taken into account, the reimbursement fee to return to customers as an incentive, and the costs of a refurbishing system, including the shipping fee of a collaborating postage partner, costs of industrial cleaning machines, heat guns, and labour for (dis)assembling and refurbishing the parts.

6.4 Reflection

Firstly, the Fast-track Life Cycle Analysis was a large part of the research during the project. However, the LCA is limited for analysis of circular products as it was made for analysing product life cycles from cradle to grave (Ecocostsvalue, n.d. (b)). Due to this limitation of the LCA, Dr. Ir. Joost G. Vogtländer stated in a personal interview that recycled materials are not to be indicated in the End-of-Life stage of the LCA to prevent a 'double-positive' impact when the recycled material is recycled yet again. The double-positive would be caused due to the fact that the recycling credit for recycling a virgin material is already implemented in the material credit of the recycled material variant. Adding a second recycling credit to this value would, therefore, be outside the scope of a cradle to grave analysis.

This working principle of the LCA gives impracticalities when analysing different product life cycles when designing for a circular product in which recycled materials either could have an incineration end-of-life or a recycling end-of-life (not taking into account other scenarios such as remanufacturing or refurbishment). If no end-of-life scenarios are indicated for recycled materials, it is not possible to differentiate between the environmental impact of products where recycled materials are incinerated and the environmental impact of products where recycled materials are recycled yet again at the end-of-life. This is a great impracticality for circular products since the impact of these end-of-life scenarios for recycled materials is clearly different.

Following Vogtländer's instructions, no recycled materials were indicated in the End-of-Life stage, not for recycling nor for incineration. However, if recycled materials could be indicated with other scenarios than recycling, the analysis would have looked differently regarding impact percentages between the product life cycle stages. In this case, another impracticality is that the border of a cradle-to-grave analysis for circular products is difficult to pinpoint, especially for materials that are not fully recycled or fully virgin in the first place. This border of when to indicate or not to indicate the end-of-life impact of recycled materials should have been better communicated at the beginning of the analysis for a better understanding of the results. Using the Circularity Calculator by Ideal & Co proved to be a better method to gain insights into the end-of-life impact in circular systems.

Secondly, looking back on my personal learning ambitions, I have successfully deepened my knowledge regarding the reuse of product materials and the challenges that come into play. Designing a sustainable, circular product is a complex task. Not only should the costs and environmental impact of all stages of the product life cycle be evaluated, but also the costs and impact of circular end-of-life scenarios and collection systems should be taken into account to choose the best sustainable alternatives. Therefore, it is much more than merely selecting alternative, more sustainable, recycled materials which are also recyclable. Regarding the latter, the suitability of the recycled material also depends on the material provider's ability to tweak the properties of recycled materials to specifications.

Thirdly, looking back on the project, I have learned that managing a project in terms of task prioritisation for the given time is just as important as project results. A challenge to overcome is eliminating distraction both outside as with regards to the project: 1) Deciding the project priorities and what only to indicate or not to do at all with regards to what you want to achieve. 2) Have a clear overview each week on the time that these priorities should be given for the time that is available. 3) Prepare for unforeseen circumstances: if no time is left, working on tasks overtime does little good for the project or a designer's health. Therefore, knowing when a task is good enough for the intended result to leave for the next task is important, improving them only when time is left.

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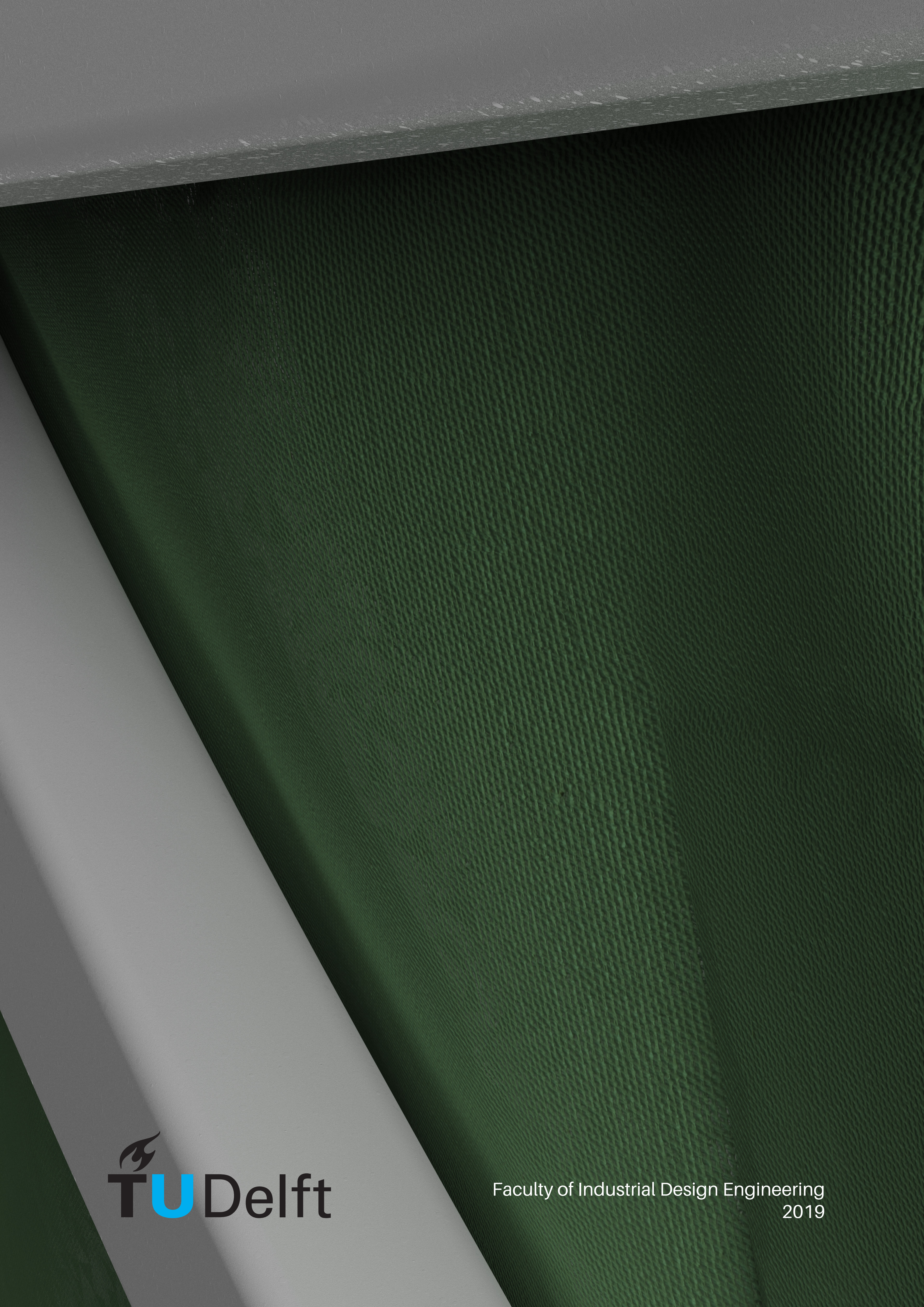

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