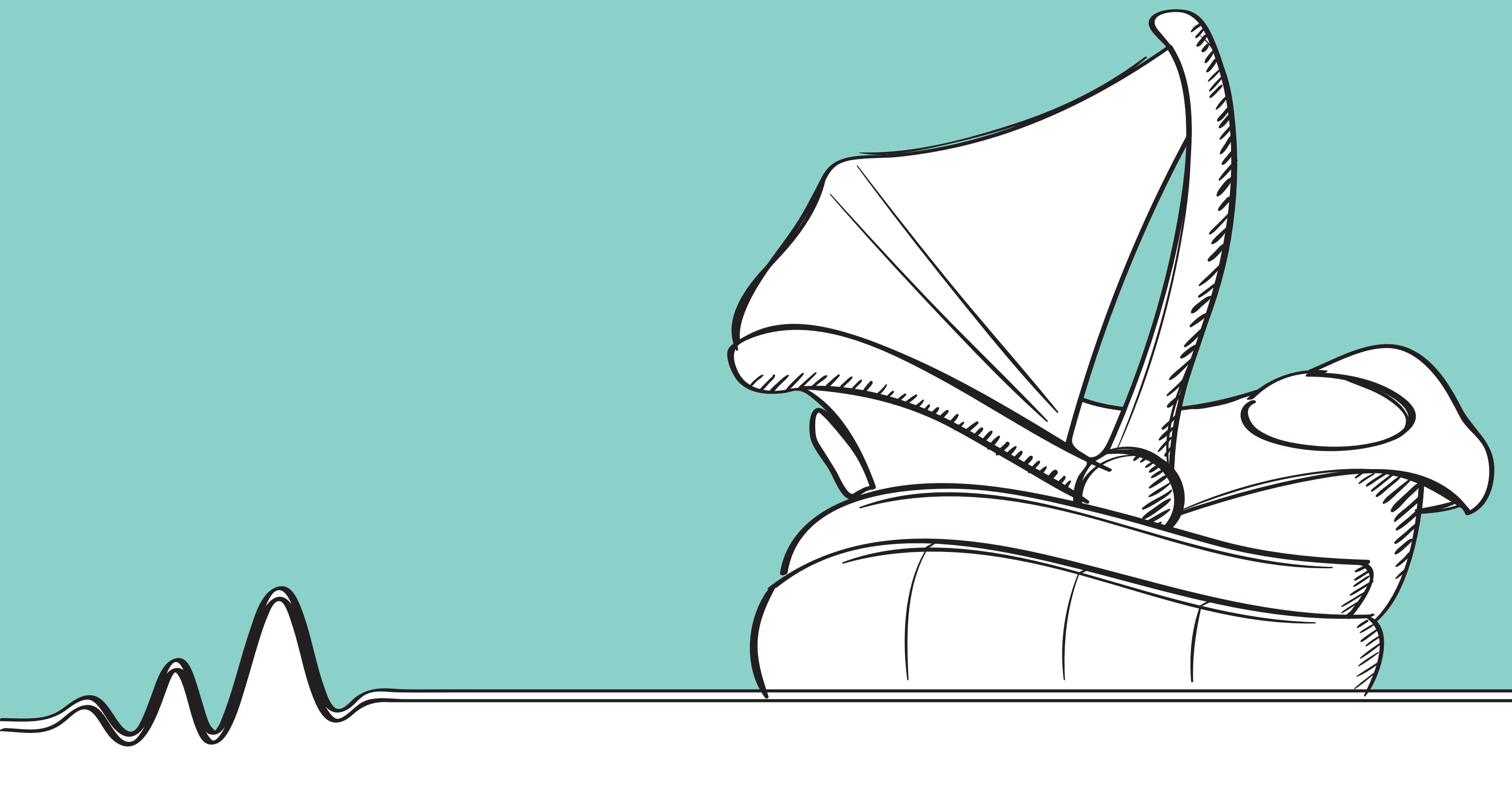
Improving health aspects and comfort of infants during travel by cargo bike

Bart van Driessche
Master Thesis Report
Integrated Product Design
Delft Univeristy of Technology



Improving health aspects and comfort of infants during travel by cargo bike

Graduation master thesis
October 2017 - September 2018

Bart van Driessche
info@bartvandriessche.nl
+31 6 28092242
Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Supervisory team
Chair: Ir. Em. Prof. B. Ninaber van Eyben
Mentor: Dr. ir. S. Silvester, Department Industrial Design, Applied Ergonomics and Design

Preface

This thesis introduces a design proposal for the use of infant safety seats on cargo bikes based on made observations and research. The thesis was the final project of the master program Integrated Product Design at the Faculty of Industrial Design Engineering at the Technical University of Delft.

I would like to thank my supervisors Sacha and Bruno for their involvement, sharing their design knowledge and expertise, and providing me with supportive feedback. I would like to thank the brothers Popal: Aryan, Daniël and Sley. They provided me all the necessary resources to complete my graduation project successfully. I would like to thank my mom, dad and brother for showing their trust and support throughout the entire project. Finally, I would like to thank Brecht Daams. Brecht provided me a letter in which she expressed her concerns about the subject of my graduation assignment. This letter was the motivator for me to come up with the best solution possible.

CON

ENT

01 Introduction

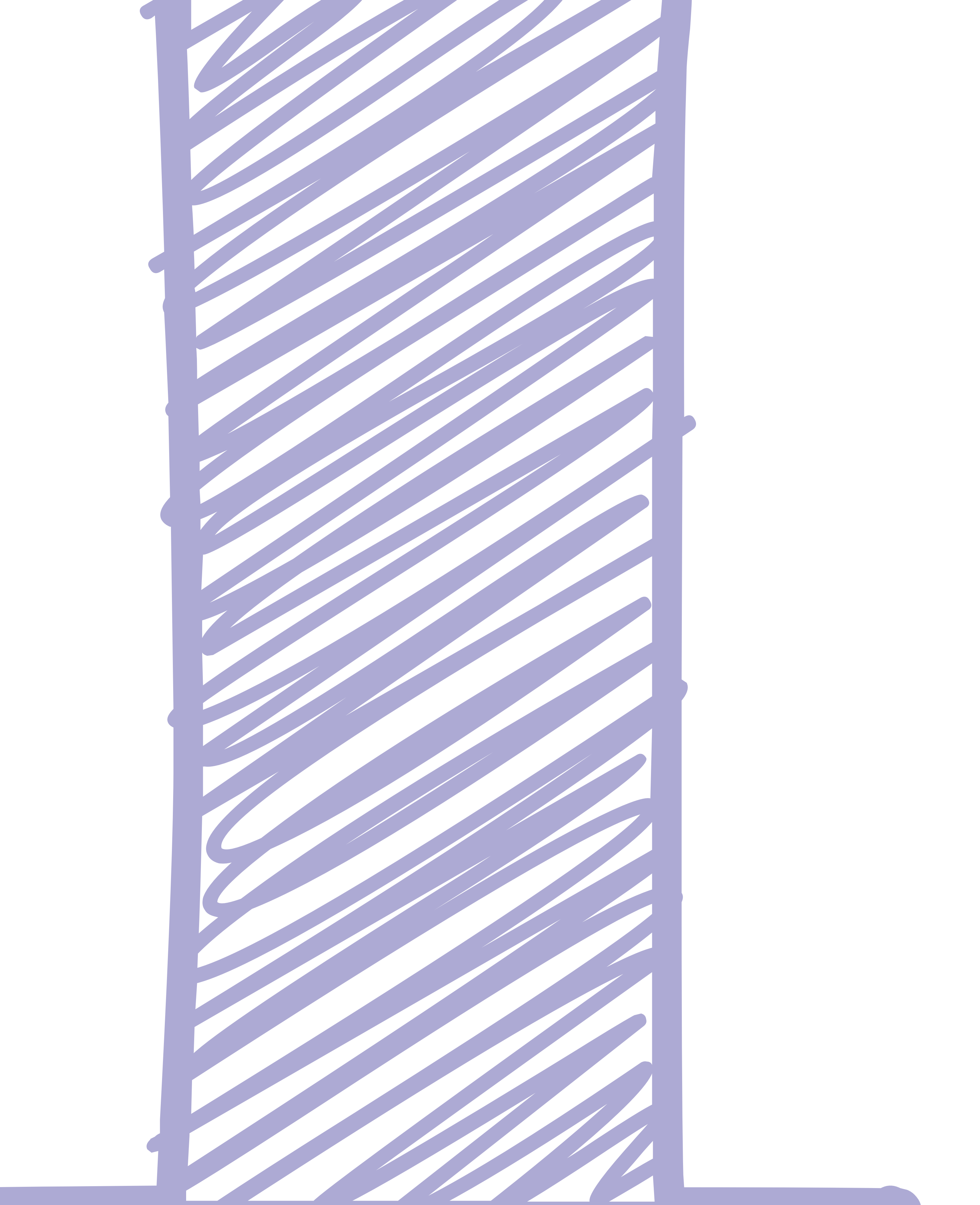
02 Analysis

03 Ideation

04 Conceptualization

05 Detailing

06 Embodiment



Introduction

This chapter provides an abstract of the graduation assignment and profile of the company where the graduation project has been executed: Popal fietsen Nederland. The subject of the graduation project, Improving health aspects and comfort of infants during travel by cargo bike, was drafted based on made observations and research.

”

Design an infant safety seat system for cargo bikes that dampens vibrations and shocks that are transmitted through the cargo bike to the infant.

It is desirable to find a correct recommendation for the use of infant safety seats on cargo bikes, according to made observations and research.

1.1 Graduation assignment

Despite the fact that children are a growing proportion of the population in many urban areas around the world, in terms of urban transport they are an overlooked and vulnerable segment of the population (Tracy McMillan, 2013). These vulnerable road users should be given special attention in road safety policy. Due to more crowded urban environments, parents are extremely cautious towards travelling with children in urban environments.

'Vibrations could be a source of discomfort and a risk to human health.'

Nowadays, there are systems that allow you to take your infant with you on your bicycle or cargo bike. Unfortunately, there are still many prejudices and concerns on this matter. Due to the transmitted vibrations, experts criticize travelling with infants on bicycles and cargo bikes (Brecht Daams (product ergonomist, The Netherlands), Hanneke Poot- van der Windt (physiotherapist, The Netherlands), Ria Nijhuis (professor of paramedical sciences at the Radboud University Nijmegen, The Netherlands) and Joseph Giacomin (director at Human Centred Design Institute at Brunel University, England). Section 2.8 provides a letter (in Dutch) in which Brecht Daams expressed her concerns about travelling with infants on a bicycle (permission for publication granted). Appendix 1 provides e-mail conversations with the three other experts and their concerns about the transmitted vibrations (permission for publication granted).

An infant safety seat is the smallest child safety seat for newborn up to 10-13 kg. The question if there are any long term health effects on infants in infant safety seats has been current on and off since the begin of the 80s when maternity hospitals started to rent out infant safety seats (Nilsson, 2005).

Although child safety seats are properly developed according to the highest standard crash tests in the automotive industry, little is known about the vibrations transmitted from the bicycle or cargo bike to a child fastened in child safety seat. Vibrations could be a source of discomfort and a risk to human health.

This graduation project introduces a design proposal for the use of infant safety seats on cargo bikes, according to made observations and research.

1.2 Popal fietsen Nederland

Popal fietsen Nederland (abbreviated as Popal) is a Dutch bicycle supplier and wholesaler founded in the Netherlands in 1999. In 1999 the Dutch bike market consisted mainly of either expensive luxury models or cheap disposable ones. The Popal brothers felt that there was room for improvement, and decided to produce good quality bikes themselves, for a reasonable price.
With more than 300 models in the collection, and more than 250 dealers in the Netherlands and abroad, Popal has an extensive product portfolio and distribution channel. The majority of Popal's contemporary bicycles (Figure 1) are manufactured in Southeast Asia. The graphic appearance (e.g. color and logo placement) is composed internally at Popal. Popal does not have an internal design and engineering team that is able to fully design and engineer bicycles until manufacturing. All bicycles are

Figure 1: Commercial context photo of one of Popal's urban bicycles, Popal County Roll+

either designed in close collaboration with external product designers, or project developers and mechanical engineers who are employed at large bicycle manufacturing plants (predominantly located in South-East Asia).

Appendix 2 provides a more detailed profile of the brand Popal.

1.2.1 Cangoo

As wholesaler, Popal only sells their products B2B to dealers. To serve other target groups, Popal has set up several subsidiaries. The work required for all subsidiaries is carried out by Popal staff, both for office and logistic jobs. The most relevant subsidiary, in relation to the graduation project, was Cangoo. In addition to city bikes and mountain bikes, Popal also offers cargo bikes. This subsidiary trades under the name of Cangoo.

"The Dutch like to keep abreast of the newest trends, but are smart enough not to pay too much for them. Which is why Popal produces affordable good-quality bikes with a contemporary design. Hip to look at, sturdy quality, but at a price to suit everyone!"

Popal's corperate vision (2018)

Analysis

Urbanisation increasingly puts pressure on traditional urban infrastructure (BBC News, 2018). As a result, emerging trends and developments are changing urban mobility and modes of transportation. This influences the way children, and especially infants, are travelling or are carried along.

The analysis will start with a brief explanation of the different road users. Afterwards, the analysis will elaborate on the mobility patterns of young children. Subsequently, the analysis will draw emphasis on cycling with an infant and the worrisome vibrational conditions thereof.

2.1 Changes in the **urban environment**

Cities around the world are turning to alternative transportation solutions to help solve congestion and pollution issues, as urbanisation increasingly puts pressure on traditional urban infrastructure (BBC News, 2018). This section elaborates on two key effects of urbanisation and their influence on urban infrastructure.

Appendix 3 shows an overview of general changes in the urban environment.

2.1.1 Urban density increases

Greater demand for core urban sites increases urban density. As a consequence, the need for compact transportation solutions increases as well. Moreover, most people buy or rent smaller apartments compared to the ones they would have in towns and villages, so they need smarter solutions to store and arrange their transportation solution(s).

On the other hand, while urban growth (defined by towns and cities of a given size) may be slowing, the drift to suburbanisation continues apace. In many countries relatively small, quite widely dispersed urban centers, are gradually integrating into large urban agglomerations as centers expand, and transport and other infrastructures tie them ever more closely together.

2.1.2 Need for sustainable urban transport intensifies

Due to the changing (sub) urban infrastructure, municipalities are trying to find ways to decrease traffic pollution. The rush (from municipalities) to increase cycling levels and improve the quality of city life is one of the greatest movement in global urbanism (WIRED, 2017).

Figure 2: The skyline of Rotterdam (the Netherlands), highlighting one of Netherlands's most densily populated city.

2.2 Moving around the city

Emerging trends and developments are changing urban mobility and modes of transportation. Nowadays, we shouldn't only focus on the mode of transportation. Instead, we should focus on travelling behavior and safe and secure mobility to help society with these changes. This section highlights the main drivers of these changes.

2.2.1 Main drivers

2.2.1.1 Shift in mobility preferences

Younger generations are leading the way towards on-demand mobility enabling a shift away from personal vehicle ownership (Matus, 2015). This shift is clearly visible in densely populated urban areas. Subcription models for mobility solutions (e.g. Swapfiets, a bicycle sharing company) are becoming more attractive, since younger generations do not want to experience the inconveniences of buying, maintaining and selling anymore.

Other on-demand mobility companies include, o.a. Uber (taxi service, Figure 3) and Amber Mobility (business car sharing platform). Appendix 4 provides a brief description of three leading or upcoming on-demand mobility companies.

2.2.1.2 Car-free zones

Many cities have moved to develop more pedestrian areas in their city centers. These efforts often include not only restricting access for cars but also making the streets themselves more attractive to pedestrians. Cities around the world are opening car-free zones (Figure 5)

Figure 3: Uber's smartphone application

Figure 4: The OV-fiets. Dutch Railways' (NS) bicycle renting platform let a traveller rent a bicycle convenietly at all larger Dutch train stations.

to pedestrians and bikers (McKinsey, 2015). Furthermore, due to urbanization, reduced parking space for cars and strong local emission laws to decrease city pollution, a bicycle is a good alternative for the car.

2.2.1.3 Traveling the last mile

The problem with moving away from car ownership is that you give up one its biggest upsides: you can usually park relatively close to where you're going. Public transit, built around permanent stations, can't offer that (Pierce, 2016). In this case, last-mile solutions (e.g. bike-share programs, Segway rentals, folding bikes) would be an efficient way of traveling. Companies who offer last mile solutions include, a.o. Lime and Bird (two electric scooter sharing platforms). Appendix 4 provides a brief description of these two companies.

2.2.1.4 New materials

Light weighting will intensify over the next decade. Today, weight is already frequently a more important decision factor than cost in purchasing. New manufacturing technologies, including 3d printing, will change the way mobility solutions are designed and assembled to enable higher performance, lighter weight, and novel design (KPCB, 2015).

Figure 5: Car-free zones, are popping up in more and more urban sites.


20
ZONE
PEDESTRIAN
ZONE
Except for
loading
and
At any
£9.95
2 course fix menu
Kids eat free every lunch time

2.2.1.5 Size does matter

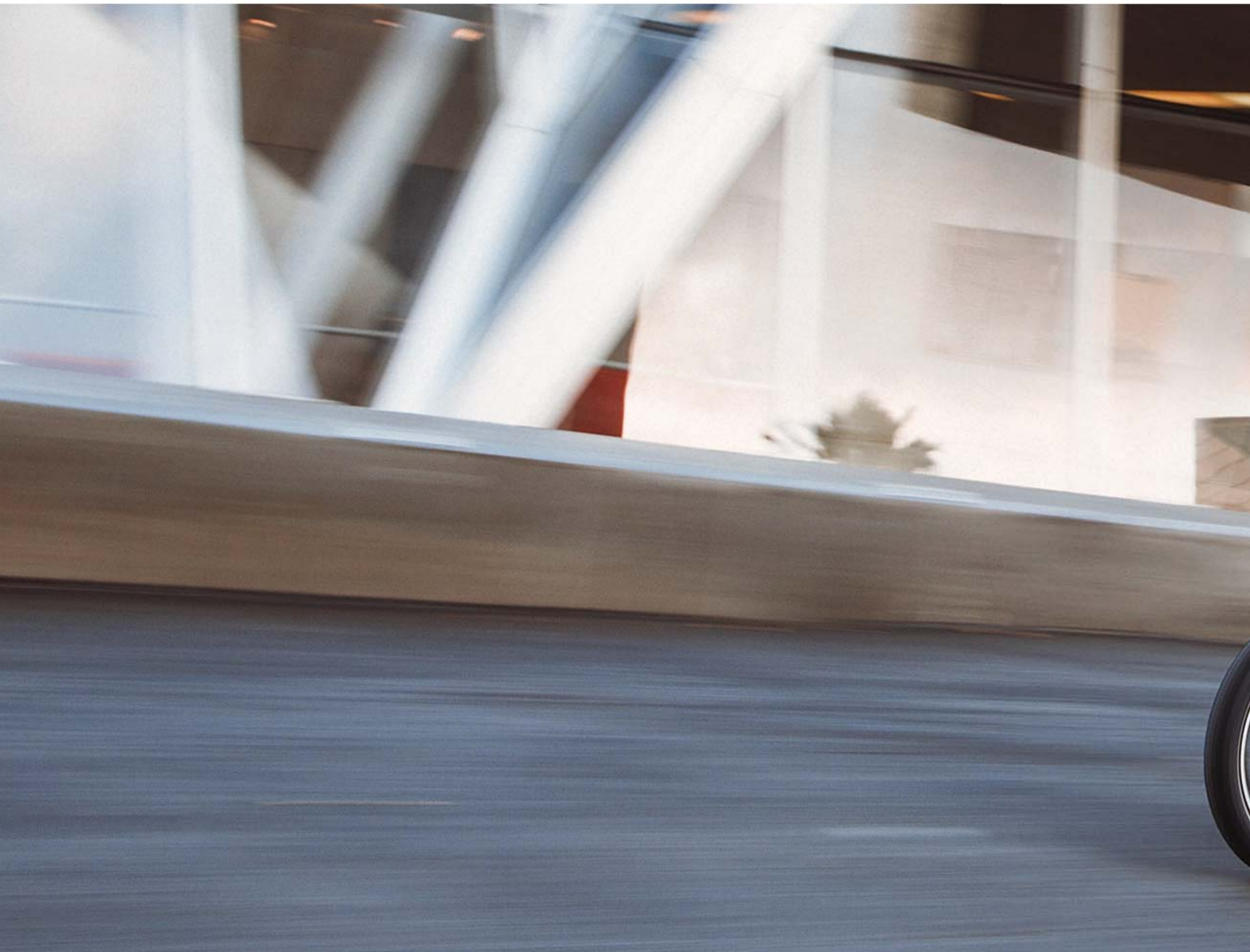
Companies and municipalities are shrinking personal mobility into ever-more compact models (Figure 6). Battery-powered personal mobility devices (e.g. self-balancing vehicles, unicycles) and transportation pods are intended to be an economical way of getting round town.

2.2.1.6 Car-ify the bicycle

Companies are trying to enhance road safety for bicycles, giving them more visibility (e.g. snap-on indicators that start blinking when you turn). However, the biggest boost for improving road safety for cyclists, could come from the emerging Internet of Things – where everyday objects have embedded sensors, smart components and connectivity. In the European Union, researchers are working on projects to see whether bicycles can communicate with traffic infrastructure and cars (BBC, 2015).

> “
> The pedestrian and cyclist should be given the space. If you consider how limited that space actually is, there is only one way to make optimal use of it, that is by taking away the car.
>
> Gerard Tertoolen, traffic psychologist.

Figure 6: Mini Citysurfer Concept. This electric scooter provides increased flexibility for individual mobility in conurbation areas.



2.2.2 Envisioned future

Future urban mobility will show a less car-based infrastructure. Despite the decline of car ownership and an increase of on-demand mobility, it is expected to see an increase in 'specific-purpose vehicle designs'. These vehicles are tailored to the type of mobility they supply and the number of occupants they serve, making them more energy -, space-, and cost-efficient compared to general-purpose vehicles (Burns, et. al., 2013).

In the next decades, bikes will remain a big part of how we move around urban areas. Active transportation — devices that enhance our natural abilities, rather than restrict them — will be an important part of the future (Mora, 2017).

2.3 Sharing the road

This section will briefly discuss several safety concerns and annoyances from the perspectives of the different types of road users. All safety concerns are based on (on-street) surveys found online.

2.3.1 Type of road users

By taking into account the needs, annoyances and physical and psychological capabilities and limits of other road users, the outcomes of the graduation project will create less resistance from these other road users. According to the SWOV (Dutch national scientific institute for road safety research (SWOV, n.d.)) six types of road users (or transport modes) can be identified: pedestrians, cyclists, motorized two-wheeler drivers, passenger car drivers, freight and order traffic drivers (e.g. trucks, delivery vans, etc.) and other modes of traffic (e.g. public transport or agricultural traffic).

2.3.1.1 Pedestrians

These road users do not make use of any vehicle, yet they are participating in traffic (mainly at footpaths). Safety concerns from a pedestrian perspective:

- Distracted walking (e.g. texting, listening to music, Figure 8) (Safety.com, 2017);
- Unpredictability of other road users (mainly passenger car drivers) (Fitzpatrick, Ullman, & Trout, 2003);
- Cyclists weaving in between pedestrians where they feel more comfortable to ride (Planetizen, 2016)

2.3.1.2 Cyclists

In the Netherlands, 25% of all transport (15 billion kilometers) is carried out by bicycle (Fietsersbond, 2016). Similar as sidewalks for pedestrians, many roads (especially in the Netherlands) have special bike lanes for cyclists. Safety concerns, from a cyclist perspective:

- Road sharing with passenger cars when there is no separated bike lane (SP-werkgroep ZuidhornHorn, 2015);
- Lack of rear visibility – what's happening behind the cyclist (Deun, 2016);
- Positioning in traffic (e.g. when pre-sorting lanes in front of traffic lights, Figure 7) (Cleays, De Barba, & Degand, 2008)

2.3.1.3 Motorized two-wheeler drivers

Uses the same road in traffic as passenger cars, trucks and buses. Safety concerns, from a motorized two-wheeler driver perspective:

- Motorized two-wheelers are small and may be difficult to see (National Highway Traffic Safety Administration, 2007);
- Bad road conditions, such as potholes or gravel (National Highway Traffic Safety Administration, 2007);

2.3.1.4 Passenger car driver

This is the most common type of vehicle on the highways and main roads. Research (Johnson, 2011) shows that passenger car drivers are mainly conditioned to worry about other vehicles and often do not see or react to cyclists. Safety concerns, from a passenger car driver perspective:

- Smartphone usage (Allsecur, 2018);
- Reckless cyclists (and pedestrians) ignoring traffic rules (e.g. running through red light, not signaling when turning) (Metronieuws, 2016);
- Cyclists riding 2 or 3 abreast on a busy two lane road (Metronieuws, 2016)

2.3.1.5 Lorries and order traffic drivers

These users are mainly present at highways or outside the city centers. Safety concerns, from a freight and order traffic driver perspective:

- Cyclists often get in a lorry's blind spot as the vehicle turns (SWOV Institute for Road Safety Research, 2012);

> Campaigns should inform all road users about the physical and psychological capabilities and limits of human beings in traffic, thereby helping to understand the behaviour of each road user group, including the need for interaction among road users.
>
> (UNECE, 2006)

Figure 7: Smakkelaarsveld (Utrecht, the Netherlands), Dutch busiest cycling area. Here, cyclist and pedestrians are constantly weaving in between each other to position themselves in traffic.

Figure 8: A road sign indicating distracted walkers

2.3.1.6 Other modes of traffic

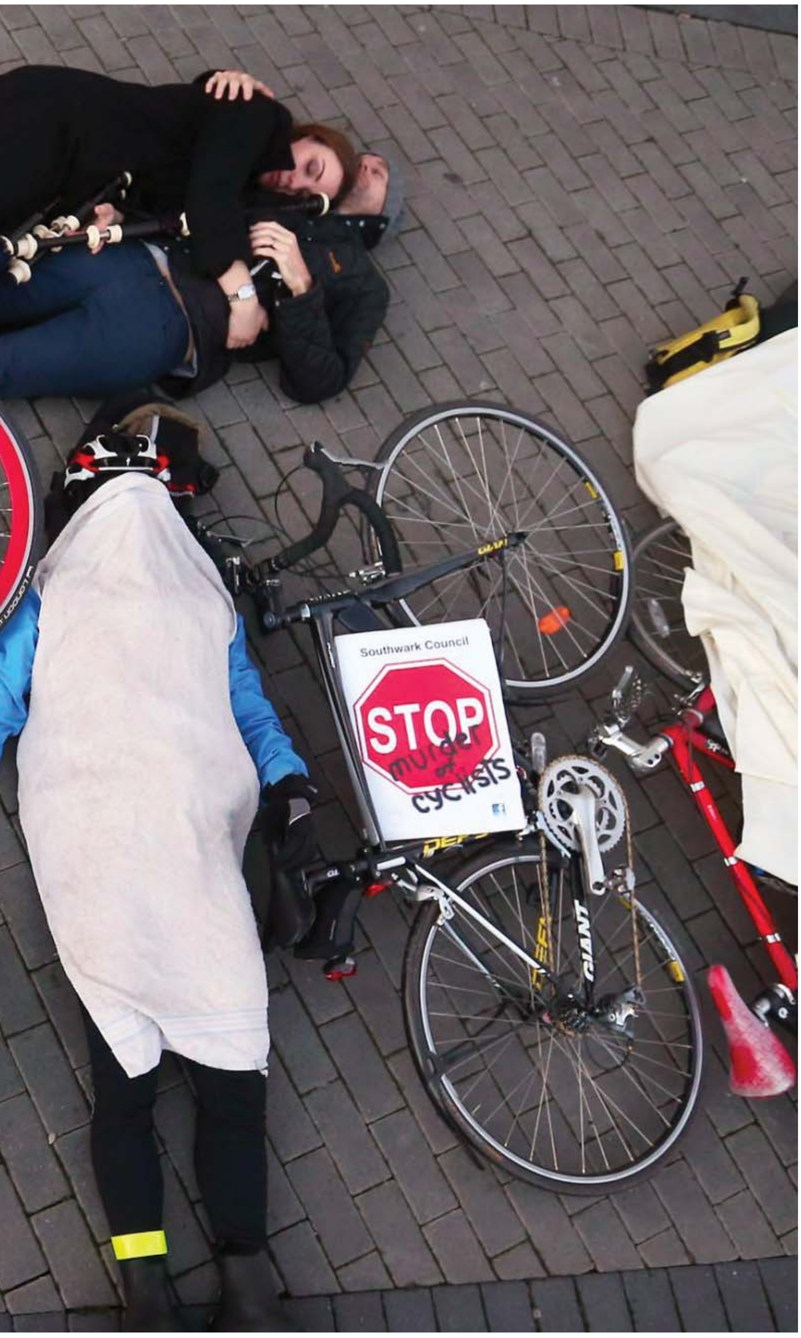
This category includes many modes of transport (e.g. public transport, cable transport and agricultural traffic). For the aim of the graduation project, this category draws emphasis solely on the safety concerns of public transport. The public transport category includes transport by road (bus) as well as by rail-transit vehicles (e.g. metro, tram and train). Air and maritime transport are excluded. Safety concerns, from a public transport passenger perspective:

- Pedestrians face risks prior to boarding transit vehicles (Foundation for Economic Education, 2006);
- Rail-transit vehicles operating on rights-of-way that intersect streets may collide with persons, vehicles, or objects that come into the path of the transit trains (Foundation for Economic Education, 2006).

2.3.2 Conclusion

Road sharing and road user interaction becomes worse when densities are excessive or the available space inadequate. In other words, problems occur more easily in urban cities. Despite the large number of cyclists, this type of road user is easily overlooked by passenger car drivers and lorry drivers. Furthermore, those who are most vulnerable are those road users without a vehicle, and thus without a shell (pedestrians) and those who use a vehicle without a shell (cyclists) (SWOV, 2012). These two types of road users are a form of self-propelled, human-powered transportation modes and are beneficial for health, economics and the environment. In many studies cycling and walking is referred as active transportation modes.

Figure 9: Cyclists stage a 'die-in' protest in London to raise awareness of road safety.



The human body, including its physical and psychological capabilities and limits were taken as starting point, and not the vehicle. This required an inside-out design approach.

2.4 Vulnerable road users

In traffic, children are physically less resilient and are still developing the skills they will ultimately use to participate in traffic in a responsible way. As independent road users children's role is limited to that of pedestrians and cyclists, which are the most vulnerable road users (SWOV, 2009). This section will elaborate on the road safety of these vulnerable road users.

2.4.1 Children: vulnerable in road traffic

Vulnerable road users can be defined in a number of ways. In all cases, the lack of external protection is important and often the task capability also plays an important role (SWOV, 2012). Children are, therefore, extremely vulnerable on roads because of their lack of experience, reduced visibility and bodily fragility (European Transport Safety Council, 2009). At least 1,219 children (0 – 14 years) died in traffic in the EU in 2007, representing around 3.5% of overall road deaths, while they make up almost one sixth of the population (ETSC, 2009).

The UN Convention on the Rights of Children is of key relevance for road safety. Children are vulnerable in road traffic for many reasons, which can be categorized in three main groups (DaCoTa – Children in road traffic, 2012):

- The causes lie within the child due to a lack of necessary skills to interact safely in traffic.
- The causes lie within other road users (especially car drivers, due to a lack of special care and consideration).
- The causes lie within traffic planning and traffic regulation due to a lack of child-friendly infrastructures, regulations and assistance for children.

2.4.2 Road safety for children aged 0 – 6 years old

The experience of childhood is increasingly urban. Over half the world's people – including more than a billion children – now live in cities and towns (Unicef - Children in an urban world, 2013).Despite the fact that children are a growing proportion of the population in many urban areas around the world, in terms of urban transport they are an overlooked and vulnerable segment of the population (Tracy McMillan, 2013).

2.4.2.1 Taking the journey

Between 15 and 20 % of all journeys undertaken are made by the younger generation (European Commission – Kids on the move, 2002). Naturally, we are thinking first and foremost of the journey to school. However, we should not overlook the fact that the majority of journeys made by children and young people are not school-linked (after-school activities, sports, leisure pursuits, visits, games, etc.).

2.4.2.2 Independent mobility restriction

Towards the end of the twentieth century parents began to restrict the independent mobility of children because of traffic safety concerns. More people began to travel greater distances due to continuing urban development thus increasing car traffic and fear of involvement in traffic crashes (Daschütz, 2006).

2.4.2.3 Mobility patterns of young children

Data about the mobility patterns of children as road users in general is scarce. In fact, little is known about children under the age of six years, because most of the statistical data starts with children at this age and older. Children in different age groups are often merged and the varying behaviours of children of different age groups neglected, e.g. longer distances travelled by older children or their greater access to different modes of transport (DaCoTA, 2012). Moreover, the way children under the age of six years travel is most often dictated by the choice of their parents.

> Despite the fact that children are a growing proportion of the population in many urban areas around the world, in terms of urban transport they are an overlooked and vulnerable segment of the population.
>
> (Tracy McMillan, 2013).

Figure 10: Wearing a bicycle helmet increases toddler's road safety

There are only few scientific projects which provide information about the mobility patterns of children (DaCoTA, 2012), e.g. Fagerholm & Broberg (2011) and Shaw et al. (2015). Or the information might be outdated, e.g. Bijur, Stewart-Brown, & Butler (1986), Finlayson (1972) and Ginsburg & Miller (1982). Moreover, many countries do not have or use thoroughly assessed exposure data, specifically about walking, cycling or travel patterns (Nilson, 1997).

2.4.2.4 Children's activity environment

It can be assumed that children's activity environment is more limited nowadays than in the past as indicated by the decreasing number of unaccompanied journeys by children and the increase in car traffic (Limbourg, 2008). The theoretical 'activity environment' – the area in which people travel or play – of toddlers and young children up to 6 years is approximately 100 metres, for children between 6 and 12 years from 330 to 400 metres and for older children and teenagers between 800 and 1000 metres (Daschütz, 2006).

2.4.3 Conclusion

Knowledge about the environment in which children are active and their mobility patterns is limited, especially for children under the age of six years. Therefore, the graduation project will draw emphasis on the travelling behavior of (parents and their) children under the age of six years. Furthermore, the way children under the age of six years travel is most often dictated by the choice of parents. Also, the increasing restrictions in terms of independent mobility of children, because of traffic safety concerns, contributes to the choice to design a transportation solution for younger children.

2.4.2.3 Improvement of road safety for children

Improvement of road safety for children under the age of six, is most likely to be achieved through combining measures to address the behaviour of all road users, improve the road environment, design vehicles that better protect both their occupants and those at risk outside the vehicle, and promote the use of appropriate restraint systems by children. Furthermore, encouraging the use of protective equipment in vehicles, such as child passenger restraint systems, booster seats and seat belts, airbags and a rear seating position for children will improve road safety (Department of Psychology – road users, 2016).

‘Emphasise on the travelling behavior of (parents and their) children under the age of six years.’

Figure 11: Children’s traffic play. Traffic exams and lessons can increase road safety for children.

2.5 children as road users How do they travel?

Data about the mobility patterns of children as road users in general is scarce. In fact, little is known about children under the age of six years, because most of the statistical data starts with children at this age and older. As a result, a quantitative research was executed to map the travelling behavior of parents travelling with children.

2.5.1 Data set

In total, 175 participants have started the online questionnaire. 111 Participants (63%) completed the questionnaire. The high number of unfinished questionnaires might be caused by its length. 38 Of the 111 participants, which accounts for 34%, lived in 1) cities, 2) municipalities that show a strong population grow according to the Dutch Regional Population and Household Forecast (2015) or 3) municipalities that have more than 100.000 inhabitants. The results of these 38 participants were used for the data analysis.

Appendix 5 provides an elaborated description of the research method.

2.5.2 Personal situation - persona

33 Of the 38 participants (87%) lived together with their partner or were married. 23 Of the 38 participants (50%, Chart 1) worked part-time with an average work load of 26 hours per week.

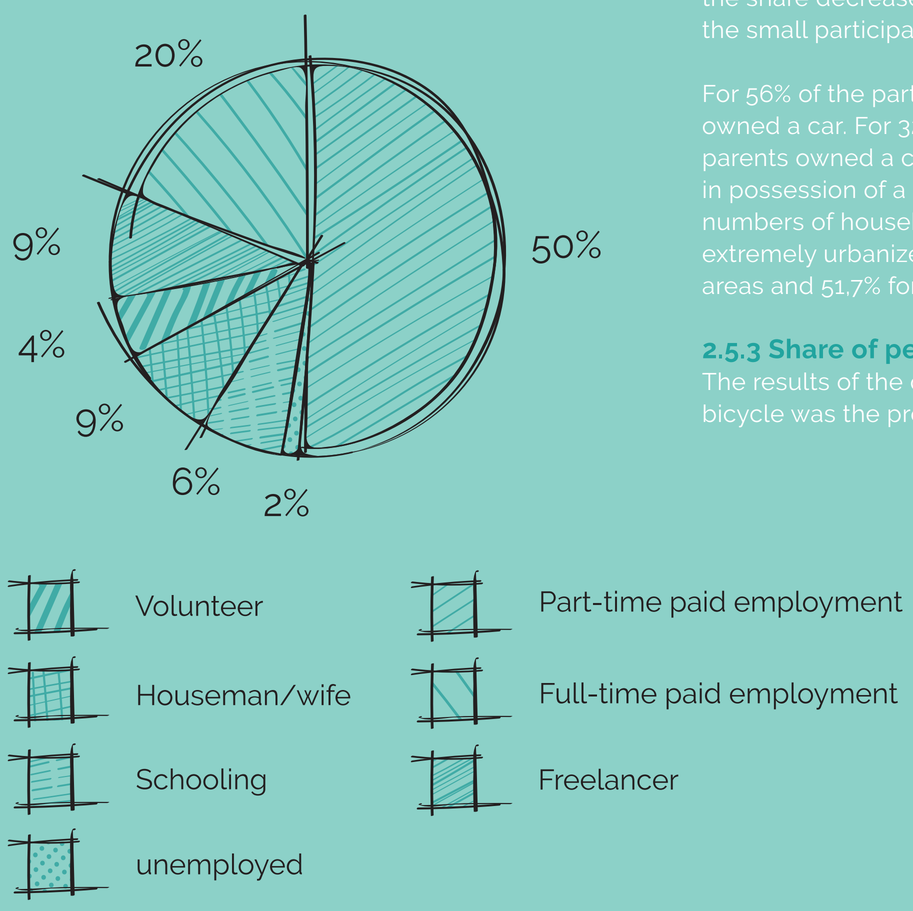


Chart 1: Current living situation of the participants who completed the questionaire.

For 20 of the 35 participants (57%, Chart 2), work was located within 15 kilometers. Within this distance, 89% (n=17) cycled to work. Above 15 kilometer, 93% took the car (n=14). According to a srudy executed by the RAI vereniging (2018), the maximum commuting distance that is still acceptable for employees who cycle to work with a normal bicycle and an e-bike, is respectively 10 and 15 kilometers. 50% Of all participants (n=17) in the quantitative research used the bicycle as main mode of transport for commuting. This number does not fully correlate with numbers found in the database of CBS. The results found in the study executed by the (CBS, 2018) stated that 49,9% of the population cycled to work if work was located in the range of 3,7 – 5 km. After this distance, the share decreased. This difference might be caused by the small participants sample used in this research (n=38).

For 56% of the participants (n=19), one of the parents owned a car. For 32% of the participants (n=11) both parents owned a car. Statistics from CBS (households in possession of a car, 2015) showed slightly smaller numbers of households owning one car: 40,6% in extremely urbanized areas, 49,6% in highly urbanized areas and 51,7% for moderate urbanized areas.

2.5.3 Share of people using bicycles

The results of the quantitative study showed that the bicycle was the preferred mode of transport for journeys up to 3 kilometers. 49% of the participants (n=18) took the car when travelling distances between 3 to 5 kilometers. In the same distance range, 49% of the participants (n=18) either cycled together with their child(ren) on a normal bicycle, cycled together with their child(ren) on an E-bike or the child cycled under supervision of a parent. After 5 kilometers, merely 8% of the participants (n=3) cycled together with their child(ren) (see Chart 3).

According to the 'Onderzoek Verplaatsingen In Nederland (Kennisinstituut voor Mobiliteitsbeleid, 2017), the share of people using bicycles for journeys more than 5 kilometers was higher: 31% and 20% for e-bikes and bicycles, respectively (Table 1). Moreover, the average distance per journey by bicycle is 3.61 km (Centraal Bureau voor de Statistiek, 2016). Assuming favorable conditions and an average cycling speed of 18 km/h (Fietsersbond, 2017), a journey would take around 12 minutes of cycling (without stops).

There might be several reasons for the difference in share between this study and the results of the 'Onderzoek Verplaatsingen in Nederland': the child is too young to take part in traffic independently (81%, n=30), the route's traffic safety for young children was insufficient (41%, n=15), crossing busy road (43%*, n=16), traffic behavior of other road users (73%*, n=27) and speeding car drivers who do not pay attention to the presence of children (54%*, n=20).

*Results from journeys with a distance of more than 5 kilometers. The total percentage is more than 100%, since participants were allowed to select multiple answers.

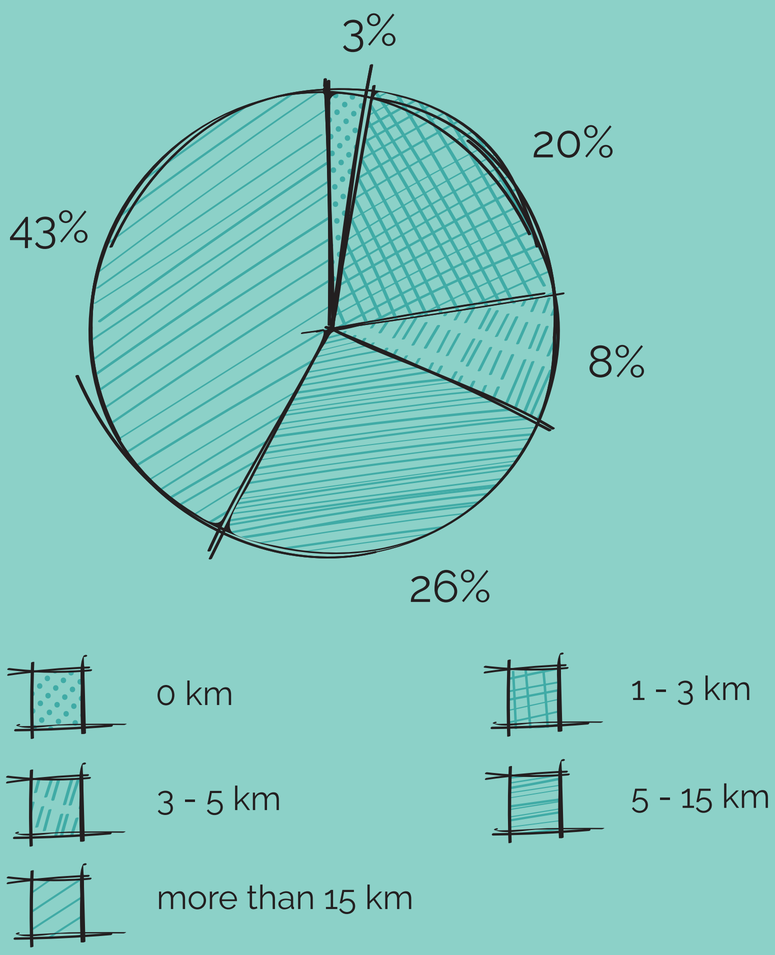


Chart 2: Distance to work, of the participants who completed the questionaire.

2.5.4 Accessibility of leisure activities

Around 80% of the participants indicated that all activities such as day care centers, outdoor recreation, shopping centers and playgrounds were located in a range of 5 km.

2.5.5 Challenges when travelling with young children

A few recurring themes could be derived from the challenges and problems participants mentioned. These themes and corresponding challenges were:

Bicycle child seats:

- Lifting (two) children on a wobbly bicycle
- When having two bicycle child seats there is no space for extra luggage
- Insufficient modularity of bicycle child seats (too tall for a baby seat, too small for a larger seat)

Babies or young toddlers:

- When children are very young you have to take a lot of extra stuff with you
- Travelling with a baby or toddler who is too young to sit independently
- Small car parking space
- Taking a baby or toddler out of his or her Maxi-cosi.
- Taking a stroller out of a car
- Securing children in their seatbelt (in the rain)

Bakfiets:

- (Uncomfortable) parking and storing at home or in the neighborhood

Distance	e-bike	normal bicycle
0,1 tot 0,5 km	3.00%	4.00%
0,5 tot 1,0 km	9.00%	11.00%
1,0 tot 2,5 km	34.00%	40.00%
2,5 tot 3,7 km	15.00%	17.00%
3,7 tot 5,0 km	7.00%	8.00%
5,0 tot 7,5 km	13.00%	12.00%
7,5 tot 10 km	5.00%	3.00%
10 tot 15 km	6.00%	3.00%
15 tot 20 km	3.00%	1.00%
20 tot 30 km	3.00%	1.00%
30 tot 40 km	1.00%	0.00%
40 tot 50 km	0.00%	0.00%
50 km of meer	0.00%	0.00%

Table 1: Distribution of bicycle and e-bike movements over distance classes, 2013-2016, CBS OViN (2013-2016); edited by KiM.

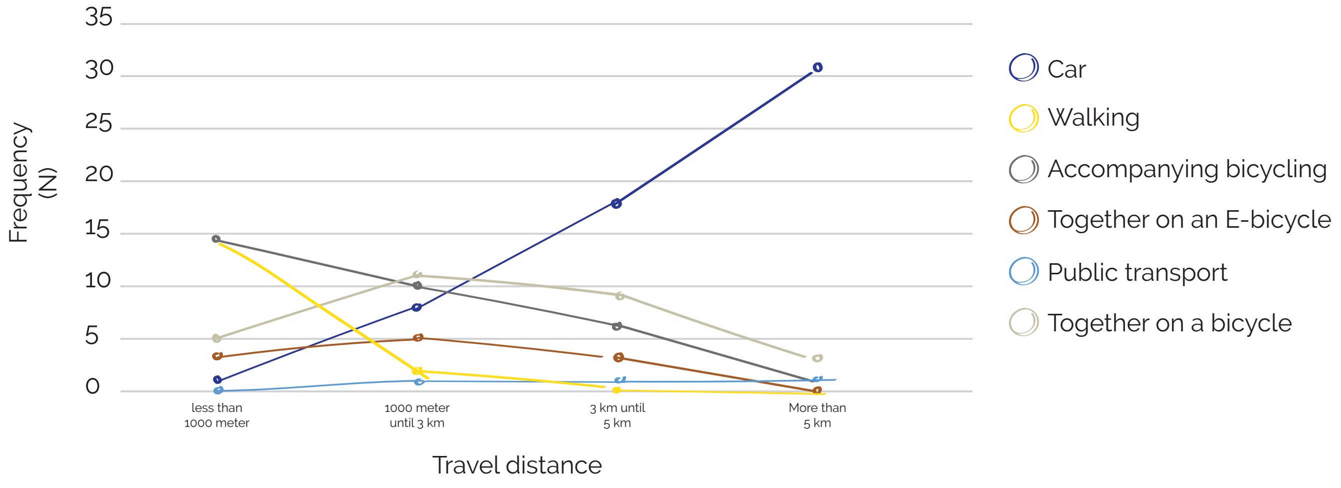


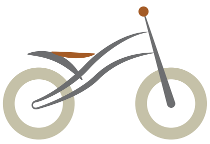
Chart 3: Preferred mode of transport, of the participants who completed the questionaire, according to different distances.

2.6 Current transportation solutions

Nowadays, a lot of different 'active transportation' systems enable safe and efficient transport with infants, toddlers and young children. This section provides a comparison between these systems, based on several topics. This section ends with the first requirements for the design proposal. Appendix 6 provides an overview of all the different systems available.

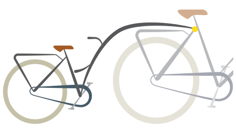
2.6.1 Current transportation solutions

Based on the different systems available, three systems were identified:



- A system in which the child takes **actively part in traffic**. Meaning independently controlling his or her mode of transportation (e.g. balance bicycle).

- A system in which the child takes **passively part in traffic**. Meaning the child does not control the mode of transportation (e.g. child bicycle seat).



- A system in which the child takes part in traffic, but not independently. Meaning the parent or any other person controls the mode of transportation. Though, the child is **actively involved** (e.g. trailer cycle).

2.6.2 Seating position

'Ouders online' (English: parents online) and the 'fietsersbond' provide parents with handy advice regarding safe travel of young children (0 – 4 years old, Figure 12). This advice is composed in consultation with VeiligheidNL. A summary of this advice is described here.

2.6.2.1 Infant

According to the Voorthuizen (2003), editor of the Fietsersbond, an infant can be transported in a maxi-cosi or 'babyschaal' attached to a bicycle when he or she is 3 months old. At this age children need to be transported in a lying or half-lying seating position. Although it cannot be found on which resources this information is based, the age of 3 months might suggest the age at which infants learn to sit with support (Gallahue, Ozmun, & Goodway, 2012).

In addition, according to VeiligheidNL (a Dutch leading and independent institution in the field of accidents and safety behavior), with the current data no clear statement can be made about the minimum age from when infants can be transported on a bicycle (VeiligheidNL, n.d.).

2.6.2.2 Toddler

9 months to 3 years old
Between the 6 and 8 months an infant starts to sit upright independently. Around this age the muscles in the back, upper body and neck are developed enough to keep the body upright (Gallahue, Ozmun, & Goodway, 2012). However, their muscles and stability are not yet developed enough to sit alone on a normal bench and they are advised to be placed in a bicycle child seat.

2,5 years to 6 years old
The muscles and core stability of these children are developed enough to sit independently on a normal bench without special seats. Moreover, they have become too tall to sit in a bicycle child seat.

2.6.3 Current solution comparison

Appendix 7 offers a complete comparison chart between child bicycle seats, the bicycle trailer, the cargo tricycle and cargo bike. The toddler bicycle seat and infant safety seat were combined into 'child bicycle seats', since both seats are placed similarly. Solutions whose main mode of transport was walking, were not included in the comparison, due to core business of Popal Fietsen Nederland.

All four solutions were compared on eight main topics: safety, handling, maneuverability, social, price, utility, comfort and maintenance. Within this chart, disadvantages, advantages and possibilities of each solution are indicated visually (respectively in red, green and blue).

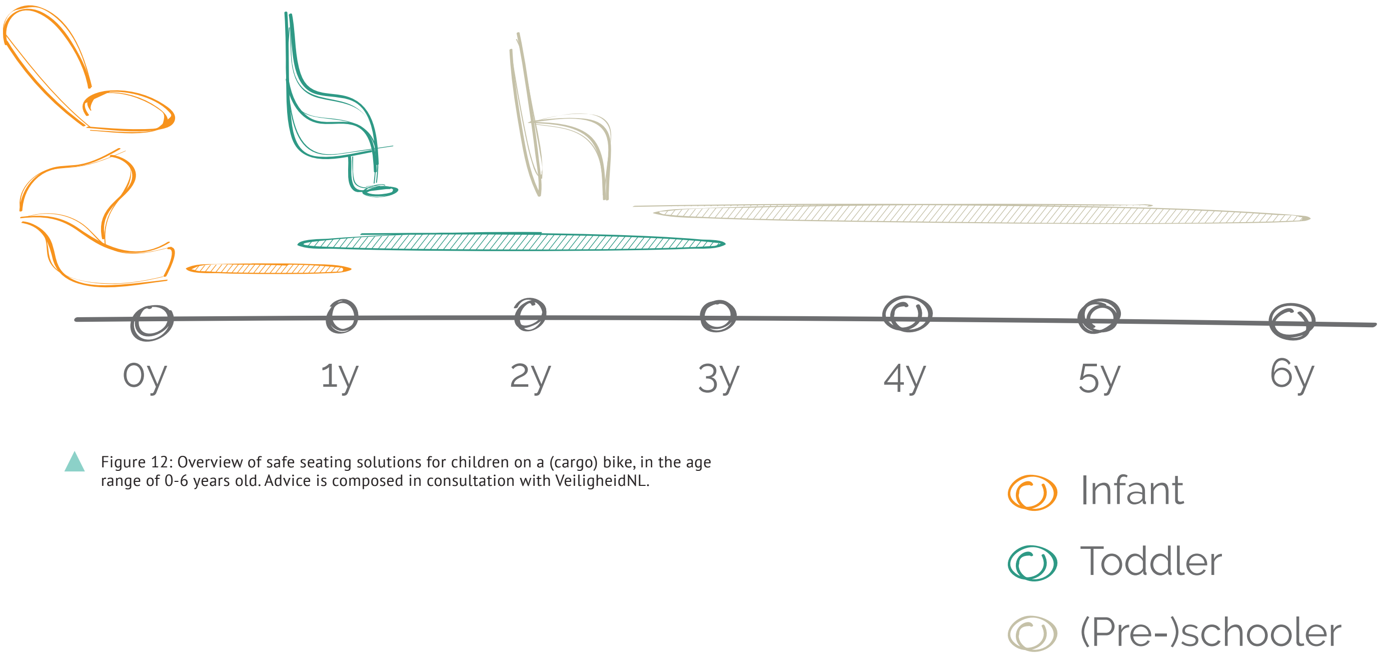


Figure 12: Overview of safe seating solutions for children on a (cargo) bike, in the age range of 0-6 years old. Advice is composed in consultation with VeiligheidNL.

2.6.3.1 Primary focus

The bicycle trailer is a solution that offers protection in case of a collision and in bad weather conditions. However, several reasons make this solution less suitable in comparison to the cargo tricycle and cargo bike:

- Interaction is difficult and inconvenient, since parent and child are relatively far away from each other
- Regarded as less safe, since children are “sticking out” into traffic.
- Due to the low mass, the bicycle trailer is highly subject to vibrations caused by road undulations.

Although, the child bicycle seat is a cheap and well-accepted transportation solution, the graduation project did not drew emphasis on this solution, because:

- The lack of storage space after a bicycle seat is placed
- High downward travel before child hits the ground in case of an accident.
- Instability when loading children onto the bicycle.

2.6.4 Conclusion

Sitting children in cargo tricycles and cargo bikes (simply put: cargo bikes) and the associated interactions were the primary focus of the graduation project. As a result, the design proposal must fit in the box of a three-wheeled cargo bike. It is, however, desirable that the design proposal fits in a two-wheeled cargo bike.

Appendix 8 provides a benchmark of four different cargo bikes.

‘Sitting children in cargo tricycles and cargo bikes (simply put: cargo bikes) and the associated interactions were the primary focus of the graduation project.’

2.7 The Cargo bike

Cargo bikes offer a number of advantages (e.g. cost effective) and are able to replace small cars in city centers, easing traffic congestion and keeping the streets safer. Furthermore, due to urbanization, reduced parking space for cars and strong local emission laws to decrease city pollution, a cargo bike is a good alternative for the car. In addition, cycling with children in a cargo bike result in more freedom, interaction and fun for both parents and children.

2.7.1 GoPro
Qualitative field observations were made to study the different interactions that occur when parents cycle with their children on a cargo bike. Prior to the field observations, three different interactions were identified:
- Interaction between parent and child;
- Interaction between children, and;
- Interaction between child and seat

Participants were asked to record their journeys on their cargo bike by using a Go-Pro action camera (Figure 13). The Go-Pro's were provided by the Delft University of Technology and were mounted in the direction of the children. Due to the sensitive footage of children, the participants were asked to sign a privacy declaration, which can be found in appendix 9 (in Dutch).

To find participants, a call was posted on the public Facebook page "bakfietservaringen" (English: cargo bike experiences) and a poster was made that was distributed among child care's in Utrecht, the Netherlands (appendix 10). Three participants have signed up:
- Female participant, living in Valkenswaard (the Netherlands). Two children: 1 and 3 years old;
- Female participant, living in Eindhoven (the Netherlands). Three children: 0, 3 and 5 years old, and;
- Female participant, living in Schijndel (the Netherlands). Three children: 1, 5 and 6 years old

2.7.1.1 Results
The field observations resulted in more than 4 hours of footage. The following observations were assessed as most valuable:
- One of the children fell asleep during a journey. The head of child did not slump in the travelling direction, but sideways instead.
- The infant lying in the infant safety seat experienced clearly visible vibrations, especially when cycling over speedbumps (Figure 14).
- The seatbelts of both the toddler bicycle seat and the seat belts of the standard wooden bench easily dropped down from the shoulders of the toddler to elbow height.

2.7.2 Kut YUP!
Due to the growing challenges of urban mobility, cargo bikes are experiencing a renaissance. And although they can be a handy solution for moving children around the city, social acceptance of these bicycles is rather debatable.

People on the street of Utrecht were asked how they thought about 'bakfietsen' (Figure 15). These findings were compared with messages on social media. Annoyances were either caused by its cumbersome size or by the parent(s) who drove them.

Appendix 11 describes the findings of this field research in more detail.

2.7.3 Having children in front or behind you?
The aim of the field research was to investigate whether parents with young children would prefer to have their children seated in front of them or behind them when cycling. The field research showed that participants preferred having their children in front of them. The fact that participants preferred having children in front, confirmed the disadvantages of the bicycle trailer and the choice to draw emphasis on the cargo bike rather than on a normal bicycle where (in most cases) the child is placed behind the parent.

Appendix 12 describes this field research in more detail.

Figure 13: (upper figure) Installation of the Go-Pro action camera on the cargo bike. The wide camera lens of the Go-Pro ensured clear footages, in which the children and roads were properly captured.

Figure 14: (middle figure) Still image of one of the Go-pro footages. Here, an infant lying in the infant safety seat experienced clearly visible vibrations. Permission to publicate granted by parents.

Figure 15: (lower figure) On-street research. “What is your opinion about cargo bikes?” People in the centre of Utrecht (the Netherlands) were asked to write down their opinion about cargo bikes on the wrapped cargo bike itself.

2.8 Cycling with an infant

Figure 16: (top left) Steco Baby Mee adapter mounted on two wooden beams.

Figure 17: (top right) Infant safety seat (Maxi-Cosi Cabriofix) mounted to the Steco Baby Mee adapter. Permission to publicate granted by the parents.

Figure 18: (bottom right) Infant safety seat (brand unknown) fastened to the bench of the cargo bike by means of seatbelts. Image found online.

Figure 19: (bottom left) Infant safety seat (brand unknown) fastened to the floor of the cargo bike by means of straps.

The recorded footage, as described in section '2.7.1.1 Results', showed that the infant lying in the infant safety seat experienced clearly visible vibrations. As a result, the emphasis of the graduation assignment shifted towards understanding the problems that occur when cycling with infants.

2.8.1 Dutch online blogs and forums

Online research showed a lack of suitable solutions for cycling with an infant. Parents come up with their own solutions without being aware of the dangers and consequences of such a solution (Figure 16-20). Dutch online blogs and forums highlight the need for a solution that enables parents to travel with their infant on a bicycle safely (translated from Dutch to English).

From Family and lifestyle blog the Mommy Diaries, topic: baby in de Babboe bakfiets (English: baby in the Babboe bakfiets):

- "Anyway, before I purchased that bike I searched the whole web for a solution to take my infant on a bike safely and did not find anything unfortunately."
- "(...) I could barely find any useful information concerning travelling with your infant on a cargo bike."

From Dutch online forum 'Dragen en Voeden: platform voor natuurlijk ouderschap' (English: Carrying and feeding: platform for natural parenthood), topic: eenvoudig leven (English: simple living):

- "We have an old foam pillow in the box of the cargo bike (...) and to buckle the Maxi-Cosi we made four loops with old inner bicycle tubes through the holes at the bottom of the cargo bike."

2.8.2 Expert opinion

The design scope was shared with different experts to discuss its relevance. Multiple experts, such as physiotherapist Hanneke Poot- van der Windt, professor of paramedical sciences at the Radboud University Nijmegen (the Netherlands) Ria Nijhuis and product ergonomist Brecht Daams replied me. Brecht Daams (Daams ergonomics) provided a letter in which she expressed her concerns about travelling with infants on a bicycle. Moreover, Brecht Daams wrote multiple colums, regarding travelling with infants on a bicycle (appendix 13), in one of Dutch most leading infant trade journals: Babywereld. Due to her appreciated work by the trade journal Babywereld, her feedback was highly determinative for the direction of the graduation assignment. The next two pages show a copy (in Dutch) of Brecht Daams her letter. Moreover, multiple online sources indicate that the concerns of cycling with infants are mainly focusing on two aspects: general safety and vibrational comfort (appendix 14).

2.8.3 The infant

According to the WHO, an infant is a child younger than one year of age (WHO, 2013). Moreover, according to Dutch safety and traffic institutions like VeiligheidNL (VeiligheidNL, n.d.), the Fietsersbond (Voorthuizen, 2003) and the Consumentenbond (Grotenhuis, 2018), an infant can be transported in a maxi-cosi or 'babyschaal' attached to a bicycle when he or she is 3-4 months old. Between the 6 and 8 months an infant starts to sit upright independently. Around this age the muscles in the back, upper body and neck are developed enough to keep the body upright (Gallahue et al., 2012). Thus, the majority of the infants sit in an infant safety seat for around 6 months.

According to the latest data of the World Health Organization (appendix 15), the weight of the P15, 3 months old, female, is 5.1 kg and the P85, 12 months old (one year of age), male, 10.8 kg.

Tilley (2001) provides average anthropometric measurements for humans starting from age 2 months. The anthropometric data of an infant (m+f, P50, 3-5 months) and of an infant (m+f, P50, 11 months) can be found in appendix 16.

Due to the expressed concerns regarding safe travelling with infants on a cargo bike, the design proposal should be suitable for infants in the range of 3 months (P15, female, 5.1 kg) to 1 year of age (P85, male, 10.8 kg).


Bakfiets


.babboe.com

Expert opinion Brecht Daams

Brecht Daams (Daams ergonomics) provided a letter in which she expressed her concerns about travelling with infants on a bicycle. This page shows a copy (in Dutch) of Brecht Daams her letter.

After Brecht Daams' letter, a meeting with Ronald Vroman, expert in the field of crash testing and infant safety seats at the Dutch Consumers Association (de Consumentenbond), was arranged to change opinions and to share an initial digital sketch (appendix 17). Two requirements were drafted based on this meeting. Both requirements can be found in appendix 22.

Figure 20: Brecht Daams, Daams ergonomie

Bij een zitsysteem voor op een fiets voor baby's en peuters is er een probleem (vooral bij jonge baby's), namelijk: fietsen genereert veel trillingen. Een volwassen persoon die op het zadel zit, krijgt die trillingen gedempt via het frame en hij of zij dempt zelf ook trillingen met zijn/haar lichaamsgewicht. Een kind dat bovenop het voor- of achterwiel zit, krijgt de trillingen bijna ongedempt door (er zit nauwelijks framedemping tussen) en door het lage eigen gewicht worden de trillingen ook niet gedempt. Bovendien is een baby gevoeliger voor trillingen dan een volwassene. Vooral de hersenen, die zich nog moeten ontwikkelen, zijn erg kwetsbaar.

Het is niet precies bekend welke trillingen voor een baby ongezond zijn, het is wel bekend dat trillingen ernstige gezondheidsproblemen kunnen veroorzaken. Trillingsschade is cumulatief (de effecten van verschillende ritjes tellen bij elkaar op - rust kan de schade dus niet op nul krijgen). Voor volwassenen zijn er heel strenge normen op het gebied van trillingen. Je kan met baby's echter alles doen wat je wilt, daar zijn geen normen voor. Dat er weinig bekend is over het effect van trillingen op baby's en ook geen normen, wil echter niet zeggen dat het geen probleem is.

Wat je ook doet met het ontwerp van een fietsstoel: die trillingen moeten onder controle gehouden worden (maar we weten dus niet welke frequentie en amplitude OK zijn). Dat is heel lastig. In het algemeen kan je wel zeggen: hoe hoger de frequentie, hoe ongezonder, en hoe groter de amplitude, hoe ongezonder.

Een tweede probleem voor hele jonge baby's (tot minstens vier maanden, of misschien wel ouder) is dat ze 'zittend' in een 'gekantelde zithouding' zuurstofgebrek kunnen krijgen doordat het hoofd voorover knikt en daardoor de luchtweg afsluit. Je hoeft niets aan het kind te merken en mogelijke gevolgen (op het gebied van gedrag en intelligentie) zullen zich pas jaren later manifesteren.

Het is niet precies bekend welke trillingen voor een baby ongezond zijn, het is wel bekend dat trillingen ernstige gezondheidsproblemen kunnen veroorzaken.

Daarom raad ik af om kinderen die niet echt goed kunnen zitten op de fiets te vervoeren. Echt goed zitten, dat wil zeggen: dat ze uit zichzelf kunnen gaan zitten zonder hulpmiddelen of hulp van buitenaf.

Ik begrijp dat deze informatie misschien niet zo motiverend is voor je project.

Het is wel een goede aanleiding om erover na te denken en de discussie op gang te brengen: moeten we met een baby wel zomaar alles doen wat we leuk vinden? Hoeveel prioriteit heeft de gezondheid van het kind? Hoe erg is het dat er een kans is dat kinderen op de lange termijn permanente schade krijgen van het gebruik van een babyfiets'stoel'?

Ik zou heel graag zien dat er onderzoek gedaan wordt naar de invloed van trillingen op baby's en ook naar de 'autostoeltjeshouding' en de gezondheid op lange termijn. Zodat we weten wat er wel en niet kan, waar de grens ligt voor de gezondheid. Maar ja, daar heb jij op dit moment natuurlijk weinig aan.

2.9 European safety standards

In Europe, there exist no legislation or safety standards that include safety requirements and test methods for either mounting infant safety seats on a bicycle or cargo bikes or for any other infant seat system which is intended to be mounted on a bicycle or cargo bike. Therefore, making it impossible for manufacturers to receive an approval label that guarantees that the infant safety seat or any other infant seat system complies with certain basic safety requirements that are normally set out in the European safety standards.

2.9.1 NEN-EN 14344:2004

Safety standard NEN-EN 14344:2004 specifies requirements for child seats for bicycles, which are intended to be mounted on pedal bicycles and electrically power assisted bicycles, in order to transport children with a weight from 9 kg up to 22 kg (approximately 9 months up to 5 years) and who are capable of sitting unaided (Nederlands Normalisatie Instituut, 2002).

Requirements that were found in international standard NEN-EN 14344:2004 were reformulated in order to be applicable to the scope of the graduation project. Among others, these requirements include:

- Requirements for child proof retention for the mounting method of the seat system and the mounting method of the infant safety seat;
- Requirements for edges, corners and projections;
- Strength and durability requirements and test methods.

These requirements were included in the list of requirements as can be found in appendix 22.

In Europe, there exist no legislation or safety standards that include safety requirements and test methods for mounting infant safety seats on a bicycle or cargo bikes.

2.10 Competitors

Although there are (universal) systems available to transport an infant on a bicycle or cargo bike (from now on called: infant safety seat carrier), the variety of universal infant safety seat carriers are rather scarce. One major contributing factor is that there are no international safety standards, making it impossible for manufacturers to receive an approval label that guarantees that the infant safety seat or any other infant seat system complies with certain basic safety requirements that are normally set out in the European safety standards. The available systems will be briefly explained in this section.

2.10.1 Brand specific solutions

Urban Arrow and Gazelle offer a solution to travel with an infant on their cargo bikes. Both solutions make use of a car seat adapter (Figure 22-24). The disadvantage of both systems is that the infant safety seat and the child are placed relatively high and less protected.

To create a safer and more protected system, the infant safety seat needs to be placed as low as possible. In other words, the center of gravity needs to be located as low as possible.

2.10.2 Non-brand specific solutions

2.10.2.1 Steco Baby-Mee (year of introduction: 2000)

Online research into the availability of new and second-hand Steco Baby-mee's on Marktplaats and websites of online retailers, and the conversations regarding cycling with infants on the Dutch Facebook page Bakfietservaringen (cargo bike experiences), indicated that the Steco Baby-Mee (Figure 21) is probably the most sold infant safety seat carrier to transport an infant on a bicycle or cargo bike. Marktplaats showed around 90 advertisements of new and second-hand Steco Baby Mee's, while the Urban Arrow adapter only showed 17

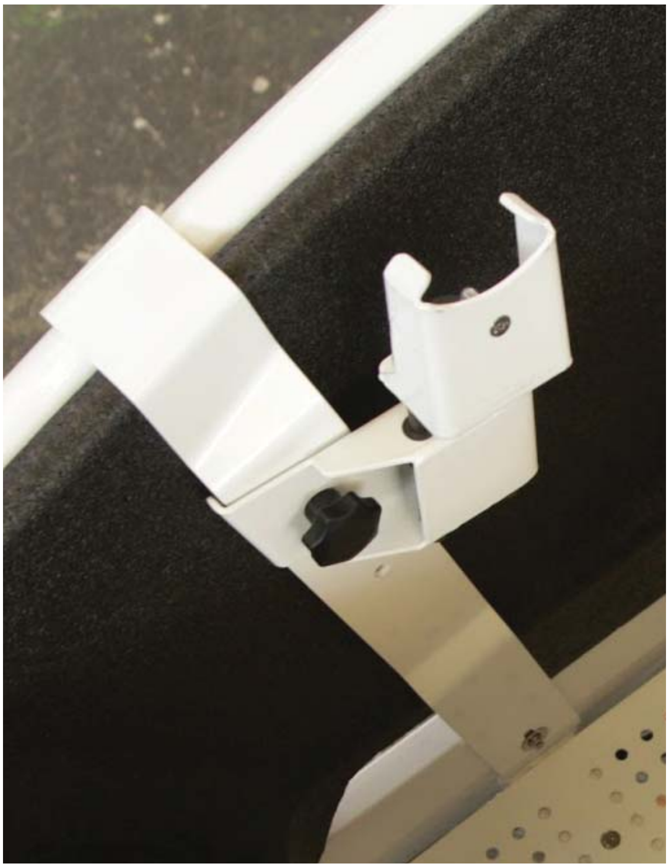


Figure 21: The Steco Baby Mee adapter can be fastened to the majority of cargo bikes and can be placed on the bench or on the floor of the cargo bike. The infant safety seat is fastened to the Steco Baby Mee by means of two elastic bands.

Figure 22: (left page) The Urban Arrow has its own solution to fasten an infant safety seat to their cargo bikes.

Figure 23: Urban Arrow's solution makes use of two spring-loaded infant safety seat adapters, made out of steel. The majority of infant safety seat brands (e.g. Maxi-Cosi) can be fastened onto these adapters. Infant safety seat adapters are also used to fasten an infant safety seat to a baby stroller.

advertisements (availability retrieved at November 11, 2018, on Marktplaats.nl).

Almost all infant safety seats are suitable to be attached to the Steco Baby-mee. The infant safety seat is fastened by means of a clamping bracket and two elastic bands. This type of fastening does not have an international approval label. Moreover, a parent expressed her concerns about the infant safety seat slightly lifting-off of its metal bracket, when cycling over a higher speedbump.

2.10.2.2 Traveljack (year of introduction: 1994)
The Traveljack (Figure 24-26) is an infant seat covered with terry fabric, which is fastened on the handlebars by means of a clamp. As a result, the parents can see their infant at any time. It has a 3-points belt to fasten the infant safely. The traveljack can only be rented for 25 euros per month.

2.10.2.3 Babybike (year of introduction: 1993)
Although the Babybike (Figure 26) is positioned as being a seat system on which an infant safety seat can be mounted, it can be considered to be as a more general child seat system. The Babybike rests on four adjustable springs and offers an option to be transformed into a system for toddlers. Furthermore, a small shelter can be attached to the Babybike. Personal communication with the owner of Babybike confirmed that the Babybike is no longer being sold. One of the reasons were legal issues for receiving a safety approval label, making it impossible to sell the system to retailers.

2.10.3 Conclusion
Transporting infants on a bicycle or cargo bike remains a niche market. Since there are no safety regulations concerning transporting infants on a bicycle or cargo bike, many manufactures consider this market as unattractive. Furthermore, since there is still no evidence-based proof of the health effects of the transmitted vibrations to infants on a bicycle or cargo bike, this market is considered to be of high risk. Nevertheless, because there are not many competitors and the fact that competitors do not innovate, the timing to introduce a completely new product might be just right.

Figure 24: (upper) The Traveljack, which can be rent for 25 euros per month.

Figure 25: (middle) The Traveljack is mounted to the handlebars, making cornering heavier.

Figure 26: (lower) The platform of the Babybike, resting on four adjustable springs.

Because there are not many competitors, and the fact that competitors do not innovate, the timing to introduce a completely new product might be just right.

2.11 Child Restraint System

A Child Restraint System (CRS) is designed to protect children from injury during motor vehicle crashes (Alsanea, Masuadi, & Hazwani, 2018) and have long been recommended as best practice for protecting child occupants less than 18 kg (American Academy of Pediatrics, 1999; Winston and Durbin, 1999, Weber, 2002). This section briefly explains relevant parameters that influenced the design proposal

Table 2: Different Child Restraint System categories suitable for newborns up to 10-13 kg, according to R44 and R129 (rearward-facing seat).

Figure 28: (Upper) Infant safety Seat (Maxi-Cosi Pebble) fastened in the car by means of seatbelts

Figure 29: (Lower) Car seat adapters enable infant safety seats (Cybex Cloud Q) to be fastened to a baby stroller. The majority of the infant safety seat brands mae use of the same adapter.

Figure 27: Isofix fastening system. Today, it is the safest fastening system available for cars as it needs to withstand extremely heavy forces in the event of a collision.

2.11.1 United Nations Standards
Every infant safety seat needs to conform to the United Nations standard, ECE Regulation 44.04 (or R 44.03) or to the new i-size regulation, R129, that is introduced in July 2013. Infant safety seats are divided into categories (Table 22), according to the weight (R44) or height (R129) of the children for whom they are suitable.

The design proposal should be suitable for 85% of the infant safety seats, manufactured by the major brands (Maxi-Cosi, Britax Römer, Besafe and Cybex).

2.11.2 Mechanical interface
The infant safety seat can be fastened by using different mechanical interfaces. Each mechanical interface serves a specific purpose. Four interfaces are identified: seat belt, car seat adapters, Isofix and custom-made constructions.

2.11.2.1 Seat belt
Infant car seats can be fastened by using the seat belt installed car seat. It is very important to guide the belt correctly and pull the car seat belt tight (Figure 28).

2.11.2.2 Car seat adapters
Every infant safety seat can be fastening to a stroller. The majority of the infant safety seat brands (around 85% of the market, e.g. Maxi-Cosi, Britax Römer, Besafe, Cybex) make use of the same mechanical interface (Figure 29). The relative distance between the left and right adapter is the same for every infant safety seat that makes use of this type of car seat adapter.

2.11.2.3 Isofix
Since 2012, Isofix is the international standardized fastening system for infant safety seats in cars. For cars produced after 2014, it is mandatory to equip the car with Isofix anchor points. Today, it is the safest fastening system available as it needs to withstand extremely heavy forces in the event of a collision.
Isofix car seats and bases have 3 Isofix points:

- 2 Isofix connectors (metal bars) fit on the anchor points (metal clips) at the base of the vehicle seat.
- A top tether or support leg
- After installing the Isofix base, the infant safety seat can be fastening to the Isofix base. Each brand uses a unique Isofix base and are not compatible with another brands.

Type of Child Restraint	Regulation	Weight Range	Approx. Age Range
Rearward-facing baby seat	R44	Group 0 0 - 10kg (22 lbs)	Birth to 6-9 months
	R44	Group 0+ 0 - 13kg (29 lbs)	Birth to 12-15 months
	R129 (i-size)	i-size (based on height rather than weight)	Up to at least 15 months
		Phase 1 Birth to 105cm	Some seats birth to 4 years

2.12 Vibrational scenario

2.12.1 Vibrational transmissibility in infant safety seats

Whatever the terrain, cycling outdoors will always involve uneven surfaces (Mavic, 2016). All these bumps in the ground produce vibrations, which are transmitted to cyclists through their cargo bike via three entry points: the feet, hands and backside (Figure 30a).

Due to the recumbent seating position of infant safety seats, vibrations on infants are transmitted through the floor of the cargo bike and, subsequently, through the infant safety seat via one entry: the whole body (Figure 30b).

Moreover, according to the results found in Olieman, Marin-Perianu, & Marin-Perianu's (2012) research, acceleration values at the front wheel of a bicycle are higher in comparison to the rear wheel of a bicycle. At the location of the infant, who is located closer to the front wheel (or between the front wheels), the input acceleration value will be higher than at the location of the parent.

The intensity of these vibrations, in frequency and amplitude, depends on (Mavic, 2016):

- The bumps (density, depth);
- Wheel rotation speed over these bumps (and thus the number of times that the wheels hit them);
- The pressure in the tires;
- The stiffness of the frame of the bicycle or cargo bike, and;
- The weight of the cyclist-bicycle system.

2.12.2 Type of vibrations

When cycling outdoor, two types of vibrations can be identified: periodic vibrations (e.g. cycling over concrete tiles, road bricks or tarmac for a longer period of time) and transient vibrations (e.g. a speed bump).

Studies in recent years have pointed to the importance of the peak values of acceleration in the vibration exposure, particularly in health effects (Nederlands Normalisatie Instituut, 1997). Due to the uneven road surfaces and speed bumps (peak values of acceleration), it was assumed that the vertical vibrations (in the z-axis) would be most dominant.

2.12.3 Damping

The vibrations that cyclists experience are damped via the bike saddle and the cyclists its body weight. Due to the low body weight of infants and the fact that current solutions offer little to none damping (only a spring is used, Figure 30c), the vibrational values are larger. The non-rigid or resilient material (the seat cushion) of the infant safety seat has the functionality of damping. However, this damping effect is too little in harsh shock environments (e.g. speed bumps or badly maintained road surfaces).

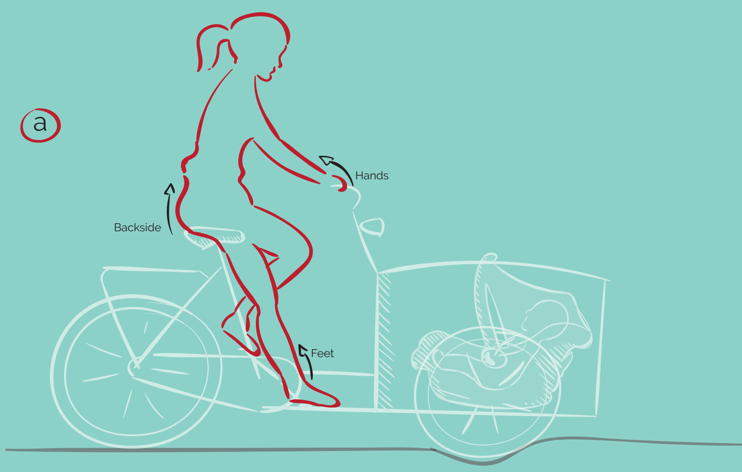
2.12.4 Double spring-mass system

For spring-damper systems, such as the one proposed in this graduation report, theories from vehicle and fluid dynamics can be used to study how the system will react to inputs from a given road. Vehicle dynamics is a part of engineering primarily based on classical mechanics; fluid dynamics describes the properties of fluid —liquids and gases in motion.

Cycling with an infant on a cargo bike can be divided into two spring-mass systems (Figure 30d):

- The cargo bike (mass) relative to the road surface, in which the wheels are considered to function as spring/damper.
- The infant safety seat (mass) relative to the floor of the cargo bike, in which the infant safety seat carrier is considered to function as spring/damper.

This double spring-mass system was considered to be similar to a quarter car model (Figure 30e).



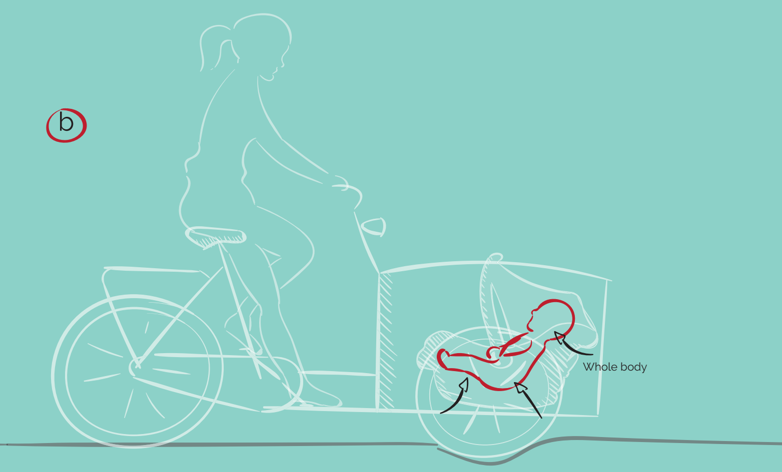
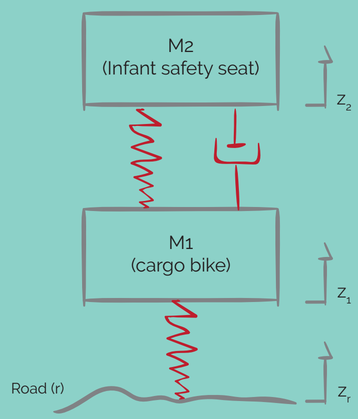


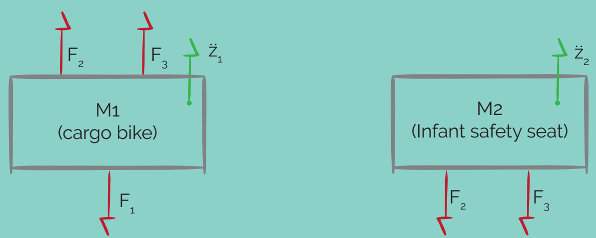
Figure 30: a) vibrations are transmitted to cyclists through their cargo bike via three entry points: the feet, hands and backside;
b) Vibrations on infants are transmitted through the floor of the cargo bike and, subsequently, through the infant safety seat via one entry point: the whole body;
c) When cycling over uneven roads, the infant safety seat starts to vibrate. In case of the Steco Baby Mee the infant safety seat bounces back and forward around centerpoint 'C'.
d) scematic representation of the double spring-mass system; infant safety seat placed in a cargo bike.
e) Free body diagram of the vibration scenario

Vertical dynamics - quarter car model

Situation



Decompostion
(Free Body Diagram)



$F_1=-k_1{}^*(z_1 - z_r)$, if r=0, then: $F_1=k_1{}^*z_1$

$F_2=-k_2{}^*(z_2 - z_1)$

$F_3=-c_1{}^*(\dot{z}_2 - \dot{z}_1)$

$\Sigma F_{M1}=m_1{}^*\ddot{z}_1$

$-F_1+F_2+F_3=m_1{}^*\ddot{z}_1$

$-(-k_1{}^*(z_1- z_r))+(-k_2{}^*(z_2 - z_1))+(-c_1{}^*(\dot{z}_2 - \dot{z}_1))=m_1{}^*\ddot{z}_1$

$F_2=-k_2{}^*(z_2 - z_1)$

$F_3=-c_1{}^*(\dot{z}_2 - \dot{z}_1)$

$\Sigma F_{M2}=m_2{}^*\ddot{z}_2$

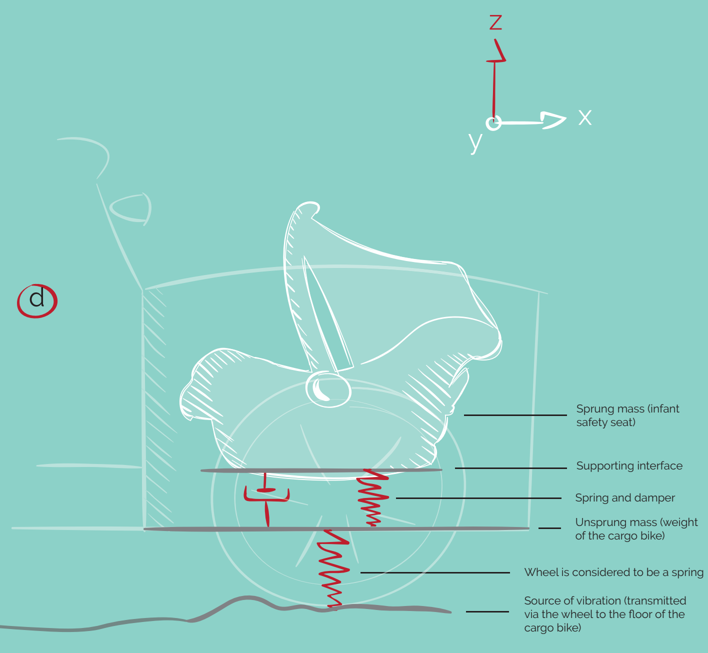
$-F_2-F_3=m_2{}^*\ddot{z}_2$

$-(-k_2{}^*(z_2 - z_1))-(-c_1{}^*(\dot{z}_2 - \dot{z}_1))=m_2{}^*\ddot{z}_2$

e

c

d



2.13 Vibration theory

This section covers the parameters that influence the magnitude of vibration and/or shock that is transmitted from the road to the infant.

The whole section is a summary from different vibration design guides from three major vibration management companies and from one shock and vibration handbook:

- **Materials Design: Vibration Isolation and Damping - the Basics (Rogers Corporation, 2012);**
- **Shock and Isolation Selection (dB Engineering, 2017);**
- **Vibration and Shock Isolation (Fabreeka, 2011), and;**
- **Harris' Shock and Vibration Handbook, chapter 2 "Basic vibration theory" (Blake, 2002)**

Mechanical vibration and shock are present in varying degrees in virtually all locations where equipment and people function (dB Engineering, 2017). Vibration management should always be considered in any engineering design (Rogers Corporation, 2012). The purpose of vibration management is to control unwanted vibration so that its adverse effects are kept within acceptable limits.

2.13.1 Oscillatory motion

Vibration is an oscillatory motion (Figure 32). The extent of the oscillation determines the magnitude of the vibration and the repetition rate (period) of the oscillation determines the frequency of the vibration (Griffin, 1990).

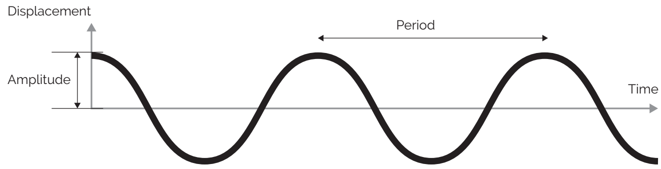


Figure 31: basic illustration of simple harmonic motion

2.13.2 Elementary parts of vibratory systems

The simplest form of mechanical vibration to consider is based on a linear system (Fabreeka, 2011). Vibratory systems comprise means for storing potential energy (spring), means for storing kinetic energy (mass or inertia), and means by which the energy is gradually lost (damper) (Blake, 2002), see Figure 33.

Figure 32: Illustration of a spring-damper system in its simplest form

2.13.2.1 Spring

In static, linear systems, the change in the length of the spring (Δx) is proportional to the force (F) acting along its length. The constant of proportionality k is the spring constant or stiffness:

$$F = k \cdot \Delta x \qquad \text{eq. 1}$$

2.13.2.2 Mass

A mass is a rigid body whose acceleration (d^2x/dt^2) according to Newton's second law is proportional to the resultant F of all forces acting on the mass (m):

$$F = m \cdot \left(\frac{d^2x}{dt^2}\right) \qquad \text{eq. 2}$$

2.13.2.3 Damper

In a damper the applied force is proportional to the relative velocity (dx/dt) of its connection points. The constant c is the damping coefficient, the characteristic parameter of the damper:

$$F = c \cdot \left(\frac{dx}{dt}\right) \qquad \text{eq. 3}$$

Appendix 18 shows a broad list of vibration management definitions that were needed to make appropriate calculations.

2.13.3 Transmissibility

In order to understand what damping is and how to apply it, it is important to understand transmissibility. Transmissibility is a measurement used in the classification of materials for vibration management characteristics. It is a ratio of the vibrational force being measured in a system to the vibrational force entering a system:

$$T = \left|\frac{A_0}{A_i}\right| := \sqrt{\frac{\left(1 + 2\cdot\zeta_1\cdot\left(\frac{Fe}{Fn}\right)\right)}{\left(1 - \left(\frac{Fe}{Fn}\right)^2\right)^2 + \left(2\cdot\zeta_1\cdot\left(\frac{Fe}{Fn}\right)\right)^2}}$$

eq. 4

With:

A_o = Amplitude of the vibrational response
A_i = Amplitude of the vibrational input
ζ = Damping ratio
f_e = Disturbing frequency
f_n = Natural frequency

Transmissibility is easier defined as the percentage of vibrational energy that is being transmitted through a structure (Rogers Corporation, 2012). If a damping material has a transmissibility of 70%, it means that 70% of the vibrating force is being transmitted through the damping material as can be seen in Figure 34.

2.13.3.1 Natural frequency and damping ratio

Natural frequency and damping are the basic properties of a spring-damper system which determine the transmissibility of a system designed to provide vibration and/or shock damping (Fabreeka, 2011). Damping is attained primarily by maintaining the proper relationship between the disturbing frequency and the system's natural frequency (Fabreeka, 2011).

Natural frequency (f_n)
Natural frequency is the frequency at which a system tends to oscillate in the absence of any driving or damping force (Bhatt, 2009):
With:

$$Fn := \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad \text{eq. 5}$$

k = Spring rate
m = Mass

Damping ratio (ζ)
Damping ratio describes how oscillations in a system decay after a disturbance:

$$\zeta 1 = \frac{c}{Cc} := \frac{c}{2\sqrt{k \cdot m}} \qquad \text{eq. 6}$$

With:

k = Spring rate
m = Mass
c = Damping coefficient
Cc = Critical damping

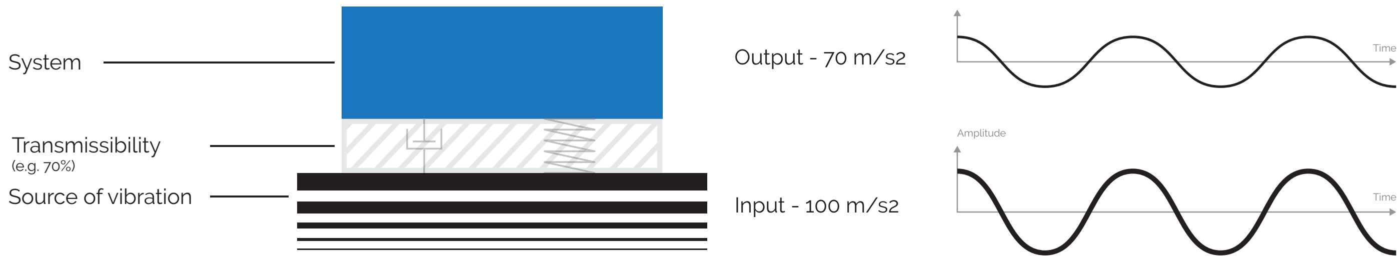


Figure 33: Illustration of vibrational transmissibility by influence of a damping material or system in a vibrating system with corresponding input and output accelerations. In this illustration, 70% of the input vibration is being measured on the other side of the system.

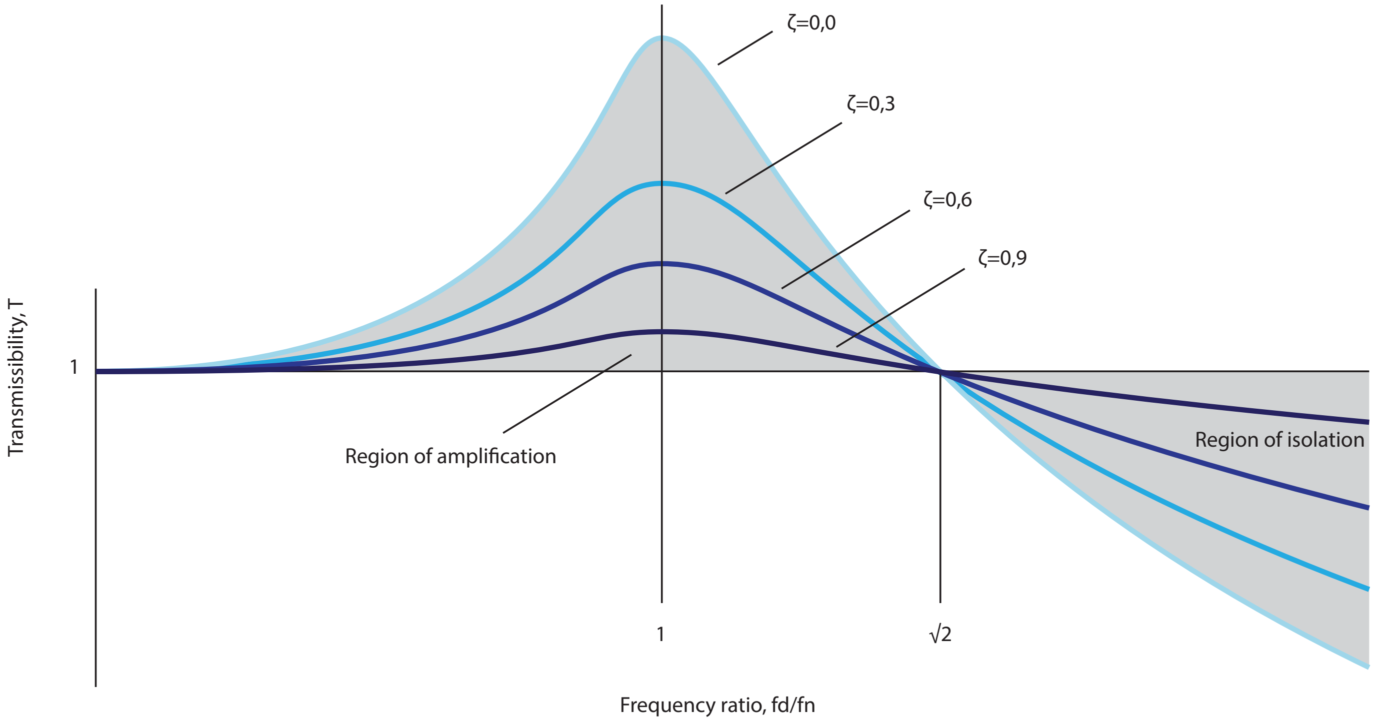


Figure 34: Transmissibility curves with different damping ratios (modified from dB Engineering, "Shock and Isolation Selection"). A small damping ratio will result in a stronger region of isolation. Yet, having a large amount of damping has a negative effect on isolation and vice versa.

Figure 35 illustrates a typical transmissibility curve for an equipment of weight W supported on a damper (or isolator) with stiffness K and damping coefficient C, which is subjected to a vibration disturbance of frequency fd.

Referring to Figure 35, it can be seen that when the ratio of the disturbing frequency fd over the natural frequency fn is less than or equals √2 (1.4), the transmissibility is greater than 1, or the equipment experiences amplification of the input.

Simply expressed, when:

$$\frac{fd}{fn} \leq \sqrt{2} \ , \quad T \geq 1$$

Theoretically, isolation begins when:

$$\frac{fd}{fn} = \sqrt{2} \ , \quad T = 1$$

2.13.3 Isolation and damping

There are two facets of vibration management: isolation and damping.

- Isolation is the prevention of vibrations from entering a system, e.g. rubber pads (Rogers Corporation, 2012).
- Damping is the absorption of the vibration energy that is entering the system and dissipating it by changing the kinetic energy of vibration into a different form of energy, e.g. shock absorber (Rogers Corporation, 2012).

2.13.3.1 Damping

There are two types of damping: passive and active (Cyberman Education Page, 2002);

- Passive damping refers to energy dissipation within the structure by add-on damping devices such as an isolator, by structural joints and supports, or by structural member's internal damping.
- Active damping refers to energy dissipation from the system by external means, such as controlled actuator, etc.

Passive damping is very robust with respect to structural uncertainties. However, the damping values that can be obtained are moderate (Holterman & de Vries, 2001). Active damping is more complicated and costly than passive damping, require maintenance, and there is a higher possibility of failure (Bankar & Aradhye, 2016). This type of damping is predominantly used in advanced technology applications, such as interferometry, microscopy, nano-fabrication and micro-hardness testing, where the lightest vibrations might already affect the application.

The fact that passive systems generally cost less than active systems and that their relative simplicity makes them more reliable and safe (Fahy & Walker, 1998) and the fact that very low damping values does not need to be obtained, the design proposal shall make use of passive damping elements.

In appendix 19 the different types of passive damping can be found.

Minimizing the vibrational transmissibility

It is possible to minimize the vibrational transmissibility by making the frequency ratio, fd/fn, >> 1. Based on equation 4 and Figure 35, this can be realised by making the spring stiffness as small as possible (use a soft spring), and making the mass large. It also helps to make the damping ratio small (Brown University School of Engineering, n.d.), since this will result in a stronger region of isolation. Yet, having a large amount of damping has a negative effect on isolation and vice versa. In Figure 35, it can be seen that as the damping ratio increases the region of isolation decreases (Rogers Corporation, 2012).

Though, there are some disadvantages to making the damping too small (Brown University School of Engineering, n.d.):

- If the system is lightly damped, and is disturbed somehow, the subsequent transient vibrations will take a very long time to die out, and;
- If the system is lightly damped, a potentially damaging resonance may occur.

Suspension design involves a bit more than simply minimizing the vibrational transmissibility. A very soft suspension generally has poor handling, so the engineers must trade off handling against vibration isolation.

2.14 Vibrational research

Nowadays, there are systems that allow you to take your infant with you on your cargo bike. Little is known about the vibrations transmitted from the cargo bike to an infant fastened in a child safety seat. This section discusses the vibrational environment and comfort aspects when cycling with an infant in a cargo bike. Appendix 20 provides a more elaborated explanation of the background information and method.

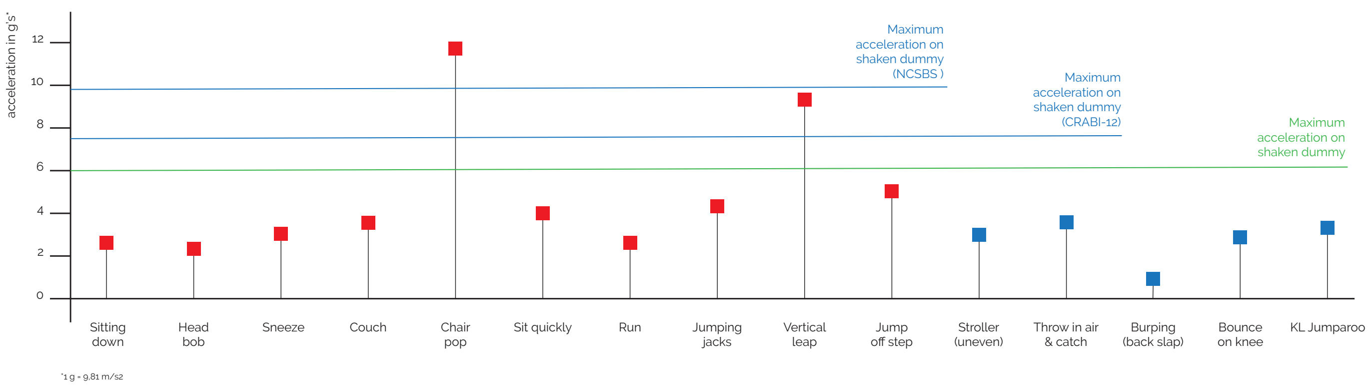
2.14.1 Shaken Baby Syndrome

In few cases, the Shaken Baby Syndrome (SBS, Figure 36) is linked to travelling with infants on a cargo bike (Mobiel21, 2010). Shaken baby syndrome — also known as abusive head trauma, shaken impact syndrome, inflicted head injury or whiplash shake syndrome — is a serious brain injury resulting from forcefully shaking an infant or toddler (Mayo Clinic, 2017).

2.14.1.1 Head acceleration in some daily activities

Shaking produces linear accelerations to the head that are similar in magnitude to accelerations measured in activities of daily living. Chart 4 shows a daily activities chart drafted from two researches (Lloyd, Willey, Galaznik, Lee, & Luttner, 2014; Zasler, Katz, & Zafonte, 2007). In addition, the Washington Post (2015) commissioned a test in which a 88-kg man vigorously shook a 10-kg crash-test dummy. The dummy also fell from a couch that was 46 cm high (supervised by biomechanical engineer Chris Van Ee). The results showed that falls with a direct impact to the head (142g) produced far more acceleration than shaking (6g). The research article by Lloyd et. al. (2014) showed slightly higher numbers 7.6g and 9.9g, for respectively a CRABI-12 biofidelic mannequin and a NCSBS demonstration doll.

Figure 35: Head movement due to severely shaking an infant. Graphic originated from: Shaken baby syndrome – review (Blumenthal, 2009).



2.14.2 ISO 2631

ISo 2631 defines methods for the measurement of periodic, random and transient whole-body vibration (Nederlands Normalisatie instituut, 1997). It indicates the principal factors that combine to determine the degree to which a vibration exposure will be acceptable.

Vibrations are measured according to a coordinate system originating at a point from which vibration is considered to enter the human body. The principal relevant basicentric coordinate system for recumbent position is shown in Figure 37.

2.14.2.1 Weighted r.m.s. acceleration

The vibration evaluation of ISO 2631 includes measurements of the weighted root-mean-square (r.m.s.) acceleration. The weighted r.m.s. acceleration is the most relevant measure of amplitude because it both takes the time history of the wave into account and gives an amplitude value which is directly related to the energy content, and therefore the destructive abilities of the vibration (Brüel & Kjær, 1982). The weighted r.m.s. acceleration is expressed in meters per second squared (m/s2) for translational vibration. The weighted r.m.s. acceleration can be calculated in accordance with the following equation:

$$a_w = \left[\frac{1}{T} \int_0^T a_w^2(t)\, dt \right]^{\frac{1}{2}}$$

Where:

- $a_w(t)$: the weighted acceleration (translational or rotational) as a function of time second squared (m/s²) or radians per second squared (rad/s²), and;
- T: the duration of the measurement, in seconds.

2.14.2.2 Vibrational comfort

Acceptable values of vibration magnitude for comfort depend on many factors which vary with each application.

Chart 4: Daily activities chart (in red) from the chapter “Biomechanics of Brain” by David C. Viano, included in “Brain Injury Medicine: Principles and Practice” (2006). Daily activities chart and maximum acceleration on shaken dummies (in blue) from the research article “Biomechanical Evaluation of Head Kinematics During Infant Shaking Versus Pediatric Activities of Daily Living” by Lloyd et. al. (2014). Maximum acceleration on shaken dummy (in green) from the test commissioned by the Washington Post (2015).

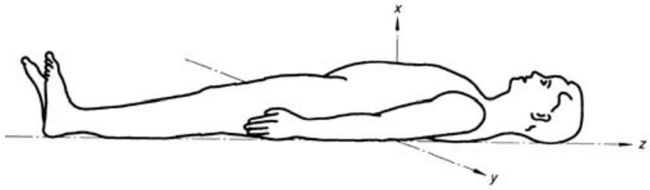


Figure 36: Recumbent position

The following values give approximate indications of likely reactions to vibration of various magnitudes (Nederlands Normalisatie instituut, 1997):

Less than 0,315 m/s²	not uncomfortable
0,315 m/s² to 0,63 m/s²:	a little uncomfortable
0,5 m/s² to 1 m/s²:	fairly uncomfortable
0,8 m/s² to 1,6 m/s²:	uncomfortable
1,25 m/s² to 2,5 m/s²:	very uncomfortable
Greater than 2 m/s²:	extremely uncomfortable

2.14.3 Vibration nuisance

The research report ‘Verhardingskeuze voor fietsverbindingen: asfalt, beton of tegels?’ (KOAC WMD, 2002), provided data concerning the measurement results of the longitudinal flatness, the visual assessment of fraying, transverse flatness, cracking and edge damage of different road surfaces. In this report, the vibration accelerations were also listed (Table 3).

Therefore, the design proposal must be tested in compliance to the three road surfaces tested by the KOAC.

Road surface	Condition	Average periodic vibration [m/s2]	Peak vibration [m/s2]
Tarmac	Perfect	0,4	0,7
	Average	0,6	1,2
	Bad	1	2,4
Concrete tiles	Perfect	0,8	1,8
	Average	1,3	3
	Bad	2	4,6
Road bricks	Perfect	0,9	2,2
	Average	1,5	3,8
	Bad	2,2	5,8

Table 3: vibration nuisance for different road surfaces. Measurements were collected with the FietsComfortMeter (FCM, appendix 20). The FCM registered acceleration of two loaded bicycle wheels that ware attached behind a minivan. Consequently, the acceleration on saddle height was calculated based on software.

2.14.4 Method

Due to lack of scientific studies that include tests to determine the influence of vibrations on the infant's body and to find out more about the vibrational environment in infant safety seats – mounted to a cargo bike –, field acceleration measurements were made.

Figure 37: (top left) Transducer 1 and 2 located at, respectively, the floor of the cargo bike and the rigid portion of the seat-back of the infant seat, horizontally mounted above Transducer 1.

Figure 38: (top right) Transducer 1 located on the floor of a cargo bike.

Figure 39: (bottom right) Transducer 3 and 4 located at, respectively the supporting surface under the lumbar vertebrae, and; the supporting surface under the head. The three transducer brackets for transducer 4 represent the height of the head of the different test dummies.

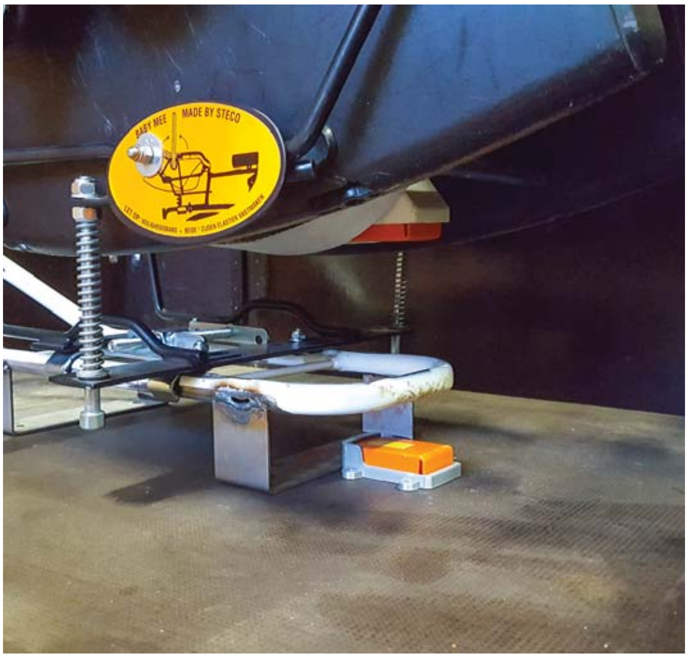
Figure 40: (bottom left) Testing scenario, loaded with a 10kg test dummy.

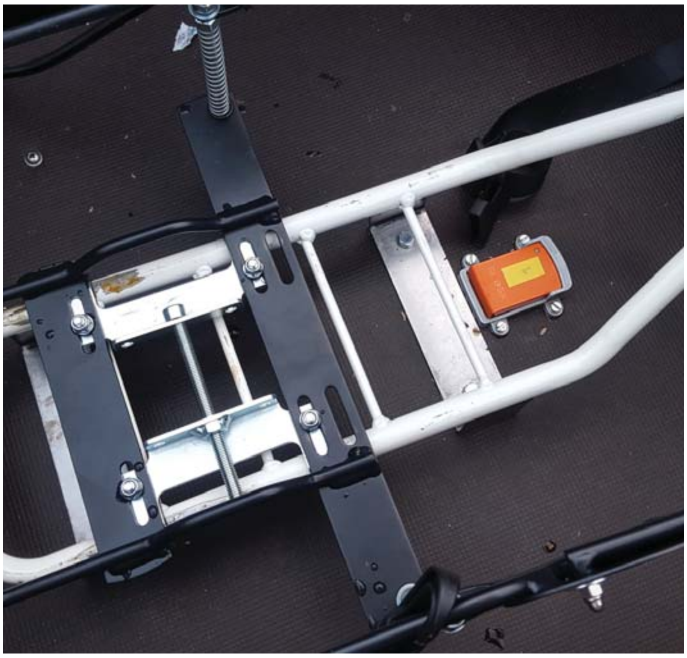
The vibration experiment consisted of measurements in infant safety seats during runs over different road surfaces.

2.14..4.1 Points of measurement

Four transducers (Figure 38-41) were located so as to indicate the vibration at the interface between the human body and the source of its vibration. One transducer was attached to a reference plane, three transducers were directly attached to the infant safety seat (transducers 2, 3 and 4):

- (Transducer 1) at the floor of the cargo bike;
- (Transducer 2) The rigid portion of the seat-back of the infant seat, horizontally mounted above Transducer 1;





- (Transducer 3) The supporting surface under the lumbar vertebrae, and;
- (Transducer 4) The supporting surface under the head.

2.14.4.2 Road surfaces

Three different road surfaces were used for this study to measure periodic vibrations (Figure 42-44): concrete tiles, road bricks and tarmac. To measure transient vibrations a speed bump was used (Figure 45).

Three test runs were performed for each road surface and each weight, meaning: 4 (road surfaces) x 3 (test runs) x 3 (different weights) = 36 test runs were performed in total.

Figure 41: (top left) Concrete tiles (periodic vibrations)

Figure 42: (top right) Paving-stones(periodic vibrations)

Figure 43: (bottom right) Tarmac (periodic vibrations).

Figure 44: (bottom left) Speed bump (transient vibration).

2.14.5 Results

2.14.5.1 Periodic vibrations in the time domain

- Floor measurements

Table 3 indicates that the unweighted r.m.s. values in the z-direction (vertical) were the most dominant values for all test scenarios (ranging up to 3.532 m/s2). The unweighted r.m.s. values in the z-direction (measured on road bricks and concrete tiles) were more than 300% stronger in comparison to its corresponding r.m.s. values in the x and y-direction.

- Infant safety seat measurements

Table 3 indicates that the unweighted r.m.s. values measured under the head, in all three directions (x, y and z), were the most dominant, in comparison to the other two transducer locations.

The unweighted r.m.s. values in the z-direction (vertical) measured under the head, were the most dominant for only 4 out of 9 test scenarios (ranging up to 3.371 m/s2). In the other 5 test scenarios, the unweighted r.m.s. values in the x or y-direction were greater than the unweighted r.m.s. values measured in the z-direction (ranging up to 3.383 m/s2).

- KOAC WMD comparison

It was found that the average unweighted r.m.s. vibration values (z-direction, floor location) measured in this study (Table 2), were much higher than the r.m.s. vibration values measured by KOAC WMD (Table 2), respectively ranging between 3,1 - 3,5 m/s2 and ranging between 0,8 - 2 m/s2 (looking at the values of concrete tiles and road bricks).

The difference might be caused by the different transducer locations between both studies (saddle height and floor of the cargo bike, for respectively KOAC's study and this study), the cycling speed, the bicycle, the road condition and the total weight. Nevertheless, the difference is noteworthy.

- Vibrational comfort

All unweighted r.m.s. values measured on the three different road types were higher than 0.5 m/s2. Referring to the indications of likely reactions to vibration of various magnitudes, this r.m.s. value corresponds with fairly uncomfortable for adults. All r.m.s. values measured under the head on road bricks and concrete tiles (18 out of 18) were higher than the limit of what adults experience as extremely uncomfortable: 2 m/s2. More specifically, the majority of the r.m.s. values measured under the head on road bricks and concrete tiles (14 out of 18) were even more than 1.5 times higher than this limit.

- Vibrational transmissibility

The last row of each weight in Table 4 shows the ratio between the unweighted r.m.s. value of the highest vibrational response (under the head) and the unweighted r.m.s. value of the vibrational input (the floor).

Referring to the vibrational transmissibility values in the z-direction in Table 4, it can be seen that 7 out of 9 values are below 100%: these values are decreased.
Referring to the vibrational transmissibility values in the x and y-direction in table 3, it can be seen that all values are above 100%, reaching values of more than 400%: these values are (highly) intensified.

- Head acceleration in some daily activities

Chart 5 illustrates an extended version of Chart 4, added with the results of the current study. The acceleration values of cycling (road bricks) and cycling (concrete tiles) correspond approximately to the accelerations when sneezing, couching, an uneven stroller and bouncing on a knee.

2.14.5.2 Transient vibrations

Table 5 shows that in all tests, the transducer located at the infant's head showed the highest peak vibration values in the z-axis (ranging up to 78.6 m/s2 when loaded with a 10 kg test dummy).

2.14.5.2 Periodic vibrations in the frequency domain (Spectral analysis)

A Discrete Fourier Transform (DFT) was performed. Chart 6 and Chart 7 present the original vibrational signals deconstructed into its individual sine wave components, measured on the three different road surfaces, for floor measurements (excitation) and measurements under the head, respectively.

The transducer located at the floor showed the highest energy of all four transducer locations. The peaks were located in the frequency interval from approximately of 8 – 9 Hz (1.16 m/s2 in Chart 6). The transducers attached under the head of the test dummy showed peaks in the frequency interval from approximately 3 – 3.5 Hz (0.97 m/s2 in Chart 7).

2.14.6 Conclusions

Since the majority of the measured r.m.s. values exceed critical levels for vibrational comfort, the values and consequences are worrying. It is, therefore, desirable to find a correct recommendation for the use of infant safety seats mounted on cargo bikes and to include a consideration of the health risks and discomfort likely to be caused by vibration.

2.14.6.1 Disturbing and resonance frequency

The DFTs of the transducer located at the floor showed that the peaks were located in the frequency interval from approximately of 8 – 9 Hz (Chart 6). The peaks represent the most dominant excitation frequency measured on

Weight	Location	Road type								
		Concrete tiles			Road bricks			Tarmac		
		rmsx	rmsy	rmsz	rmsx	rmsy	rmsz	rmsx	rmsy	rmsz
5 kg	**Floor**	0.730	0.751	3.145	0.843	0.741	3.208	0.511	0.488	1.399
	Seat-back	1.501	1.796	2.055	2.372	1.754	2.142	0.955	0.934	0.815
	Lumbar	1.580	1.377	2.037	1.795	1.847	2.339	0.910	0.944	0.768
	Head	3.224	2.767	3.371	2.934	3.074	3.118	1.093	1.228	1.066
Vibra. Trans.		**442%**	**368%**	**107%**	**348%**	**415%**	**97%**	**214%**	**252%**	**76%**

Weight	Location	Road type								
		Concrete tiles			Road bricks			Tarmac		
		rmsx	rmsy	rmsz	rmsx	rmsy	rmsz	rmsx	rmsy	rmsz
8 kg	**Floor**	0.799	0.954	3.416	1.011	0.729	3.286	0.584	0.632	1.256
	Seat-back	1.832	1.871	2.077	1.988	1.815	2.178	0.978	0.997	0.768
	Lumbar	1.975	1.514	2.284	1.655	1.719	2.461	0.870	0.971	0.710
	Head	3.145	3.298	3.159	3.383	2.685	3.099	1.022	1.251	1.041
Vibra. Trans.		**394%**	**346%**	**92%**	**334%**	**368%**	**94%**	**175%**	**198%**	**83%**

Weight	Location	Road type								
		Concrete tiles			Road bricks			Tarmac		
		rmsx	rmsy	rmsz	rmsx	rmsy	rmsz	rmsx	rmsy	rmsz
10 kg	**Floor**	0.828	0.772	3.267	1.491	1.775	3.532	0.524	0.635	1.274
	Seat-back	1.567	1.662	2.043	2.921	2.545	2.214	1.002	1.011	0.915
	Lumbar	1.645	1.528	2.129	2.820	2.406	2.290	0.930	0.949	0.874
	Head	2.142	2.624	2.766	3.367	2.853	3.107	1.254	1.371	1.295
Vibra. Trans.		**259%**	**340%**	**85%**	**226%**	**161%**	**88%**	**239%**	**216%**	**102%**

Table 4: average unweighted r.m.s. values [m/s2] of all test dummies, measured on all three road surfaces that were used to measure periodic vibrations. The last row shows the ratio between the r.m.s. value of the highest vibrational response/output (under the head) and the r.m.s. value of the vibrational input (the floor, highlighted in blue).

Weight	Location	Min. acc.	Max. acc.
5 kg	**Floor**	-18.429	24.511
	Seat-back	-18.354	16.547
	Lumbar	-17.997	15.863
	Head	-23.298	44.804

Weight	Location	Min. acc.	Max. acc.
8 kg	**Floor**	-19.081	22.247
	Seat-back	-17.476	21.615
	Lumbar	-14.688	21.674
	Head	-44.416	74.875

Weight	Location	Min. acc.	Max. acc.
10 kg	**Floor**	-21.165	21.319
	Seat-back	-21.133	23.695
	Lumbar	-13.564	23.590
	Head	-32.076	78.559

Table 5: Minimum and maximum accelerations [m/s2] when cycling over a speedbump with the Steco Baby Mee, measured at the four transducer locations. It can be seen that the accelerations measured under the head were the highest for all three different weights.

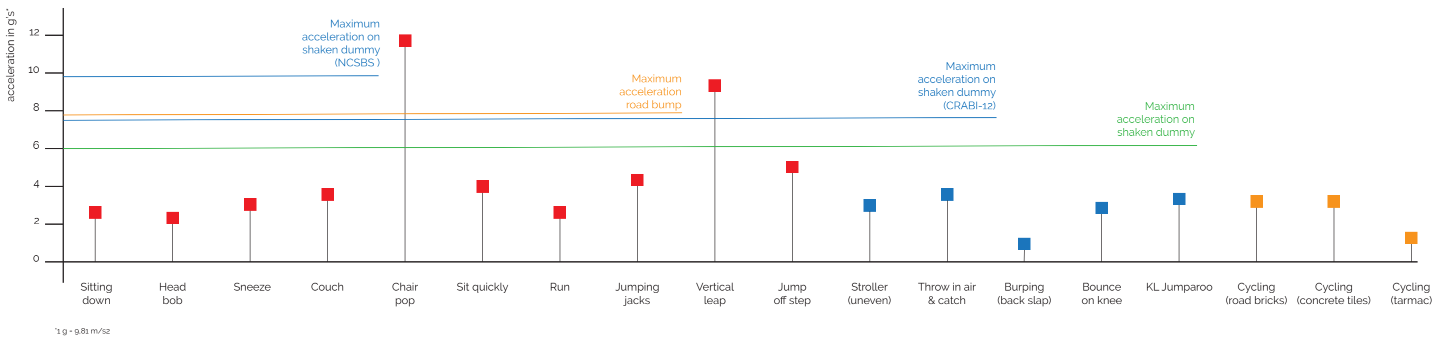


Chart 5: Results of the current study added to the original daily activities chart (Chart 4). Showing the average unweighted r.m.s. values of the three different road surfaces (in orange) and the maximum measured acceleration when cycling over a speed bump.

the floor (the disturbing frequency, f_d), defined as the number of oscillations per unit time of an external force or displacement applied to a system. Thus, the disturbing frequency is located in the frequency interval from approximately 8 – 9 Hz.

The DFTs of the transducers attached under the head showed peaks in the frequency interval from approximately 3 – 3.5 Hz. This might suggest that the infant safety seat appeared to have a first resonance frequency at approximately 2.5 – 3.5 Hz.

NOTE: until section '6.7 User scenario', all r.m.s. acceleration values of the current study of the graduation project were unweigthed. This was caused by the fact that the transfer functions for frequency weighting filters for each individual signal required significant time and effort to understand and implement.

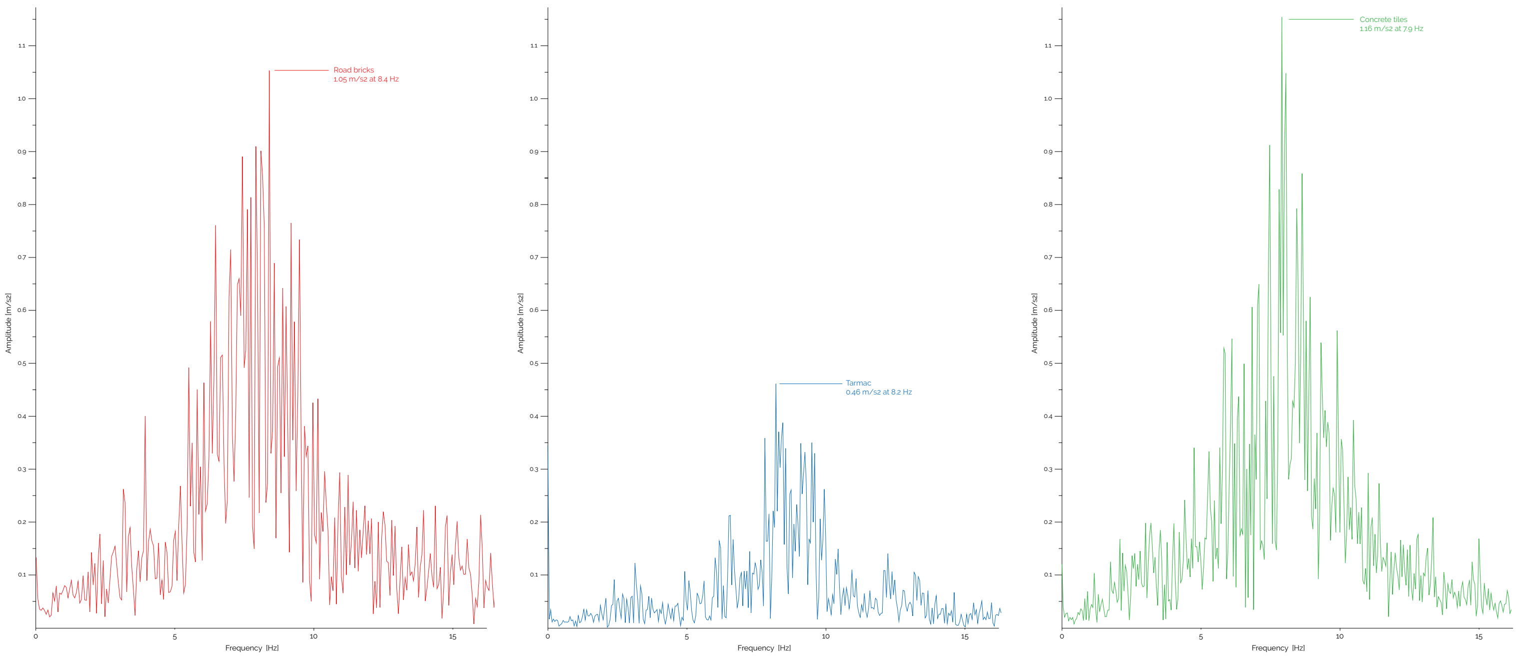


Chart 6: Discrete Fourier Transform. presenting the original vibrational signal deconstructed into its individual sine wave components, measured on the three different road surfaces, *on the floor of the cargo bike* with the 8kg test dummy

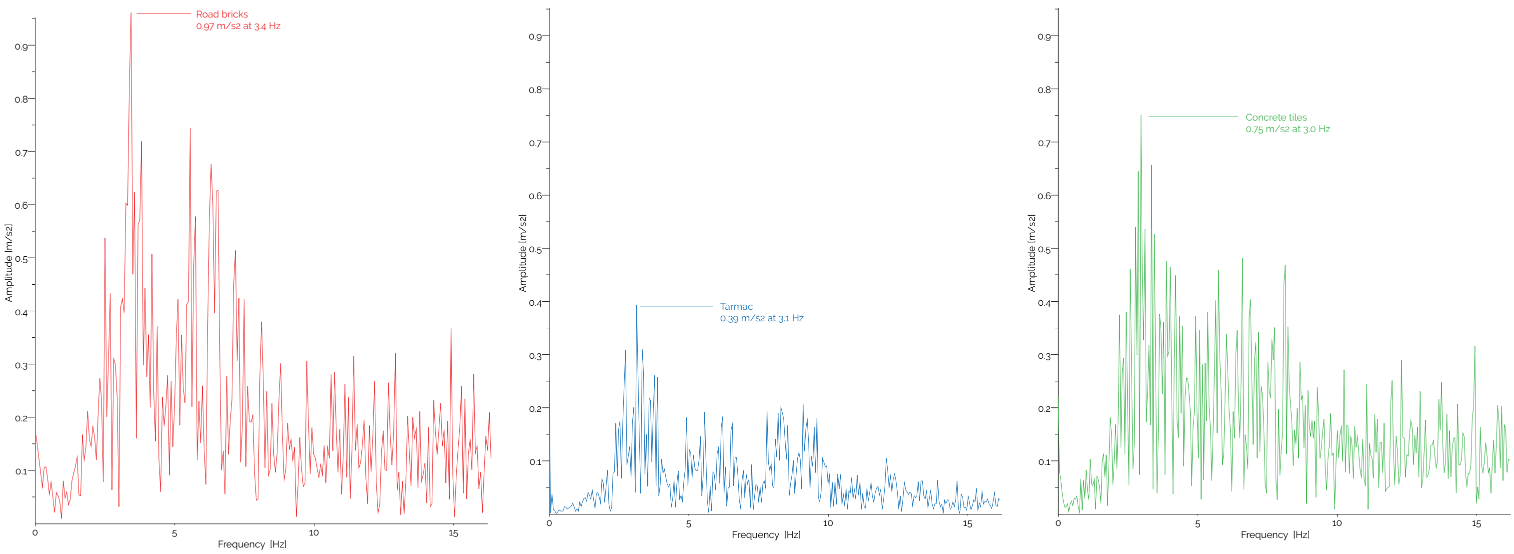


Chart 7: Discrete Fourier Transform. presenting the original vibrational signal deconstructed into its individual sine wave components, measured on the three different road surfaces, *under the head of the infant* with the 8kg test dummy

It is desirable to find a correct recommendation for the use of infant safety seats mounted on cargo bikes and to include a consideration of the health risks and discomfort likely to be caused by vibration.

2.15 Infant health and comfort

2.15.1 Health guidance caution zones

ISO 2631 provides 'health guidance caution zones' that indicate potential health risks for r.m.s. values of the frequency-weighted acceleration for an expected daily exposure. The health guidance caution zones are indicated by dotted lines in Chart 8. In the zone, caution with respect to potential health risks is indicated and above the zone health risks are likely.

In section 2.5 'children as road users: How do they travel?' the duration of a single jouney was calculated to be around 12 minutes. Assuming a return journey (e.g. bringing other children to school and going back), the total daily exposure would be 24 minutes. Based on the zones in Chart 8, this would mean that below a r.m.s. value of the frequency-weighted acceleration of 1.2 m/s2 health risks are minimal.

2.15.2 Acceleration in other vehicles

Table 6 shows 6 tests of two different studies in which acceleration values were measured for infant safety seats placed in a car. In total, 14 acceleration values were measured at the location of an infant safety seat. The r.m.s. values up to and including measurement 8 were measured on a moderate road surface quality, similar to the road surfaces 'road bricks' and 'concrete tiles' used in this study. The lowest r.m.s. value was 1.243 m/s2 (measurement 3); the highest was 1.86 m/s2 (measurement 8); the average r.m.s. value was 1.58 m/s2.

The r.m.s. values found in this study and Nilsson's study (measurement 9 up to and including 14) show that tarmac provides less vibrational energy in comparison to the other road surfaces. As a result, the impact on the infant's health and comfort was regarded as minimal.

2.15.3 Conclusion

After testing the product, the weighted r.m.s. acceleration value shall not exceed 1.45 m/s2, measured on the surface supporting the head in the z-axis. This value has a close similarity to the average r.m.s. value on average conditioned road bricks and concrete tiles (Table 3) and the average r.m.s. value based on measurement 1 up to and including 8 found in Table 6. Yet, it is desirable that the weighted r.m.s. acceleration value does not exceed 1.20 m/s2 as indicated in Chart 8.

Assuming a floor excitation r.m.s. value of 3.5 m/s2 (maximum value measured in this study for road bricks and concrete tiles, Table 4), this is equivalent to at least a vibrational reduction of 59% and desirable 66%. Or in terms of vibrational transmissibility, a value of 41% and 34%, respectively.

Moreover, It is desirable that the peak values in the frequency interval from approximately 2.5 - 3.5 Hz are reduced by 50% for all transducers attached to the infant safety seat.

		20 km/h	**30 km/h**		**40 km/h**	**50 km/h**	
	Car brand	not known	Volvo	Opel	not known	Volvo	Opel
Research	**Road surface**	Cobblestone	Gravelled road		Cobblestone	Country road (tarmac)	
Giacomin (2003)	Driver's seat	1.07			1.41		
	Driver's seat guide	1.66			2.4		
	Child seat guide	1.8			2.5		
	Child seat	**1.44** (1)			**1.86** (8)		
Nilsson (2005)	Driver seat		0.765	0.704		0.266	0.312
	Floor		0.851	0.963		0.258	0.424
	Isofix seat		**1.701** (2)	**1.775** (5)		**0.511** (9)	**0.526** (12)
	Base seat		**1.243** (3)	**1.574** (6)		**0.401** (10)	**0.516** (13)
	Belt seat		**1.301** (4)	**1.716** (7)		**0.406** (11)	**0.5** (14)

Table 6: Six tests of two different studies in which r.m.s. acceleration values [m/s2] were measured for infant safety seats placed in a car. The numbers in blue highlights the acceleration values measured at the child seat and were used to compare with the results of the study in this graduation report. The numbers between brackets ease efficient communication.

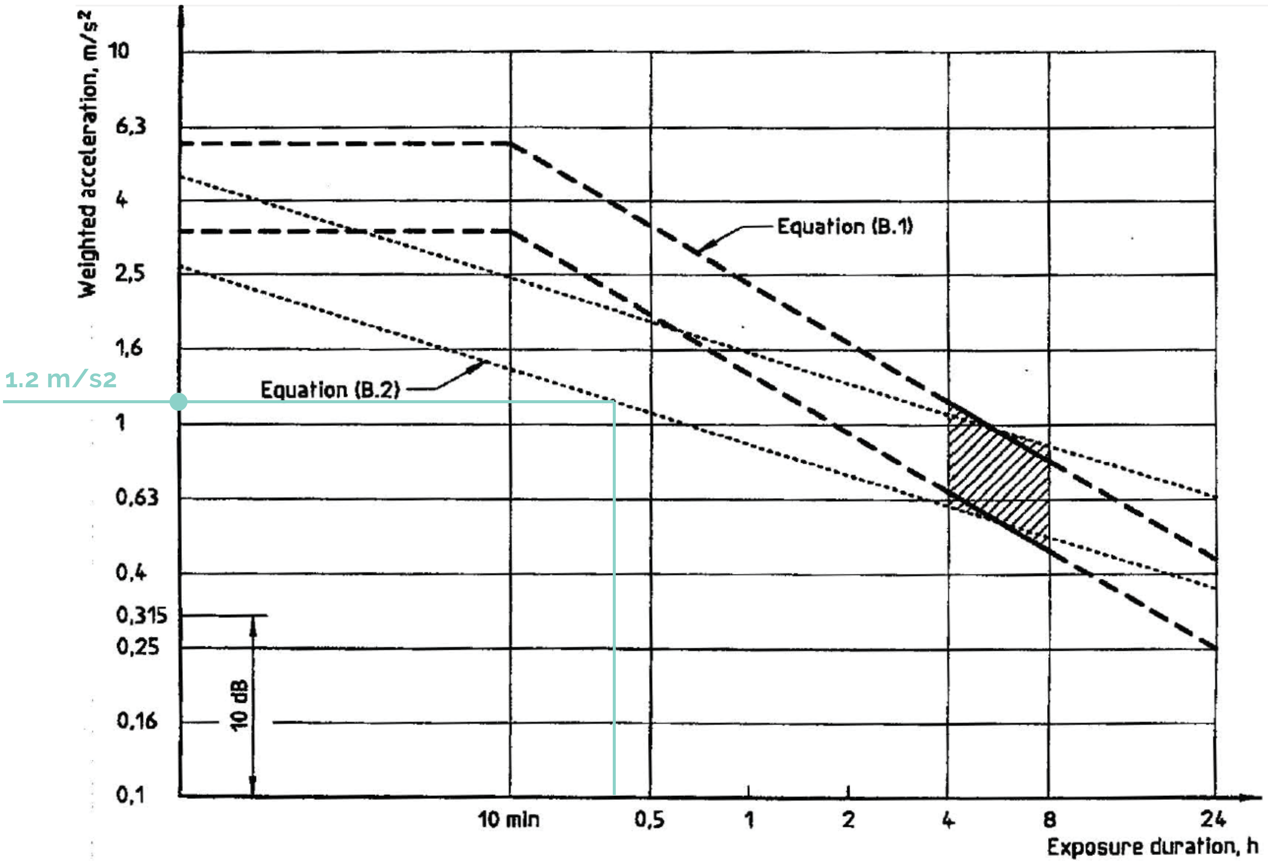


Chart 8: Health guidance caution zones. The r.m.s. value of the frequency-weighted acceleration can be compared with the zone shown here at the duration of the expected daily exposure.

”

Design an infant safety seat system for cargo bikes that dampens vibrations and shocks that are transmitted through the cargo bike to the infant.

2.16 Design brief

Cargo bikes have long since been transformed from an insider tip in the eco-niche to an urban trendsetter. In recent years cargo bikes have picked up speed, not least thanks to electric drives that can be used to effortlessly carry multiple children. More and more families appreciate the practicality of cargo bikes. Moreover, for many families a cargo bike can be considered to be a worthy alternative for a first car.

Problem
Parents who travel with infants experience significant problems in terms of seating safety and comfort. Little to none emphasis is drawn on the physical and psychological capabilities and limits of younger children who are less/ not able to sit up unsupported: the infant (0 to 1 year old). In particularly, vibrational comfort and health risk aspects of cycling with infants on a cargo bike is a matter of concern according to experts.

Target audience
Infants that are transported on a cargo bike.

Sales potential
Around 6.000 potential users (see appendix 21 for used statistics)

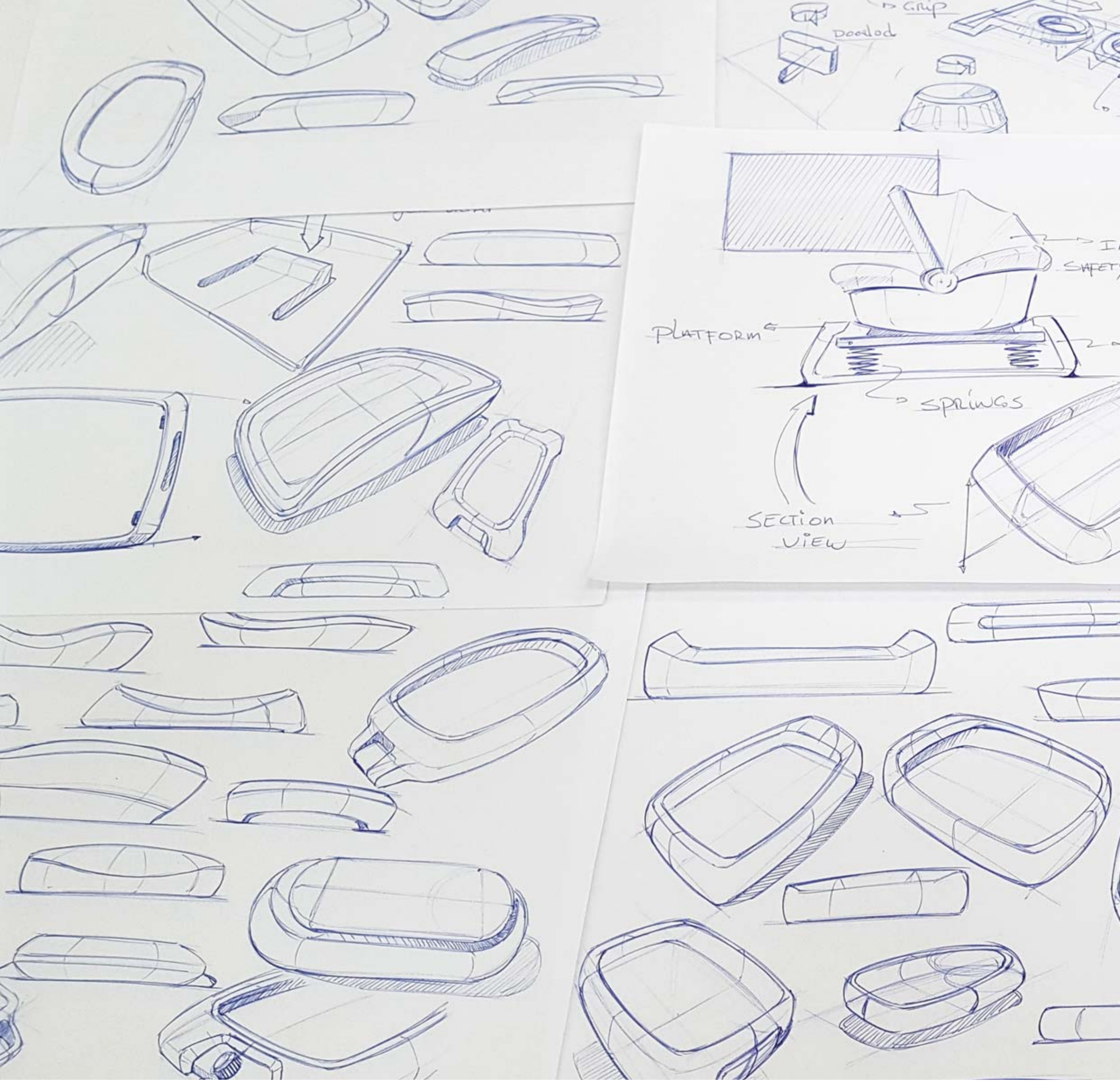
Key objectives
Current research highlights the need for a better seating solution that dampens the vibrations that are experienced by infants on a cargo bike.
The lack of solutions creates the need for an universal seating solution that enables an infant to be transported safely and comfortable on a cargo bike.
Health risk aspects and comfort need to be the starting point.

Requirements
The list of requirements has been constantly updated throughout the graduation project. The first requirements were drafted during the analysis phase. However, many requirements were added after this phase. The full list of requirements can be found in appendix 22.

3

Ideation

Based on the vibrational research, there is a noticeable, justifiable concern, particularly among the experts introduced in this graduation report, in terms of cycling with infants. As a result, three constructions were designed and tested to decrease the vibrations that are transmitted to the infant. Prior to building the constructions, a brief ideation session drew emphasis on different shape variations and locking mechanisms of one of these constructions. This ideation session resulted in several requirements.



3.1 First ideation session

This ideation session drew emphasis on different shape variations and locking mechanisms. The first idea that came to mind after analyzing the competitors, was a platform upon which an infant safety seat could be placed (Figure 45). The platform could be attached to the bottom of a cargo bike. Inspired by the Babybike, this platform would rest on four adjustable springs. The platform would be wrapped by a (plastic) cover, thereby covering the spring mechanism and offering protection against entrapment.

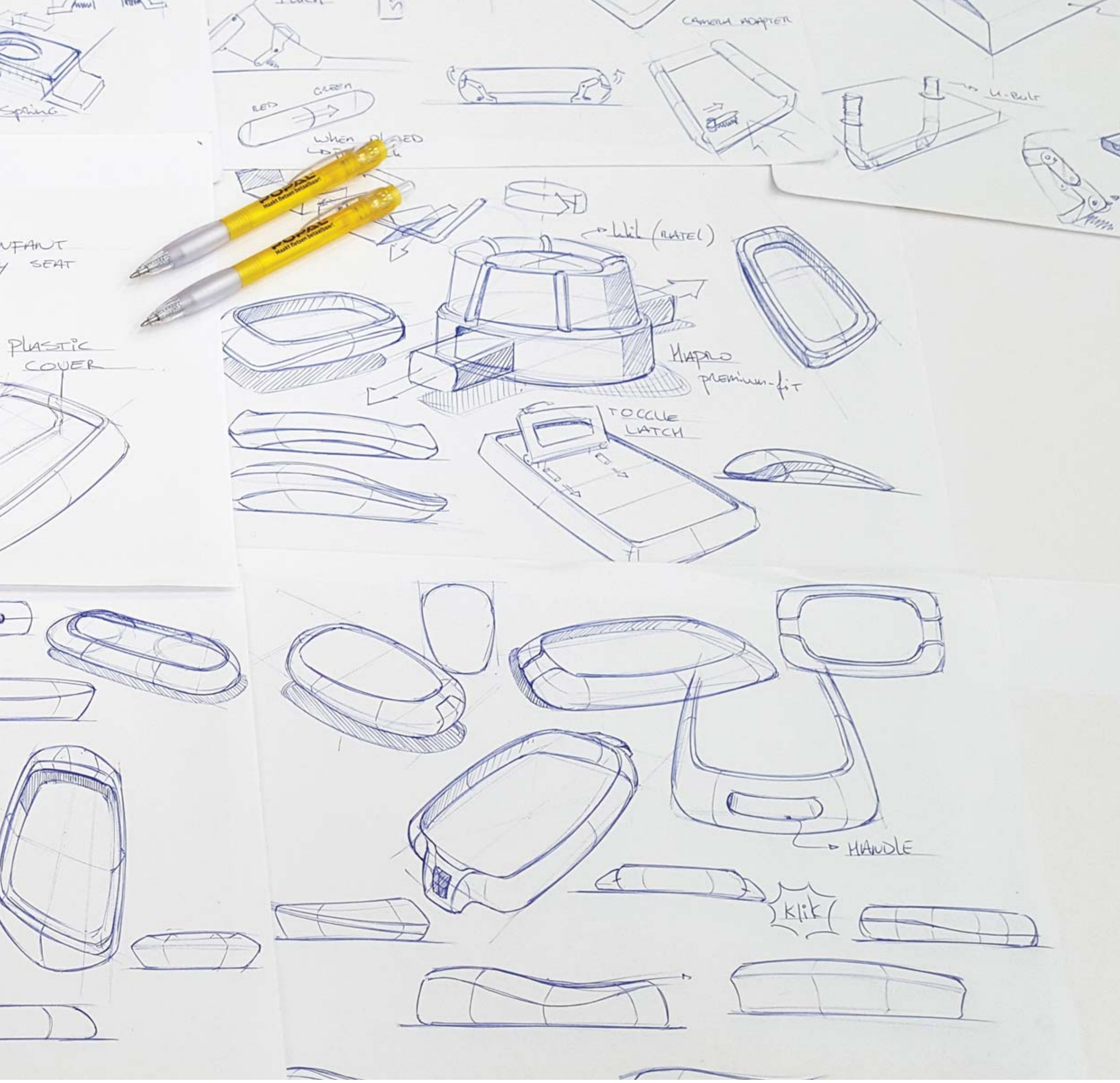


Figure 45: Blue pen hand sketches, showing different shape variations and locking mechanisms. In the middle, the idea of the initial damped seat system (a platform) can be found.

3.1 Conclusions

During this ideation session it became clear that spring-loaded locking mechanisms (to lock the system to the floor of the cargo bike) would significantly increase the system's complexity. Moreover, in most cases, these mechanisms require delicate parts, thereby increasing the part quantity, costs and vulnerability of the system. Parts that make use of a toggle principle might be a proper and cheap alternative.

In addition, any locking mechanism that is permanently fastened to the floor of the cargo bike results in protrusions. These protrusions are vulnerable and should be engineered to withstand high impact strengths (e.g. a child stepping on it).

3.2 Seat constructions

Three constructions were designed and tested to decrease the vibrations that are transmitted to the infant. Firstly, the study method will be explained. Halfway, a collage shows the building process and the broad range of used dampers and isolators. The section ends with the test results and the most important lessons learned during the tests.

3.2.1 Constructions

The most universal product available today that can be attached to a cargo bike (the Steco Baby Mee) was used as benchmark for designing a new seating system. Eventually, three different constructions were made (Figure 47-50):

- Platform, consisted of a horizontal plate that was supported by a damping element: 176 test runs, divided over 11 different damping elements
- Parallelogram, consisted of two parallel placed panels of equal length and one horizontal plate: 84 test runs, divided over 5 different damping elements
- Double diagonal, consisted of two diagonally placed panels, attached near the edge of a triangular base and top construction: 8 test runs, divided over 1 damping elements

3.2.2 Method

The constructions were tested in front of Bigline's bicycle shop: a properly maintained paving-stones road surface. The test track in front of Bigline's bicycle shop was 50 meters long. The average vibration measurement for periodic vibrations lasted approximately 10 seconds (18 km/h).

The vibration measurement was started and stopped after the cyclist had crossed the line that was drawn at the beginning and end of the test track by means of sidewalk chalk (Figure 46).

3.2.2.1 Seat basket

In his PhD-thesis, Giacomin (2003) chose five parameters to define the sitting posture on an infant: backrest section length (L1), lower section length (L2), width (L3), the

Figure 46: The constructions were tested in front of Bigline's bicycle shop. A start and stop line was drawn on the road by means of sidewalk chalk.

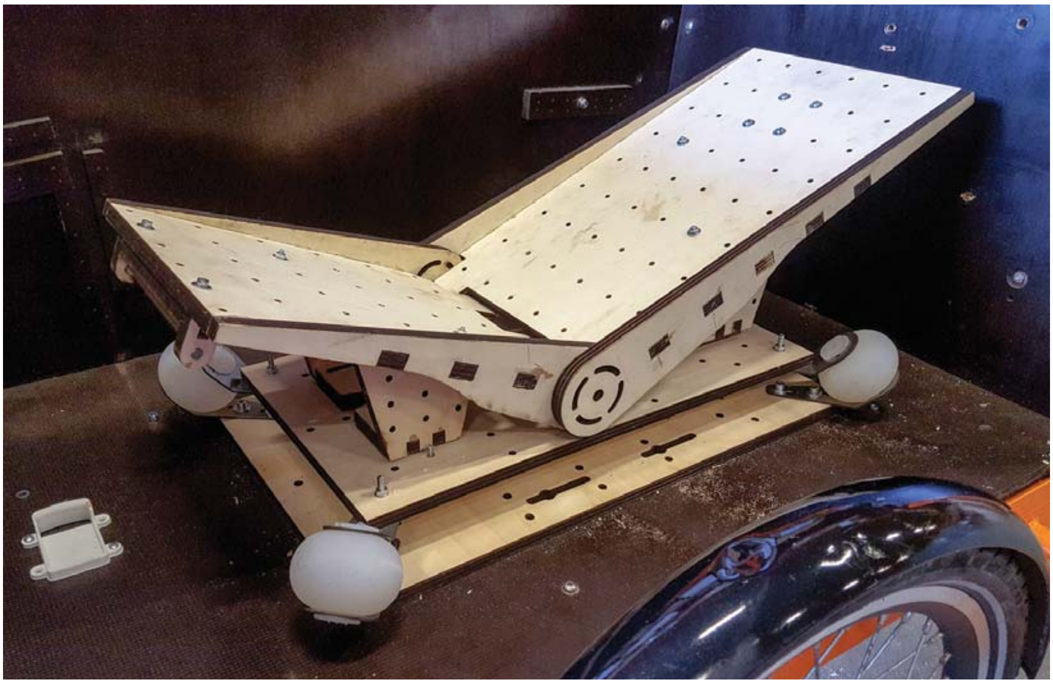


Figure 47: (upper) Platform construction. Here, mounted with inclined rubber damping balls.

Figure 48: (middle) Parallelogram construction. Here, mounted with a shock absorber. The side panels of the cargo bike were removed to enable efficient and fast adjustment and removal of the shock absorber.

Figure 49: (lower) Double diagonal construction. Here, mounted with a shock absorber.

included angle (α) between the two sections L1 and L2 and the seat angle with respect to the horizontal (β). Based on Giacomin's five parameters and Tilley's (2001) anthropometric data, a modular seat basket was made (Figure 51), with:

- A lower section length (L1) of 300mm;
- A backrest section length (L2) of 450mm;
- A width (L3) of 280mm;
- An included angle (α) between the two sections L1 and L2 of 140 degrees, and;
- A seat angle with respect to the horizontal (β) of 20 degrees

The seat basket was fabricated out of 9 mm plywood, which was lasercutted and glued together. The basket was securely fastened to each of the three constructions, ensuring a stiff and rigid construction and minimal vibration resonance near the mechanical interface.

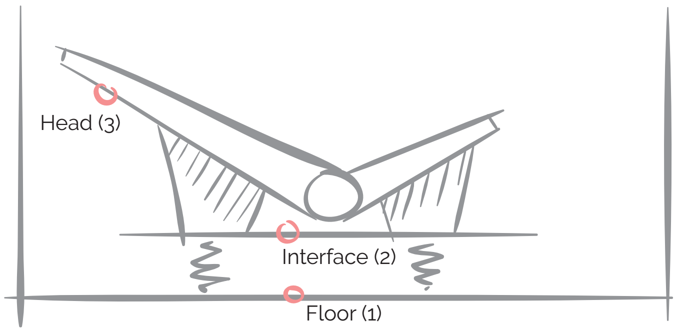
3.2.2.2 Transducer location

In each test construction three transducers (Figure 50) were used, placed at:

- At the floor of the cargo bike (transducer 1);
- The horizontal interface between the seat basket and the damping element(s) (transducer 2), and;
- The seat-back section, slightly above the head (transducer 3).

Due to space limitations, the exact position of transducer 1 and transducer 2 changed slightly per construction. The assumption was made that this had no major impact on the test results.

The next four pages gives a visual impression of building the test constructions and provides test insights of different damping materials used in the test construction. A maple file of calculations, based on theoretical values, for a simplified spring-damper system can be found in appendix 23.



▲ Figure 50: Location of the three transducers

▼ Figure 51: Seat basket made out of laser cutted plywood.

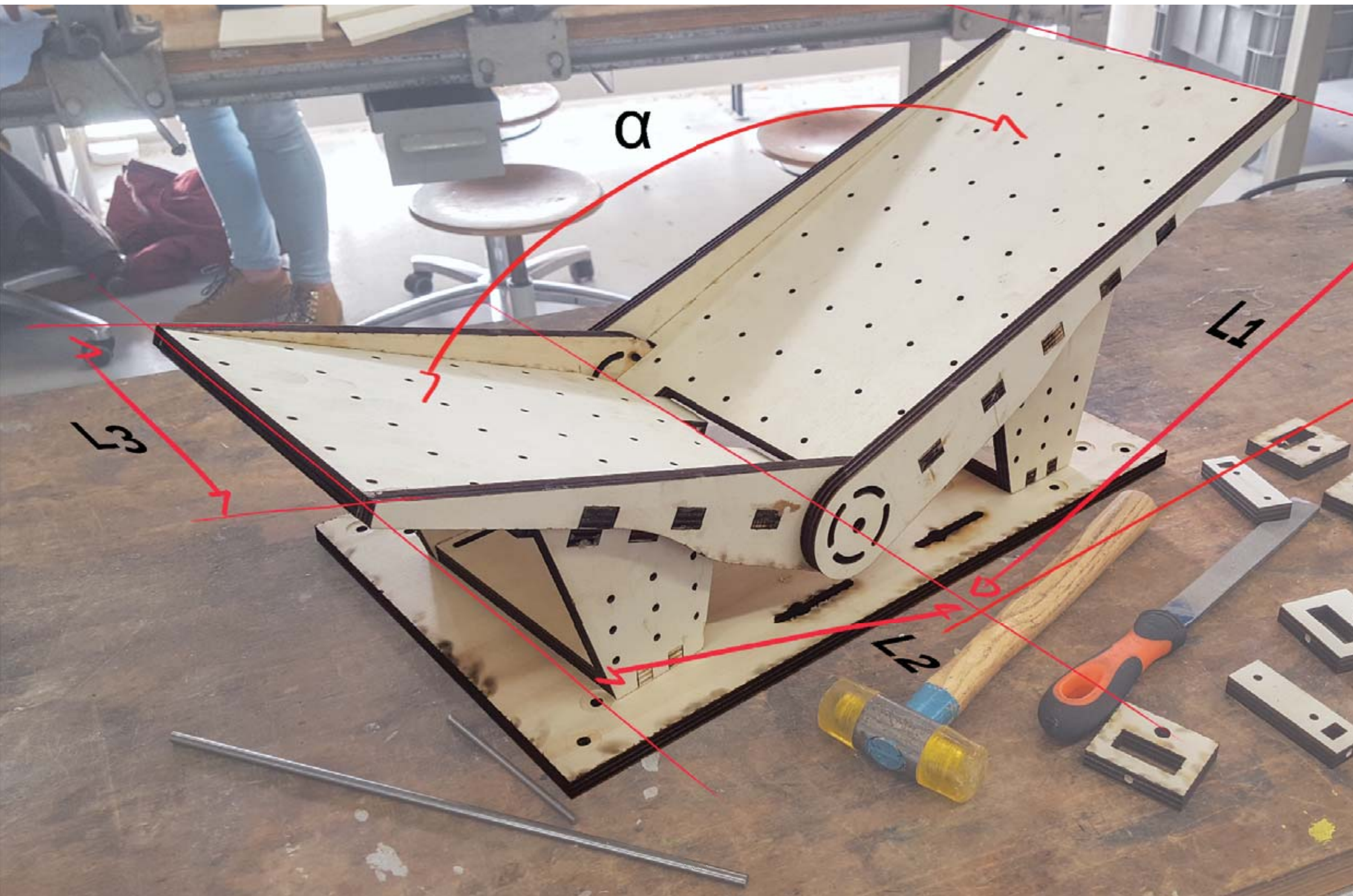
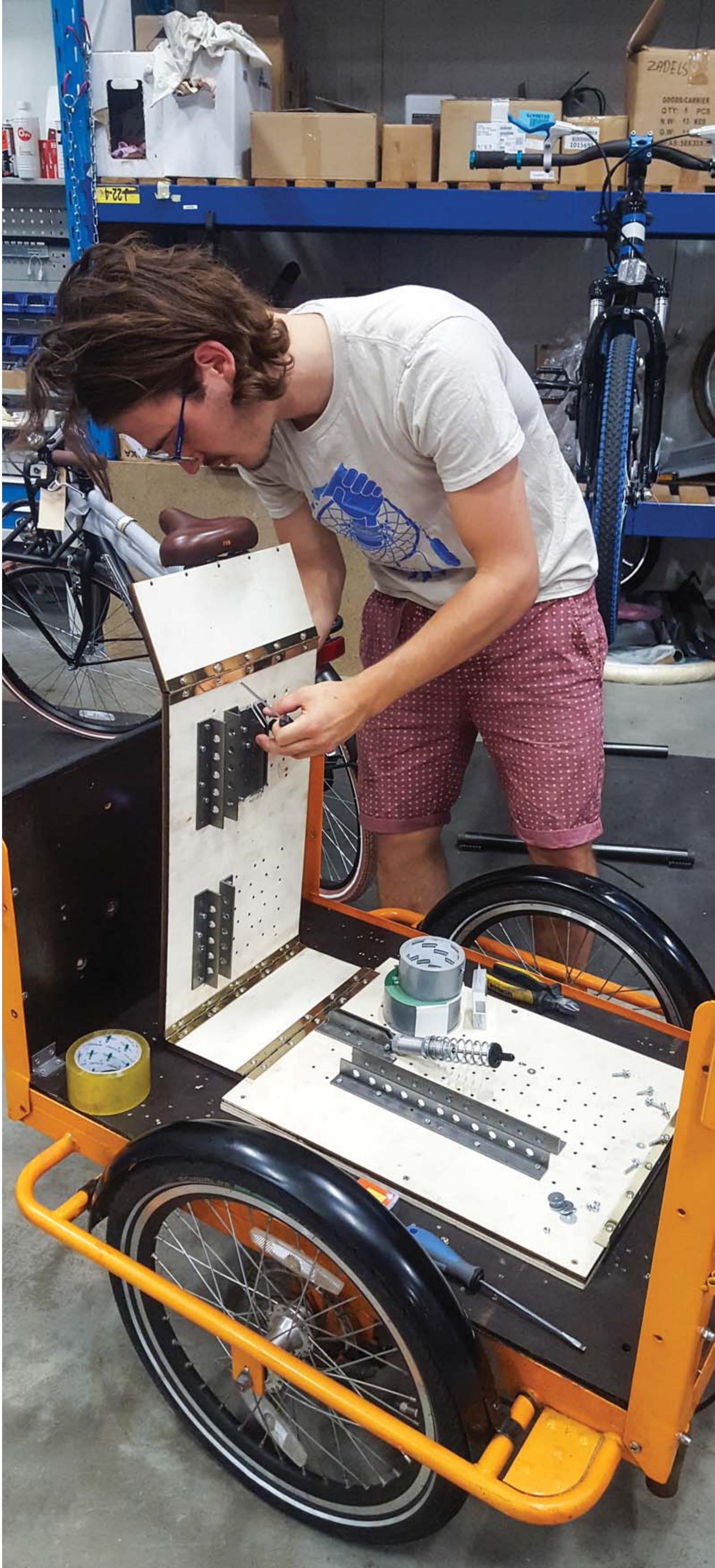


Figure 52: Installing the paralellogram construction at Bigline's workshop



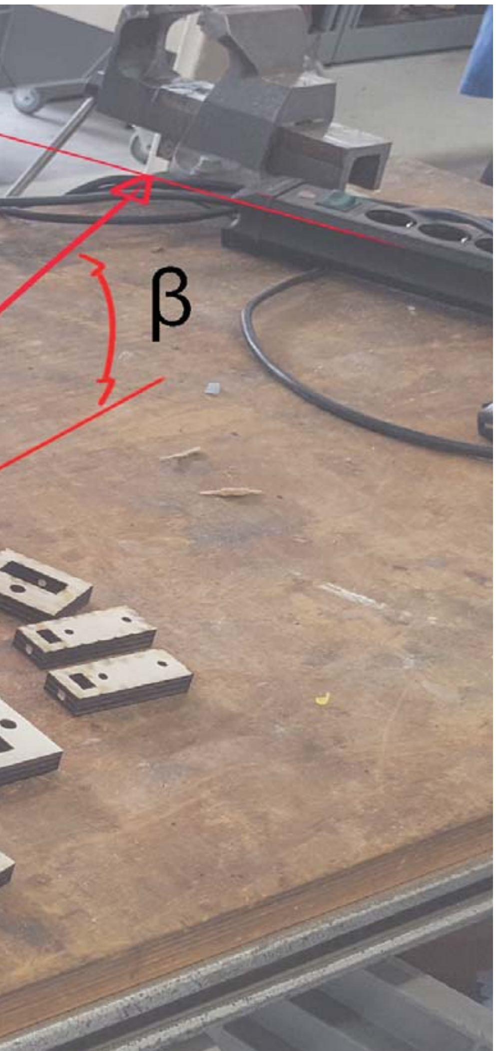


Figure 53: An inflatable mat was cut and glued together to fit in the cargo bike. The inflatable mat was too unstable and wobbly.

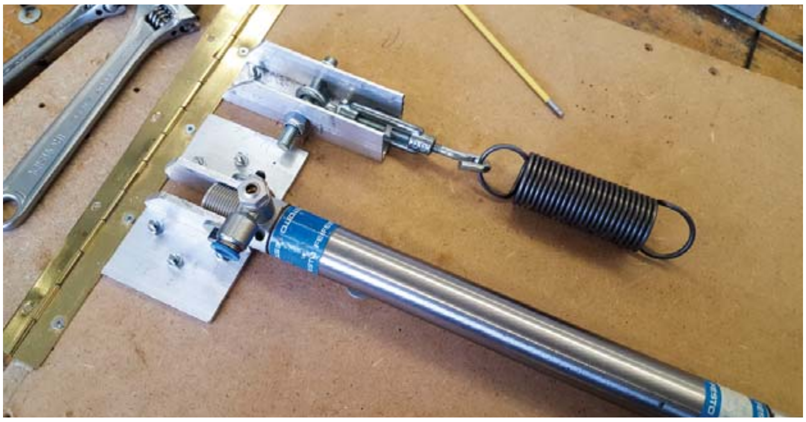


Figure 54: A Festo pneumatic cylinder was used in the parallelogram construction

Figure 55: Exploded view of a shock absorber.

Figure 56: Out of a Regufoam ® foam plate, multiple hexagons were cut that served as damping material. The vertical wood construction on the sides served as guidance.

Figure 57: Possibilities were being evaluated to make rubber damping balls airtight. This would create some sort of air suspension.

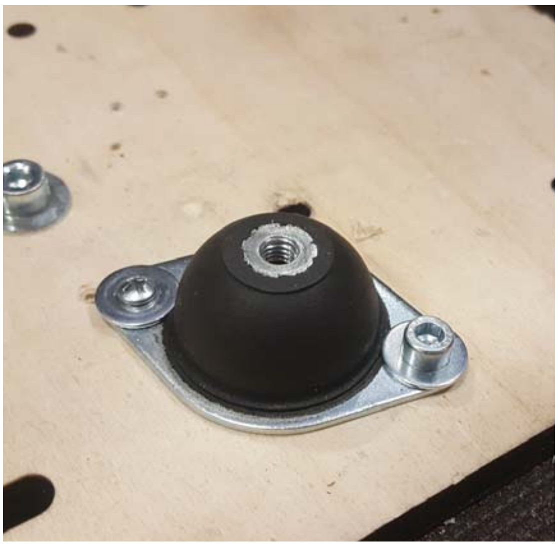


Figure 58: Several purchase rubber damping elements were used, such as dome mounts and ring mounts.

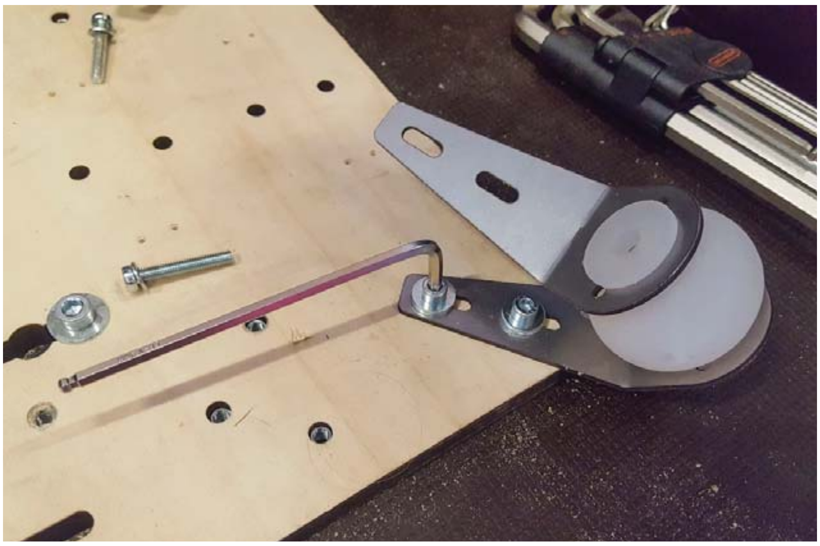


Figure 59: For maximum elastically supported stability, rubber isolators should be positioned at an angle to the vertical loads, resulting in a combination of shear and compression.

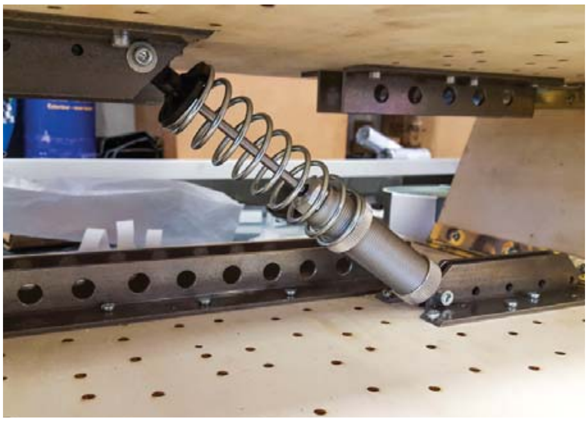


Figure 60: A 1:8 shock absorber was used in the parallelogram and double diagonal construction. The holes in the metal brackets made it possible to adjust the shock absorber angle.

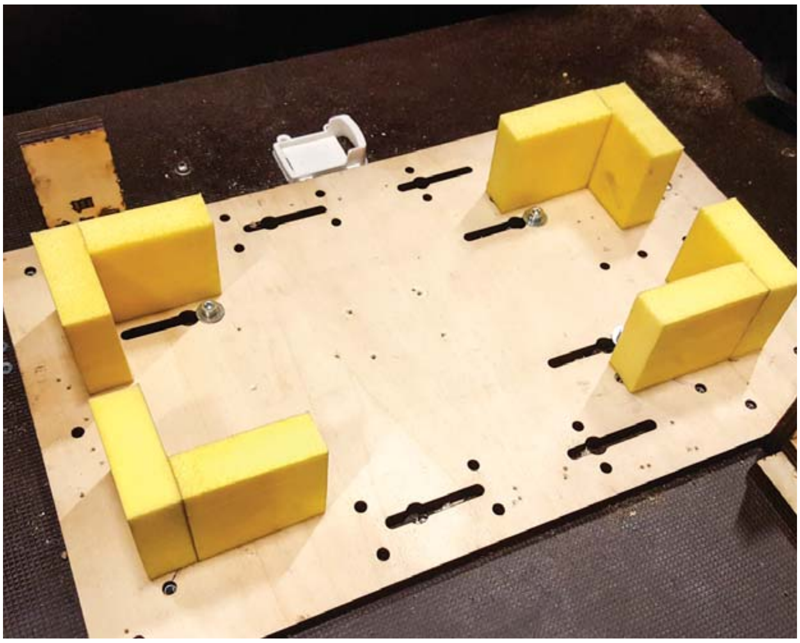


Figure 62: Foam materials are designed to absorb high impact energy by controlling the rapid deceleration. However, for controlling vibration these materials were less suitable.

Figure 61: Test set-up to validate the spring rate, consisting of an incised aluminium tube and a bent nail that moved in the incision.

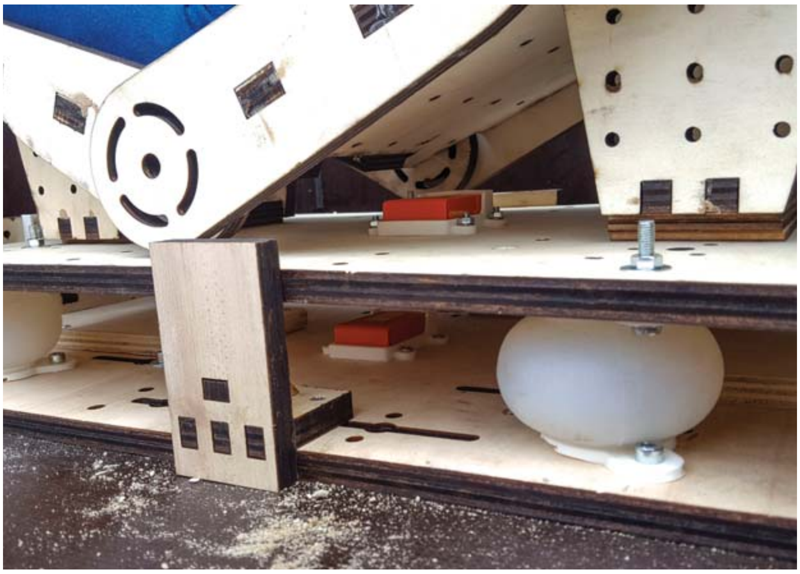


Figure 63: Rubber damping balls are not stable in the radial direction and need some sort of guidance (e.g. a wooden bracket).

Figure 64: Syringes in different volumes were used. Syringes are rigid elements and cannot expand in volume (as opposed to a balloon, e.g.). The damping of these elements make use of air pressure change and no volume change as normal air suspension does.

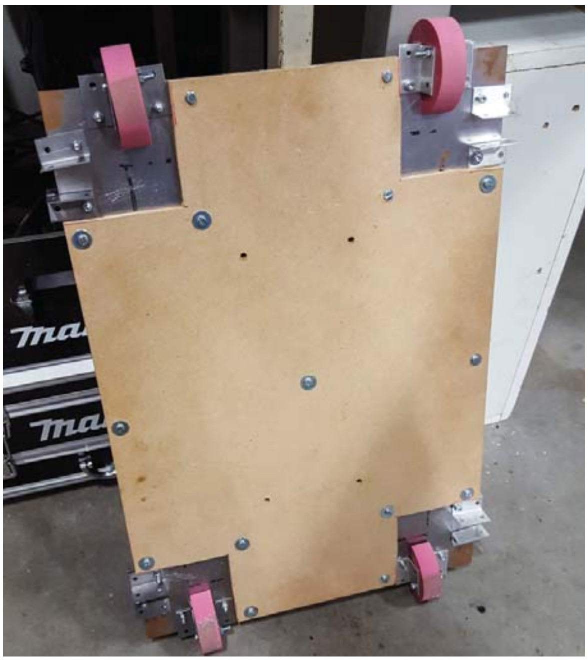


Figure 65: In collaboration with an international company that designs and produces anti-vibration mounts, a construction was proposed based on Sylomer® damping foam.

Figure 66: In order to let the shock absorber react precisely to bumps in the road, both holes of the piston were drilled larger in steps of 0.5 mm after each test.

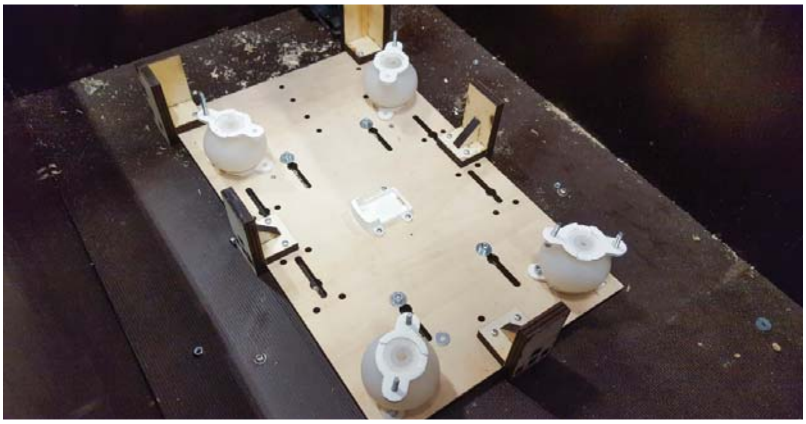


Figure 67: Four rubber damping balls were placed at the corners of the platform construction. Inspiration was found from drones that use rubber damping balls to stabilize camera images.

Figure 68: A gas spring pushes with a constant and preset force. Whether the system worked, depended on the resulting force between the gas spring, the tension spring and the weight that was laid on the parallelogram.

Figure 69: Canned aluminum brackets were attached to the 'interface surface'. Yet, they were considered to be not stiff enough and might have resulted in a certain degree of resonance.

Figure 70: Friction damping between a plastic and foam surface. Lubrication was added to smoothen the friction.

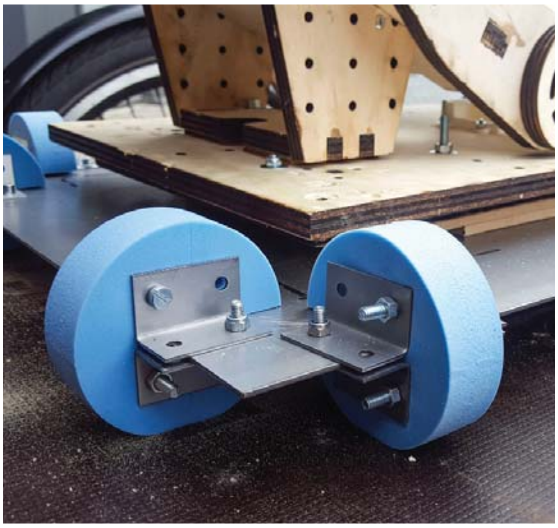


Figure 71: Sylomer® foam cylinders attached to a metal platform. After static loading, the Sylomer® foam was already compressed in such a way that only small deflections were possible.

Figure 72: This type of isolator used a coil spring together with a solidified silicone gel for damping.

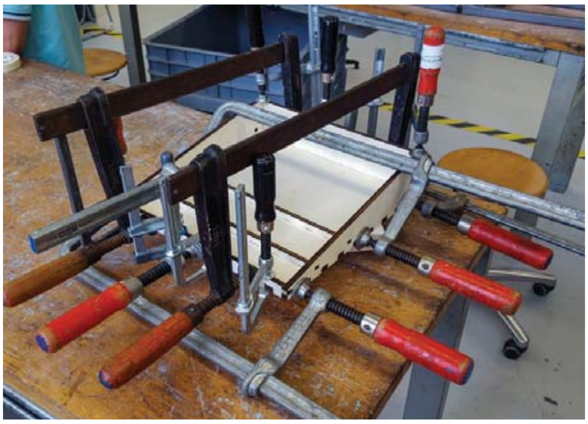


Figure 73: Glueing the laser cutted double diagonal construction.

Figure 74: Placing the syringes next to the platform resulted in a lower center of gravity, thus creating more stability.

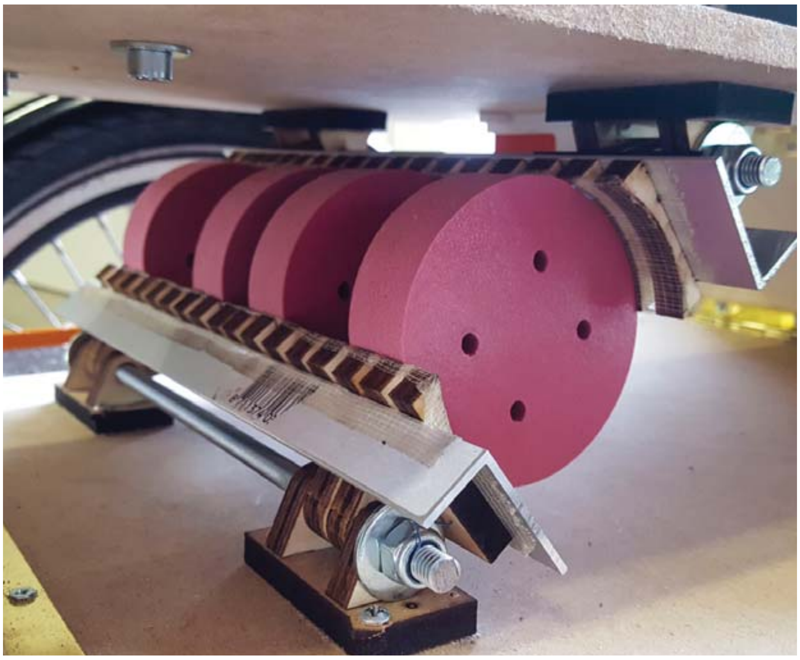


Figure 75: The cylindrical foam parts that were provided by AMC were also tested in the parallelogram construction. The different densities, as well as the quantity of the cylindrical foam parts, were tested.

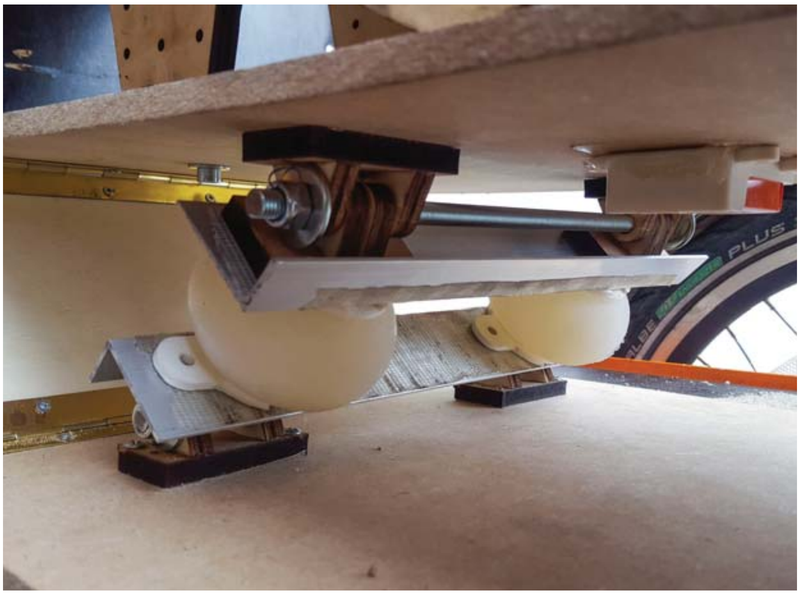


Figure 76: Placing one rubber damping ball was insufficient to withstand the weight that was placed on the parallelogram: the rubber damping ball collapsed. Placing two rubber damping balls worked better.

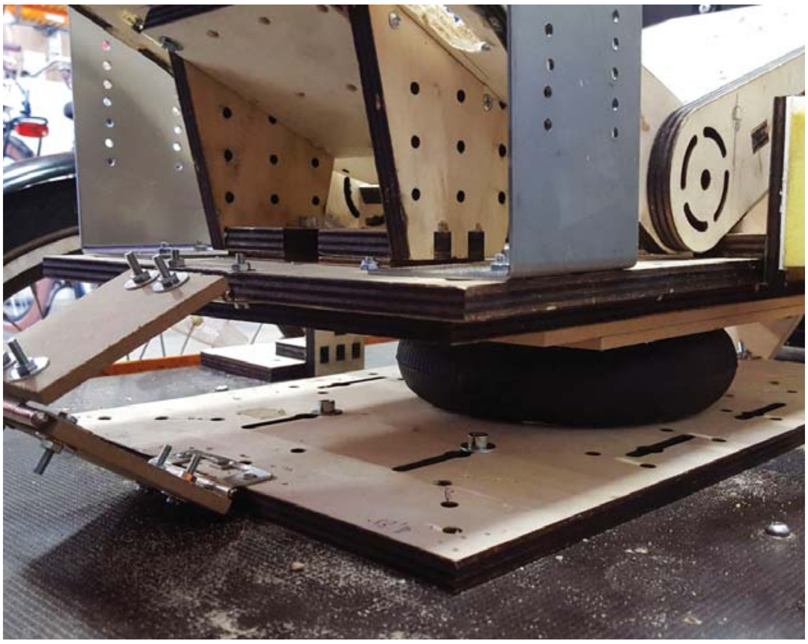


Figure 77: Within this construction, the platform was mounted on top of an inflated wheelbarrow inner tube.

Figure 78: small, medium and large rubber damping balls were poured with self-made molds.

The results of the double diagonal showed a vibrational transmissibility reduction of 47.9% in comparison to the Steco Baby Mee (both loaded with 8 kg).

3.2.3 Results

Table 8 shows the unweighted r.m.s. acceleration values of the Steco Baby Mee and the different test constructions. The damping elements that showed the lowest acceleration values are denoted underneath the visualizations of each construction.

The road brick street that was used to test the Steco Baby Mee was considered to be of moderate road surface quality. The test track in front of Bigline's bicycle shop, however, was considered to be of perfect road surface quality. Therefore, the vibrational transmissibility (output/input ratio expressed in percentage) was considered to be a realistic comparison measure, since it tells something about how much the vibrations are damped per test. The higher the percentage, the more vibrations will be transmitted to the infant. Giacomin (2003) uses a similar approach in his PhD thesis. In addition, Jo Spronck, associate professor mechatronic system design and metrology, suggested to focus predominantly on vibrational transmissibility (personal communication, Jo Spronck, December 12, 2018). The vibrational transmissibility was calculated between the transducer located under the head (output) and the transducer located on the floor (input).

3.2.3.1 Vibrational transmissibility comparison

Out of the test constructions, in the z-direction, the platform construction showed the highest vibrational transmissibility (117%), the double diagonal showed the lowest (49%).

In the z-direction, the results of the double diagonal showed a vibrational transmissibility reduction of 47.9% in comparison to the Steco Baby Mee (both loaded with 8 kg).

The higher vibrational transmissibility in the z-axis measured on the platform construction, might be caused due to a lack of stability in the x and y-axis. If the damping elements are not perfectly aligned, they create undesired tilting of the platform and friction. Furthermore, if the load is not evenly distributed over the seat basket, therefore shifting the center of gravity to a certain side of the construction, the damping elements are not evenly compressed. In practice, this will always be the case since the infant moves.

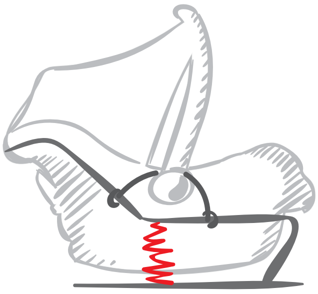
All test constructions showed a vibrational transmissibility of more than 100% in the x and y-direction: the acceleration values were intensified. The increase in the y-direction is most likely caused by the lateral stiffness of the constructions, which does not dampens roll and side-to-side motions (Figure 82). The increase in the x-direction, on the other side, is most likely caused by the fact that the construction does not yet react precisely to road undulations.

3.2.3.2 Acceleration in other vehicles

Table 7 shows the tests in which acceleration values were measured for infant safety seats placed in a car once more. In total, 14 acceleration values were measured at the location of an infant safety seat. In 8 out of the 14 acceleration values (1 up to and including 8), the parallelogram and the double diagonal constructions showed lower unweighted r.m.s. acceleration values (z-direction, measured under the head). In comparison to the acceleration values of the two 50 km/h tests (9 up to and including 14), the unweighted r.m.s. acceleration values of the test constructions were higher.

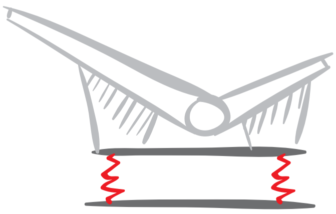
		20 km/h	**30 km/h**		**40 km/h**	**50 km/h**	
	Car brand	not known	Volvo	Opel	not known	Volvo	Opel
Research	**Road surface**	Cobblestone	Gravelled road		Cobblestone	Country road (tarmac)	
Giacomin (2003)	Driver's seat	1.07			1.41		
	Driver's seat guide	1.66			2.4		
	Child seat guide	1.8			2.5		
	Child seat	**1.44** (1)			**1.86** (8)		
Nilsson (2005)	Driver seat		0.765	0.704		0.266	0.312
	Floor		0.851	0.963		0.258	0.424
	Isofix seat		**1.701** (2)	**1.775** (5)		**0.511** (9)	**0.526** (12)
	Base seat		**1.243** (3)	**1.574** (6)		**0.401** (10)	**0.516** (13)
	Belt seat		**1.301** (4)	**1.716** (7)		**0.406** (11)	**0.5** (14)

Table 7: Six tests of two different studies in which r.m.s. acceleration values [m/s2] were measured for infant safety seats placed in a car. The numbers in blue highlights the acceleration values measured at the child seat and were used to compare with the results of the study in this graduation report. The numbers between brackets ease efficient communication.



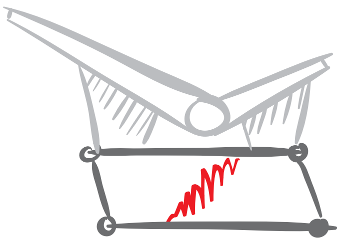
Steco Baby Mee
Compression spring

Weight	Location	Road type		
			Road bricks	
		rmsx	rmsy	rmsz
8 kg	**Floor**	1.011	0.729	3.286
	Seat-back	1.988	1.815	2.178
	Lumbar	1.655	1.719	2.461
	Head	3.383	2.685	3.099
Vibra. Trans.		**334%**	**368%**	**94%**



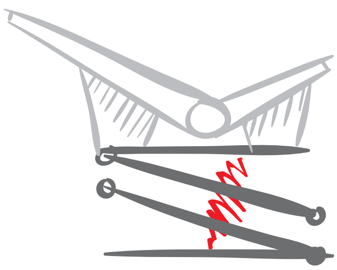
Platform
Syringe 20 ml

Weight	Location	Road type		
			Test track	
		rmsx	rmsy	rmsz
8 kg	**Floor**	0.788	0.812	1.66
	Interface	0.869	0.964	1.664
	Head	1.241	0.978	1.941
Vibra. Trans.		**157%**	**120%**	**117%**



Paralellogram
Shock absorber

Weight	Location	Road type		
			Test track	
		rmsx	rmsy	rmsz
8 kg	**Floor**	0.684	0.752	1.82
	Interface	1.137	0.918	0.906
	Head	1.040	1.005	1.236
Vibra. Trans.		**152%**	**134%**	**68%**



Double diagonal
Shock absorber

Weight	Location	Road type		
			Test track	
		rmsx	rmsy	rmsz
8 kg	**Floor**	0.63	0.516	2.114
	Interface	0.481	0.596	0.675
	Head	0.732	0.649	1.031
Vibra. Trans.		**116%**	**126%**	**49%**

Table 8: Unweighted r.m.s. acceleration values [m/s2] of the Steco Baby Mee and the different test constructions. The r.m.s. acceleration values measured at the floor are highlighted in blue. These r.m.s. acceleration values were used as input for calculating the vibrational transmissibility values.

3.2.3.3 Shock absorber

A 1:8 RC shock absorber (viscous damping with oil) showed to be highly suitable for this application. This damping element showed the lowest vibrational transmissibility when placed in the double diagonal construction: 49%. By optimizing the radii of the orifices holes of the piston, the shock absorber could react precisely to bumps in the road. An elaborated explanation of this damping element, its fluid dynamics and damping characteristics and how the spring rate was empirically validated, can be found in appendix 24.

3.2.4 Conclusions

Since both the parallelogram and double diagonal construction showed a decrease in vibrational transmissibility, both constructions were selected for further development. In addition, these constructions showed significant lower unweighted r.m.s. acceleration values in comparison to the existing product.

The platform construction showed an increase in vibrational transmissibility and was excluded from further development.

3.2.4.1 Viscous damping

Based on the test results and the vibration and damping theory, it was concluded that viscous damping was needed to reduce the vibrations that are transmitted to the infant. As a result, the oil-filled 1:8 RC shock absorber was chosen to be used in the conceptualization.

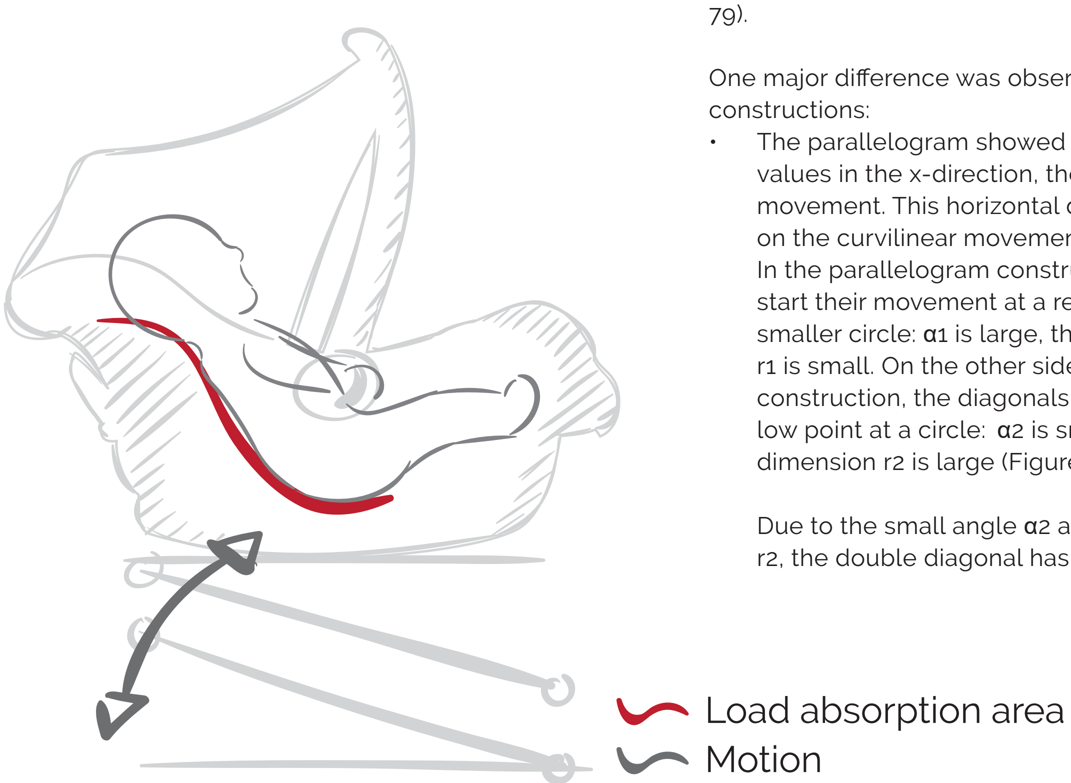


Figure 79: Curvilinear movement. It was assumed that if the double diagonal construction was to bottom out, the resulting shock load felt by the infant would be spread over the infant's buttocks and back.

3.2.4.2 The effects of the moment of inertia

Both the parallelogram as well as the double diagonal make clever use of the moment of inertia (or angular mass) that acts on the systems when the cargo bike accelerates or de-accelerates.
In the thesis 'Design, Modelling and testing of a Forklift seat suspension system' by Andrew Mac Guinness (2014), Andrew mentions the following about his diagonal suspension seat:

"The concept chosen to model and run simulations on was picked because it was felt that due to the diagonal motion of the suspension system during the compression stroke would reduce the occurrence of bottoming and topping. ***If the system was to bottom out the resulting shock load felt by the operator would be spread over the operators buttocks and back, rather than transmit the shock vertically up through the operators spine compressing the vertebra."***
(Guinness, 2014)

The same phenomenon applies to the curvilinear motion (motion represented by a curved line) of the seating system constructions proposed in this graduation project. Figure 79 illustrates the curvilinear motion and the load absorption area, due to bottoming (Figure 80).

3.2.4.1 Radial dimensions and starting angles influence curvilinear movement

In essence, the construction causes the upper part to move in a curvilinear motion relative to the floor (Figure 79).

One major difference was observed between the two constructions:

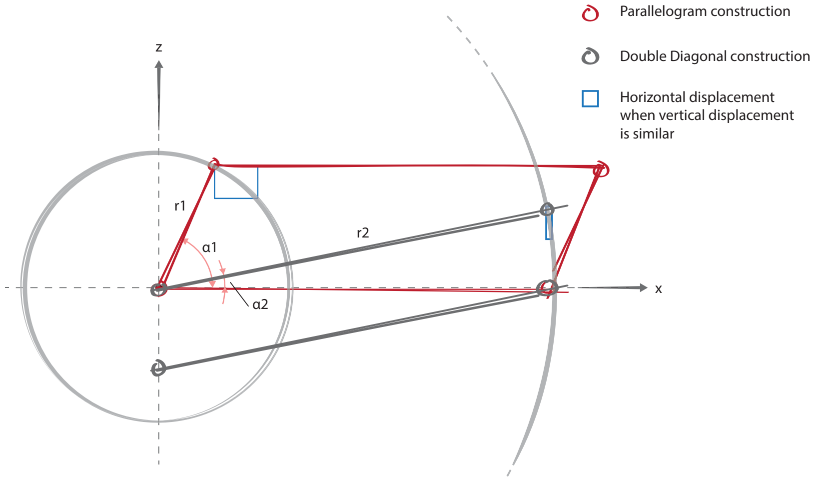
- The parallelogram showed higher acceleration values in the x-direction, the back and forward movement. This horizontal displacement depends on the curvilinear movement the 'diagonals' make. In the parallelogram construction, the diagonals start their movement at a relatively high point on a smaller circle: $\alpha 1$ is large, the diagonal with dimension r1 is small. On the other side, in the double diagonal construction, the diagonals start at a relatively low point at a circle: $\alpha 2$ is small, the diagonal with dimension r2 is large (Figure 80).

  Due to the small angle $\alpha 2$ and large dimension of r2, the double diagonal has a smaller horizontal displacement in comparison to the paralellogram construction, when they both move with the same vertical travel.

NOTE: Bottoming out, definition: the state in which a suspension element (e.g. a spring) is fully compressed. In this state, the suspension element has reached its lowest point and hits the 'bottom'.

NOTE: Appendix 25 elaborates explicitly on the main findings of each construction and used damping elements. To provide a clear and comprehensible overview, the main findings of each construction were listed by damping type.

NOTE: Appendix 26 - 29 provides the vibrational data of all the constructions and damping materials that were used during the test.



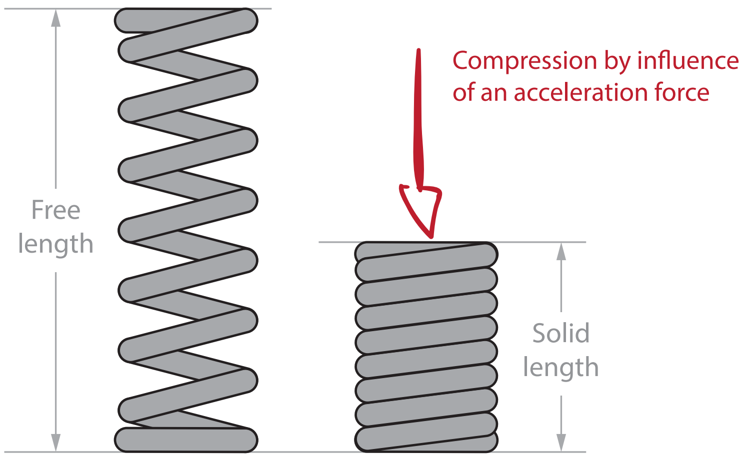
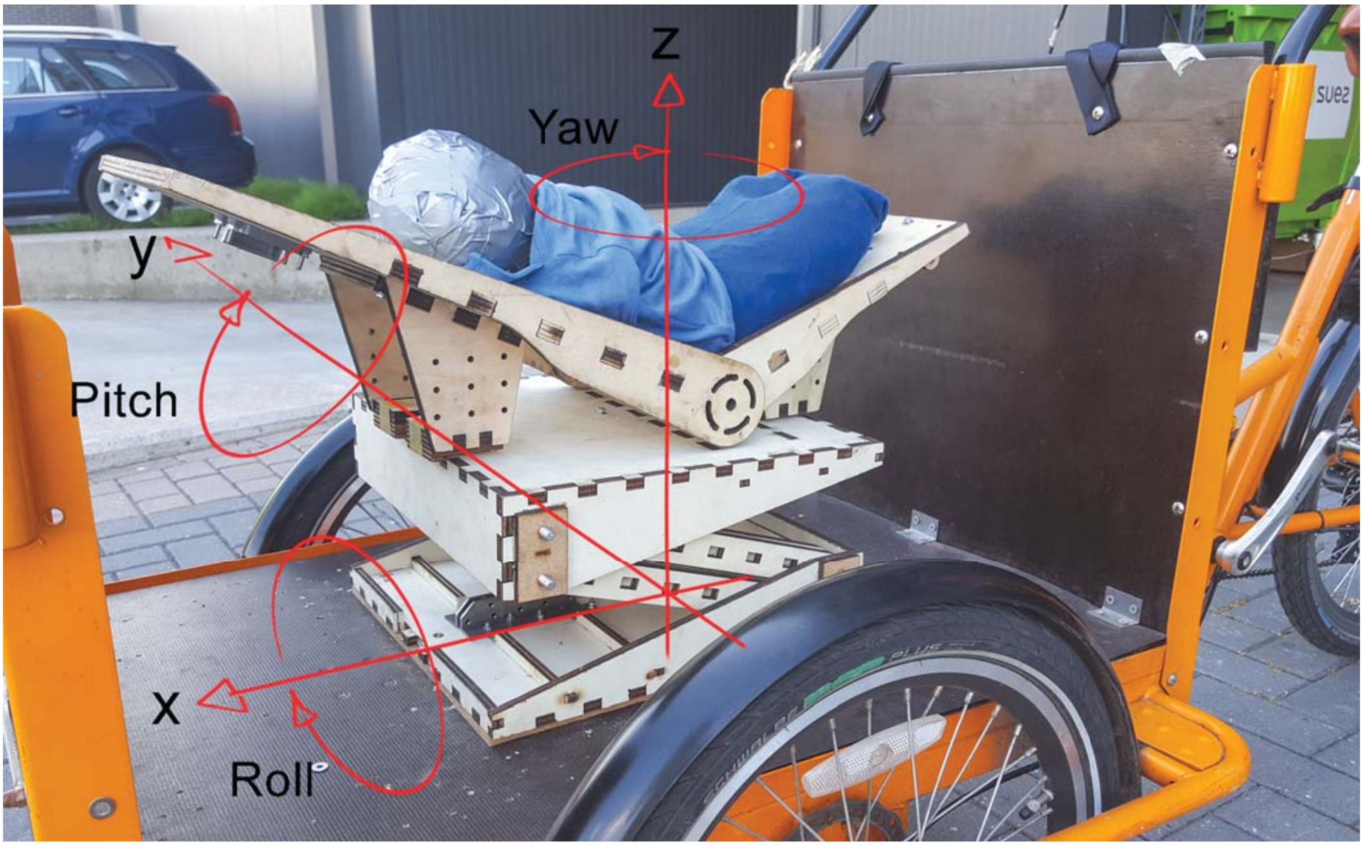


Figure 80: (Upper) Illustration of the curvilinear movement of the paralellogram construction (red) and the double diagonal construction (grey). Due to the small angle, α2, the double diagonal has a smaller horizontal displacement in comparison to the paralellogram construction, when they both move with the same vertical travel.

Figure 81: (Lower) Illustration of bottoming of a spring. The unloaded spring (left) has a free length. When an acceleration force is too high (the spring cannot longer withstand the applied acceleration force), the spring reaches its solid length. The coils are pressed together - the spring is bottomed out, resulting in a heavy shock.

Figure 82: Yaw, roll and pitch. The lateral stiffness of the constructions, which does not dampens roll and side-to-side motions, might be the cause of the increase in acceleration values in the y-direction.



Lessons learned

Based on the different constructions, several lessons learned were made during the tests.

1. Lower the center of gravity

The center of gravity was higher in comparison to the center of gravity in the existing product (Figure 83). A higher center of gravity results in less stability and could also result in more sideways displacement.

2. Purchased rubber isolators are used for steady state vibration problems

Purchase rubber isolators are less suitable for isolating the vibrations and shocks that are transmitted during cycling, due to their relatively high natural frequency, low stiffness and low possible deflection (vertical travel). These damping elements are predominantly suitable for steady state vibration problems where the vibration environment is controlled and constant (e.g. isolating the vibrations of a running car engine or isolating the vibrations of large factory equipment like HVAC systems).

3. Build quality is key!

When designing a spring-damper system or any other system that is in motion building quality is of utmost importance. A significant larger amount of time was spend building the parallelogram and double diagonal construction. Consequently, the construction was more rigid and accurate, therefore ensuring vibrational resonance at the pivots was kept minimum.

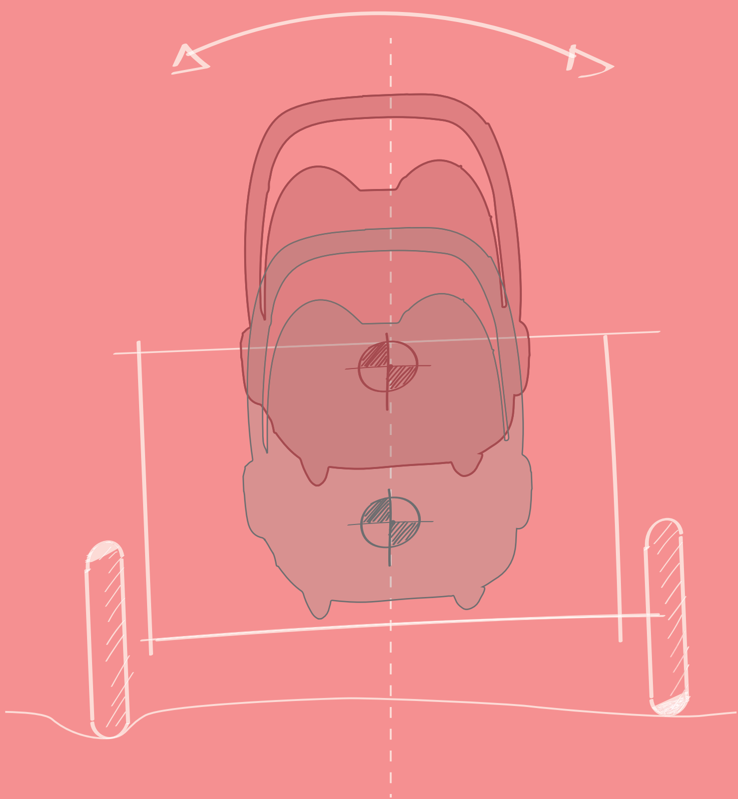


Figure 83: A higher center of gravity results in less stability and could also result in more sideways displacement.

4. A spring-damper system needs stability

Damping elements alone are not stable and need some sort of guidance. A shock absorber, for example, needs a strong piston and piston rod that accurately slides up and down a metal housing filled with oil. Another example: the parallelogram construction delimited sideways movement.

The rubber damping balls attached to the platform construction showed insufficient stability, because these elements were not stable in the radial direction (Figure 84). As a result, the system showed higher acceleration values. When attached to the parallelogram construction, however, the results were significantly better.

5. Placing a damping element at an angle affects its efficiency

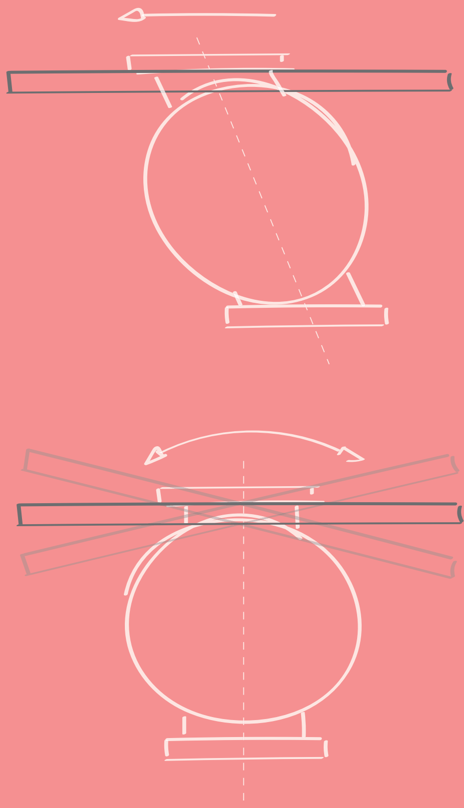
Shock absorbers are at their highest efficiency when mounted vertically, but may offer some improvement to lateral stability when fitted angled in at the top. Fitting shock absorbers at an angle reduces their effectiveness, expected life and compliance bush life (Australian Street Rod Federation, 2013, Figure 88).

In addition, the greater the installed angle, the stiffer the spring rate must be to support the same weight (QA1, n.d.). To compensate for installations at different angles, the spring rate must be divided by the angle correction factor (ACF) – the efficiency, which is calculated by means of the cosine value of the angle.

Example:

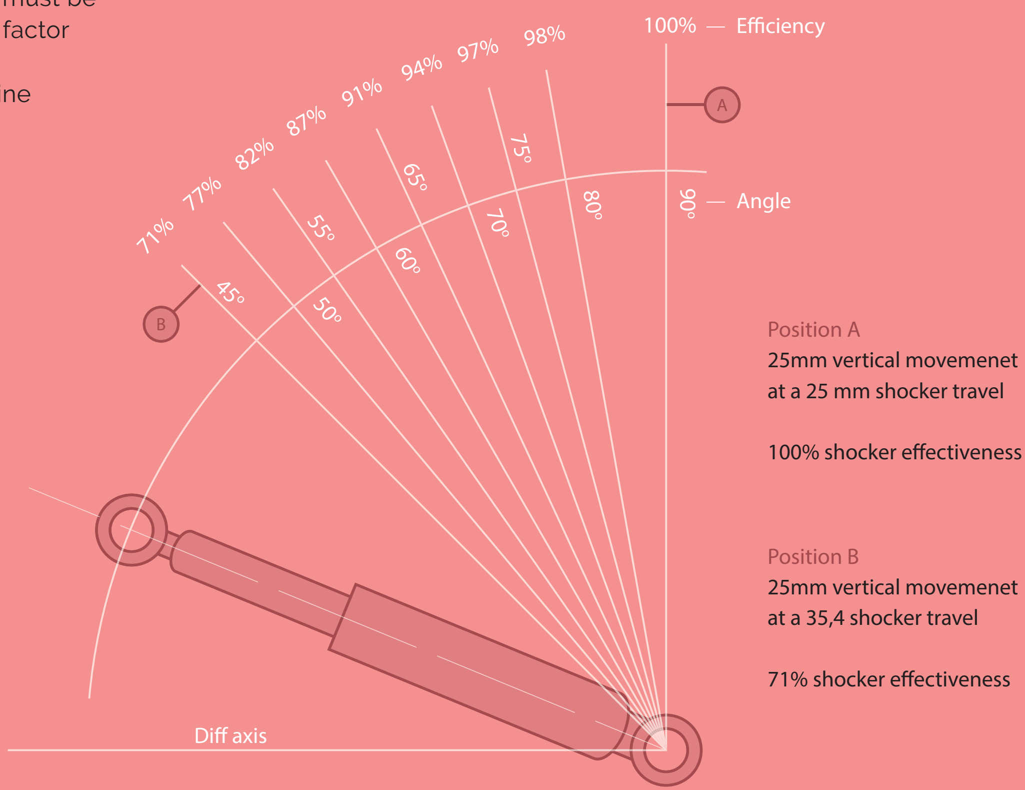
Straight Mounted Spring = 200 kg.
Spring Mounted at 60˚ = 200/0.87 = 230 kg.

The 230 kg represents the spring rate needed when mounted at a 60˚ angle to equal the desired spring rate of 200 kg. when standing straight up.



▲ Figure 84: Rubber damping balls need guidance. Without guidance, the construction might move sideways, due to the lack of lateral stiffness. (upper). In addition, the lack of stability in the radial direction, might cause rotation of the construction (lower).

▼ Figure 85: Shock Absorber Efficiency Verses Installation Angles. Originates the National Guidelines for the Construction and Modification of Street Rods in Australia (Australian Street Rod Federation, 2017)



4

Conceptualization

Three constructions were conceptualized: a parallelogram, a double diagonal and cross construction. First, anthropometric data was used to assess possible space limitations of the test constructions. The three concepts were created based on the design features and requirements that were drafted during the ideation phase. The concept selection was considered to be insufficient to assess the concepts. As a result, a renewed design proposal was made thereafter.

Anthropometric design and validation 4.1

A 1:1 P50 2 to 3 year old cardboard mannequin was made to evaluate whether the test constructions would result in entrapments or limited available space when one or two other children would be sitting in the cargo bike as well. The model was made in Illustrator and is based on existing data sets and scientifically validated (in conjunction with Dr. Johan F.M. Molenbroek).

The majority of the total Dutch population lives in a household with children: 54% (CBS, 2018b). Of these 54%, according to the CBS (2018a), 43% of Dutch families have at least one child, 42% have two children and 15% have three children or more. The age differences between the first and second and second and third child are respectively: 2,5 years and 3 years. It is, thus, very likely that apart from the infant, other children will be sitting in the cargo bike as well. Appendix 30 provides an infographic with patterns, changes and trends, in relation to parenthood, housing, families and children.

The infant safety seat in Figure 86 (8 kg's included), is positioned above the knees of the child. However, in the case of a large shock (e.g. high speedbump), the infant safety seat, including the weight of the infant, might end up on the knee of the child with a high speed.

Figure 87 shows that the child's knees might become entrapped by the low positioned infant safety seat (8 kg's included). Furthermore, zooming in at Figure 87, it can be seen that the foot of the 2 to 3 year old mannequin partially obstruct the test construction. In this situation, the knees can be positioned next to the infant safety seat.

Turning the whole configuration around (the other children are now placed on the front bench, rather the rear bench) would create slightly more space between the knees of the children and the infant safety seat (Figure 88). Nevertheless, in the case of a frontal collision, the child's head will make a huge swing backwards. Thus, although creating more space, this configuration has a detrimental effect on the collision safety of the other children.

4.1 Conclusions

When the design proposal will be positioned higher than the knee height of the other child(ren), the design proposal might end up on the knee of the child in case of a large shock/bump. As a result, the front side of the infant safety seat that is mounted to the design proposal may never be positioned higher than the knee height of a 2-3 year old child (male+female): 269 mm. Moreover, the design proposal may not obstruct the child's feet. If the feet of the child are positioned underneath the infant safety seat, the infant safety seat may not hit the child's feet, in the event of a large shock/bump.

Figure 86: (upper) Mannequin showing the child's knees might become entrapped by the low positioned infant safety seat (8 kg's included)

Figure 87: (middle) Anthropometric detail showing that the foot of the 2 to 3 year old mannequin partially obstruct the test construction

Figure 88: (lower) The whole construction turned around. Tthe other children are now placed on the front bench, rather the rear bench.

4.2 Concepts

Based on the ideation, three concepts were created:

- **Concept 1: parallelogram construction**
- **Concept 2: double diagonal construction**
- **Concept 3: Cross construction**

4.2.1 Concept 1: **Parallelogram** construction

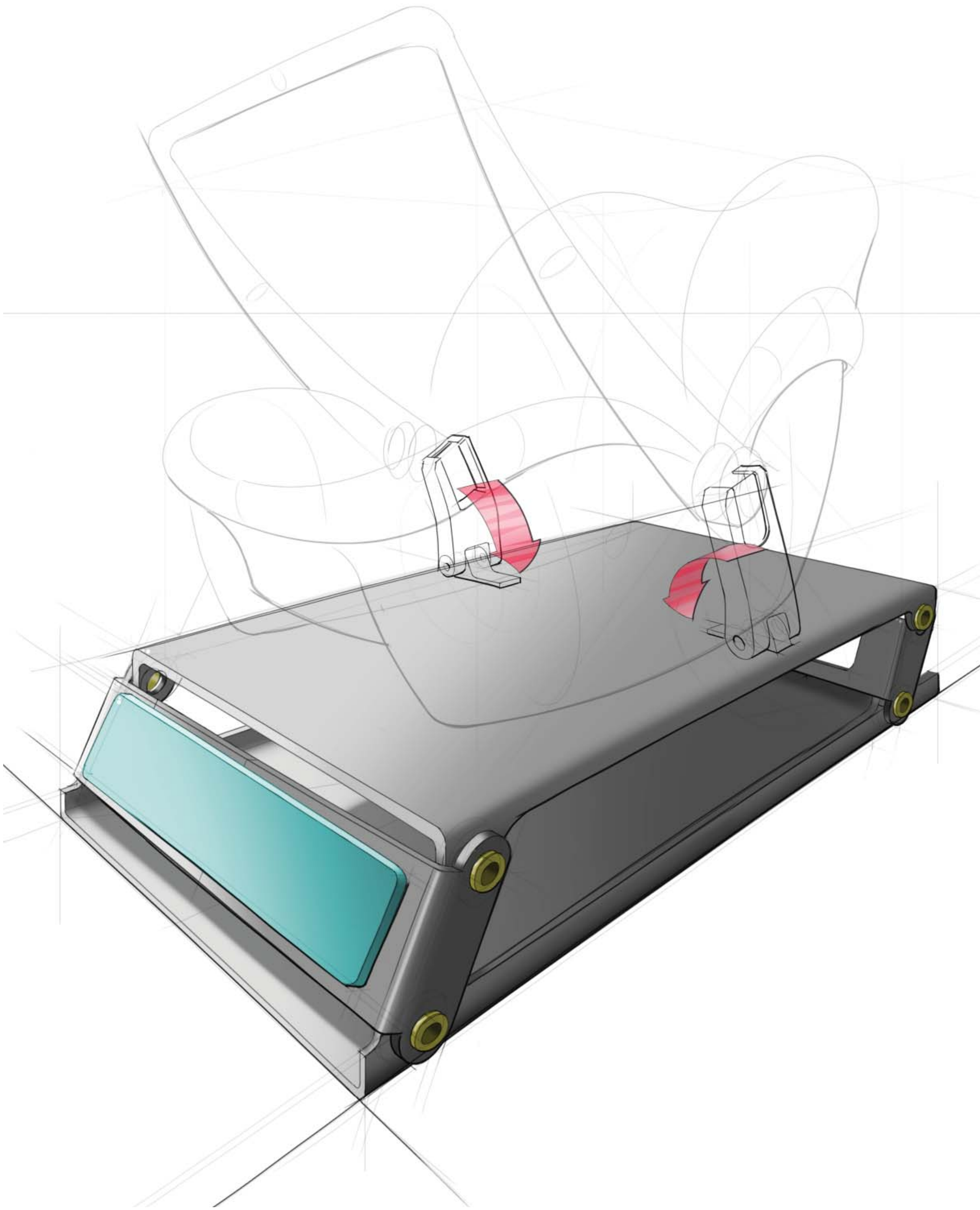
Concept 1 consists out of a sheet metal baseplate, two sheet metal panels and a top plate. Two foldable car seat adapters make it possible to fasten the infant safety seat to the system. The shock absorber is placed underneath the top plate and fixed to the baseplate. Flanged bearings make sure the pivots rotate as smooth as possible.

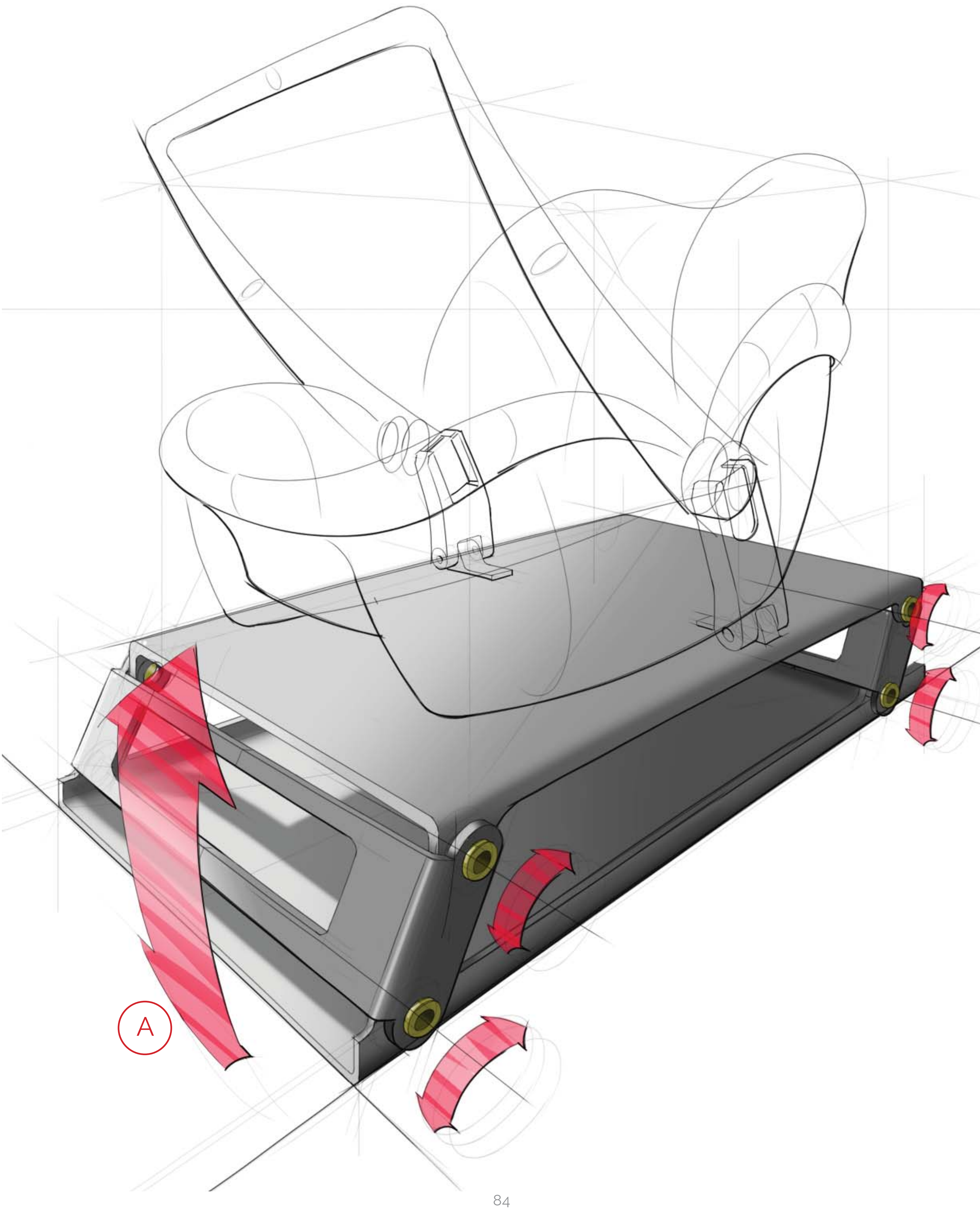
A plastic cover plate can be clicked into the metal panels, ensuring children's feet cannot become trapped between the system. This enables the possibility of easy customization.

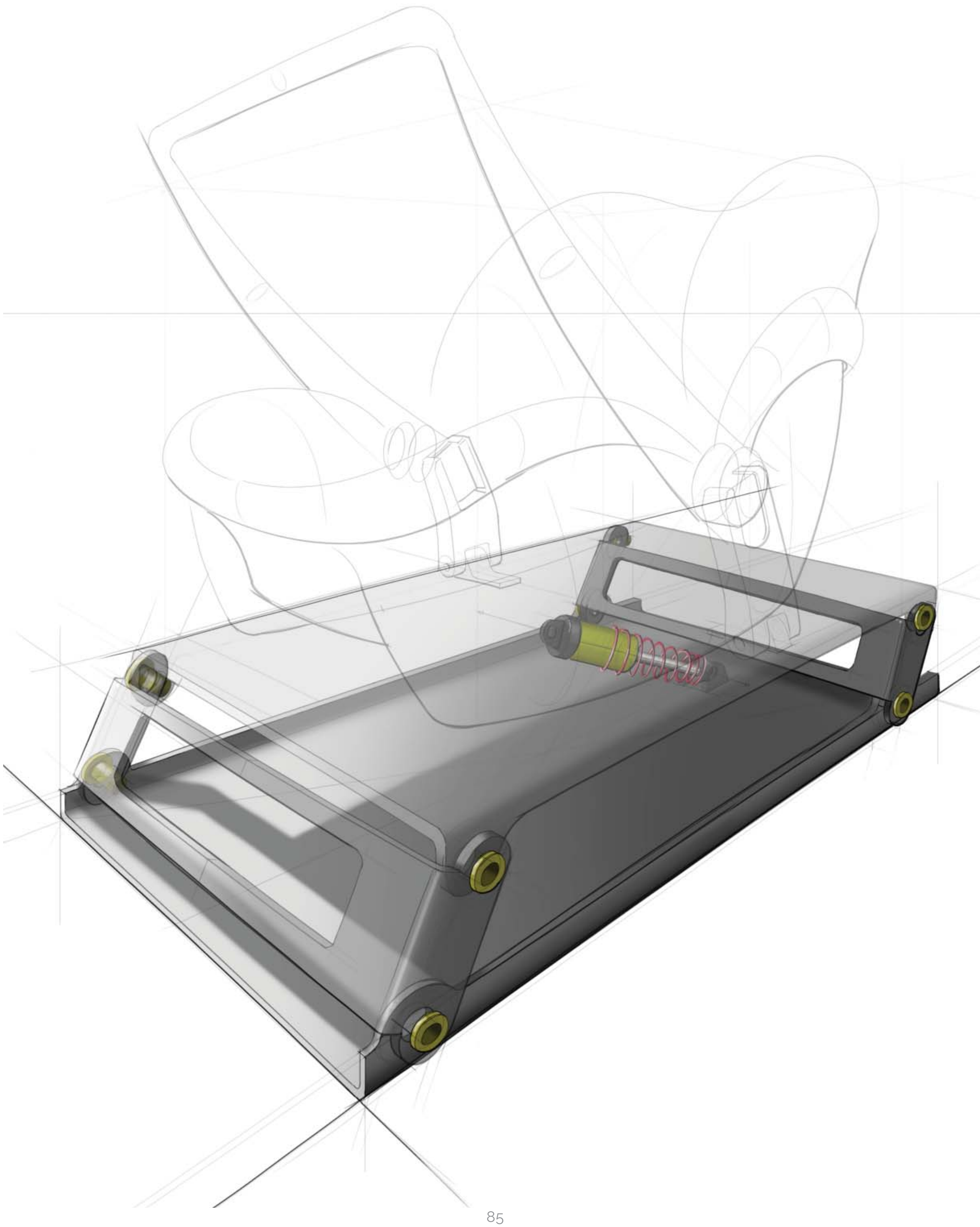
In the event of a shock, the construction makes clever use of the moment of inertia: the construction 'swings' in a curvilinear movement (arrow A).

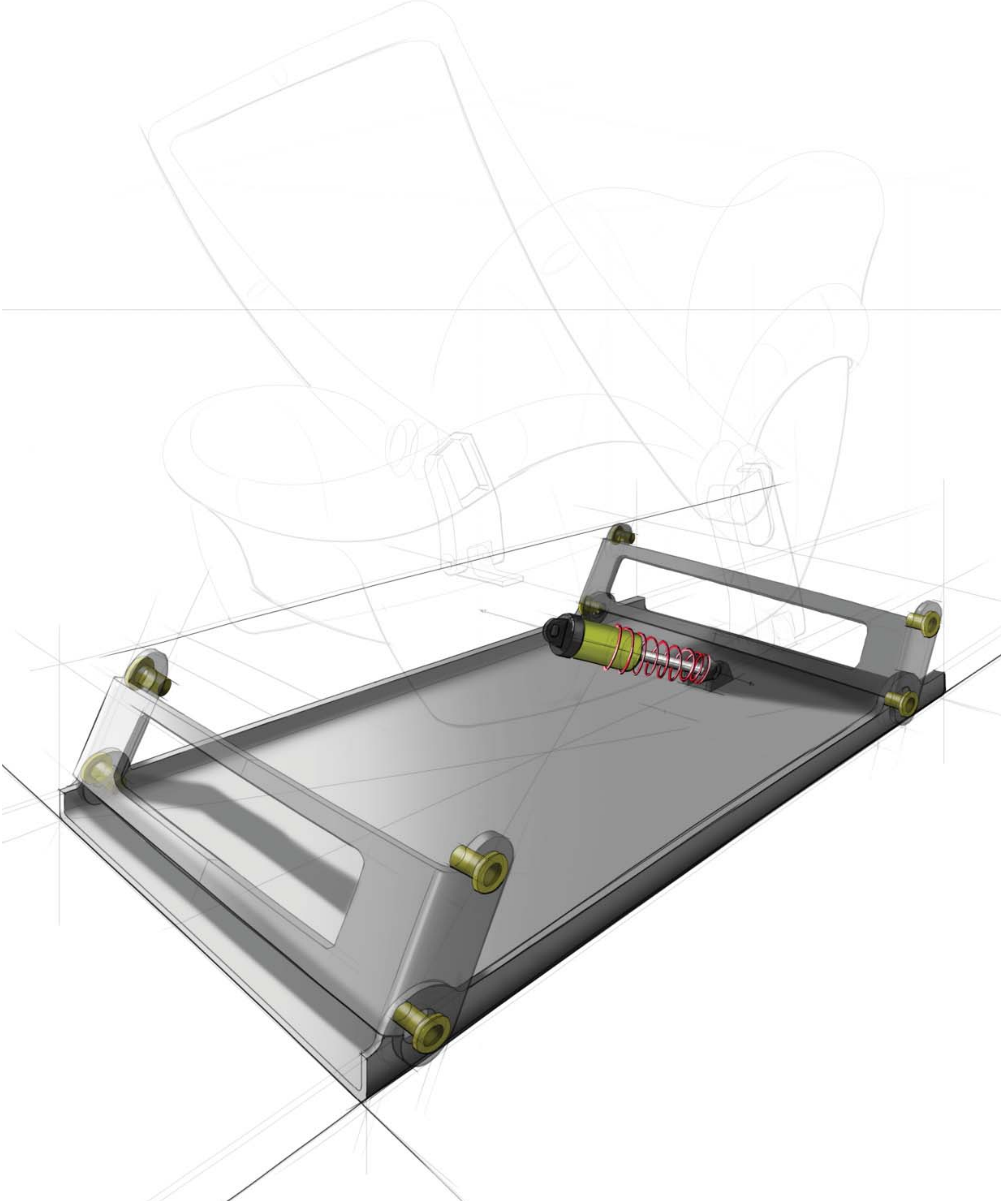
4.2.1.1 Vulnerability

The two foldable car seat adapters are vulnerable protruding parts. When other objects, such as groceries, are placed on top of the system these parts are easily damaged. However, the folding feature minimizes damage or even breakage to some extent.




A





4.2.2 Concept 2: **Double diagonal** construction

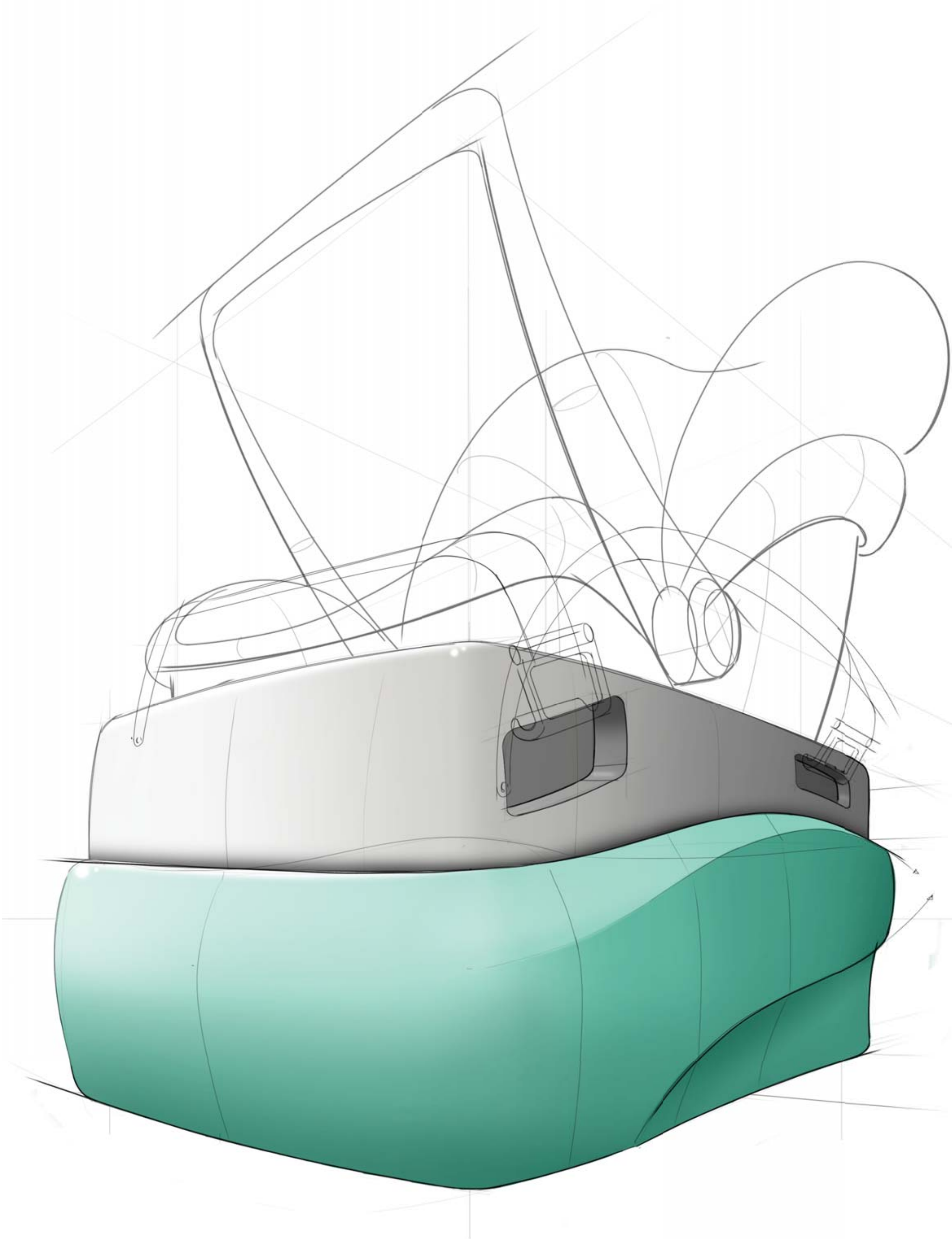
Concept two consists out of a sheet metal baseplate, two diagonal beams placed on each side of the construction and a metal tray. The metal tray ensures a lower center of gravity, since the infant safety seat is partially recessed. The shock absorber is attached to the bottom of the metal tray and to the baseplate.

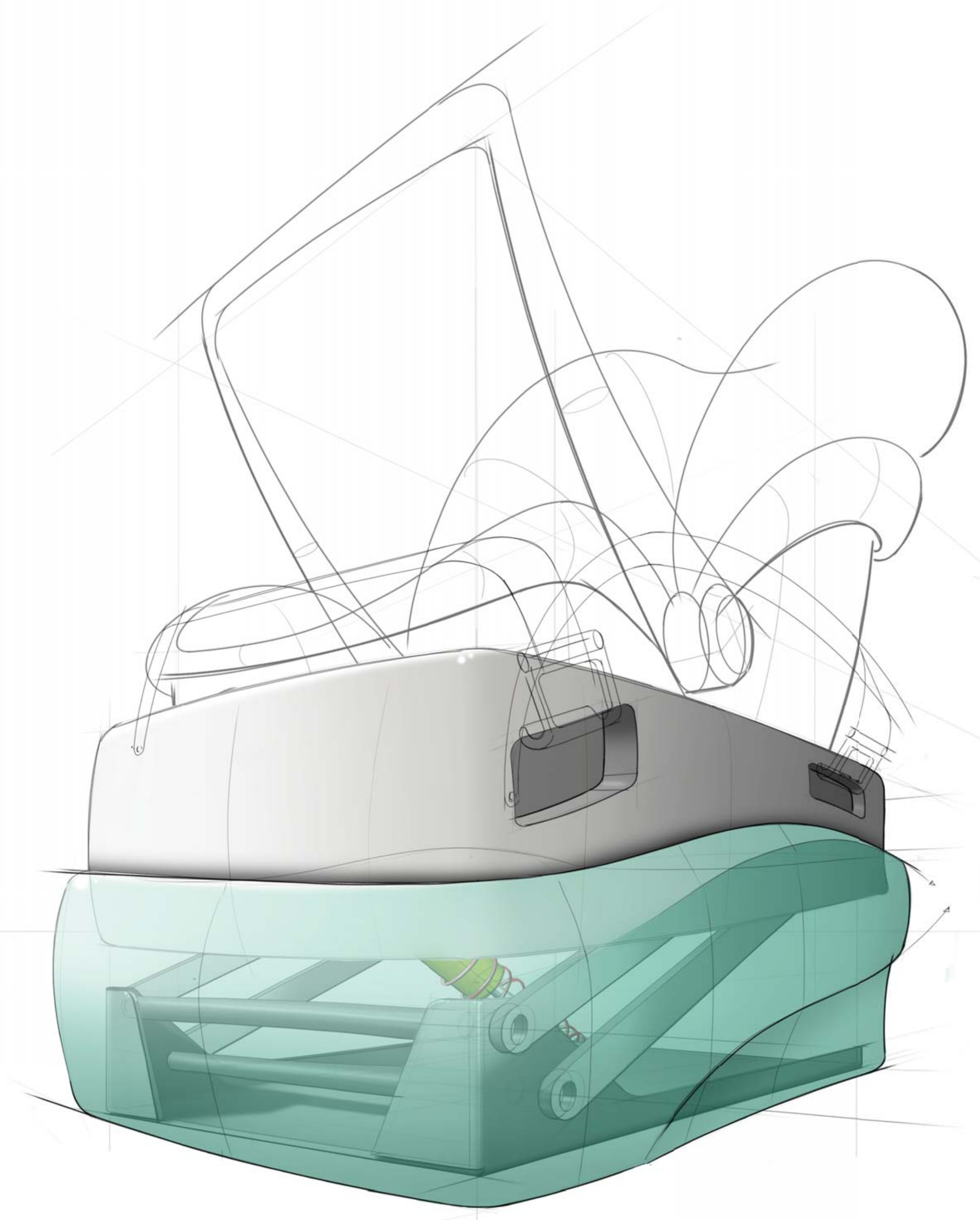
Two large plastic covers ensure that children's feet cannot become trapped between the diagonal beams. The top plastic cover is attached to the tray and moves congruently with the movement of the diagonals. The lower plastic cover is attached to the metal baseplate. The infant safety seat is securely fastened to the system by means of belts or elastic bands: one at the front, one at the back.

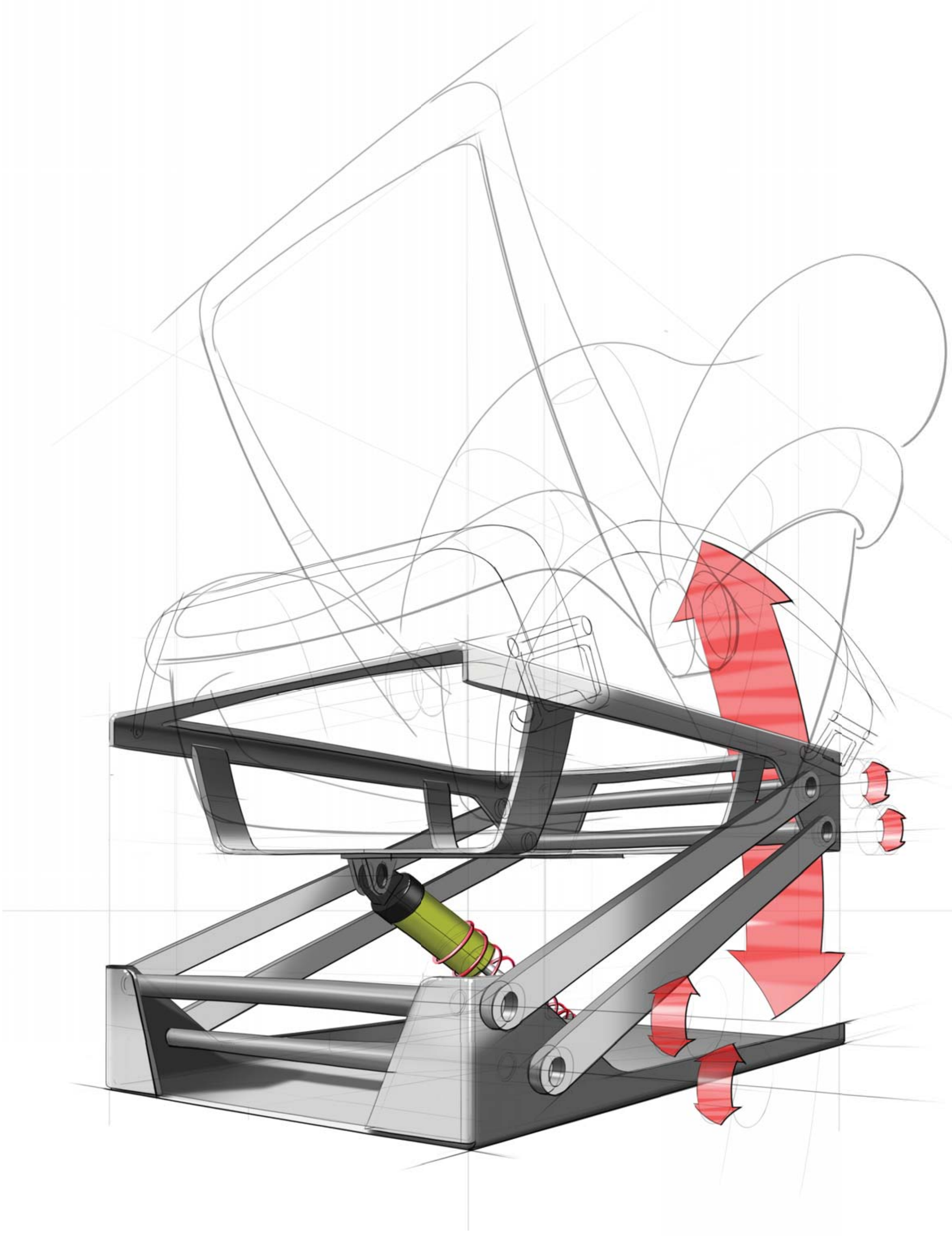
Similar as concept one, the movement concept two makes is circular.

4.2.2.1 Vulnerability

Concept two shows little to none vulnerable parts. The inside construction is fully covered and due to the seat belt fastening system no protrusions can break in the case of improper use.







4.2.3 Concept 3: Cross construction

The construction of concept three originated from (mini) motorcycle lifts that are often used to lift a motorcycle on a ramp or as support when removing the wheels. The simplistic construction consists out of two wings that together form the cross structure. The wings are connected to each another at the center, by means of a metal rod.

The wings are fixed at one end. On the other end, two rollers on both side of the wings are placed to enable smooth horizontal movement. The spring and damper are separated: a tension coil spring ensures the cross structure is pulled back when the seat is loaded, the separate oil damper ensures the vibrations are damped. The cross construction made it possible to lay down the shock absorber and place it horizontally, therefore, lowering the seat and lowering the center of gravity. This also had the additional benefit that the damping efficiency would be 100% in all circumstances.

The four rollers are placed in two guidance profiles (top and bottom). Due to the cross construction, the seat only moves up and down. In the event of a shock, the rollers move horizontally and the whole construction will compress and decompress (vertically) until the system reach its rest position again. As a result, back and forward movement (in the x-direction) will not be possible. A detrimental effect that might occur when fixating the movement in the x-direction, is that more stress will be put on the pivots and construction members (the wings).

4.2.3.1 Load absorption area

Figure 89 illustrates the cross construction that has vertical travel only and the load absorption area, due to bottoming. In this construction, heavy shocks will be transmitted vertically up through the infant's spine, compressing the vertebra. In comparison with the other two concepts, this vertical bottoming might have more health risks and effect on the infant's comfort.

4.2.3.2 Vulnerability

The two fixed car seat adapters are very vulnerable protruding parts. When other objects, such as groceries, are placed on top of the system these parts are easily damaged.

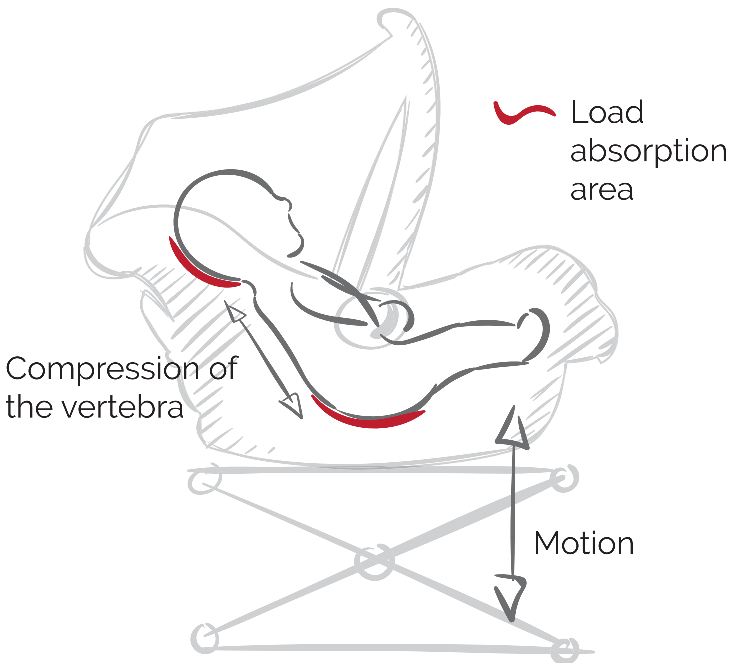
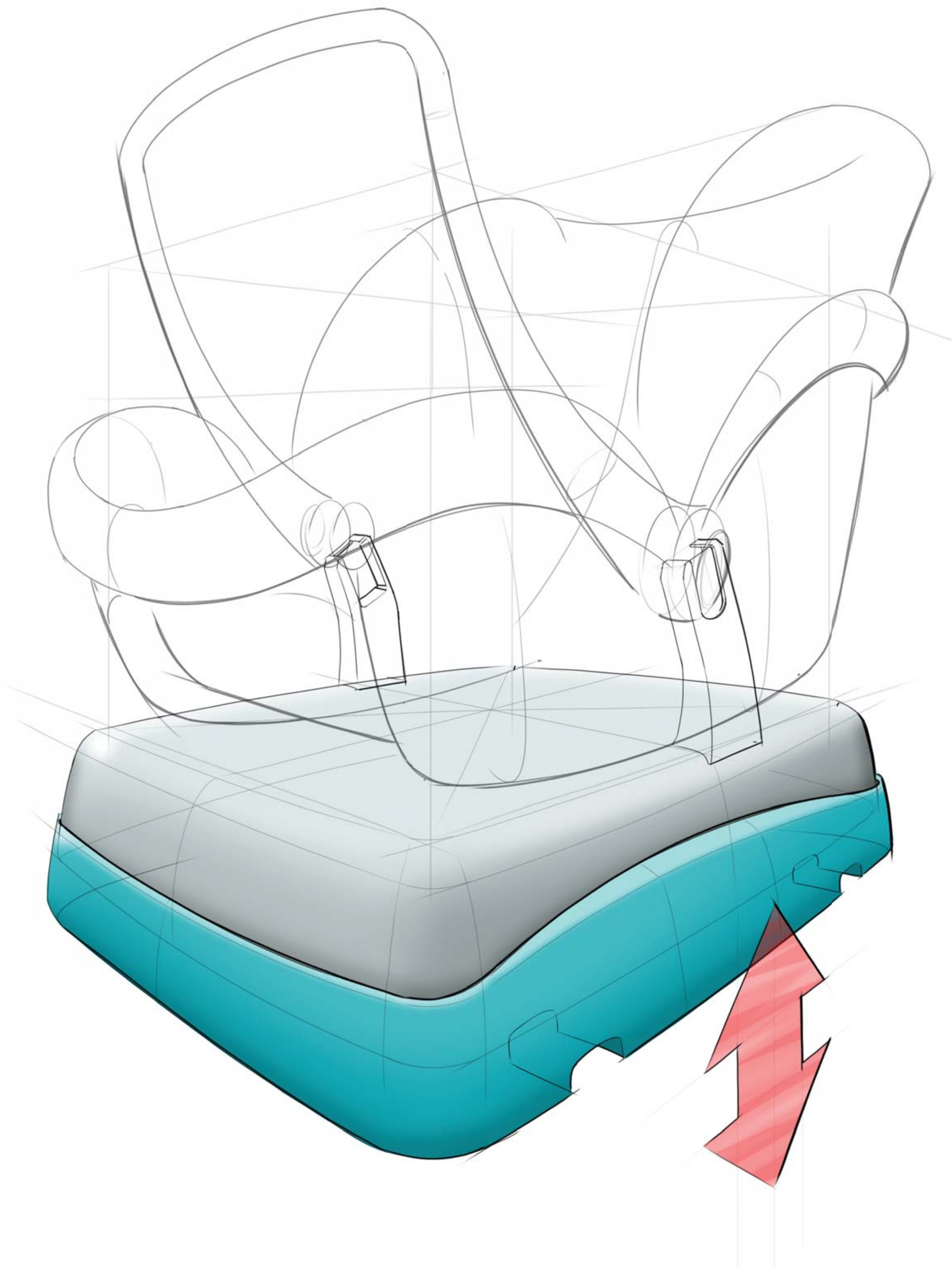
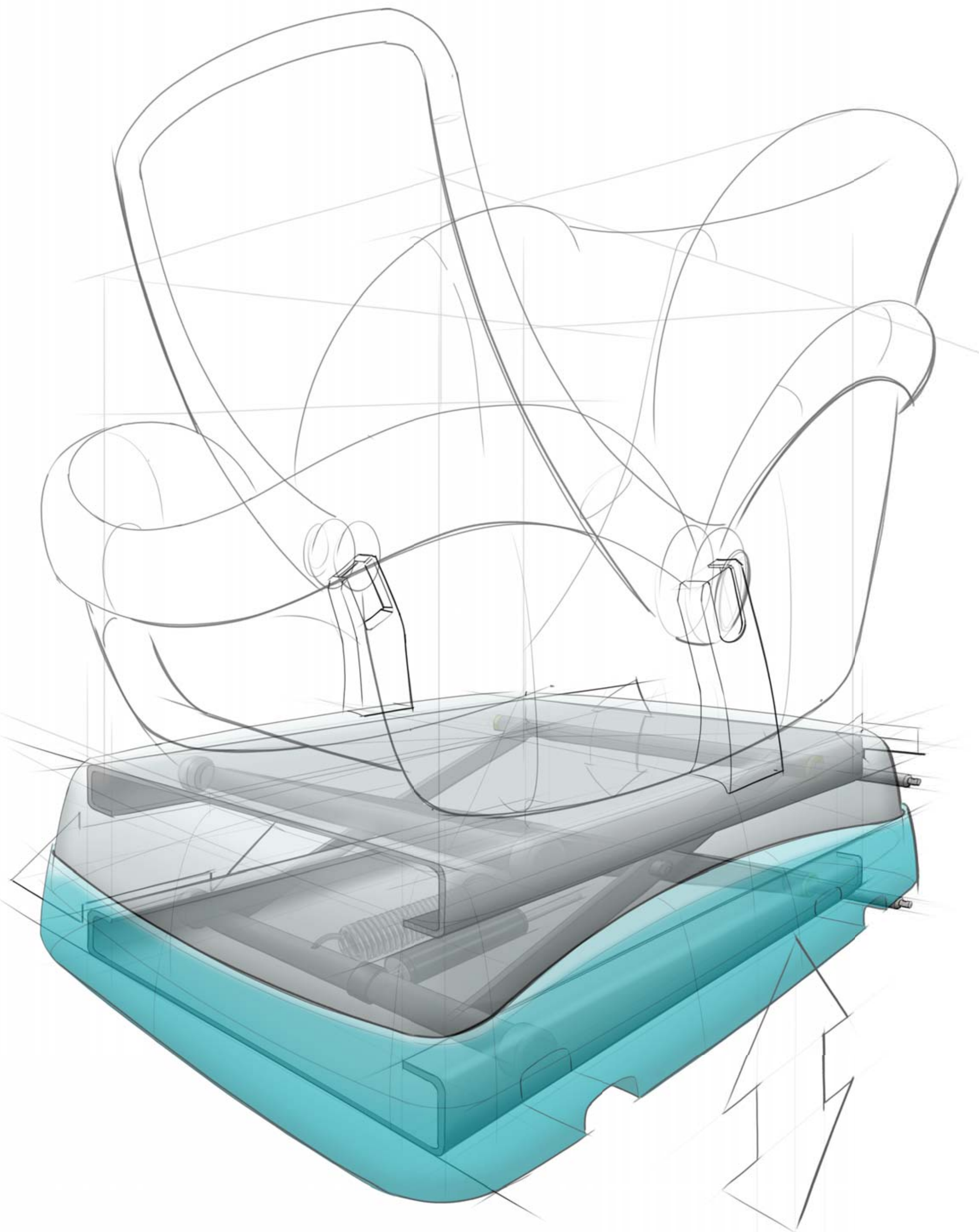
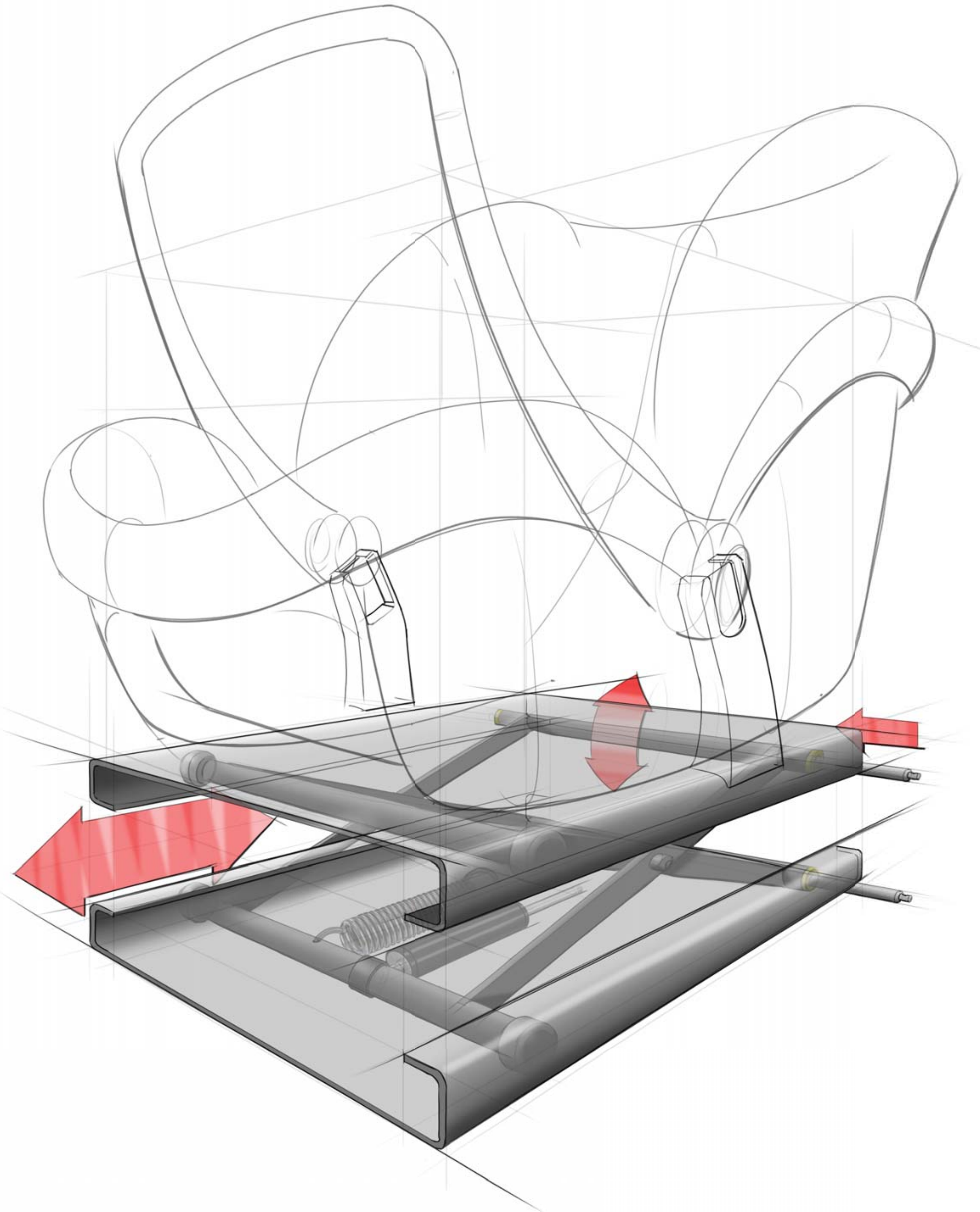
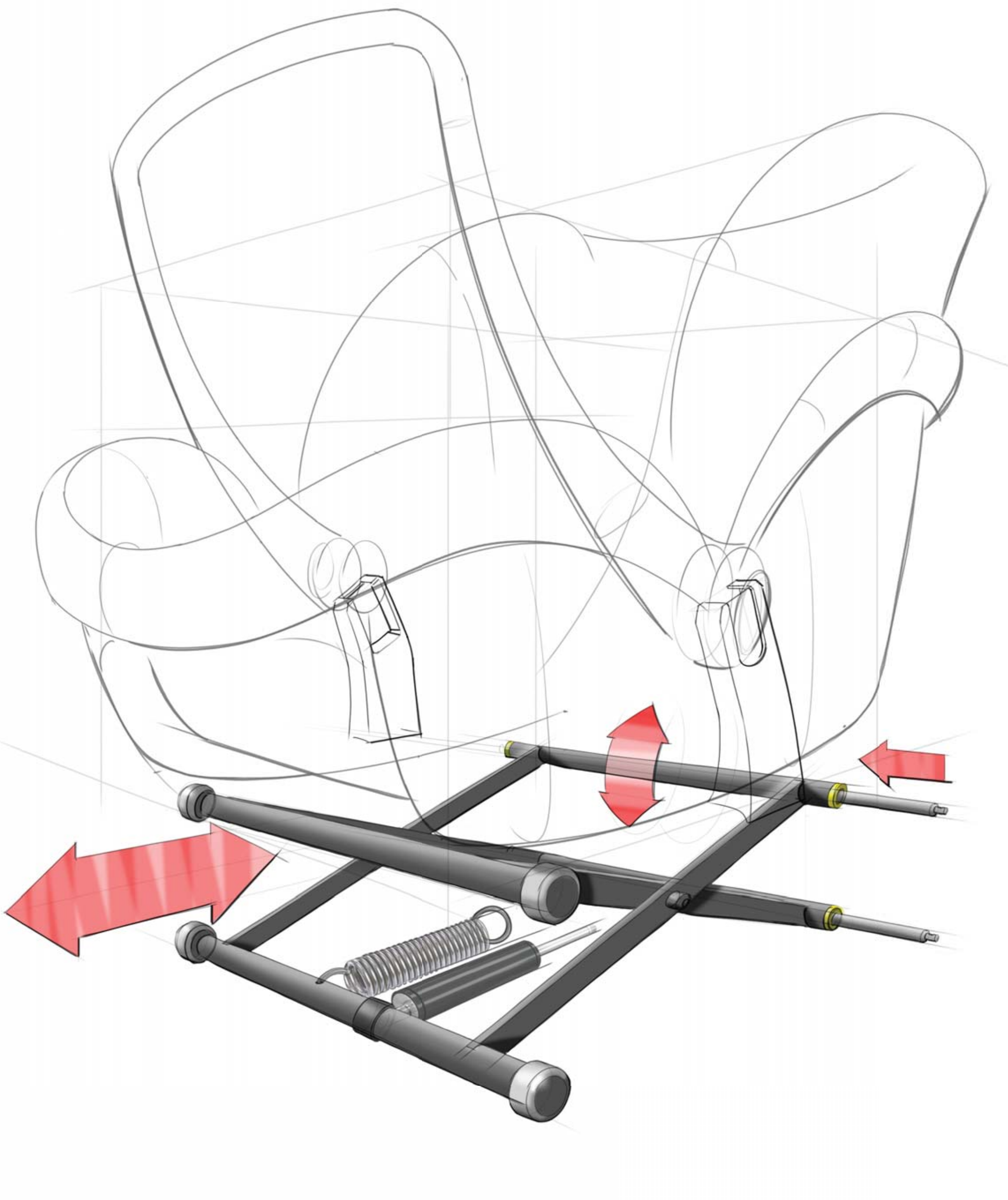


Figure 89: Vertical travel and load absorption area of the cross construction, due to bottoming









4.3 Concept selection

The concepts were assessed by means of a Harris profile (Table 9). 10 Wishes were included in the Harris profile and were weighted based on importance: center of gravity was weighted most important, protrusions was weighted as least important. Subsequently, the wishes per individual concept were assessed by assigning them with scores ranging from -2 (two red blocks) to +2 (two green blocks).

Based on Table 9, concept three, the cross construction, was assessed as the best concept. Although not initially tested, this construction made it possible to lay down the shock absorber and place it horizontally, therefore, lowering the seat and lowering the center of gravity. Nevertheless, the cross construction still showed one uncertainty: the load absorption area. Based on Guinness (2014) statement in his thesis, as described in section '3.2.5.2 The effects of the moment of inertia', it was felt that the curvilinear motion of concept one and concept two were so beneficial that it must be a requirement rather than a wish.

In essence, the construction of concept one is the simplest of the three concepts. It requires a minimum quantity of parts and the parts itself are easily to produce. Despite this simplicity, the concept is rather 'stripped', leaving little protection against entrapment of feet and hands.

The center of gravity can be placed much lower.

The outcome was discussed with the supervisory team of the TU Delft. They found that the two most important wishes, center of gravity and damping efficiency, could not yet be assessed in the current constructions. By keeping the same principle of each construction, yet making clever use of the spaces next, in front or behind the infant safety seat, the center of gravity could be lowered to a significant extent. This might also influence the damping efficiency. Consequently, the concept constructions needed to be adjusted and refined to resolve the issue of the center of gravity.

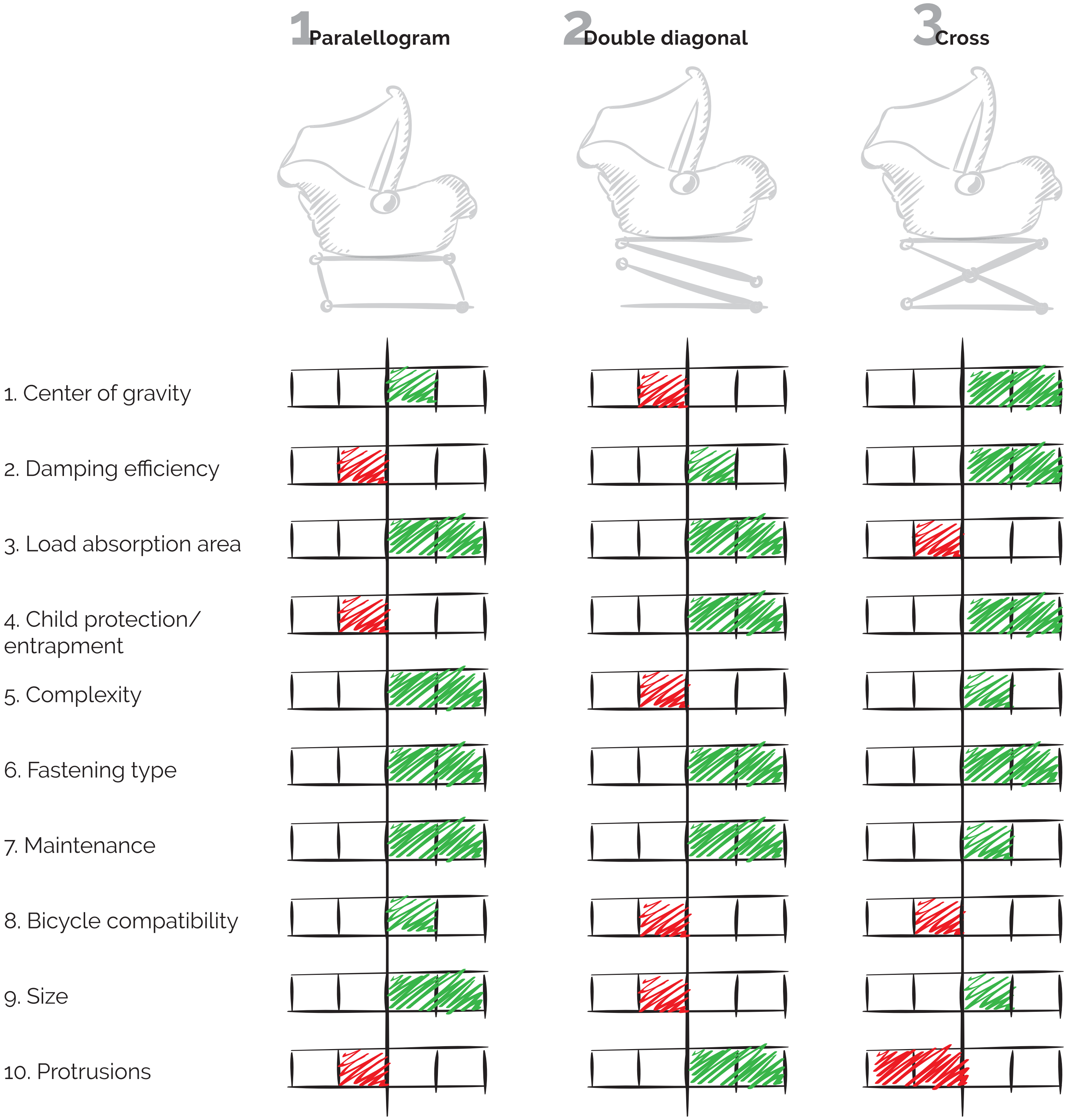


Table 9: All three concepts were assessed by means of a Harris profile that included 10 wishes. The wishes per individual concept were assessed by assigning them with scores ranging from -2 (two red blocks) to +2 (two green blocks).

4.3.1 Design proportions

To get an idea about the sizes of the concepts, two foam models were made: one with the dimensions of the double diagonal construction (Figure 91) and one in which the infant safety seat could be placed as low as possible (Figure 90). The models were painted grey, so that the shape and lines were easier to interpret.

After finishing the foam models and fitting the infant safety seat on them, it became rather obvious that placing the infant safety seat on top of the system or partially recessed would still position the infant safety seat too high. It was clear that there were a lot of possibilities to lower the whole system and that this would be a necessity to deliver a promising design proposal.

The proportions and aesthetics were also explored by a quick form study. Side sketches were made, ranging from squared proportional sketches to rectangular proportional sketches. By placing a printed infant safety seat on top of each quick sketch, the proportions and aesthetics were explored and assessed based on look and feel. Similarly as for the foam models, the quick sketches made clear that lowering the center of gravity would not only be beneficial in terms of stability, but also result in a more aesthetic and logic whole.

Figure 90: (Upper) foam model in which the infant safety seat could be placed as low as possible.

Figure 91: (lower) foam model with the dimensions of the double diagonal.

Figure 92: (Upper left) Multiple layers of foam where glued together, cut and polished to get the desired shape.

Figure 93: (Lower left) Maxi-Cosi Cabriofix placed in the foam shape.

Figure 94: (Right) The models were painted grey, so that the shape and lines were easier to interpret.

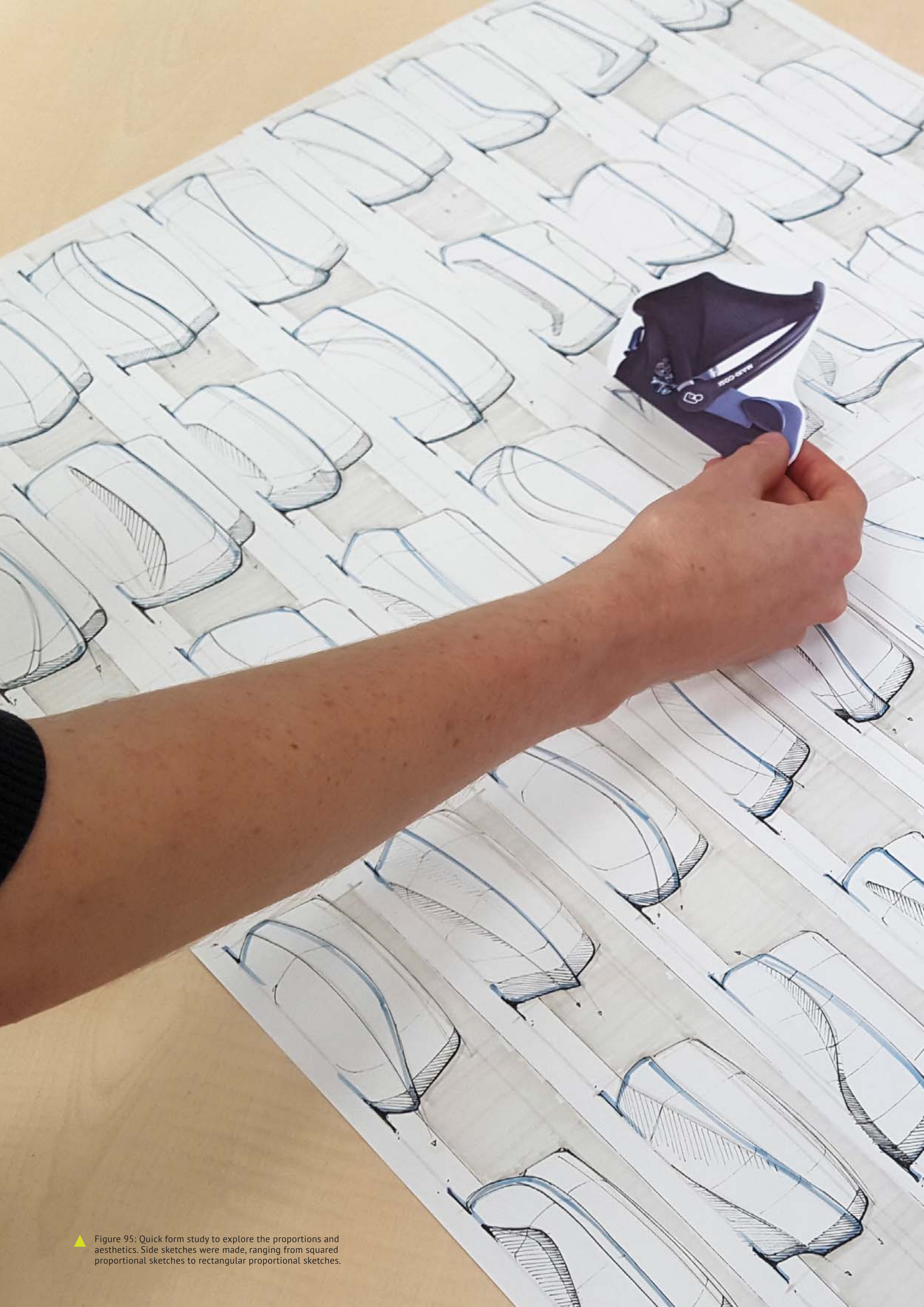
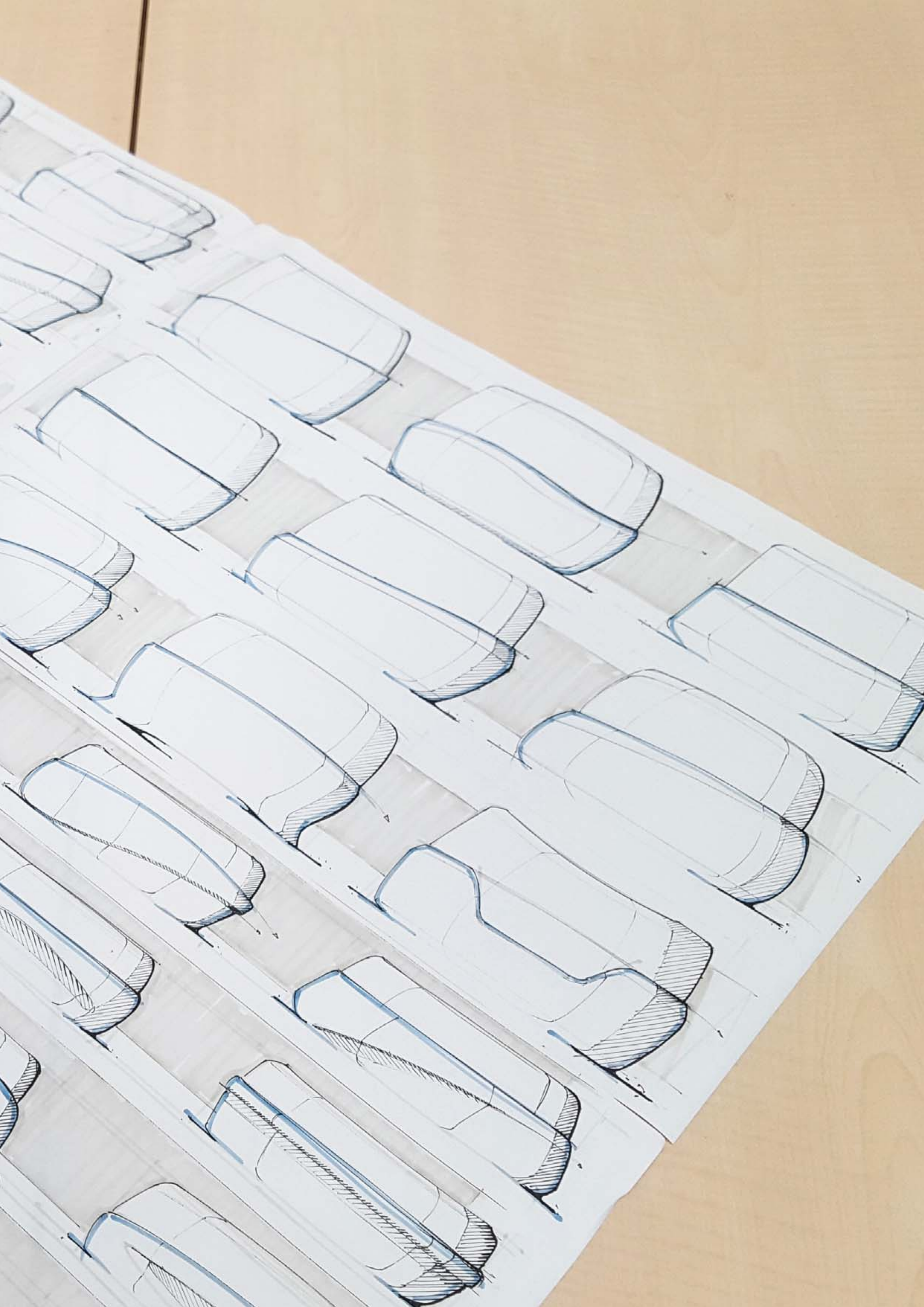
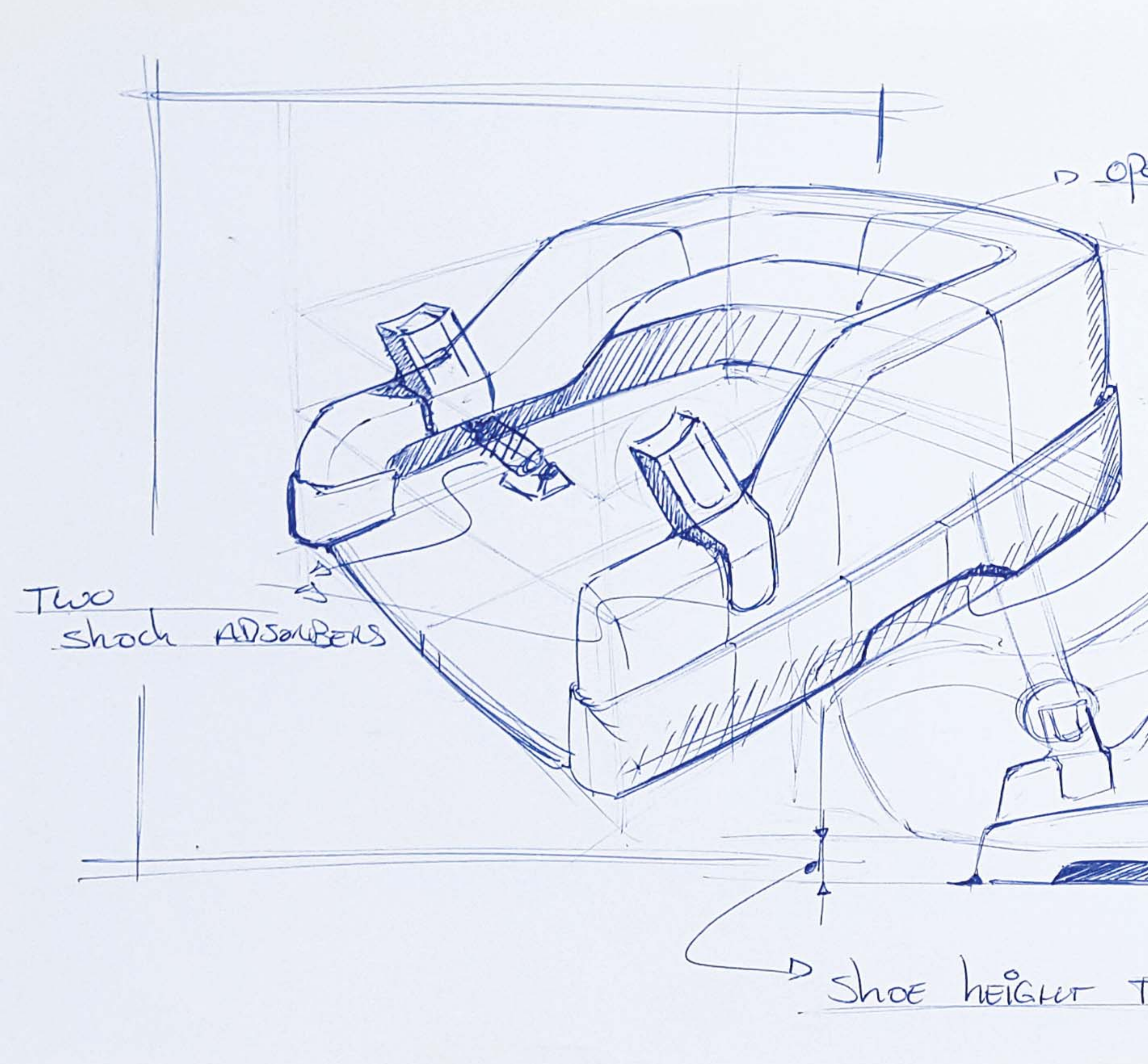


Figure 95: Quick form study to explore the proportions and aesthetics. Side sketches were made, ranging from squared proportional sketches to rectangular proportional sketches.





4.5 Concept proposal

Figure 96 shows the new concept proposal based on the revised concept iteration (appendix 31). The new concept consists of a U-shaped construction. The double diagonals are placed next to the infant safety seat.

By making clever use of the space behind the infant safety seat, and by removing the front linkage beam between the left and right side, the whole construction could be moved backwards. Not only resulted this in less material, this also left a high enough gap to prevent children's feet becoming entrapped underneath the construction.

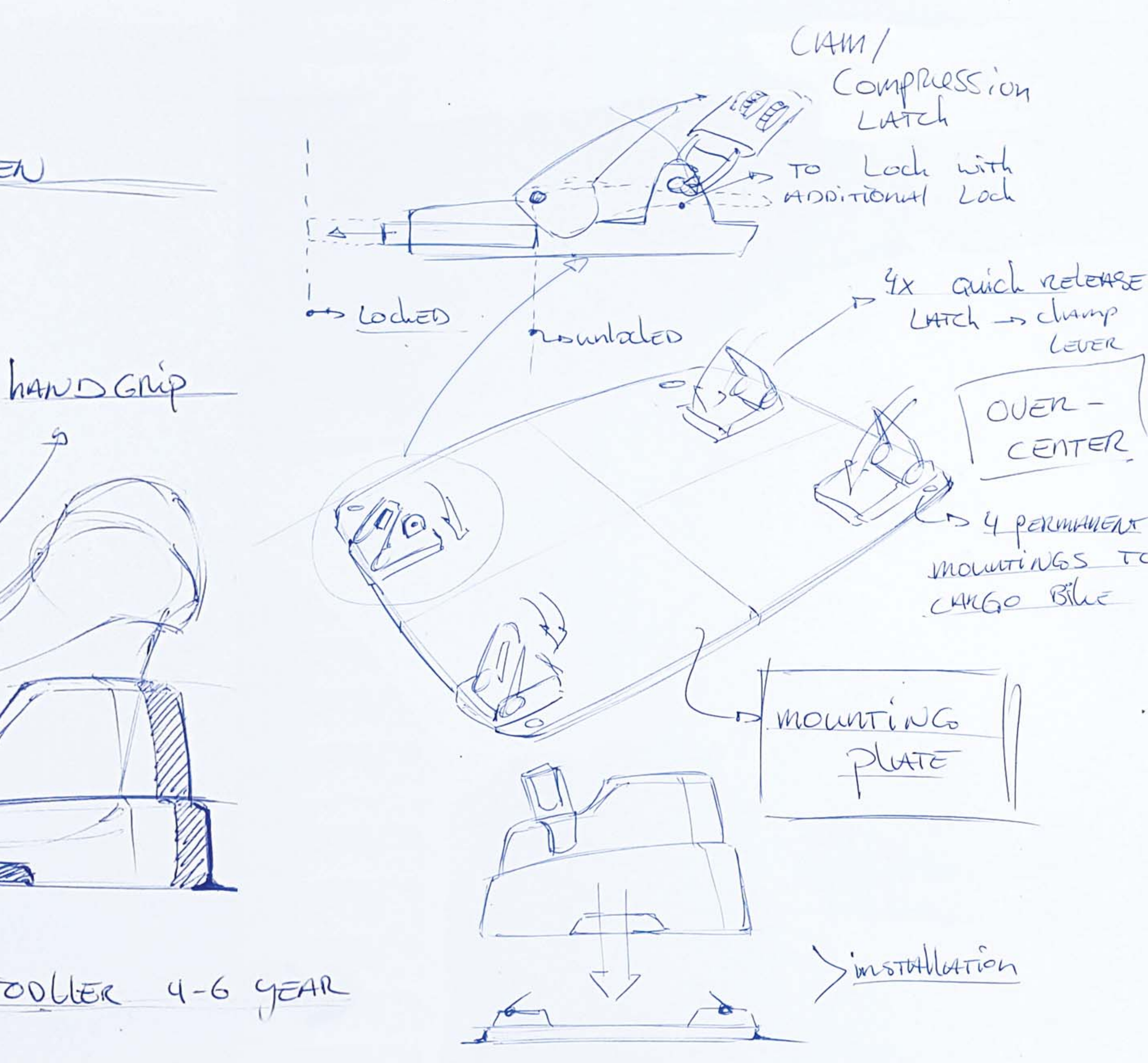


Figure 96: Concept sketch of the new concept proposal based on the revised concept iteration, illustrating the desired aesthetics, usage and locking mechanisms.

The U-shape has several other benefits:

- It creates a smaller footprint, in comparison with the O-shape of the original concept.
- Less material is needed for the plastic covers (almost 50% less material)
- The product weights less

The concept has two handgrips on both side of the construction that enable easy handling when the construction needs to be detached (e.g. when the infant does not need to be transported). Figure 96 shows a solution of a possible mounting plate. The mounting plate will be anchored to the bottom of the cargo bike.

The whole construction can be attached to the mounting plate by means of quick release latches (or a similar principle). A small lock can be used to lock the whole construction to the mounting plate.

The infant safety seat can be placed on the car seat adapter. This mean of mechanical interface was chosen, due to its computability with the majority of infant safety seat brands.

The double diagonal construction was chosen, at the expense of the parallelogram construction, due to its higher vibrational transmissibility..

5

Detailing

The construction of the design proposal causes the upper part to move in a curvilinear motion relative to the floor, as described in section '3.2.5.2 The effects of the moment of inertia'. This motion has influence on the shape of the covers and, therefore, needs to be carefully defined to prevent entrapment. Moreover, the aesthetics of the product are defined in this chapter. Lastly, the spring characteristics that are essential for proper functioning of the system are determined.

5.1 Defining the circular movement

If a (plastic) cover is attached to the upper part it may not intersect with the (plastic) cover that is attached to the lower part when moving. In fact, it is required that there is a minimal gap between the two covers: small enough so that small fingers cannot become entrapped, yet large enough so that the covers do not touch. Therefore, the shape of the upper cover needs to be carefully modelled. This section provides a description of how this shape should look like and according to which circular movement it should move.

5.1 Simple circular movement

Due to the two diagonal beams, the upper part makes a circular movement (Figure 97).

In Figure 97, point O is set as origin of the lower part. This coordinate system is fixed.

Point C is set as origin of the upper part. This coordinate system moves according to a circle, 1, with radius L1 and center O.

5.2 Shifted circular movement

In Figure 98, Point D is a fictive point at the upper part, at distance ($-x_c$, $-y_c$) from origin C. To find the coordinates of the center of the circle, the distances ($-x_c$, $-y_c$) should be projected around origin O. The projected circle, 2, has its center at point E with coordinates ($-x_o$,$-y_o$) and radius R1. Point O, C, D and E make a parallelogram. Therefore, R1 equals to L_1, x_c equals x_o and y_c equals y_o.

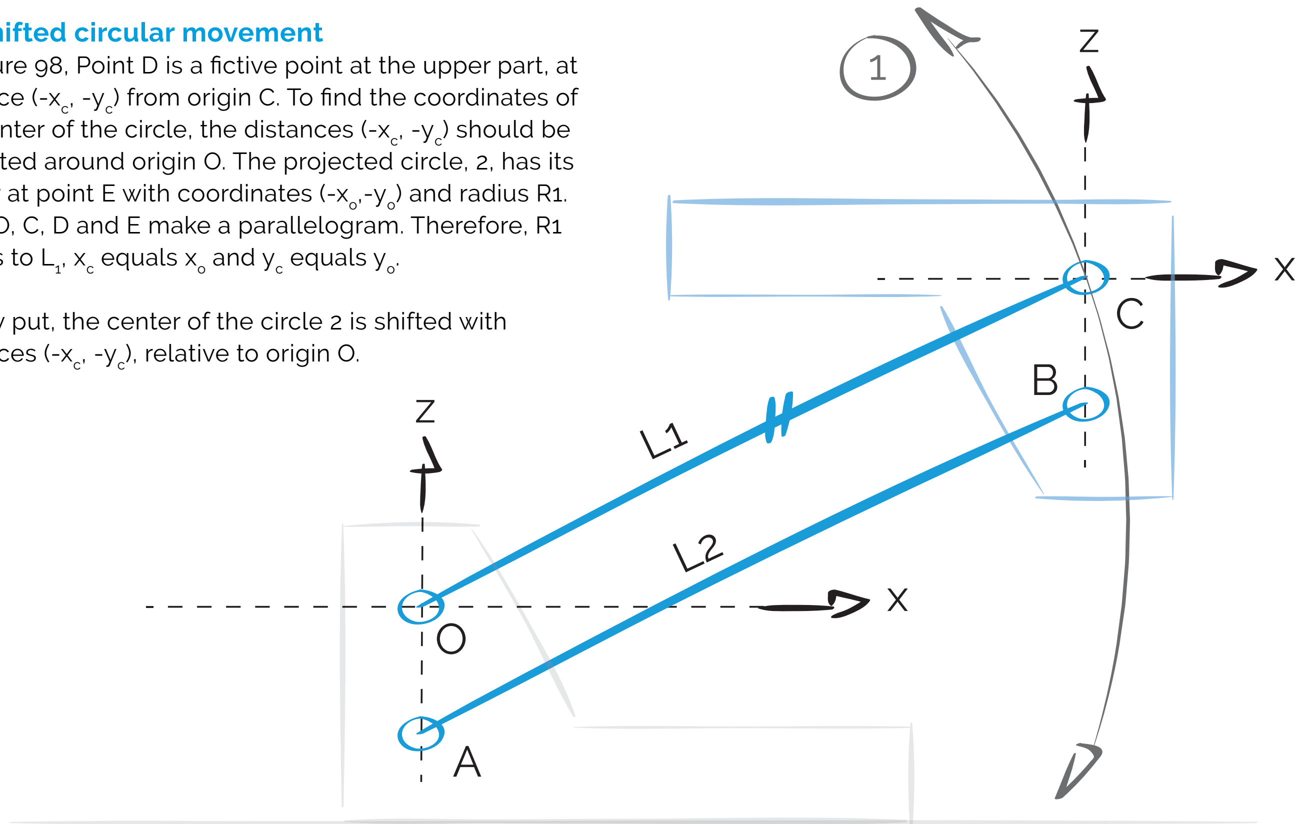
Simply put, the center of the circle 2 is shifted with distances ($-x_c$, $-y_c$), relative to origin O.

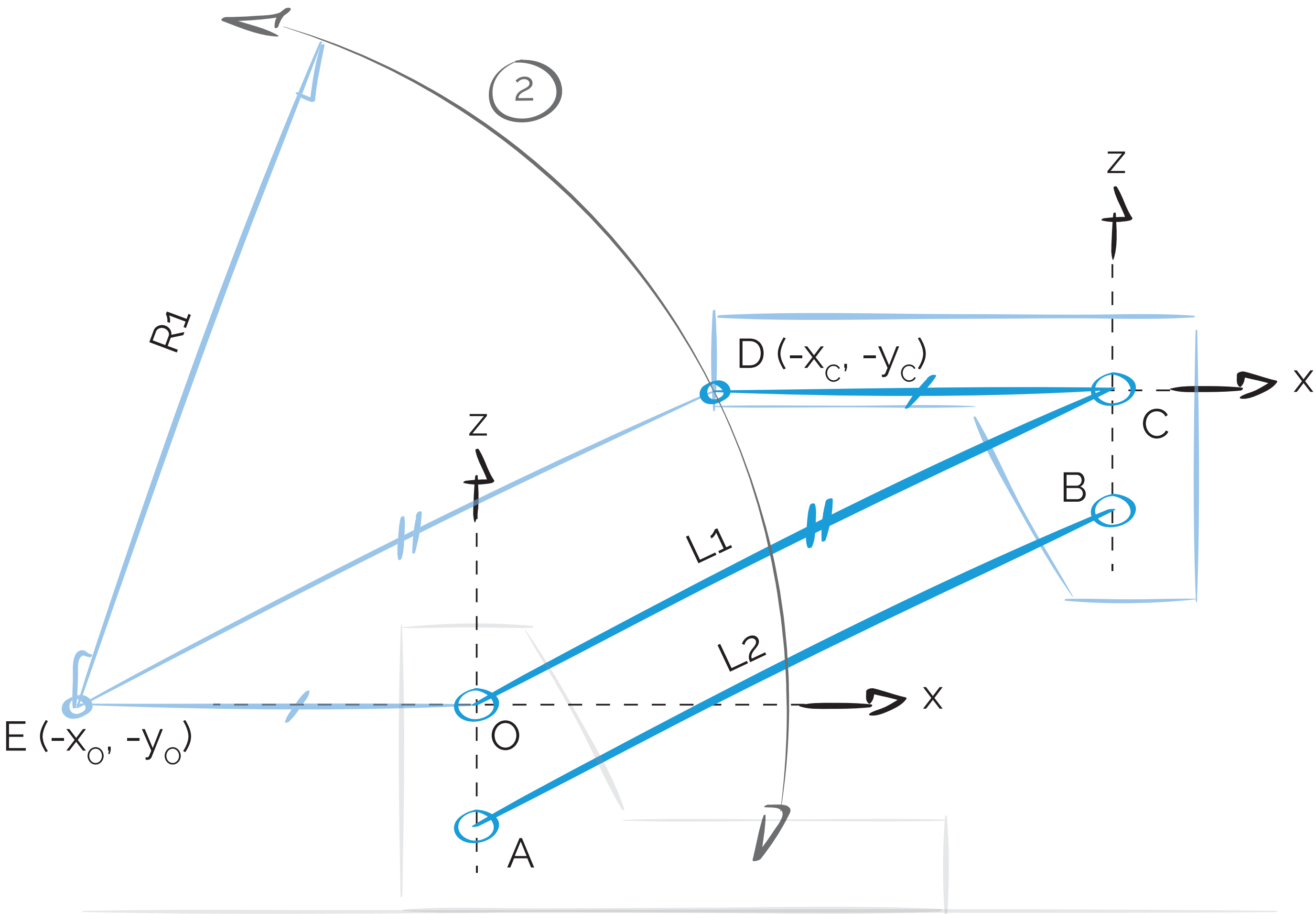
5.3 Cover circular movement

In Figure 99, point F is a fictive edge of a plastic cover attached to the lower part, positioned at ($-x_o$,$-y_o$) away from origin O. To make sure both parts do not intersect, the distances ($-x_o$,$-y_o$) should be projected around origin C. The projected circle, 3, has its center at point G with coordinates ($-x_c$, $-y_c$) and radius R1. Point O, C, G and F make a parallelogram. Therefore, R1 equals to L1, x_c equals x_o and y_c equals y_o.

In summary, to avoid intersection between the lower and upper plastic cover, the front edge of the upper plastic cover (grey area in Figure 99) must be modelled as a circular shape, circle 3, with radius R2 and center G (-xo,-yo).

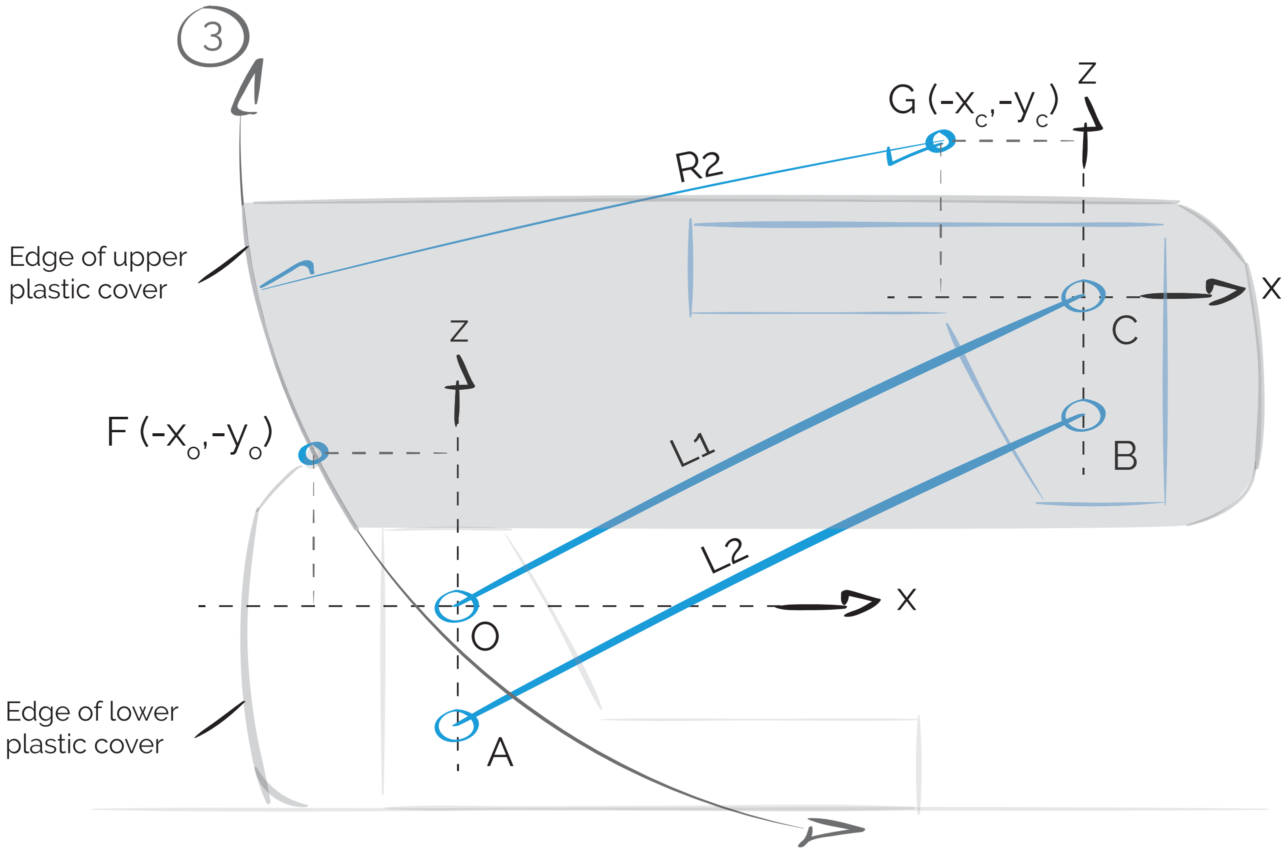
Figure 97: Circular movement of the upper part (light blue). The upper part rotates around the fixed origin of the lower part, O.





▲ Figure 98: Circular movement of a fictive point D. Point D moves according to a projected circle 2 and has its center at point E with coordinates (-xo,-yo) and radius R1.

▼ Figure 99: To avoid intersection between the lower and upper plastic cover, the front edge of the upper plastic cover must be modelled as a circular shape, circle 3, with radius R2 and center G (-xo,-yo)



5.2 Form language

The main functionality of the product was keeping the infant free from vibration as much as possible when travelling in a cargo bike. Therefore, the product should have aesthetic characteristics that reflect this functionality. Based on own preferences and existing products, a list of aesthetic characteristics was drafted that, together, formed the inspiration for an infant friendly shape.

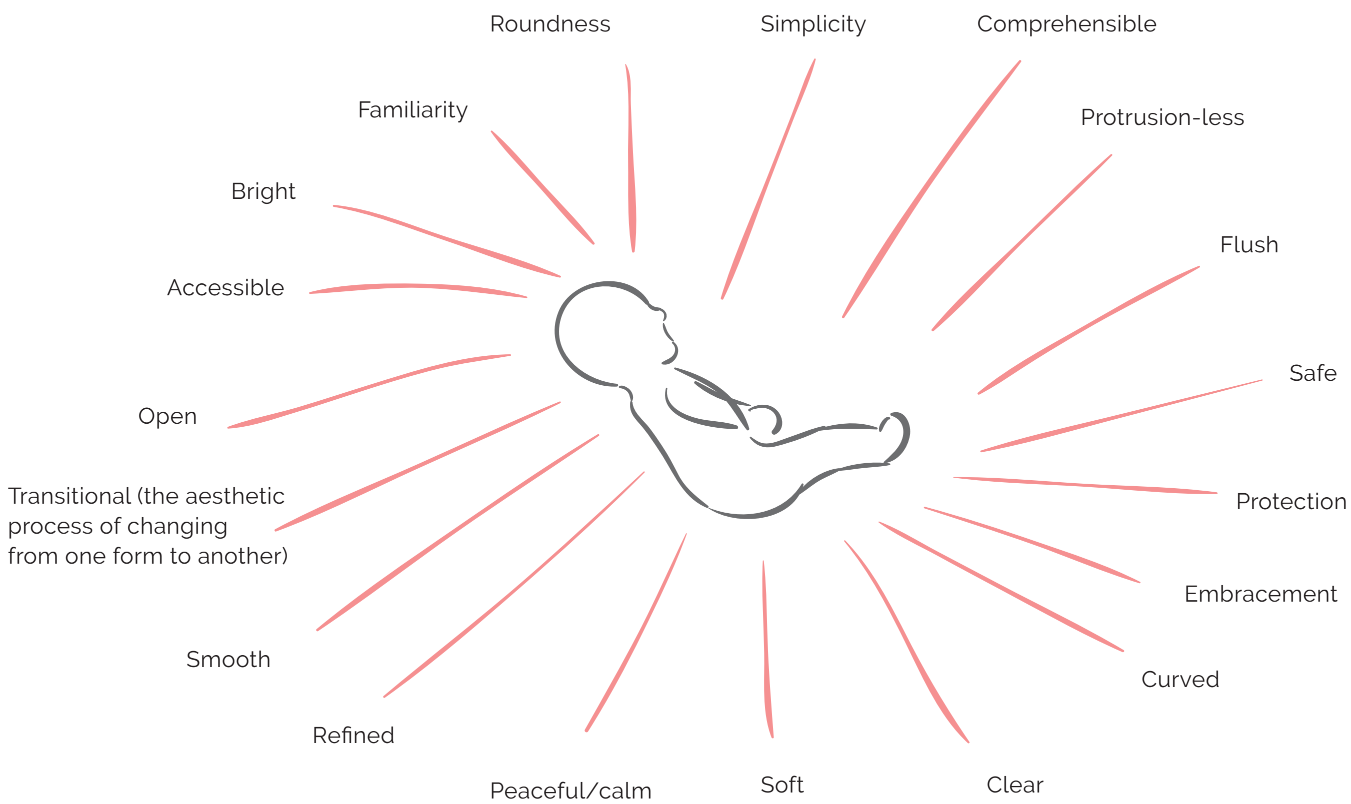


Figure 100: Mind map with words that characterizes the 'infant shape'.

Figure 101: Remote control. Visual characteristics: Vivid color contrast, Simplicity and Roundness

Figure 102: Chair. Visual characteristics:

Figure 103: Rocking Chair. Visual characteristics: the 'legs' show a sense of lightness or elevation

Figure 104: Infant safety seat. Visual characteristics: a feeling of protection and safety. Round shapes and curved lines.

Figure 105: Headphone. Visual characteristics: at the outer part of the ear cushions (above the letter b) a smooth shape transition is clearly visible.

Figure 106: Product unknown. Visual characteristics: Vivid color contrast, Simplicity and Roundness. The see-through space in the middle of the product creates openness.

Figure 107: Infant safety seat. Visual characteristics: Vivid color contrast and roundness. The area around the pivot point of the handle highlights a properly designed transition

Figure 108: Spoon. Visual characteristics: simplicity. The spoon is broken in two parts by means of an interesting transition

Figure 109: Toddler car seat. Visual characteristics: the flush handle is neatly integrated into the car seat, resulting in a protusion-less shape.

Figure 110: Time trial bicycle helmet. Visual characteristics: smooth curvature

Figure 111: Audi concept car. Visual characteristics: smooth curvature

Figure 113: Camera. Visual characteristics: roundness and the use of soft colors.

Figure 114: Child safety camera. Visual characteristics: built up out of primary shapes: block and sphere. Yet, in combination a perfectly balanced and familiar shape arises.

Figure 115: Toddler car seat. Visual characteristics: proper use of color contrast. The flush handle is neatly integrated into the shape of the car seat.

Figure 116: House robot. Visual characteristics: simplicity. Built up out of one primary shape: a (truncated) cone. Suddenly, a technical product feels accesible and comprehensible.

Figure 112: Interior concept design. Visual characteristics: the soft pastel purple arches at the left and right side highlight the feeling of protection and embracement. As a whole, the interior and exterior feels calm and peaceful.

Figure 117: Watch. Visual characteristics: color contrast. Roundness and soft. Elegant

5.3 Aesthetics

To translate the form language into a 'child friendly' shape, different templates, side views and foam models were used. This section briefly explains the aesthetic or styling process for the design proposal.

5.3.1 Sketching from a side view
In its most simplistic form, the design proposal consists out of two side pieces. These two side pieces created a rather new product form that I hadn't seen before in any product. A template, showing a side view, was used to determine the silhouette of the product as a whole (Figure 118).

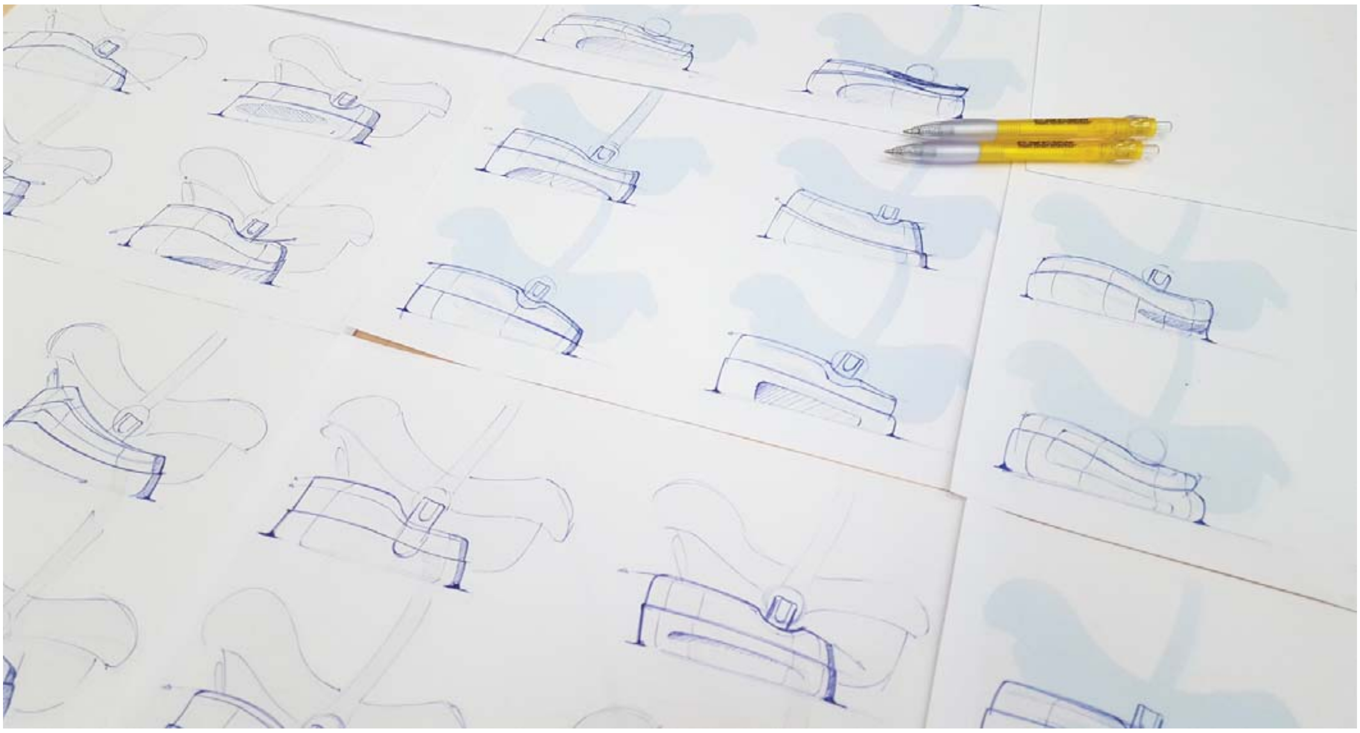
5.3.2 Changing view
This view was regarded as less useful, since the product will most often be viewed from above. Thereafter, a top view and 3D view (looking diagonally from above) were used to sketch the two side pieces (Figure 119).

Because the product is most frequently viewed from above, the visual weight of the product should be placed at the front. Furthermore, due to diagonal movement of the product, the side profile of the upper side piece needed to have a fixed curvature. This limited the aesthetic possibilities of the upper side piece.

5.3.3 Foam models
To get an idea about the form, the construction was roughly made out of cardboard. Consequently, foam shapes were formed that could be placed on top of the construction. By photographing the construction in a grey box and mirroring the shapes in Adobe Photoshop (Figure 121), the look and feel of the product, when placed on the floor of a cargo bike, could be simulated rather well. I tried to find a shape that represented the aesthetic characteristics as listed in section 5.2 Form language. Predominantly, a combination of openness, transition, embracement and curvature (Figure 122).

Figure 118: Contour sketches. A template, showing a side view, was used to determine the contour of the product as a whole

Figure 119: Sketches from a top view and 3D view (looking diagonally from above) were used to sketch the two side pieces of the product proposal



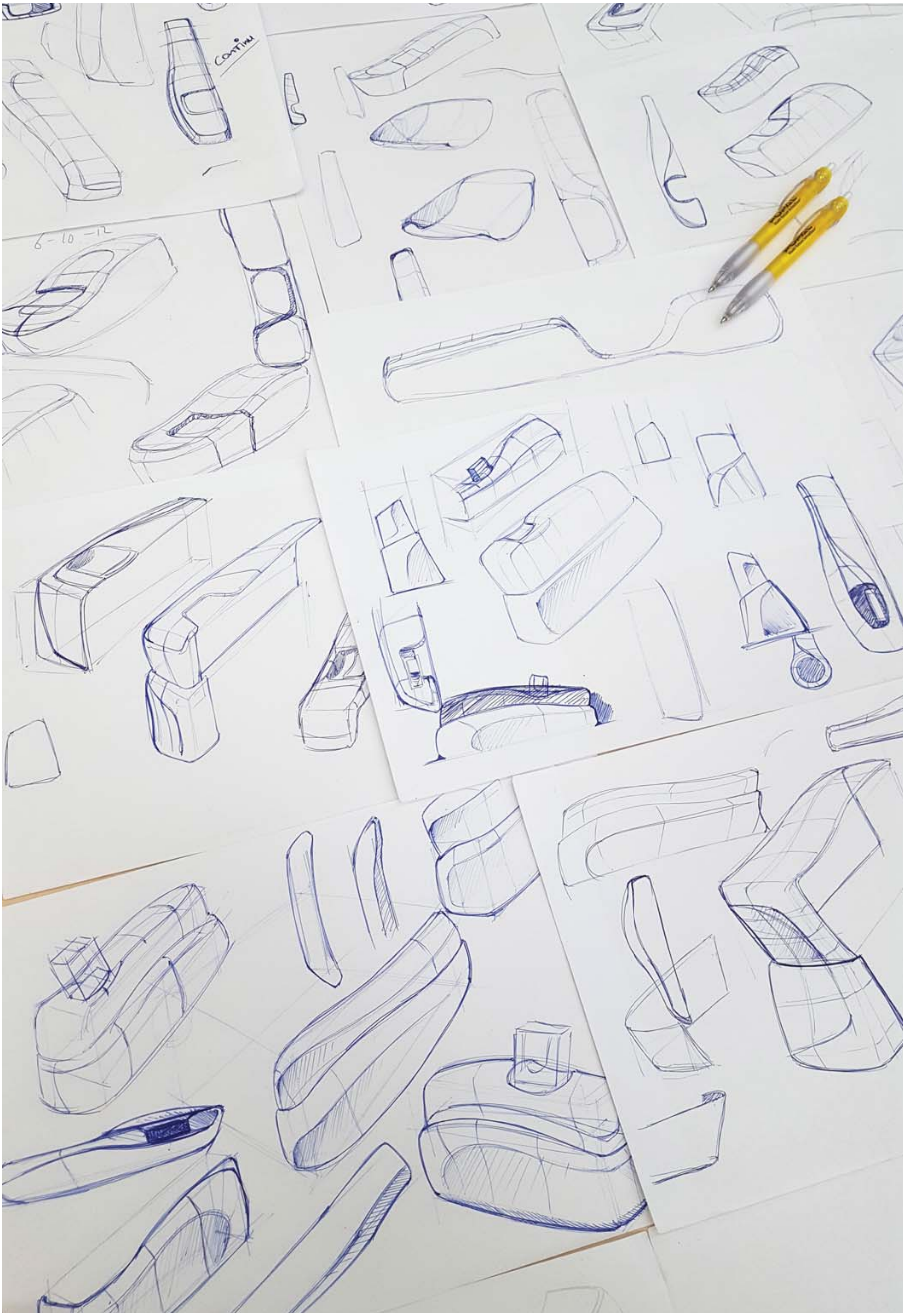


Figure 120: Cardboard representation of the construction. Foam shapes were formed that could be placed on top of the construction. The same side profile (a smooth waving curvature) was used for all foam models. The sketches that formed the starting point for the foam models are displayed on the table as well.

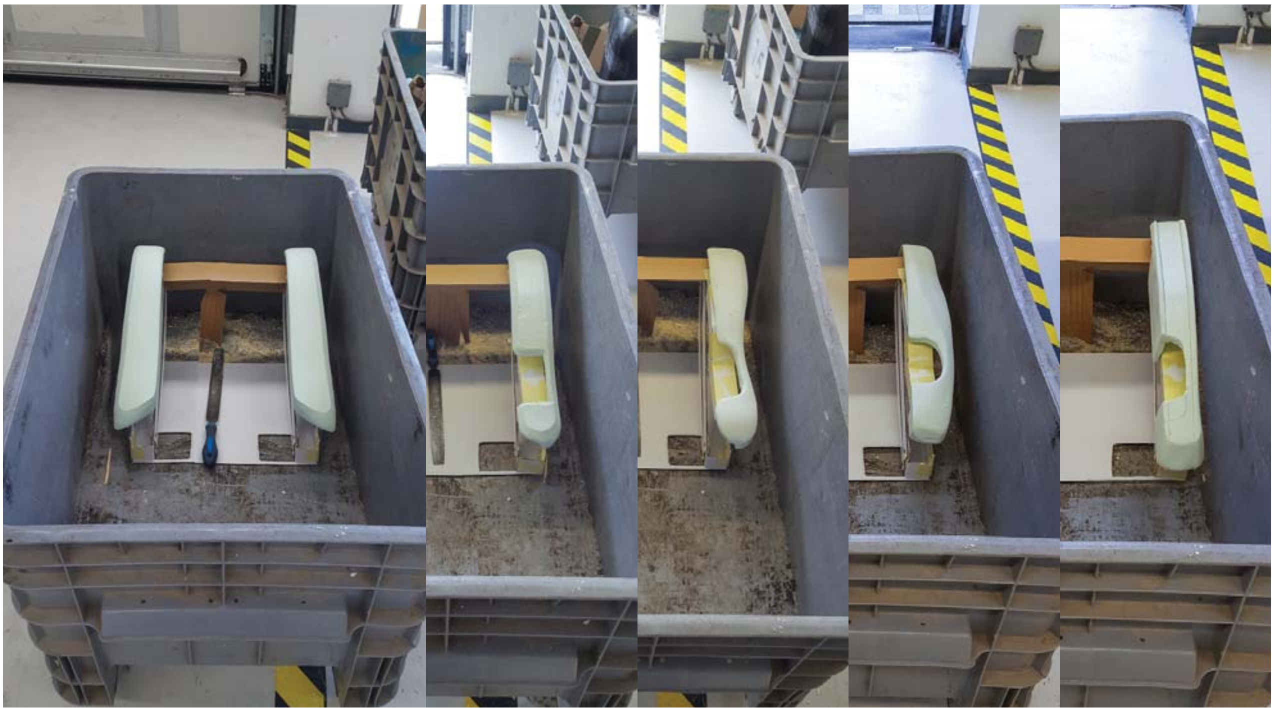


Figure 121: The construction and foam shapes were placed in a grey box and photographed. In Adobe Photoshop the shapes were mirrored. By doing so, the look and feel of the product, when placed on the floor of a cargo bike, could be simulated rather well.

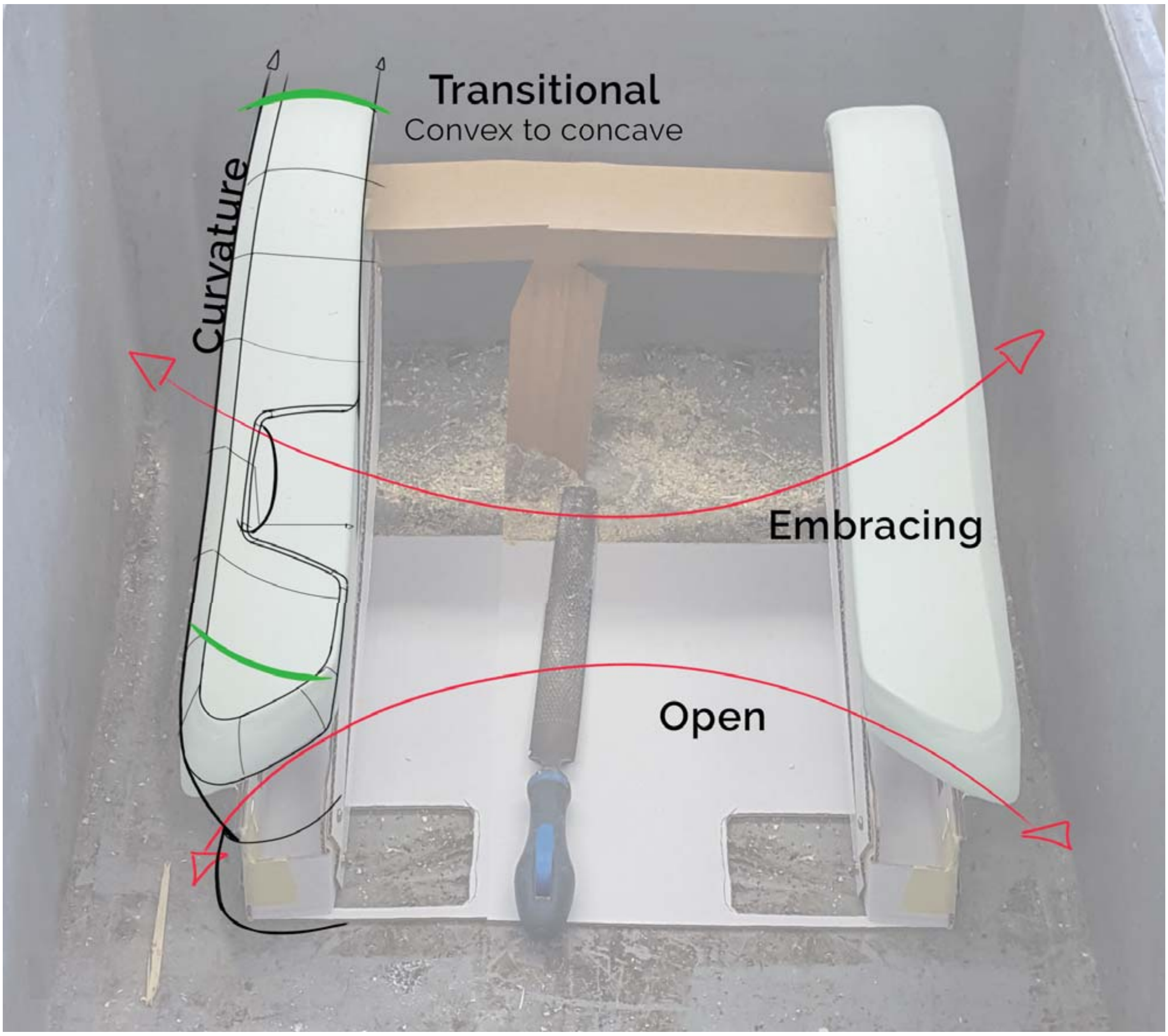


Figure 122: Aesthetic characteristics: a combination of openness, transition, embracement and curvature.

5.4 Spring characteristics

The minimum and maximum weight that is loaded onto the seating system determines the required shaft length of the damper and mechnical properties of the coil spring. These parameter are described in this section.

5.4.1 Weights

To determine the characteristics of the coil spring of the shock absorber, the total maximum weight should be known. The total maximum weight depends on the weight of the infant and the infant safety seat. According to the latest data of the World Health Organization (WHO), the weight of the P15, 3 months old, female, is 5.1 kg and the P85, 12 months old, male, 10.8 kg. The weight of infant safety seats ranges from 3.5 kg (Maxi-Cosi Cabriofix) to 4.7 kg (Britax Romer Baby-safe). The heaviest infant safety found, the Cybex Cloud Q, was due to its heavy weight, excluded.

The lowest possible weight is the sum of the P15, 3 months old, female and the Maxi-Cosi Cabriofix: 5.1 + 3.5 = 8.6 kg.

The highest possible weight is the sum of the P85, 12 months old, male and the Britax Romer Baby-safe: 10.8 + 4.7 = 15.5 kg.

Adding 2 kg. due to the weight of the construction this would mean the following total weights: 10.6 kg and 17.5 kg. The weight increase of 65% makes it more difficult to select a spring rate that satisfies both the lightest and heaviest possible weight. To put this in perspective, the total weight of a car, when occupied with 5 passengers of 80 kg, is only increased by 30-40%, depending on the initial weight of the car itself.

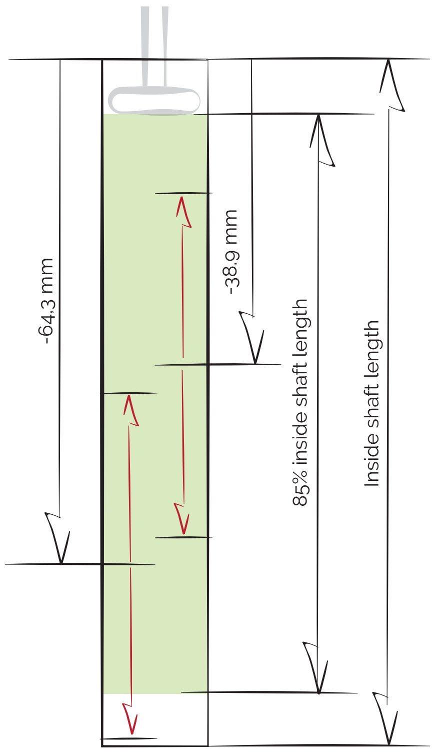


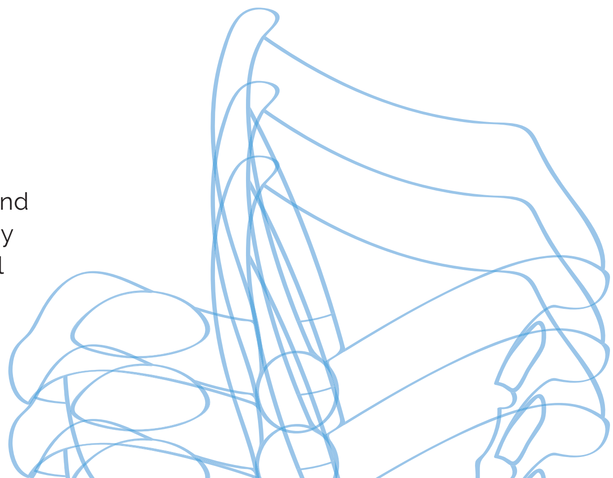
Figure 124: Vertical stroke of the piston by influence of the minimum and maximum weight. The red arrows correspond with 20mm stroke up and down (manhole cover depth).

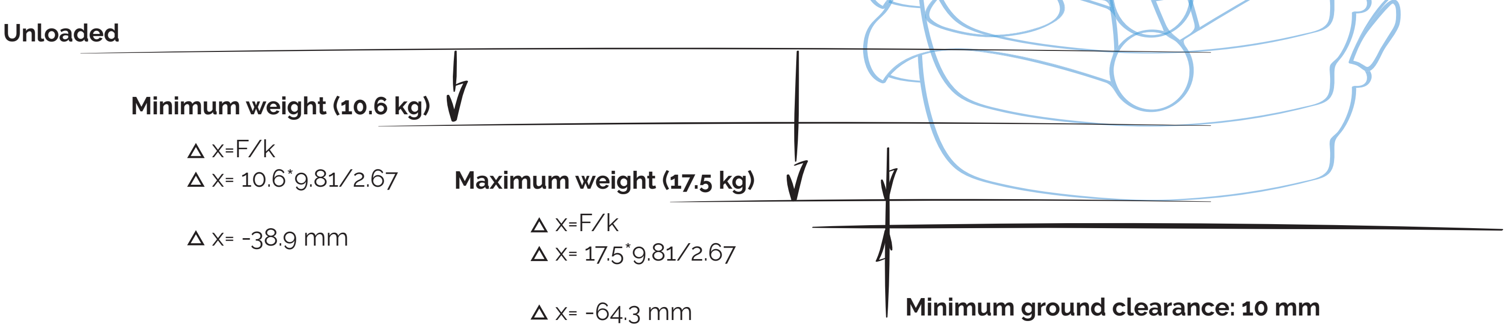
5.4.2 Spring compression

The measured spring rate of the shock absorbers was 2.67 N/mm. Because the spring rate as well as the weights were known, the compression could be calculated with the formula: x=F/k.

Figure 123 shows the compression of the spring by influence of the minimum and maximum load. The scematic damper, in Figure 124, illustrates the stroke ranges of each weight. The red arrows correspond with 20mm stroke up and down (manhole cover depth). 85% Efficiency of the total inside shaft length is a good baseline for typical industrial shocks (Korane, 2016).

Figure 123: Compression of the spring by influence of the minimum and maximum weights





6

Embodiment

In this chapter the construction is developed in accordance with technical and economic criteria, to the point where subsequent detail design can lead directly to production. Optimizing the adjustment of the play in the construction resulted in a rigid construction that showed little to none vibration in the pivoting points. This was realized 1) proper bearing selection and dimensioning, 2) increasing the sideways stiffness of the construction and 3) by keeping the shafts of the construction on tension. The chapter starts by describing these three means. Moreover, a system was proposed that enabled the parent to attach and detach the whole product if needed. The chapter ends with the optimization of the prototype.

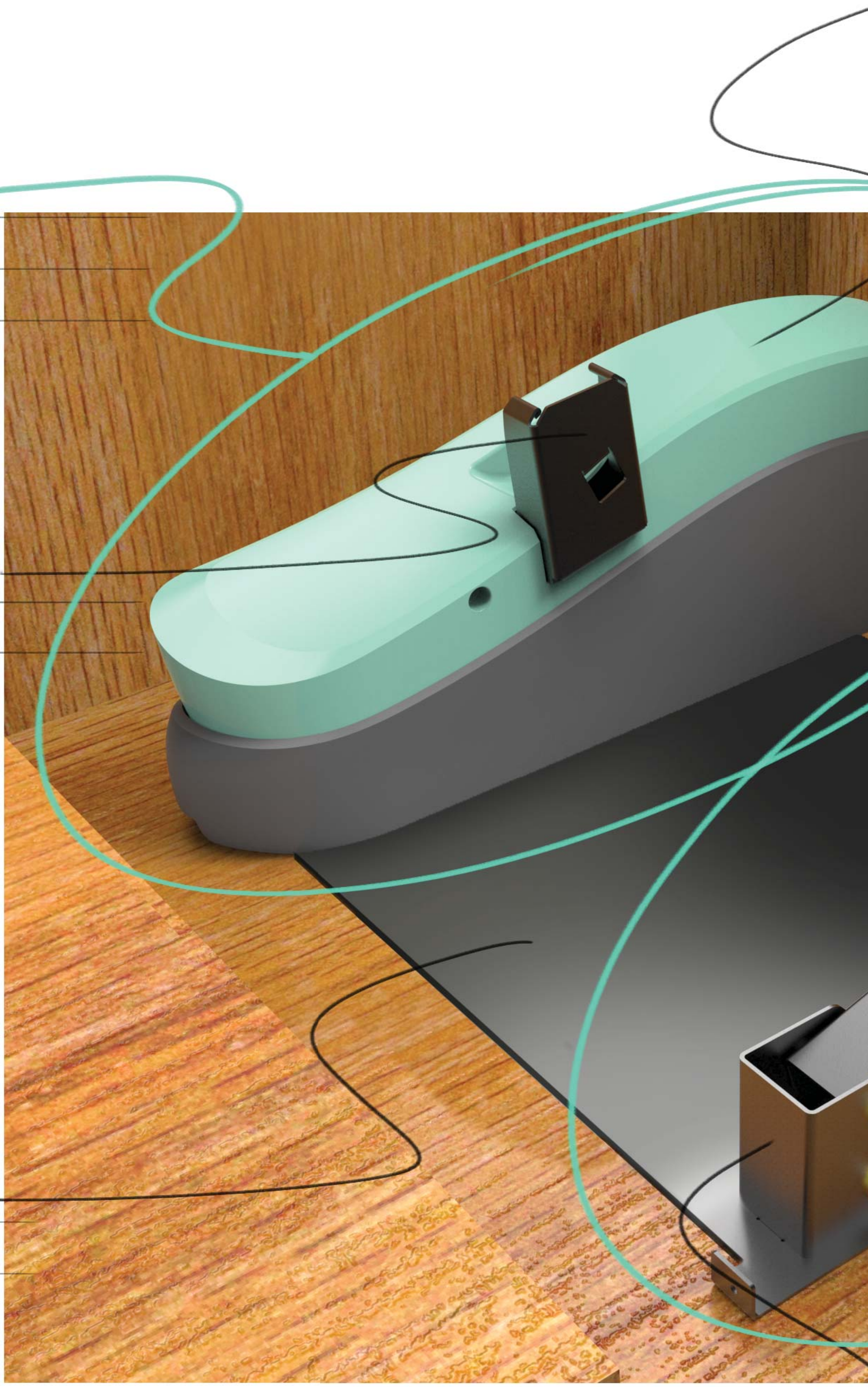
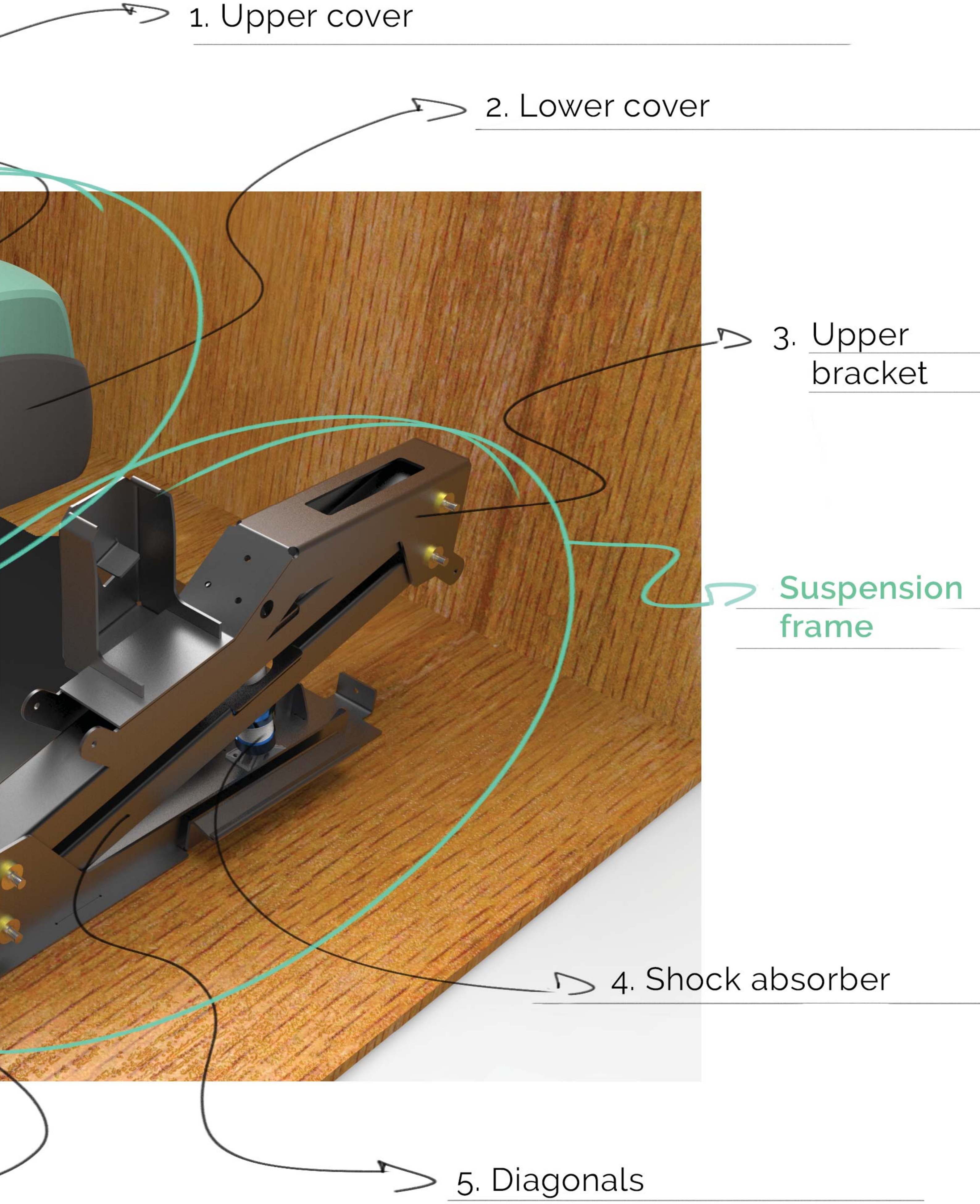


Figure 125: The design proposal with its main components modelled in Solidworks.


1. Upper cover
2. Lower cover
3. Upper bracket
Suspension frame
4. Shock absorber
5. Diagonals

Product description

The product consists out of two covered suspension frames. Underneath the covers, the suspension frame is found. Each suspension frame consists out of five main parts (apart from bearing elements):

- A lower bracket;
- Two diagonals;
- An upper bracket;
- A car seat adapter, and;
- A damping element (shock absorber)

The lower cover is screwed to the bottom plate, the upper cover is screwed to the upper bracket.

6.1 Bearings

Generally speaking, a bearing is a device that is used to enable rotational or linear movement, while reducing friction and handling stress (Thomas, n.d.). This section will briefly assess the type of bearing and material that would be suitable for the application of an infant seat system.

6.1.1 Bearings

There are many types of bearings, each used for different purposes. These include a.o. ball bearings, roller bearings and plain bearings (or bushings).

Bushings operate with sliding motion between the moving surfaces. Bushings were selected based on the relatively low rotating speed and the applied weight. Furthermore, most bushings do not require additional lubrication to operate and are cost effective. A bushing needs to be pressed inside a H7 hole (Figure 126).

6.1.2 Materials

There are many materials for bushings on the market today, including metal, polymer, and composite.

Metal materials include solid bronze, sintered bronze and brass. Polymer materials include polyester, PTFE polyamide and POM. Composite materials include PTFE composites, POM composites, phenolic resin bonded composites and glass fiber composites. Appendix 32 provides a product guide of different bushing materials (property of SKF).

Choosing an appropriate material requires extensive knowledge of both application and materials and depends on many variables. Therefore, the material choice was carefully chosen based on personal communication with suppliers and the product guide. Appendix 33 provides a description of different bushing materials.

Based on the low price level and high temperature range, a PTFE composite material would be the most suitable material for the application.

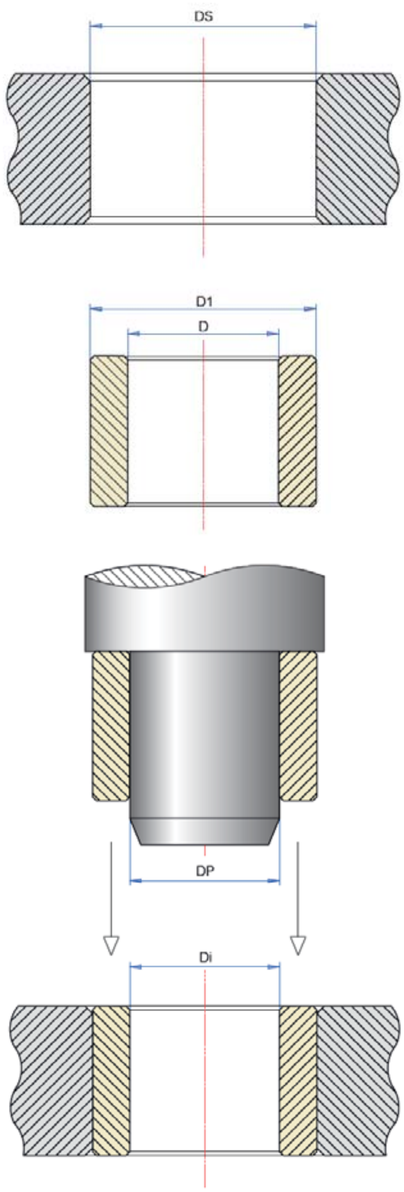


Figure 126: Installation of solid bushing. The bushings are pressed in with the help of a mandrel press. When the bearing is pressed in, the "fit" becomes smaller.

6.2 Side stability

Sideways movement is a problem that occurs in every pivoting construction, but this can be easily prevented and solved by optimum adjustment of the play in the construction (keeping the shafts of the construction on tension). When the clearances are correct, the construction can function without too many problems. An increase in clearances accelerates the wearing process extensively (Marc Dalebout, August 21, 2018, personal communication).

6.2.1 Initial bushing construction

The seat system was inspired by the construction of marine suspension pedestals (Figure 127). The majority of these construction use two thick marine steel diagonals at each side of the construction, which are linked to each other by a steel beam of plate. Because the infant safety seat is placed in between both sides of the construction, rather than on top of the construction, the only linkage possible was at the back of the construction (Figure 129).

Figure 128 (Left) shows the initial bearing construction proposal with 4mm steel diagonals. This construction showed unwanted sideways movement. In collaboration with several bearing suppliers, this construction was evaluated (see appendix 34 for conversation).

6.2.2 New construction proposal

In the initial construction the ratio between thickness and length of the diagonals was too small. These diagonals would bend too much when side forces occur. The construction can be made stiffer by using a U-profile or hollow (squared) profile. By welding an axis to these profiles, these parts can be perfectly used as pivoting diagonals (Edwin van Varsseveld, September 14, 2018, personal communication). Figure 128 (Right) shows the new bearing construction.

6.2.3 Finite Element Analysis

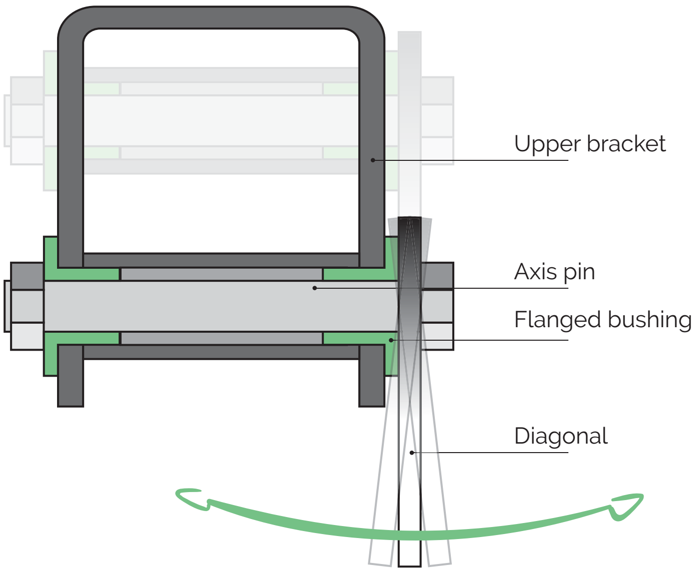
A Finite Element Analysis (FEA, appendix 35) was used to evaluate the side stability of the construction. The first iteration consisted out of two 4 mm diagonals (Figure 129). A plastic redesign (Figure 130) was proposed to reduce the weight of the diagonals and to create more stiffness. Although a the displacement was smaller, the results still showed a too large displacement.

The middle beam was considered to be a rather protruding and cumbersome piece of the construction. Furthermore, a cut-out in the (plastic) covers would be needed to enable the possibility to mount the middle beam to both upper brackets. In collaboration with the supervisors of the TU Delft, it was decided to find a solution that would make it possible to eliminate the middle beam.

A way to do this would be to mount a stiff U-profile in between the upper brackets, rather than next to it. Apart from creating more stiffness, this solution would also reduce the width of the suspension frame (Figure 131).

The results showed an acceptable displacement of 4.0 mm for aluminium, for a U-profile having the following dimensions: 32 x 50 x 32 x 2 mm.

Figure 127: X-Craft X-System suspension system, designed by X-craft in Hoorn, The Netherlands. It is the original and very versatile suspension system that can be used in a wide range of different craft and can be fitted with all types of seats.



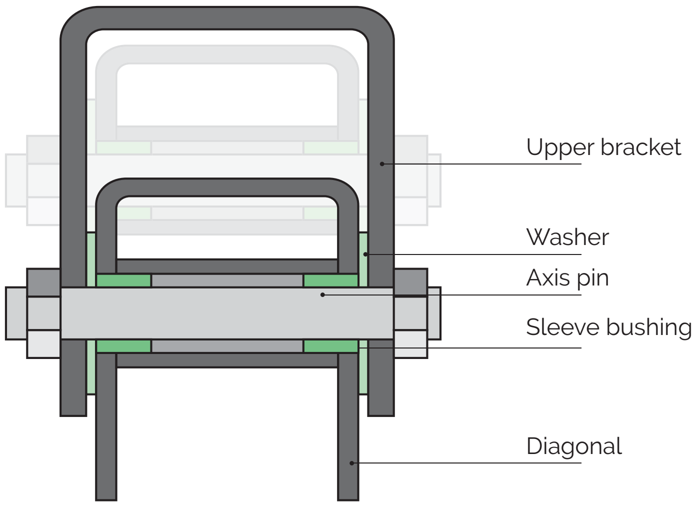
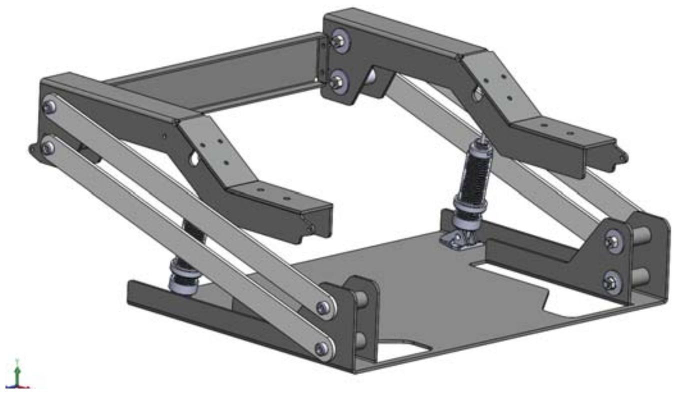


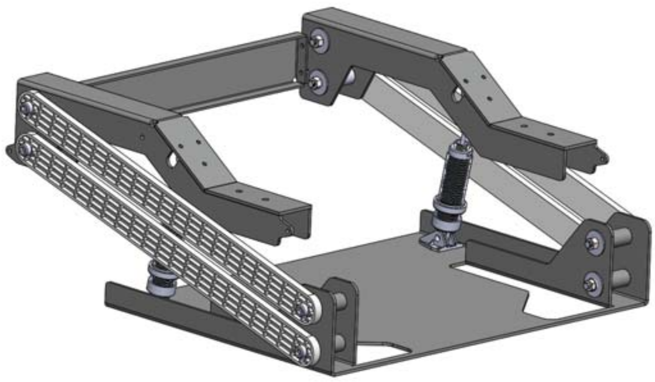
Figure 128: (Left) Initial bearing construction proposal with 4mm steel diagonals. This construction showed unwanted sideways movement. (Right) The construction was made stiffer by using a U-profile or hollow (squared) profile.

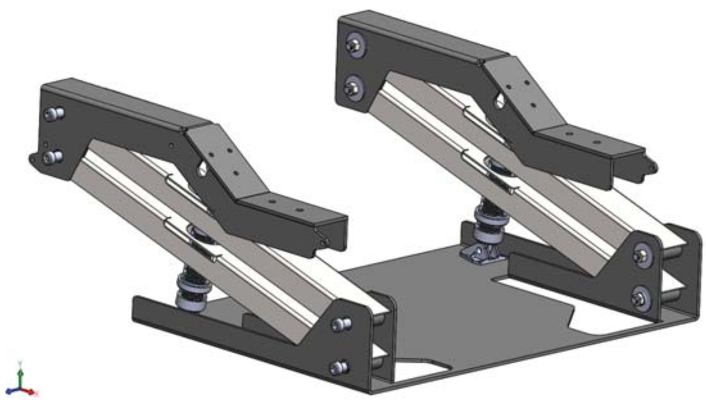
Figure 129: (Upper) Initial bearing construction proposal with 4mm steel diagonals. The left and right side are linked by a steel beam at the back of the construction.

Figure 130: (Middle) Plastic redesign to reduce the weight of the diagonals and to create more stiffness.

Figure 131: (Lower) new bearing construction. The left and right side of the construction are not linked to each other and serve as individual suspension elements.







6.3 Mounting

The small questionnaire that was distributed to parents who owned an infant carrier (e.g. Steco Baby Mee), described in section '2.8 Cycling with an infant' and included in appendix 14, provided insights regarding usage and experiences of their current solution. Although a small number of parents completed the questionnaire (n=9), 4 out of 9 parents found that their current solution (Steco baby mee) took up too much space. A mounting proposal was desirable that enables the parent to attach and detach the whole product if needed.

6.3.1 Initial mounting proposal

The mounting proposal (Figure 132) consisted of two main parts: a ground tile that is anchored to the cargo bike having two slots on the front and back, and the seat system.

Two clamps are screwed to the bottom plate. The seat system is placed over the ground tile. An over-centered handle pushes a steel pin in the slots of the ground plate.

Several concerns were mentioned about this mounting proposal:

- Would the proposal be strong enough to withstand the forces when a parent rapidly needs to brake or, worse, in the event of a collision?
- By removing a lot of material of the bottom plate, this part loses the majority of its rigidity. If a parent has to detach the seat system, it might feel wobbly and unsecure.
- The closure between the pins and the ground tile act in the middle of the construction. However, the majority of the external forces act on the side of the construction (near the covered suspension frame). As a result, the covered suspension frames have little support: these sides could flap (appendix 36).

6.3.2 Renewed mounting proposal

To ensure maximum safety, a new mounting proposal was made (Figure 134). Inspiration was found in vehicle and aircraft floor tracking systems that add flexibility to a vehicle's or aircraft's seating configuration. Appendix 36 describes the creative process that resulted in the renewed mounting proposal. The major difference in comparison with the initial proposal was that the covered suspension frames were disconnected from the mounting plate and became two individual subparts.

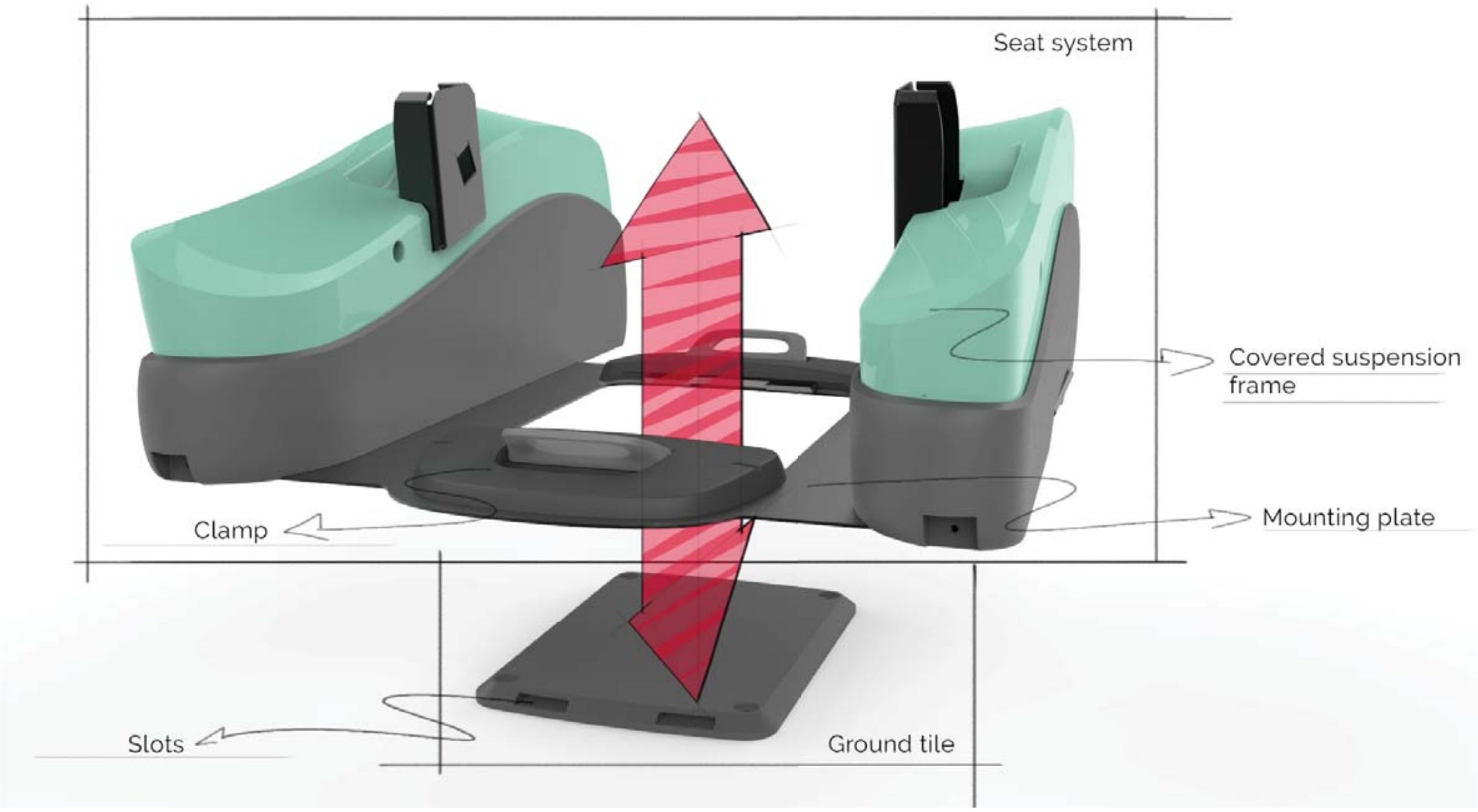


Figure 132: The initial mounting proposal consisted of two main parts: a ground tile that is anchored to the cargo bike having two slots on the front and back, and the seat system.

Figure 133: At the end of the extrusion profiles a horizontal handle enables the operation to clamp the covered suspension frames.

6.3.2.1 Base frame

A base frame is anchored to the bottom of the box of the cargo bike by means of 6 bolts. At the end of the extrusion profiles a horizontal handle enables the operation to clamp the covered suspension frames (Figure 133).

The base frame consisted out of:

- Two extrusion profiles that have two lasercutted tracks;
- Two steel plates.
- Two bended profiles, having two lasercutted slots, that moves inside of the extrusion profiles.
- Two handles that are positioned at the end of the extrusion profiles.
- Two linkages that connect the handle with the bended profiles.

6.3.2.2 Covered suspension frames

Two small steel feet are welded at the bottom of the covered suspension frame. Simply locate these feet into the tracking and press down the handle.

By rotating the handle downwards the linkage is moved backwards. The bended profiles is moved backwards too. As a result, the two steel feet are clamped between the edges of the bended profile and the extrusion profile.

When the covered suspension frames are fully positioned, the horizontal clamp is nicely integrated into the covered suspension frames, creating a flush whole without protrusions. This is beneficial for the center of gravity, since possible protrusions that would be positioned below the infant safety seat might higher the seat.

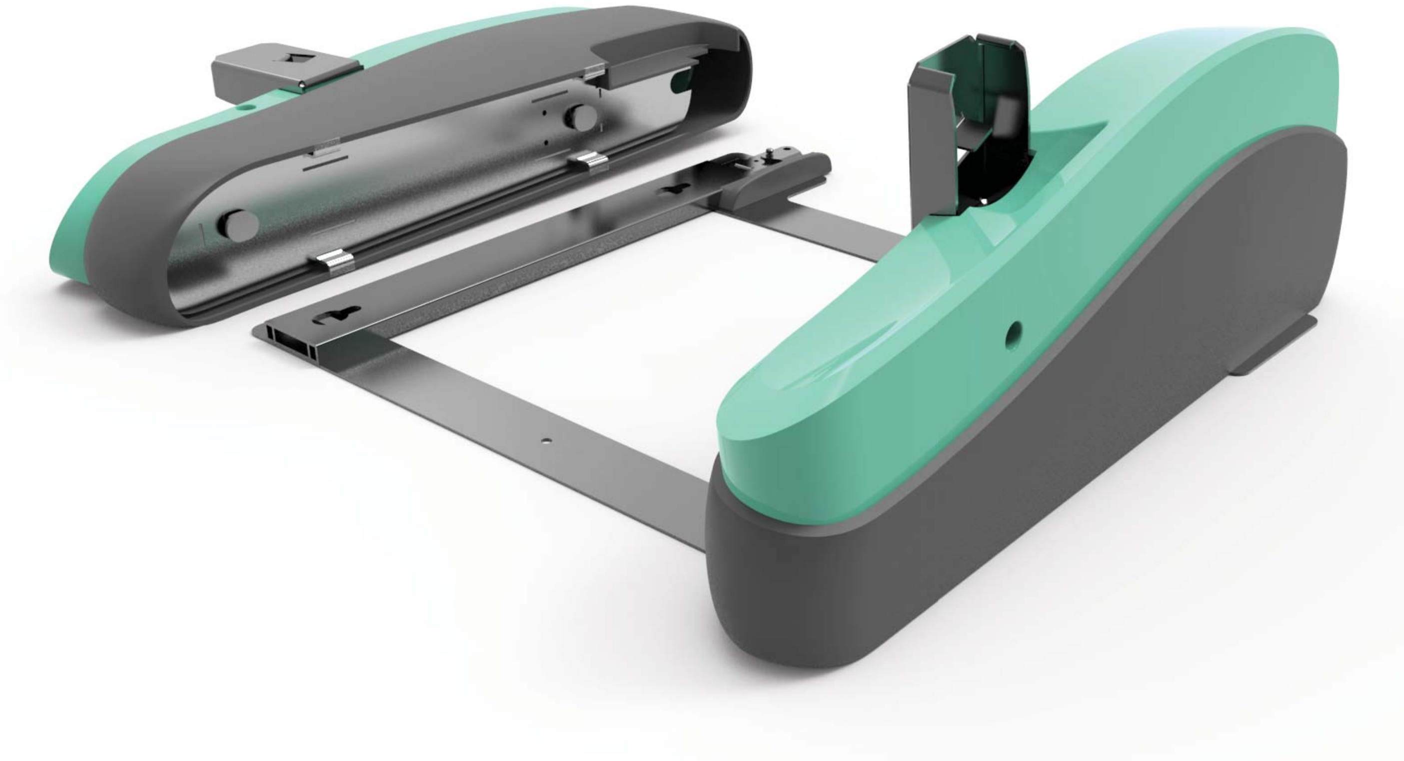


Figure 134: To ensure maximum safety, a new mounting proposal was made. In this proposal, the covered suspension frames were disconnected from the mounting plate and became two individual subparts.

6.4 Production

This section describes which production methods and materials would be most suitable for each manufacturing part. Since the product acceptance was regarded as having a high risk - transporting infants on a bicycle or cargo bike is still a niche market - the production method of each part was based on a first production quantity of 500 pieces.

6.4.1 Production batch

Although cargo bikes are a common mode of transport in the Netherlands, Belgium and Germany, the yearly sold quantities are still not very high. It is estimated that around 30.000 cargo bikes are sold yearly in Europe (Aryan Popal, October 15, 2018, personal communication). Based on current data, the total sales potential was estimated to be 6.000 potential users, as described in 'Appendix 21 Sales potential'. The first production batch shall most likely be small, ranging from 200 to 500 pieces the first year. It is estimated to produce 500 – 700 pieces the second year. After the third year 3000 pieces should be sold.

6.4.2 Production methods

6.4.2.1 Suspension frame

All main parts of the suspension frame will be manufactured by means of laser cutting and bending. Laser cutting is a very accurate technique used to easily cut tailor-made sheets. Laser cutting is done using light amplification, made possible by an induced radiation transmission. The width of the light bundle is only a fraction of a millimeter. As a result, the intensity of the light beam is focused on a very small area – so intense that it can cut. After the plates are cut in the right shape, the flat shape is bent into its final 3D shape.

6.4.2.2 Covers

Several production methods are available to manufacture complex plastic shapes. Injection molding, vacuum forming, rotation molding and blow molding are the four main production techniques for plastic parts.

- Blow molding is used to create hollow products. Although theoretically suitable, the shape of the covers does not lend itself for blow molding. A lot of post-processing is necessary (e.g. milling the bottom).
- Rotation molding might be suitable at first. However, this production method is predominantly used for very big products, such as canoes or roof boxes. The initial investment is low, yet the costs per product are high (see appendix 37 for requested invoice)
- Vacuum forming is a relatively cheap process. Though, it offers little design freedom. Furthermore, the required draft angle of at least 5 percent (Toolcraft Plastics, n.d.) makes this method less suitable: if the upper covers is inclined and it moves downwards, the gap between the upper and lower cover increases (Figure 135).

Due to the complexity, the covers will be manufactured by means of injection molding with an aluminium mold (appendix 38 will elaborate on the decision of an aluminium mold).

6.4.3 Materials

6.4.3.1 Suspension frame

Steel and aluminum are the two most popular materials used in bent parts. Each material has a defined and distinct set of characteristics that make it a more or less suitable material for the job. Appendix 39 provides a rough trade-off between each material based on five material properties.

Car seat adapter

Injection moulding a car seat adapter would be too costly, due to the high investment of an aluminium or steel mould. Although limiting the design freedom, sheet metal is an appropriate alternative. Urban Arrow's car seat adapter is also made out of sheet metal.

Two car seat adapters were measured: Easywalker and Pipa. To limit swinging in the y-direction around the car seat adapter, the car seat adapter needs to fit perfectly. The width of this part was extremely important: 65mm.

One of the main advantages of steel is its rigidity. Since the car seat adapter is considered to be a rather fragile part (it's protrusive and vulnerable to improper use) this part needed to be very stiff and strong. This requirement was determinative in terms of selecting the right material for the car seat adapter.

Upper bracket

Consequently, since aluminium and steel are more difficult to weld on each other, the upper bracket needed to be made out of steel as well.

Other parts of the suspension frame

Moreover, the whole construction needed to be very stiff to minimize sideways deformation. As a result, steel was chosen for the other parts (diagonals and lower bracket) as well. The steel parts need a corrosion resistant coating after it's been laser cutted and bent. It was assumed that these costs are marginal when taking in mind the total material costs and the total costs for laser cutting and bending.

6.4.3.2. Covers

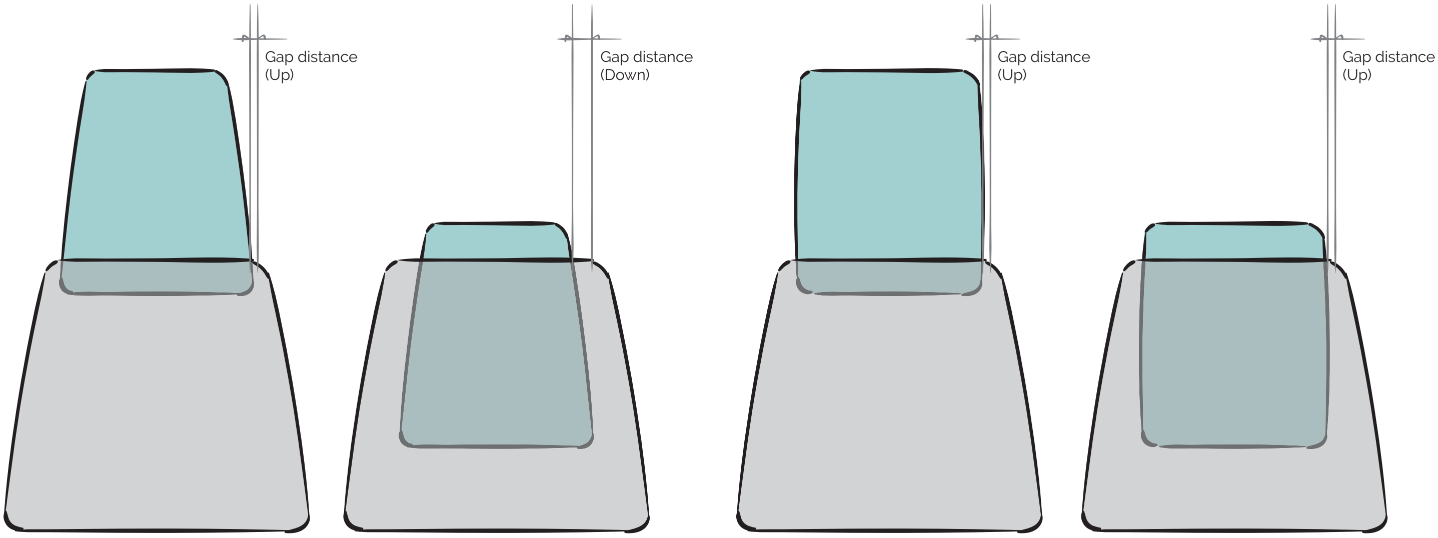


Figure 135: Front view of a covered suspension frame. If the upper cover is inclined and it moves downwards, the gap between the upper and lower cover increases (left). If the upper cover is not inclined (right), there is no gap difference.

The main functionality of the covers is to prevent entrapment of children's feet and arms. They are not subjected to heavy loads. The covers will be used outdoor. Immediately, this requires certain physical properties of the material: weather and UV resistant.

Moreover, the covers may not break if a child accidently kicks to it. Therefore, impact strength is important. In order for a material or object to have a high impact strength the stresses must be distributed evenly throughout the object. It also must be relatively tough and should have a low modulus of elasticity and a high material yield strength.

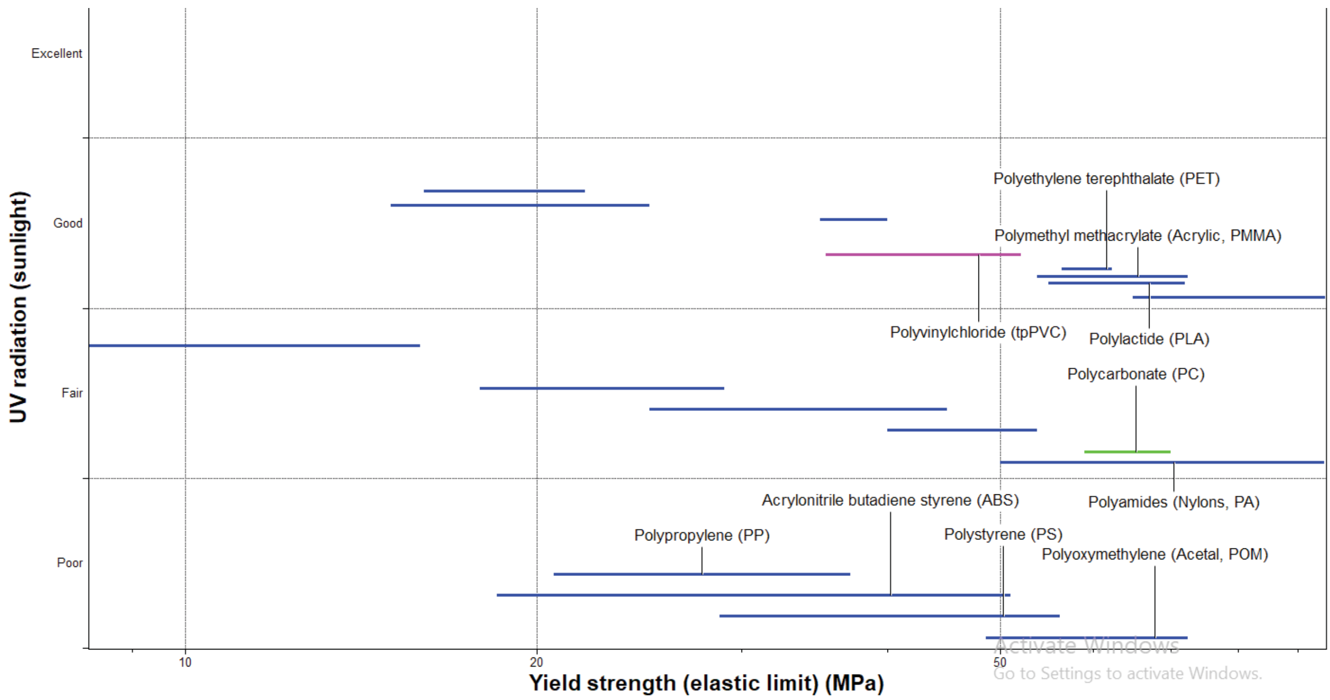
Chart 9 shows different thermoplastic materials, in which the yield strength on the x-axis is plotted against UV radiation on the y-axis. Out of all the thermoplastic materials, PVC has one of the best yield strength/UV radiation ratios (colored in fuchsia in Chart 9). This material is often used as boat fenders and is easy to form and to color (CES, 2018). In addition, PVC is one of the cheapest and most widely used polymers (1,52 – 1,57 euro per kg).

An alternative is PC (colored in lime in Chart 9). PC is often used because of its impact resistance, for example bicycle helmets. Although more expensive, PC might be a worthy alternative (1,87 – 2,28 euro per kg).

In short, both PVC and PC are suitable materials for the application. Based on price, PVC is more suitable.

An estimation of the total cost price containing suspension frame, cover and shock absorber can be found in appendix 40.

Chart 9: different thermoplastic materials. The yield strength on the x-axis is plotted against UV radiation on the y-axis



6.5 Color study

The process of the color selection is a rather complicated one and plays a significant role in design. To use color effectively in design, it is important to have a proper understanding of the concepts and color terminology. Something as simple as changing the exact hue or saturation of a color can evoke a completely different feeling.

Color can be verified visually by measurement of its properties such as hue, saturation, chromaticity, and value (Tubik Studio, n.d.):

- Hue: denotes an object's color
- Saturation: refers to how a hue appears under particular lighting conditions.
- Chromaticity (chroma): purity of a color. A hue with high chroma has no black, white, or gray added to it.
- Value (lightness): it refers to how light or dark a color is. Lighter colors have higher values.

A color study (appendix 41) was made to understand the meaning colors would evoke when applied to the design proposal. Photoshop was used to change the color properties.

6.5.1 Conclusion

Since the product proposal has a 'subservient' role, an achromatic and neutral tone was chosen: grey. The lower part is colored dark grey, anthracite. The upper part is colored cool grey, which has a noticeably bluish/greenish hue. Putting two tones together results in color harmony: as a whole, the colors are orderly, calm and pleasing, and can be considered to be the most attractive and effective way for users' perception.

The (cool) grey tones can be perfectly combined with any infant safety seat's color palette (Figure 137-142). Although vivid colors (e.g. lime and magenta) are considered to be more infant-friendly colors, these colors does not match with other vivid colors (of the infant safety seat). For example, a lime color (of the product proposal) does not nicely match with a magenta color (of the infant safety seat).

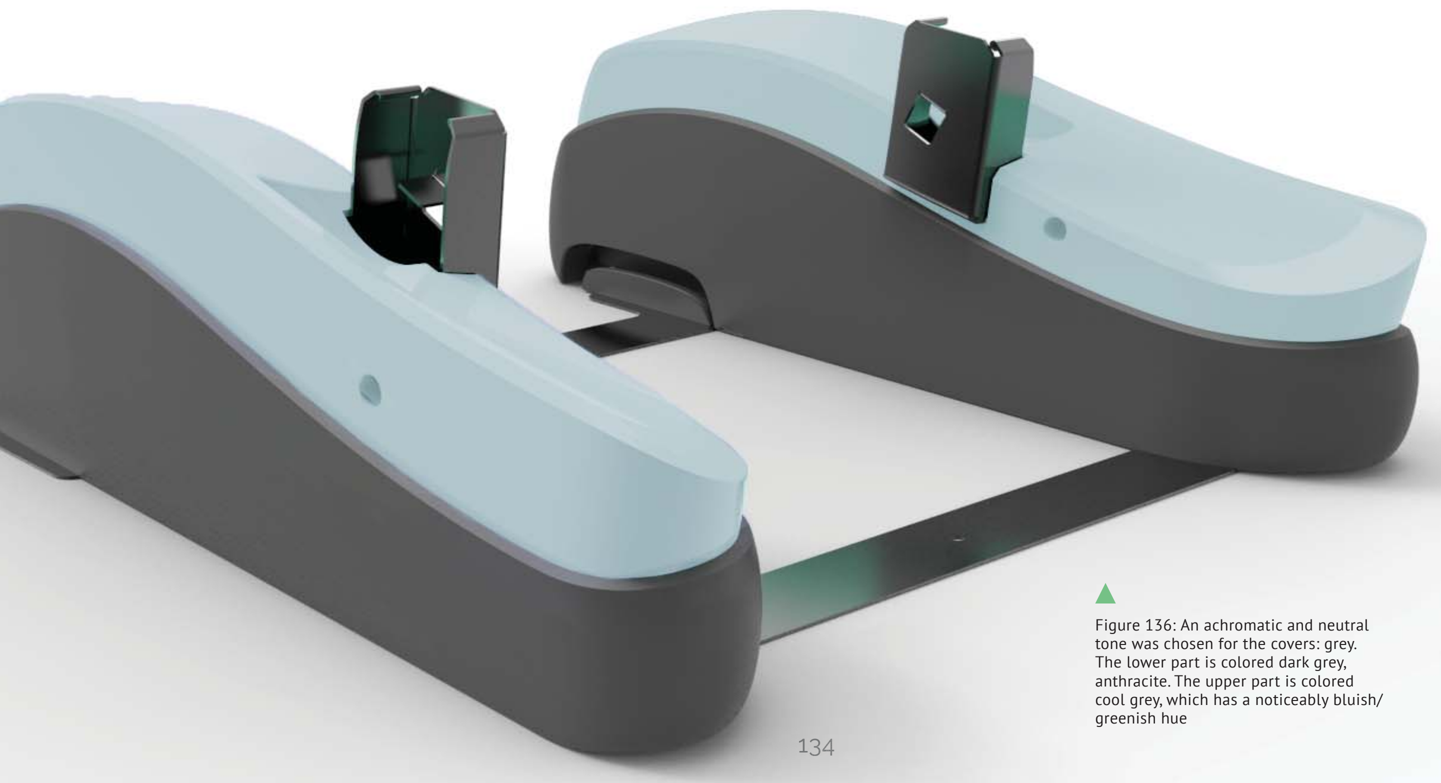


Figure 136: An achromatic and neutral tone was chosen for the covers: grey. The lower part is colored dark grey, anthracite. The upper part is colored cool grey, which has a noticeably bluish/greenish hue

Figure 137: The two colors of the design proposal (left and middle color) combined with the prominent color of the GB Gold Artio: Lizard Khaki (right).

Figure 138: The two colors of the design proposal (left and middle color) combined with the prominent color of the Kiddy Evolution Pro 2: pink (right).

Figure 139: The two colors of the design proposal (left and middle color) combined with the prominent color of the Doona: Green (right)

Figure 140: The two colors of the design proposal (left and middle color) combined with the prominent color of the Cybex Cloud Q Plus: hot spicy (right).

Figure 141: The Maxi-Cosi Cabriofix attached to the steel prototype


MAXI-COSI
PLUS

6.6 Prototyping

The purpose of the fully functioning prototype (Figure 142) was validating whether the weighted r.m.s. accelerations measured did not exceed the requirements as set in '7. Human Health and Comfort', in appendix 22. The double diagonal mechanism was manufactured by an external manufacturing company. Appendix 42 provides a description of building the prototype as well as the technical drawings that were released to the external manufacturing company.

The prototype (Figure 142) was tested on road bricks and concrete tiles that were also used for the Steco Baby Mee (Figure 143) and the wooden test model (Figure 144). A test on tarmac was considered redundant, because the unweighted r.m.s. acceleration values measured on this road surface were significantly lower (1 – 1.5 m/s2) and fell within the zone 'minimal risk to health' (Chart 8, section 2.15).

6.6.1 Results

The results of the steel prototype showed a vibrational transmissibility in the range of 47% to 51% in the z-direction, depending on which relative weight of the test dummy and road type were compared.

The average unweighted r.m.s. acceleration values measured on the floor of the tests with the wooden test model were much higher (highlighted in green in Table 10: 4.6 to 5 m/s2) in comparison to the tests with the Steco Baby Mee and the steel prototype (3.2 to 3.9 m/s2). This difference was most likely caused by signal interference that resulted in inaccurate readings.

As a consequence, calculating the ratio between the

Concrete tiles

Weight	Steco rmsz	Test model rmsz	Proto rmsz
5 kg	3.145	4.597	3.854
8 kg	3.416	4.607	3.917
10 kg	3.267	4.818	3.704

Road bricks

Weight	Steco rmsz	Test model rmsz	Proto rmsz
5 kg	3.208	4.772	3.510
8 kg	3.286	4.992	3.830
10 kg	3.532	4.841	3.766

Table 10: overview of the r.m.s. acceleration values [m/s2] for the road surfaces 'road bricks' (bottom) and 'concrete tiles' (top) of all three models, measured on the floor of the cargo bike in the z-direction. The floor measurements of the test model (green) are much higher.

vibrational transmissibility values was not considered to be a reliable standard. In this case, calculating the ratio between the absolute unweighted r.m.s. acceleration values was considered to be more adequate. After all, according to ISO 2631, the absolute weighted r.m.s. acceleration values are used to assess the health risk aspects.

6.6.1.1 Steco Baby mee vs. steel prototype

The absolute unweighted r.m.s. acceleration values in the z-direction were reduced by 39% to 52%. The absolute unweighted r.m.s. acceleration values in the x and y-direction were reduced by 41% to 44%.

6.6.1.2 Steco Baby mee vs. wooden test model

The absolute unweighted r.m.s. acceleration values in the z-direction were reduced by 40% to 57%. The absolute unweighted r.m.s. acceleration values in the x and y-direction were reduced by 32% to 65%.

6.6.1.3 Conclusion

The wooden test model performed better in all tests when cycling on concrete tiles (6% to 10%). On road bricks, only the result of the 10-kg test dummy of the wooden test model was better (16%) than the steel prototype.

NOTE: the exact values of the reductions depend on which relative weight of the test dummy and road type were compared. These exact values can be found in appendix 43.

6.6.2 New prototype configuration

Overall, the wooden test model showed the best results. All differences between the wooden test model and the prototype were summarized in one list. This list can be found in appendix 44. The list provides a description of what the difference means and what the possible effect of each difference has on the vibrational transmissibility values. Moreover, it also made clear whether a parameter could possibly have a big influence on the vibrational transmissibility values or not. A modular test model was made to test several parameters (Figure 142). The parameters that were assessed as having a big influence on the vibrational transmissibility values were:

- Mechanism weight;
- Center of gravity;
- Diagonal length;
- Diagonal angle;
- Orifice holes, and;
- Shock absorber angle

Figure 142: (top) Modular test model in which the length and angle of the diagonals and angle of the shock absorber could easily be changed and tested. Loaded with 5 kg.

Figure 143: (bottom left) Steco Baby Mee loaded with a 8-kg test dummy

Figure 144: (bottom right) Wooden test model loaded with a 8-kg test dummy

Consequently, the best setting of each parameter, as described in appendix 44, was implemented into a new prototype configuration (Figure 145).

Results

Table 8 in appendix 45 shows the unweighted r.m.s. acceleration values (for all weights) of the new prototype configuration for road bricks and concrete tiles. Unfortunately, the results of the new prototype showed a marginal improvement in comparison to the previous configuration: around 3%.

The unweighted r.m.s. values in the z-direction (vertical), measured under the head, were in the range of 1.607 - 1.709 m/s2, depending on weight and road surface. The vibrational transmissibility between the floor of the cargo bike and the surface supporting the head, ranged from 39.7% (concrete tiles, 5 kg) to 47.8% (road bricks, 5 kg).

Appendix 46 shows the transient vibrations (speed bump) of the new prototype configuration. The transducer located at the location of the pelvis showed the highest peak vibration value in the z-axis (ranging up to 27.7 m/s2 when loaded with a 10 kg test dummy).

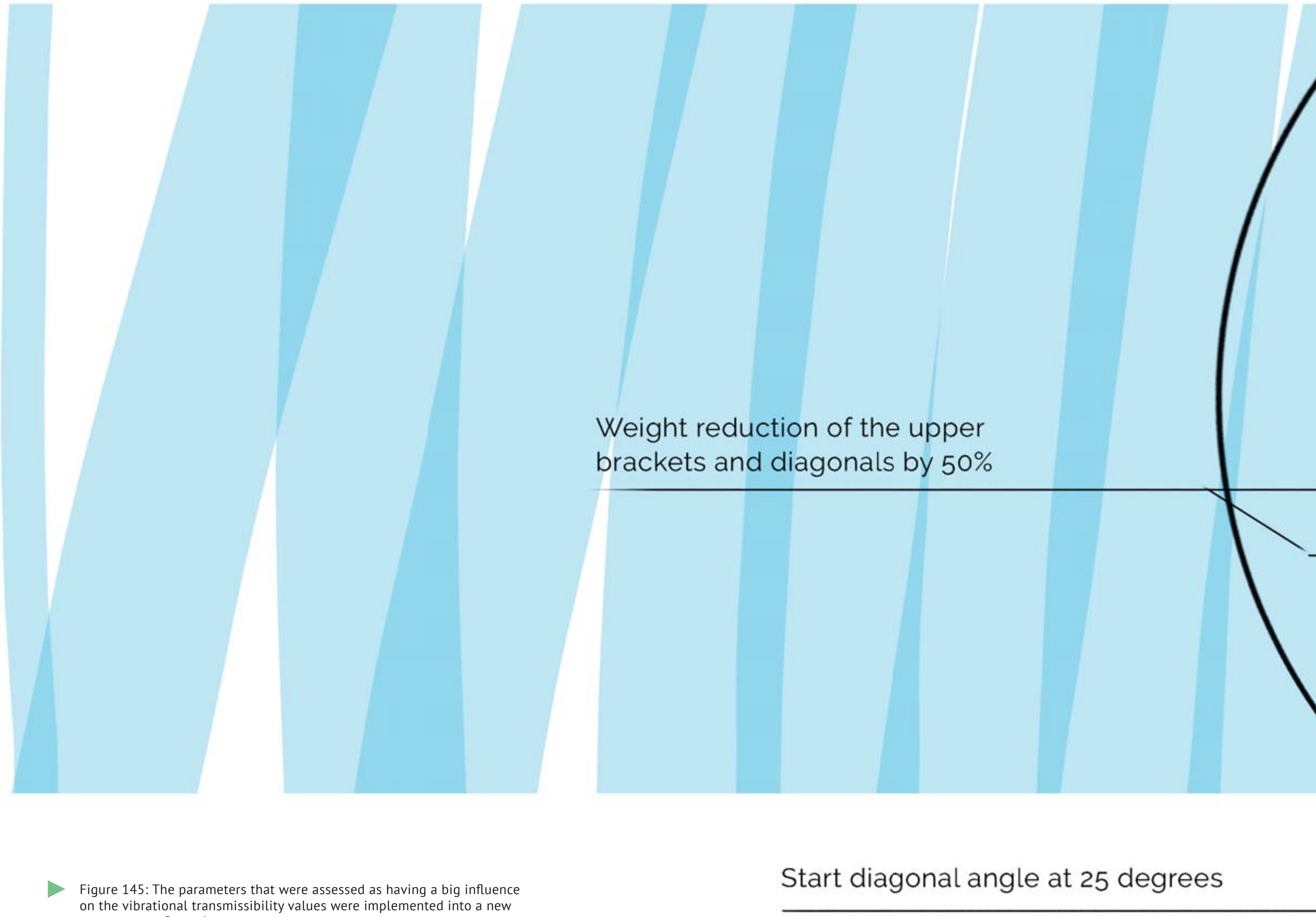
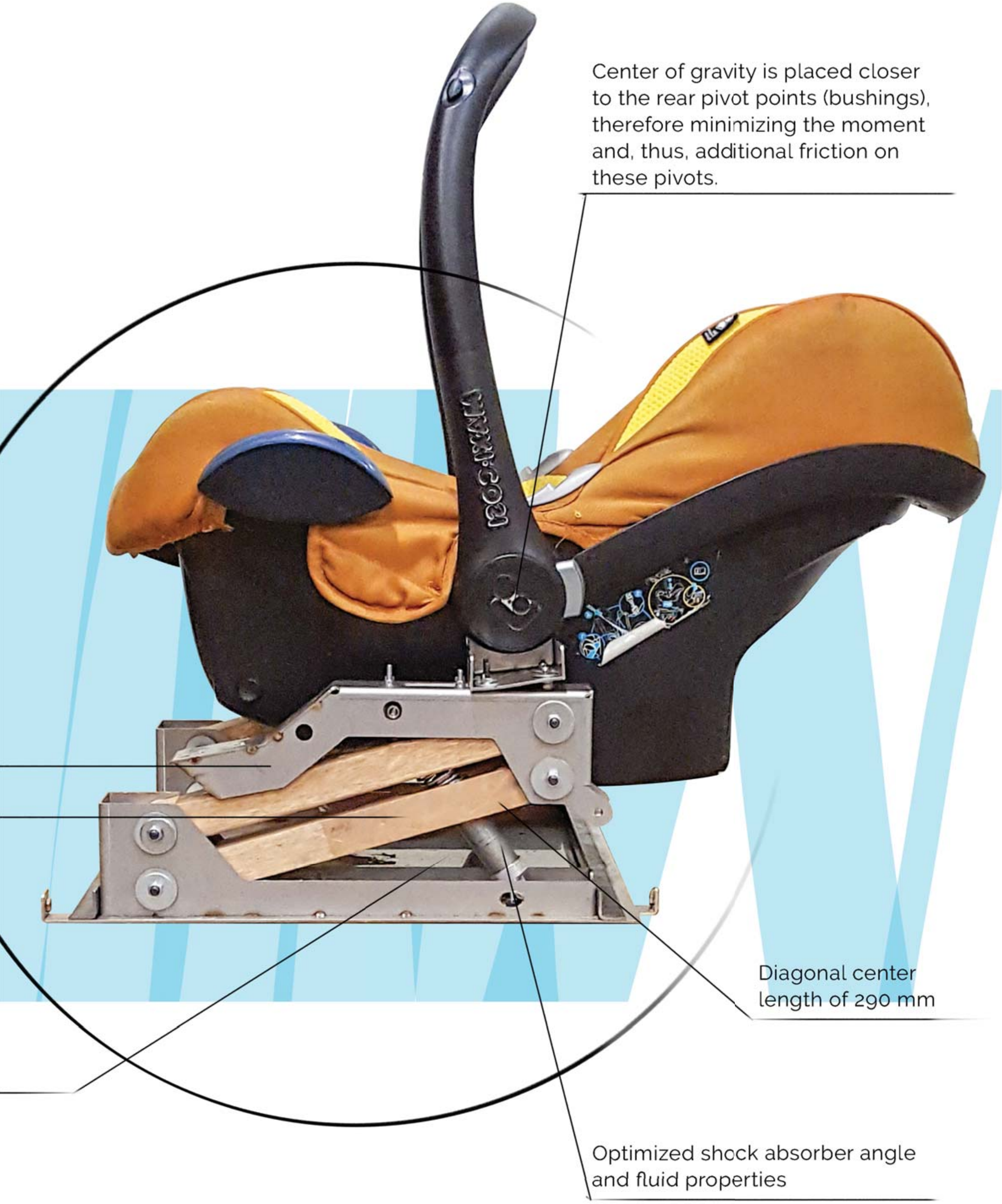


Figure 145: The parameters that were assessed as having a big influence on the vibrational transmissibility values were implemented into a new prototype configuration.


Center of gravity is placed closer to the rear pivot points (bushings), therefore minimizing the moment and, thus, additional friction on these pivots.
Diagonal center length of 290 mm
Optimized shock absorber angle and fluid properties

7.1 Conclusion
The numbers

Although there are systems that allow you to take your infant with you on your bicycle or cargo bike, there were still many prejudices and concerns on this matter before this graduation project. Due to the transmitted vibrations, experts criticized travelling with infants on bicycles and cargo bikes. This section will provides the final values of the new prototype configuration.

7.1.1 Weighted r.m.s. acceleration value

The new prototype configuration was tested in compliance to two of the test roads as specified in requirement '7.1 Road conditions': road bricks and concrete tiles. All head measurements (x, y and z-direction) were passed through frequency weighting filter Wj.

Table 11 provides an overview of the weighted r.m.s. acceleration values of the Steco Baby Mee and the new prototype configuration. The weighted r.m.s. values in the z-direction (vertical), measured under the head, were in the range of 1.316 - 1.520 m/s2, depending on weight and road surface.

In comparison to the Steco Baby Mee, the weighted r.m.s. acceleration values in the z-direction were reduced by 45% to 51%. The weighted r.m.s. acceleration values in the x and y-direction were reduced by 45% to 55%.

Only 3 out of the 18 weighted r.m.s. acceleration values in the x, y and z-direction on road bricks and concrete tiles, measured on the new prototype configuration, exceeded the required weighted r.m.s. acceleration of 1.45 m/s2. Yet, the highest weighted r.m.s. acceleration value of 1.520 m/s2 (road bricks, 8-kg test dummy) was only 5% higher than the set requirement.

Moreover, the weighted r.m.s. acceleration values in the x

Weight	Location	Road type: Concrete tiles rmsx	rmsy	rmsz
5 kg	Head	1.962	2.584	2.488
8 kg	Head	2.383	2.295	2.654
10 kg	Head	1.983	2.364	2.893

Weight	Location	Road type: Road bricks rmsx	rmsy	rmsz
5 kg	Head	2.706	2.030	2.622
8 kg	Head	2.727	2.468	2.779
10 kg	Head	2.695	2.685	2.999

Weight	Location	Road type: Concrete tiles rmsx	rmsy	rmsz
5 kg	Head	1.263	1.239	1.316
8 kg	Head	1.225	1.273	1.458
10 kg	Head	1.169	1.292	1.436

Weight	Location	Road type: Road bricks rmsx	rmsy	rmsz
5 kg	Head	1.309	1.041	1.345
8 kg	Head	1.320	1.330	1.520
10 kg	Head	1.226	1.450	1.465

Table 11: Overview of the weighted r.m.s. acceleration values of the Steco Baby Mee (left) and the new prototype configuration (right) for concrete tiles and road bricks. This table only shows measurements of the transducer located at the supporting surface under the head.

and y-direction approximate the desirable value of 1.2 m/s2: the highest weighted r.m.s. acceleration value in the x and y-direction (1.450 m/s2, road bricks, 10-kg test dummy) was 17% higher than the desired value.

Apart from 3 measurements, I can conclude that requirement '7.1.1 Weighted r.m.s. accelerations measured on the surface supporting the head' has been achieved.

NOTE: one might notice that the weighted r.m.s. acceleration values are lower than the unweighted r.m.s. acceleration values. The cause of this difference is explained on the next page.

7.1.2 First resonance frequency

The Discrete Fourier Transforms (DFT) of the transducers attached under the head, in the new prototype configuration tests, showed peaks in the frequency interval from approximately 2.3 - 2.7 Hz. This first resonance frequency interval was slightly lower than the first resonance frequency found in the Discrete Fourier Transforms of the Steco Baby Mee tests (Chart 10-11): 3 - 3.4 Hz. This shift is most likely caused by the difference in spring-damper characteristics between the Steco Baby Mee and the new prototype configuration.

The amplitude area in the frequency interval of 2.5 - 3.5 Hz, was lowered by 42% and 37% for road bricks and concrete tiles, respectively. As a consequence, requirement '7.1.3 first resonance frequency amplitude' (reduction of 50%) has not been achieved.

7.1.3 Acceleration in other vehicles

Table 12 shows 4 tests of two different studies in which acceleration values were measured for infant safety seats placed in a car (8 measurements). Since the prototype was not tested on tarmac, due to the low vibrational energy when cycling over tarmac, measurement 9 and 14 of the original table (Table 6) were excluded in Table 12.

Only 2 out of the 8 acceleration values measured in a car at the location of an infant safety seat (Table 12: 3 and 4) were lower than the weighted r.m.s. values measured in the cargo bike, ranging from 6% to 18% lower, depending on which measurement was compared. 5 Acceleration values (Table 12: 2, and 5 until 8) were higher, ranging from 20% to 41% higher. One acceleration value (Table 11: 1) fell within the weighted r.m.s. acceleration values of this study.

7.1.4 Transient vibrations (speed bump)

Table 5 in section '2.14 Vibrational research' showed that in all tests with the Steco Baby Mee, the transducer located at the infant's head showed the highest peak vibration value in the z-axis (ranging up to 78.6 m/s2 when loaded with a 10 kg test dummy).

Appendix 46 shows the transient vibrations of the new prototype configuration. Here, in 5 out of 6 tests, the maximum values were found at the location of the seat-back or pelvis. This was caused by bottoming or topping: when cycling over the speed bump a 'steel on steel' sound was heard. Nevertheless, the transient vibrations were reduced by 43% to 67%, depending on which weights were compared.

		20 km/h	30 km/h		40 km/h
	Car brand	not known	Volvo	Opel	not known
Research	**Road surface**	Cobblestone	Gravelled road		Cobblestone
Giacomin (2003)	Driver's seat	1.07			1.41
	Driver's seat guide	1.66			2.4
	Child seat guide	1.8			2.5
	Child seat	**1.44** (1)			**1.86** (8)
Nilsson (2005)	Driver seat		0.765	0.704	
	Floor		0.851	0.963	
	Isofix seat		**1.701** (2)	**1.775** (5)	
	Base seat		**1.243** (3)	**1.574** (6)	
	Belt seat		**1.301** (4)	**1.716** (7)	

Table 12: Four tests of two different studies in which r.m.s. acceleration values [m/s2] were measured for infant safety seats placed in a car. Total measurements in this table: 8. Original table (Table 6) consisted of 14 measurements. These last 6 measurements measurements, tested on perfect road conditions, were excluded for further analysis.

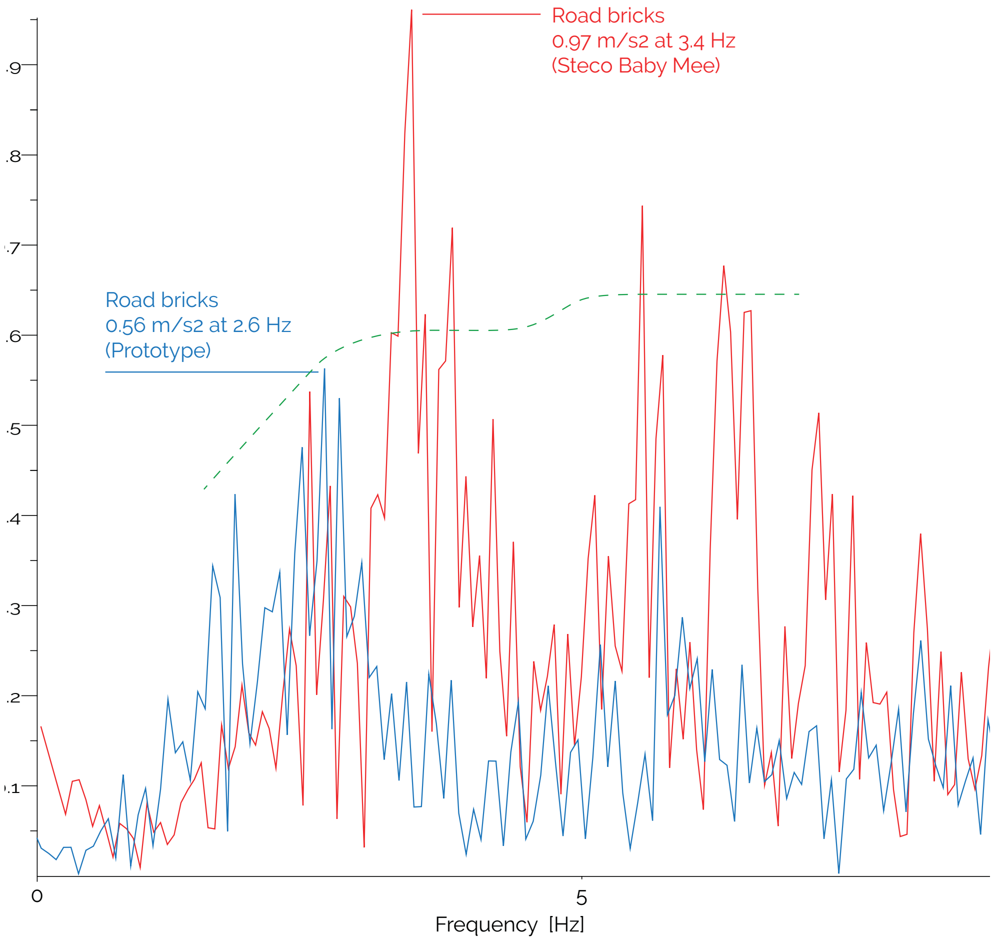


Chart 10: Discrete Fourier Transform, presenting the original vibrational signal deconstructed into its individual sine wave components, measured on road bricks, *under the head of the infant* with the 8kg test dummy, for the Steco Baby Mee (red) and the prototype (blue). The green dotted line indicates the first section of the frequency curve Wj.

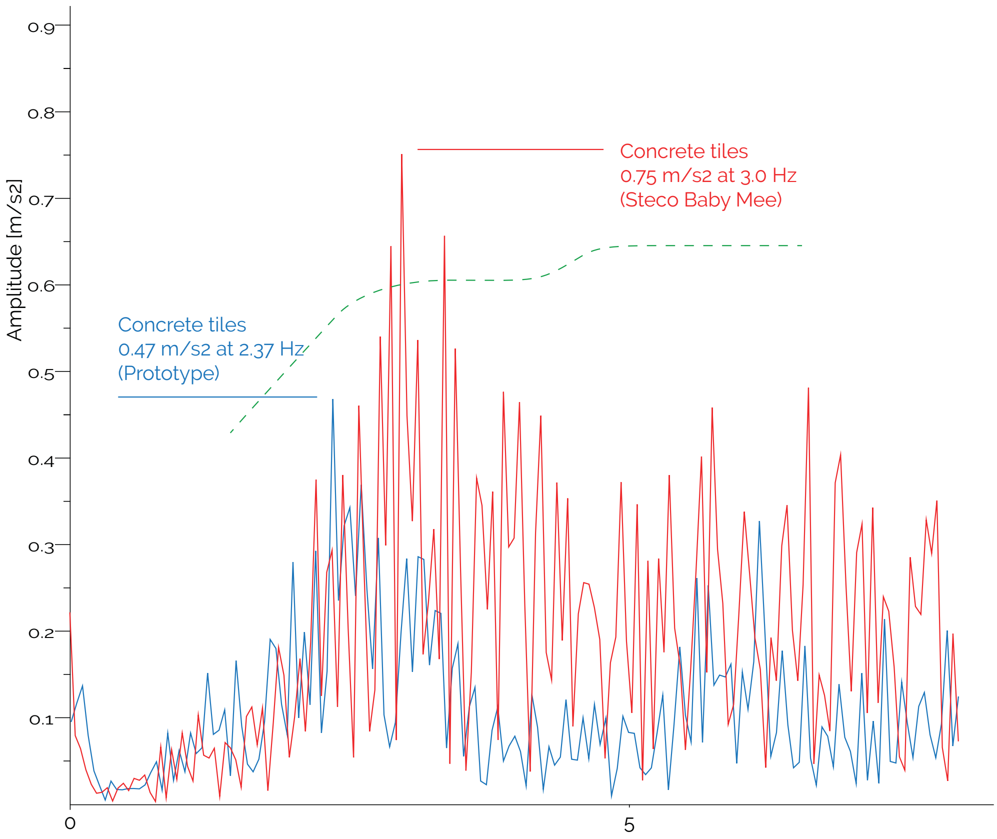


Chart 11: Discrete Fourier Transform, presenting the original vibrational signal deconstructed into its individual sine wave components, measured on concrete tiles, *under the head of the infant* with the 8kg test dummy, for the Steco Baby Mee (red) and the prototype (blue). The green dotted line indicates the first section of the frequency curve Wj.

Frequency weightings

The frequency weightings are shaped in such a manner as to attenuate the signal (reduce the amplitude value) at those frequencies which don't have much effect on the human subjective perception, while passing through those frequencies which are most problematic. The frequency weightings are shaped by following the mechanical response of the human body. At frequencies near the resonance, where even a small input vibration will make the person move a lot, the weighting curve is high. At frequencies where the human body seems to remain still, even when the input amplitude to the buttocks or feet becomes substantial, the frequency weighting will be near zero in magnitude.

According to the values of frequency weighting Wj (of ISO 2631) vibrations under the head of a recumbent person are more sensitive to frequencies in the 8 – 60 Hz range (Nederlands Normalisatie instituut, 1997). The green dotted line in Chart 10 and Chart 11 indicates the first section of the frequency curve Wj. The Discrete Fourier Transforms showed that the first resonance frequency, measured under the head, seemed to appear in the frequency interval from approximately 2.3 - 2.7 Hz, much lower than the 8 - 60 Hz. As a result, the weighted signal will be attenuated.

7.2 Conclusions
The health risk aspects

The graduation project aimed to find a correct recommendation for the use of infant safety seats mounted on cargo bikes and to include a consideration of the health risks and discomfort likely to be caused by vibration. Limitations that will not be explicitly discussed in this section were the small size of the study, lack of official crash test dummies used and limited data of real-time measurements with infants.

72.1 Product description
The product (Figure 146) consists out of two covered suspension frames. Underneath the covers, the suspension frame is found. Each suspension frame consists out of five main parts (apart from bearing elements):

- A lower bracket;
- Two diagonals;
- An upper bracket;
- A car seat adapter, and;
- A damping element (shock absorber)

The lower cover is screwed to the bottom plate, the upper cover is screwed to the upper bracket.

7.2.2 Likely reactions to vibration
The measured r.m.s. acceleration values were in the range of 0,8 m/s^2 to 1,6 m/s^2. According to the approximate indications of likely reactions to vibration of various magnitudes for adults (Nederlands Normalisatie instituut, 1997), these values are uncomfortable.

7.2.3 Head acceleration in some daily activities
Chart 12 illustrates an extended version of Chart 4 and Chart 5, added with the results of the new prototype configuration. The maximum peak values of the new prototype configuration (transient vibrations) are much lower in comparison to the peak values of the shaken dummies. Moreover, the differences between the periodic vibrations of the new prototype configuration (the two orange blocks) and the peak values of the shaken dummies are even larger. It is, therefore, highly unlikely that cycling with an infant in the new prototype configuration causes SBS. Furthermore, it can be seen that cycling with an infant is lower than all other daily activities except for one: Burping (back slap). However, since Chart 12 does not take into account the total exposure time, comparisons between daily activities should be treated with caution.

7.2.4 Mechanical response adults and infants
The frequency weightings are shaped by following the mechanical response of the human body. More specifically, the adult's response. It might be possible that the infant's mechanical response differs with respect to those of adults. If so, it is uncertain whether the standards such as ISO 2631 are useful to evaluate the effects of whole-body vibration on the infant's health and vibrational comfort. Subsequently, absolute weighted r.m.s. value might be different.

7.2.5 Clinical significance
The outcomes of the graduation project does not provide a definite answer regarding the clinical significance or potential health risks posed by the vibration values identified in this graduation project. More research is needed to quantify these effects, and to investigate how best to avoid them if they are clinically significant. Moreover, the vast majority of scientific vibrational studies draw emphasis on the vibrational comfort and health aspects of adults. As a result, there is a need for larger studies to investigate the effect of vibrations transmitted to infants and young children, regardless of the type of vehicle.

7.2.6 Physiological, biochemical and behavioral effects
This graduation project proposed a design solution that makes use of an infant safety seat for cars. There are concerns that the prominent back of the head seen in babies may push the head forwards when they sleep in these seats, and possibly obstruct the airway (National Health Service, 2016). A pilot study in a simulated moving vehicle (Arya et al., 2017) showed that the total number of desaturations was significantly increased when infants were placed at 30°, in comparison to the baseline observations. At 40°, or with vibration, respiratory and heart rates increased and oxygen saturation decreased significantly (Arya et al., 2017).

The findings of this graduation project and concerns of experts suggest that it might be beneficial to do more research on the physiological, biochemical and behavioral effects of cycling with infants. Cardiorespiratory measurements (e.g. heart rate, oxygen saturation, respiratory rate) or the COMFORT scale (appendix 47) might help to identify any potential adverse effects.

Moreover, in cars, protecting infants in the event of a collision has the highest priority. Yet, on a cargo bike, where traffic conditions are more favorable, comfort and health risk aspects must be emphasized.

Figure 146: Product proposal. The infant safety seat (not part of the designed solution) is attached to the new seat system.

7.2.7 Social and economic effect

At night, an infant processes what he or she has experienced during the day. The vibrations might be considered to be a sensory overload (also referred to as overstimulation). Overstimulation happens when a baby or young child is flooded by more experiences, sensations, noise and activity than the developing brain can cope with (Williams, 2016). Overstimulation may lead to sleeplessness, which in turn might cause behavior, mood, memory or performance problems.

Moreover, headache is a health problem that occurs frequently in children. Headache is usually caused by tension in the muscles of the head or by stimulation of nerves, blood vessels or meninges (Ostheopathie Eindhoven, n.d.). Vibrations might be one of the causes of headache.

Overstimulation, headache, and other psychological symptoms, caused by whole-body vibrations, might harmfully affect society and economy. These psychological symptoms can manifest themselves years later, causing long-term mood, memory or performance problems at school, work or at home.

7.2.8 Time recommendation

To be able to make a recommendation for how long cycling with infants on a cargo bike causes minimal health risks, more research is needed. ISO 2631 provides a chart with health guidance caution zones (Chart 12). Yet, this recommendation is mainly based on exposures in the range of 4 h to 8 h. Shorter durations should be treated with extreme caution (Nederlands Normalisatie Instituut, 1997). Moreover, for exposures below the zone, health effects have not been clearly documented and/or objectively observed (Nederlands Normalisatie Instituut, 1997). Without evidence-based studies, a time recommendation is not relevant. In other words, the exact influence of the vibrations on the health aspects and comfort of infants, and the evaluation thereof, remains an open question.

7.2.9 Ethically acceptable?

In Europe, there exist no legislation or safety standards that include safety requirements and test methods for either mounting infant safety seats on a bicycle or cargo bikes or for any other infant seat system which is intended to be mounted on a bicycle or cargo bike. Moreover, most parents were fully unaware of the dangers and consequences of cycling with infants and assumed that every consumer product sold today on the Dutch market was tested according to strict safety standards. For the majority of consumer products this is true. Yet, due to the lack of knowledge and awareness of Dutch organizations and institutions (e.g. National Institute for Health and Environment (RIVM), the consumer association (consumentenbond), VeiligheidNL), this product segment is barely supervised.

Although I am truly convinced of the safety benefits my design proposal offers in comparison to the current product, the outcome of this graduation project can also considered to be a serious call-to-action to producers, manufacturers and designers: is it ethically acceptable to design and manufacture products without knowing the long-term health risks?

The outcomes encourages further researchers to investigate how to improve health aspects and comfort of infants during travel by cargo bike. This may lead to a revision of current recommendations for infants' suitability for travel by cargo bike, placed in an infant car seat, and also have implications for the design of infant seat systems that emphasize comfort and health.

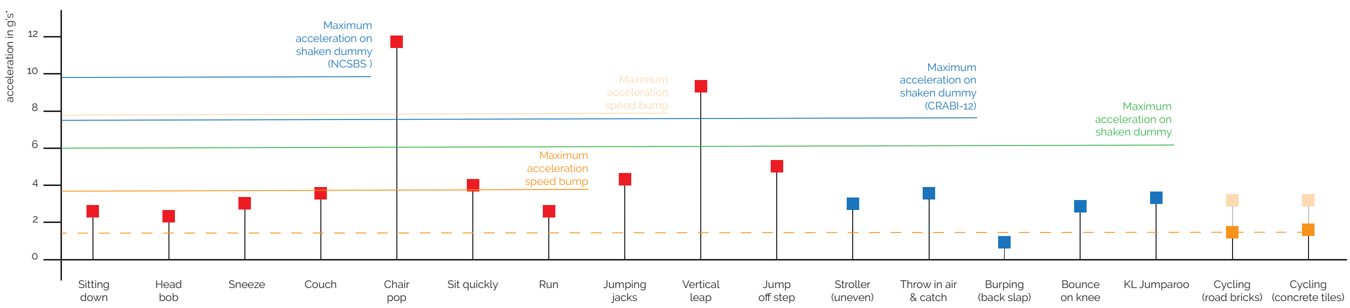


Chart 12: Results of the new prototype configuration added to the original daily activities chart (Chart 4). Showing the average r.m.s. values of the new prototype configuration for road bricks and concrete tiles (in orange) and the maximum measured acceleration when cycling over a speed bump. The orange blocks with low opacity show the initial values of the Steco Baby Mee.

Figure 147: Context photo. Infant placed in an infant safety seat. The infant safety seat is attached to the design proposal. Permission to publicate granted by the parents.


BeSafe
BeSafe

Figure 148: Context photo. Cycling with an infant on a cargo bike (Cangoo Scoobi). Permission to publicate granted by the parents.


Cangoo

8 Recommendations

During the graduation project several aspects about the design proposal were not fully developed. This section provides recommendations that need to be addressed in a next prototype.

1. Cost reduction

a. The plastic covers require a large investment. Moreover, none of them are identical. This means that for all four plastic parts (two left, two right), four moulds are needed. The costs can be reduced significantly (factor two) by creating symmetry in the parts itself.
b. The prototype was quoted with a stainless steel material. A standard coated steel could reduce the costs even more.

2. Weight reduction

The prototype weights around 7 kg and can considered to have an over dimensional size. More detailed Finite Element Analysis (FEA) can highlight parts that can be made thinner or locations were material can be removed.

3. Mounting system

A mounting system was proposed in section '6.3 Mounting'. The ease of which the mounting system can be installed is strongly dependent on the weight of the construction. A heavy weighted construction will negatively affect the ease-of-use. In addition, more elaborated engineering and FEA is needed to assess the rigidity of the mounting system in the event of a collision.

5. Construction play

The prototype construction was optimized with custom-made plain bushings and hexagon socket head shoulder screws with a precise diameter of 8mm. The tolerance between each pivot point was in the range of +0.1 mm to +0.15 mm. This tolerance still resulted in some construction play. Construction play might affect how precisely the system reacts to vibrations. Moreover, due to construction play, the plastic covers might not nicely slide past each other.

6. Lateral stiffness

The prototype barely damped roll and side-to-side motions. Cancelling body roll and side-to-side motions greatly eliminates head toss and reduces cornering g's, as the cargo bike rocks side-to-side. For future research, cancelling body roll might be worth investigating.

7. Usage

The infant safety seat can be released from the car seat adapters by pressing two spring-loaded buttons (appendix 49). However, space limitations, the heavy weight and the lack of a proper grip make this operation fairly uncomfortable. One way of improving this operation could be adding a (spring-loaded) press button or toggle to the car seat adapter itself.

For future development, I suggest drawing more emphasis into the user scenario.

8. Design for Assembly (DfA)

Little attention has been paid to optimizing the design proposal in terms of assembly and disassembly. Improving for DfA can lower labour costs and increase lead times. Appendix 50 provides an illustration of aspects that can be improved for DfA.

9. Progressive rate spring or dual rate spring

When optimizing for comfort during periodic vibrations, a relative soft spring rate is desirable: it increases the ratio between fd/fn and, therefore, decreases the vibrational transmissibility. When optimizing for comfort during transient vibrations (e.g. speed bump), a slightly harder spring rate is desirable: the spring must be stiff enough to withstand the forces that depend on the velocity and, thus, to prevent bottoming. In appendix 46 it can be found that the peak values are lower when using a spring rate of 3.67 N/mm, as compared to the spring rate of 2.67 N/mm that was used for optimizing comfort during period vibrations.
As a consequence, linear rate springs (as used in this graduation project) are less suitable. A progressive rate spring or dual rate spring might be a suitable alternative (Figure 149). Figure 149 specifies the spring characteristics of a dual rate spring based on the test results. Yet, more research is needed to accurately specify the needed spring characteristics.

10. Damping close to the source of vibration

In cars, vibrations are damped at the wheels, relatively close to the source of vibration. In addition, by damping at the wheels, the whole mass of the car contributes to optimizing the right handling and ride quality settings.
In the design proposal, the infant safety seat is damped after the source of vibration. As a result, the mass is low, making it more difficult to select the spring rate settings that satisfies both the lightest and heaviest possible weight. The box of the cargo bike can easily weigh 20 kg, with children the total weight of the box can easily reach 50 kg. The added mass increases the ratio between fd/fn and, therefore, decreases the vibrational transmissibility.
It might be worth investing whether there are possibilities to simply implement a suspension system at the source of vibration: the wheels.

11. Requirement 7.3

Requirement 7.3 set a value for the vibrational transmissibility that had to be obtained, assuming a floor

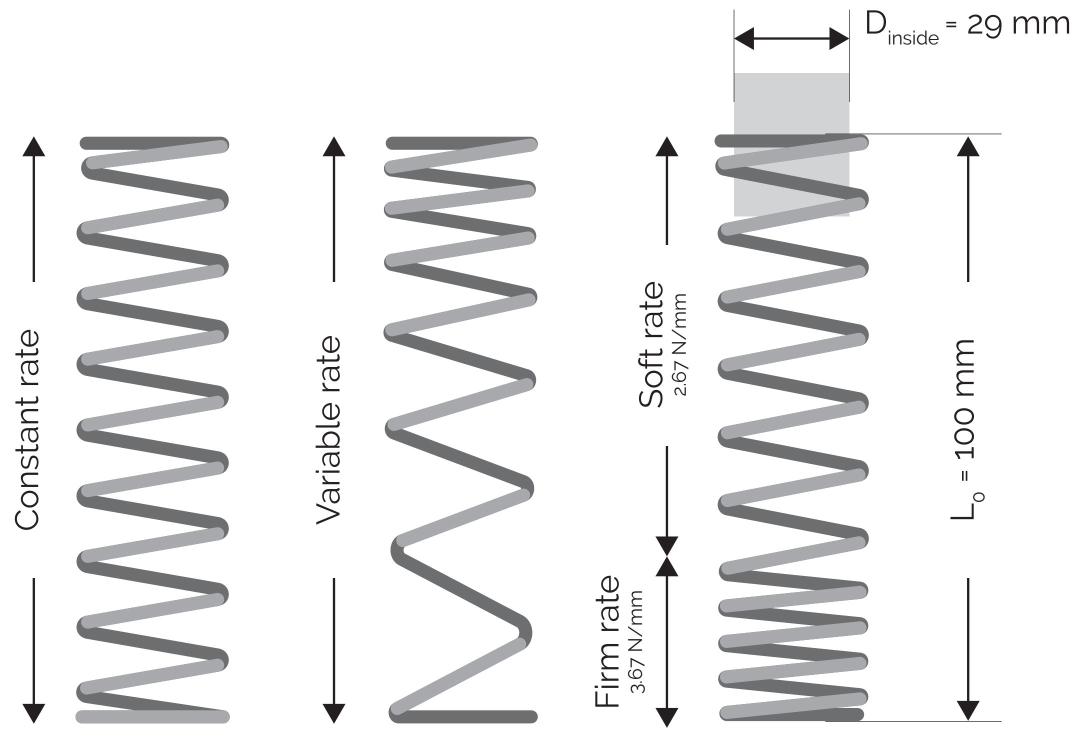


Figure 149: Three types of springs: constant (left), variable (middle) and dual (right). The values indicated in this figure specifies a possible spring setting.

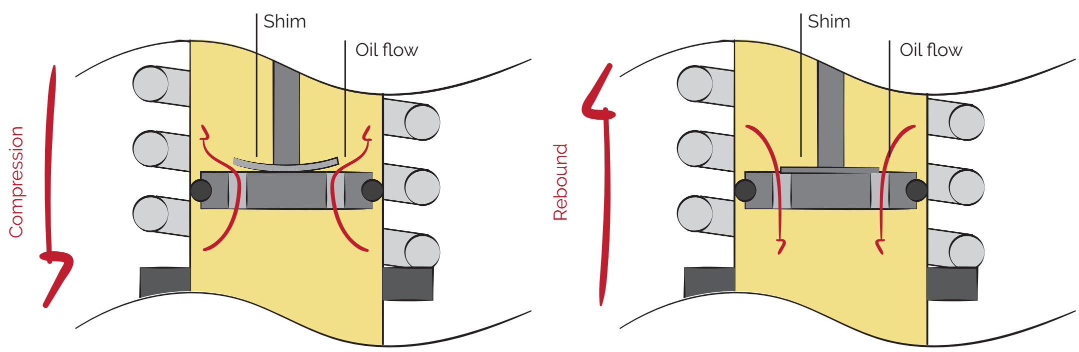


Figure 150: Flow for a shock absorber with shim valve. In compression, the shim bends, enabling oil to flow easily. In rebound, the shim is pushed against the piston. As a result, the shim (partially) blocks the orifice holes to create a higher damping ratio.

excitation r.m.s. value of 3.5 m/s2. However, the floor excitation value can greatly differ per road surface and cycling speed, making this requirement less useful. For health risk aspects and comfort it is better to compare the absolute r.m.s. acceleration values.

12. Compression and rebound

The used damper has the same damping ratio for the compression and rebound movement. In reality, it is more desirable to have a lower damping ratio in compression and higher damping ratio in rebound (around ratio 1:3). Shims placed on one side of the piston (Figure 150) can affect the compression or rebound movement of oil passing through the orifices, depending on their arrangement. A shim valve is relatively easy to set up accurately with consistent results.

13. Width of the construction and the covers

The seat system fits in the box of a three-wheeled cargo bike as set in requirement '16.1 Size'. However, the seat system including the covers was too wide to be placed in a two-wheeled cargo bike.

The covers require substantial space to slide past each other. Without the covers, the seat system is 1.5 times less wide.

Moreover, since the shock absorber is positioned in between each suspension frame, the diameter of the shock absorber has a large influence on the total width of each suspension frame. To reduce the total width of the construction, it is desirable that the diameter of the shock absorber is as small as possible without effecting the functionality of the system. One side, however, is that when the cylinder diameter decreases, the piston area decreases as well. Consequently, the force decreases (Force = pressure x area). To maintain the same damping characteristics, the differences in operating pressure needs to be increased. This is done by optimizing the orifices hole diameters and quantity.

Further development should look at possibilities to decrease the width, enabling the design proposal to be placed in two-wheeled cargo bike as well.

9 Reflection

The thesis was the final project of the master program Integrated Product Design at the Faculty of Industrial Design Engineering at the Technical University of Delft. Reflecting on this graduation project challenged me to strengthen my understanding of designing. I have experienced both positive and negative feelings by multiple phases throughout the project. Overall, I am very satisfied with the outcome of the graduation project. I identified a relevant and topical design problem and was able to translate this problem into a feasible design proposal.

Engineering-centered design process

In my opinion the graduation project was too much engineering-centered. Already from the ideation I experienced difficulties with the vibrational theory and how to bring this theory to practice. Due to the identified vibrational health risk aspects and concerns with cycling with infants and, thus, the need for a 'vibration-free solution', I was forced into a possition I did not feel comfortable with.

One of my strengths as product designer is identifying unexplored or immature industries and search fields. That's what I am good at. Yet, the heavy task of understanding, processing and implementing theories that were necessary to solve the design problem led to stress, fatigue and anxiety. As a consequence, I tried to bypass the vibration theory to some extent during the ideation and tried to create a whole new spring-damper element myself (e.g. casting rubber damping balls). However, creating a spring-damper element requires significant knowledge, experience and time. Investing more time in to understanding the theory beforehand, would have saved me a lot of time.

Furthermore, spending the vast majority of time into engineering and testing led to the consequence that several requirements with respect to usage, size, Design for Assembly (DfA) and design strategy did not receive sufficient attention. Yet, these aspects of design have a great influence on the feasibility of the design proposal.

Specifying a damper: an immensely complex task

The full specification of a damper can be immensely complex, covering all the dimensional data, plus solid material specifications, manufacturing methods, liquid specifications, gas pressurisation, and performance specifications with tolerances (Dixon, 2007). Moreover, according to Marco Amabili, Research Chair Professor at the Department of Mechanical Engineering at the McGill University (Canada), experimental data are necessary for that component (the damping coefficient) or something similar installed in similar conditions (Amabili, 2018). Otherwise numbers are really fantasy.

It was extremely difficult to find formulas that model damping realistically, and even more difficult to find values for the damping parameters. The outcome of the graduation project was mainly based on basic vibrational theory and equation and trail-and-error.

Ethically acceptable

One of my task as product designer is to make the world safer, according to my best intentions. Therefore, I believe it is very reasonable to ask yourself whether it is ethically acceptable to design and manufacture products without knowing the long-term health risks. It was a serious wake-up call and I became aware of the fact that the highest priority of many products is profit, without seriously having taken into consideration the user and his or her physical or psychological limits.

Prototyping: think simple, fast and agile

During the project I spent significant time into prototyping. This is an absolute necessity in a design process. My supervisors providing me with supportive feedback and prototyping resources. With some design iterations, I wanted to make use of additive manufacturing and laser cutting techniques to quickly. In stead of thinking how a part could be made easily, I immediately tried to think in possibilities of additive manufacturing and laser cutting. Yet, I needed to think simple: "which materials and tools can I use right now, at this exact moment, for this job?".

Lack of recourses and references

This graduation project was a unique study — the first to look at the effect of vibration on infants placed in a car safety seat while travelling by cargo bike. As a consequence, recourses (e.g. scientific studies) could barely be found. Also a first search in the medical literature did not yield any results and suggest that information concerning vibrational comfort of infants is scare.

The lack of resources and references made it very difficult to assess the qualities and limitations of the outcome of the graduation project. In addition, it raised questions regarding the reliability of the results.

”

This graduation project was a unique study — the first to look at the effect of vibration on infants placed in a car safety seat while travelling by cargo bike.

Reference list

1. Abdelghaffar, A., Hendy, A., Desouky, O., Badr, Y., Abdulla, S., & Tafreshi, R. (2014). Effects of Different Tire Pressures on Vibrational Transmissibility in Cars, (145), 1–7.

2. Abercromby, A. F. J., Amonette, W. E., Layne, C. S., McFarlin, B. K., Hinman, M. R., & Paloski, W. H. (2007). Vibration exposure and biodynamic responses during whole-body vibration training. Medicine and Science in Sports and Exercise, 39(10), 1794–1800.

3. Allsecur. (2018). Smartphonegebruik grootste ergernis in het verkeer. Retrieved November 5, 2018, from https://pers.allsecur.nl/smartphonegebruik-grootste-ergernis-in-het-verkeer/

4. Alsanea, M., Masuadi, E., & Hazwani, T. (2018). Use of child restraint system and patterns of child transportation in Riyadh, Saudi Arabia. PLoS ONE, 13(1), 1–9.

5. Araki, T., Yokota, H., & Morita, A. (2017). Pediatric Traumatic Brain Injury: Characteristic Features, Diagnosis, and Management. Neurologia Medico-Chirurgica, 57(2), 82–93.

6. Archer, W. (2011). Whole-body vibration: causes, effects and cures.

7. Bankar, V. K., & Aradhye, A. S. (2016). A Review on Active, Semi-active and Passive Vibration Damping, 6(6), 2187–2191.

8. Bhatt, P. (2009). Maximum Marks Maximum Knowledge in Physics. Allied Publishers.

9. Blumenthal, I. (2009). Shaken Baby Syndrome. Postgrad Med J 2002;78:732–735, 106(13), 732–735.

10. Bouton, S., Knupfer, S. M., Mihov, I., & Swartz, S. (2015). Urban mobility at a tipping point. Retrieved December 3, 2018, from https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/urban-mobility-at-a-tipping-point

11. Bovenzi, M. (2006). Risks of Occupational Vibration Exposures Annex 21 to Final Technical Report. Health (San Francisco).

12. Brockmann, M. (2009). Basics of Baby's Anatomy. Retrieved August 10, 2018, from http://www.babywearingadvice.co.uk/anatomy.htm

13. Brüel & Kjær. (1982). Measuring Vibration, 1–40

14. Brüel & Kjær. (1989). Human Vibration.

15. CBS. (2018). 4 procent lopend naar het werk. Retrieved December 3, 2018, from https://www.cbs.nl/nl-nl/nieuws/2018/14/4-procent-lopend-naar-het-werk

16. Cenziper, D., Schroeder, L., Bollag, S., & Zambelli, A. (2015, March 20). A disputed diagnosis imprisons parents - Shaken Science.

17. Cleays, S., De Barba, A.-V., & Degand, P. (2008). Fietsers en de Wegcode.

18. Creative Mechanisms. (n.d.). The Benefits of Aluminum Mold Tools For Injection Molding. Retrieved October 16, 2018, from https://www.creativemechanisms.com/blog/aluminum-mold-tools-for-injection-molding

19. Cyberman Education Page. (2002). Vibration Damping. Retrieved August 10, 2018, from http://www.mfg.mtu.edu/cyberman/machtool/machtool/vibration/damping.html

20. DaCoTA. (2012). Children in road traffic, Deliverable 4.8c of the EC FP7 project DaCoTA.

21. Daschütz, P. (2006). Flächenbedarf , Freizeitmobilität und Aktionsraum von Kindern und Jugendlichen in der Stadt.

22. dB Engineering. (2017). Shock and Isolation Selection, 51–66.

23. Deun, M. (2016). Improving Traffic Safety For Dutch Cyclists.

24. El Sayed, M., Habashy, S., & El Adawy, M. (2012). Evaluation of Whole-Body-Vibration Exposure to Cairo Subway (Metro) Passengers. Global Advanced Research Journal of Engineering, Technology and Innovation, 1(7), 168–178.

25. Enidine. (n.d.). About Industrial Shock Absorbers | Benefits of Shock Absorbers. Retrieved October 17, 2018, from https://www.enidine.com/en-US/Resources/Industrial-Shock-Absorbers/

26. European Transport Safe Council. (2010). Reducing Child Deaths on European Roads, (1), 1–16.

27. Fabreeka. (2011). Vibration and Shock Isolation Theory.

28. Fagerholm, N., & Broberg, A. (2011). Mapping and characterising children's daily mobility in urban residential areas in Turku, Finland. Fennia, 189(2), 31–46.

29. Fahy, F., & Walker, J. (1998). Principles of Passive Vibration Control: Basics. In Fundamentals of Sound and Vibrations. New York.

30. Fietsersbond. (2009). Trillingshinder: cijfers over slechte verharding van fietspaden. Retrieved August 9, 2018, from https://www.fietsersbond.nl/nieuws/trillingshinder-cijfers-over-slechte-verharding-van-fietspaden/

31. Fietsersbond. (2016). Hoeveel wordt er gefietst in Nederland? Alle cijfers op een rijtje. Retrieved November 5, 2018, from https://www.fietsersbond.nl/ons-werk/mobiliteit/fietsen-cijfers/#.Vflx_

32. Fitzpatrick, K., Ullman, B., & Trout, N. (2003). On-Street Pedestrian Surveys of Pedestrian Crossing Treatments, 250.

33. Foundation for Economic Education. (2006). How Public Transit Undermines Safety. Retrieved November 5, 2018, from https://fee.org/articles/how-public-transit-undermines-safety/

34. Gallahue, D. L., Ozmun, J. C., & Goodway, J. (2012). Understanding Motor Development: Infants, Children, Adolescents, Adults (7th editio). New York: McGraw-Hill.

35. Giacomin, J. A. (2002). an Experimental Investigation of the Vibrational Comfort of Child Safety Seats (Vol. 22).

36. Giacomin, J. A., & Gallo, S. (2003). In-Vehicle Vibration Study of Child Safety Seats.

37. Gilles, E. E., & Nelson, M. D. (1998). Cerebral complications of nonaccidental head injury in childhood. Pediatric Neurology, 19(2), 119–128.

38. Grotenhuis, ten, L. (2018). Je baby meenemen op de fiets. Retrieved December 3, 2018, from https://www.consumentenbond.nl/fietsstoeltje/fietsen-met-je-baby

39. Guinness, A. Mac. (2014). Design, Modelling and testing of a Forklift seat suspension system.

40. Hall, D. E., & Boydston, W. (1984). Pediatric neck injuries. Journal of Neurosurgery, 60(4), 700–706.

41. Holterman, J., & de Vries, T. J. A. (2001). A Comparison of Passive and Active Damping Methods based on Piezoelectric Elements, 4.

42. Huelke, D. F. (1998). An Overview of Anatomical Considerations of Infants and Children in the Adult World of Automobile Safety Design, 93–113.

43. Jayawant, S., Rawlinson, A., Gibbon, F., Price, J., Schulte, J., Sharples, P., … Kemp, A. M. (1998). Subdural haemorrhages in infants: population based study.

44. Jordan, W. C., Burns, L. D., & Scarborough, B. A. (2013). Transforming Personal Mobility. Retrieved from http://wordpress.ei.columbia.edu/mobility/files/2012/12/Transforming-Personal-Mobility-Aug-10-2012.pdf

45. KOAC WMD. (2002). Verhardingskeuze voor fietsverbindingen : asfalt , beton of tegels?.

46. Korane, K. (2016). Industrial shock absorbers: The sizing process. Retrieved October 12, 2018, from https://www.fluidpowerworld.com/size-industrial-shock-absorbers/

47. Limbourg, M. (2010). Prävention in NRW. Kinder unterwegs im Straßenverkehr.

48. Lloyd, J., Willey, E. N., Galaznik, J. G., Lee, W. E., & Luttner, S. E. (2011). Biomechanical Evaluation of Head Kinematics During Infant Shaking Versus Pediatric Activities of Daily Living. Journal of Forensic Biomechanics, 2, 1–9.

49. Mackett, R. L. (2013). Children's travel behaviour and its health implications. Transport Policy, 26, 66–72.

50. Mansfield, N. J. (2005). Human response to Vibration. CRC Press.

51. Matus, J., & Heck, S. (2015). Understanding The Future Of Mobility. Retrieved December 3, 2018, from https://techcrunch.com/2015/08/08/understanding-the-future-of-mobility/

52. Mavic. (2016). The Phenomenon of Vibration in Cycling: the Ortholite Solution. Retrieved August 10, 2018, from http://engineerstalk.mavic.com/en/the-phenomenon-of-vibration-in-cycling-the-ortholite-solution/

53. Mayo Clinic. (2017). Shaken baby syndrome - Symptoms and causes. Retrieved August 9, 2018, from https://www.mayoclinic.org/diseases-conditions/shaken-baby-syndrome/symptoms-causes/syc-20366619

54. Mccaslin, S. (2017). Composite Bushings & Bearings: 3 Benefits. Retrieved December 3, 2018, from http://www.bearing-news.com/composite-bushings-bearings-3-benefits/

55. Mens en Gezondheid. (2016). Motorische ontwikkeling - Wat kan 'n kind op welke leeftijd. Retrieved December 3, 2018, from https://mens-en-gezondheid.infonu.nl/kinderen/26174-motorische-ontwikkeling-wat-kan-n-kind-op-welke-leeftijd.html

56. Metronieuws. (2016). Deze irritante fietstypes herkent iedereen. Retrieved November 5, 2018, from https://www.metronieuws.nl/nieuws/binnenland/2016/04/deze-irritante-fietstypes-herkent-iedereen

57. Mobiel21. (2010). Op pad met fiets en kids, i, 1–44.

58. Moskvitch, K. (2015). How to get a city cycling. Retrieved December 3, 2018, from http://www.bbc.com/future/story/20150324-how-to-get-a-city-cycling

59. Moura, A. (2017). The future of transportation is already here. Retrieved December 3, 2018, from https://ideas.ted.com/the-future-of-transportation-is-already-here/

60. National Highway Traffic Safety Administration. (2007). Share the Road With Motorcycles, (February), 2007.

61. Nederlands Normalisatie instituut. (1997). NEN-ISO 2631-1, (01 5).

62. Nederlands Normalisatie instituut. (2002). NEN-EN 14344, 14344.

63. Nilson, G. (1997). Methods and necessity of exposure data in relation to accident and injury statistics, IRTAD Special report. IRTAD Special report.

64. Nilsson, M. (2005). Health risk aspects and comfort of infants in infant seats for cars. VTI notat (Vol. 24).

65. Pierce, D. (2016). It's Too Bad Electric Scooters Are So Lame, Because They May Be the Future. Retrieved December 3, 2018, from https://www.wired.com/2016/01/electric-scooters-uscooter-future/

66. Planetizen. (2016). Bicyclists on Sidewalks: Why They're Not Going Away, and What We Can Do About It. Retrieved November 5, 2018, from https://www.planetizen.com/node/84910/bicyclists-sidewalks-why-theyre-not-going-away-and-what-we-can-do-about-it

67. Porter, B., Linse, M., & Barasz, Z. (2015). Six Transportation Trends That Will Change How We Move. Retrieved December 3, 2018, from https://www.forbes.com/sites/valleyvoices/2015/01/26/six-transportation-trends-that-will-change-how-we-move/#56f54d7466a4

68. Prasad, M. R., Ewing-Cobbs, L., Swank, P. R., & Kramer, L. (2002). Predictors of outcome following traumatic brain injury in young children. Pediatric Neurosurgery, 36(2), 64–74.

69. QA1. (n.d.). Street Performance & Racing Spring Rate Tech. Retrieved October 8, 2018, from https://www.qa1.net/technical-support/street-performance-racing-spring-rate-tech

70. RAI vereniging. (2018). Feiten en cijfers - Fietsen 2018.

71. Rogers Corporation. (2012). Materials Design : Vibration Isolation and Damping , the Basics, 1–7.

72. Safety.com. (2017). Distracted Walking: Common Risks & Tips to Stay Safe. Retrieved November 5, 2018, from https://www.safety.com/distracted-walking-a-major-pedestrian-safety-concern/#gref

73. Seidel, H., & Heide, R. (1986). Long-term effects of whole-body vibration: a critical survey of the literature. International Archives of Occupational and Environmental Health, 58(1), 1–26.

74. Shaw, B., Bicket, M., Elliott, B., Fagan-Watson, B., Mocca, E., & Hillman, M. (2015). Children's Independent Mobility: an international comparison and recommendations for action. Policy Studies Institute.

75. Showa Corporation. (n.d.). Shock Absorbers - Rear cushions. Retrieved October 16, 2018, from https://www.showa1.com/en/product/motorcycle/shock_absorber_r.html

76. Sinicropi, S. (2016). Infant Spine Development - From The “C” Curve to the “S” Curve. Retrieved August 10, 2018, from https://sinicropispine.com/infant-spine-development-c-curve-s-curve/

77. SP-werkgroep ZuidhornHorn. (2015). Veilig verkeer in de gemeente Zuidhorn.

78. Sucha, M. (2016). Road Users - Traffic Psychology 1 PCH/DP1. Department of Psychology.

79. SWOV. (n.d.). SWOV Publications - topics Transport Mode. Retrieved November 5, 2018, from https://www.swov.nl/en/publications/swov/type/factsheet/topics/transport-mode

80. SWOV. (2009). SWOV Fact sheet Road safety of children in the Netherlands. Statistics. Retrieved from https://www.swov.nl/sites/default/files/publicaties/gearchiveerde-factsheet/uk/fs_children_archived.pdf

81. SWOV. (2010). SWOV Fact sheet - Vulnerable road users, (November), 1–5.

82. SWOV. (2012). Risky traffic behaviour among young adolescents. Leidschendam.

83. SWOV. (2012). SWOV Fact sheet - Blind spot crashes, (December), 1–6.

84. Thomas. (n.d.). General Types of Bearings and How They Work. Retrieved October 14, 2018, from https://www.thomasnet.com/articles/machinery-tools-supplies/bearing-types

85. Tilley, A. R. (2001). The Measure of Man and Woman: Human Factors in Design, Revised Edition.

86. Toolcraft Plastics. (n.d.). Vacuum Forming Design Advice Guide. Retrieved October 16, 2018, from https://www.toolcraft.co.uk/vacuum-forming/advice/advice-vacuum-forming-design-guide.htm

87. UNECE. (2006). Safety of pedestrians. Revision of the Consolidated Resolution R.E.1.

88. VeiligheidNL. (n.d.). baby op de fiets. Retrieved November 6, 2018, from https://www.veiligheid.nl/kinderveiligheid/op-de-fiets/mee-op-de-fiets/baby-op-de-fiets

89. Voorthuizen, A. van. (2003). Hoe vervoer je een baby in een fietskar? Retrieved November 6, 2018, from https://www.fietsersbond.nl/onderweg/kinderen-mee-op-de-fiets/hoe-vervoer-je-een-baby-in-een-fietskar/

90. WHO | Definition of key terms. (2013). WHO. Retrieved from https://www.who.int/hiv/pub/guidelines/arv2013/intro/keyterms/en/

91. Wieckowski, D. (2013). Frequency analysis of vertical vibrations acting on a baby transported in a child car seat

92. WIRED. (2017). The Best Cycling Cities on the Planet. Retrieved November 5, 2018, from https://www.wired.com/story/world-best-cycling-cities-copenhagenize/

93. Zasler, N. D., Katz, D. I., & Zafonte, R. D. (2007). Brain Injury Medicine: Principles and Practice. Demos.