EVOLUTION

Handbike

Appendix

Development of an attachable handbike

Suyanto Ten-Jet-Foei

Appendix A

Project assignment

Title graduation project: **Handbike for existing wheelchairs**

Student name : Suyanto Ten-Jet-Foei

Chair supervisory team : Ir. Joost F. Prins
Department/section : DE / PE
Mentor of supervisory team : Ir. Iemkje A. Ruiter
Department/section : AED

Company name : Van Raam BV
Country : Netherlands
Company mentor : Jan-Willem Boezel
Start date : February 2009
End date : July 2009

Introduction:
Van Raam BV is located in Varsseveld and is a specialized bicycle producer for people with a disability. Van Raam makes people mobile with specialized and unique bicycles like tandems, wheelchair bikes, tricycles and comfort bikes. The whole production process from development till assembly is done in house, so they can control and adjust designs to customer needs. Van Raam would like to tackle the next step into the future by expanding their product assortment by developing a new "Handbike" (by hand driven transmission system for comfortable and faster movement) which is easy to mount on and off on wheelchairs.

Problem definition:
Wheelchair users like to be more accessible, agile and move more comfortable and faster. To fulfill this need handbikes where integrated on three wheeled low cycle which is used for racing. However recreational wheelchair users would like to use a handbike in traditional seating position. Existing handbikes are difficult to couple on and off while maintaining a proper balance. The current mounting system of competitors is too complicated and the handbike designs don't match with the wheelchair looks.

Assignment:
Develop a handbike for existing wheelchairs which allows the user to clamp on a handbike attachment, without assistance, while staying seated in the chair.

- The handbike attachment should not require tools and should take less space in storage.
- The handbike must be easy and convenient to handle and fast to assemble by the users, so users instantly can transform the typical everyday wheelchair into a road-ready handbike.
- The handbike should have the possibility to be driven by an electric engine.
- The appearance of the current Handbikes is old fashioned and need to fit current wheelchair designs, so it becomes attractive to users and differentiate itself from competitors.

Results:

- A final report containing a detailed product design
- A working prototype to prove the product design the principle
- A prototype that will be evaluated by a user study
- A poster presentation
- An oral presentation

Planning graduation project:

Orientation: *3 weeks*

- Exploring the subject (PFG course), problem definition
- Visit stakeholders, compare products & techniques, internet research topic
- Assignment formulation and project planning

Result: Assignment formulation*, planning*

Analysis phase: *2 weeks*

- Product analysis, trends and techniques
- Existing methods, production methods and available materials
- User research (needs and abilities of user group), interviews, observation
- Program of demands

Result: design guidelines

Concept development: *4 weeks*

- Idea generation (sketching)
- Concept development

Result: 3 concepts

Concept testing *3 weeks*

- Elaborate each concept
- Concept choice

Result: design proposal

Optimalisation *4 weeks*

- Concept detailing
- Computer modeling
- Materializing

Result: detailed design

Prototype *2 weeks*

- Prototype building

Result: working prototype

Usability testing *2 weeks*

- Test prototype with users for feedback
- Apply improvements to final design

Result: recommendation and improvements

Completion *3 weeks*

- Report
- Evaluation
- Presentation, poster

Result: final report, presentation, poster

Appendix B

Van Raam & Welzorg

Van Raam

Some common products of Van Raam assortment

	**Tavara Balance, comfort bike** The balance is a comfortable and safe bicycle. Because of better forward pedal force the power of the legs can be used efficient. When the user is not cycling the feet can touch the ground. By the unique sitting posture the wrist, neck and shoulders are not overloaded.
	**Velo plus 2** This is a wheelchair bike where the user stay in a wheelchair and can be cycled around by parents or friends. The wheelchair can be rolled on the plate and fixed. This is appropriate for institute and nursery homes.
	**O-pair 2** Wheelchair bicycle to cycle the user around. The opair is easy to dismantle and transport to different environments.
	**Fun2go** Independent cycling with partner, child or friend. Easy get on and off. Comfortable seat posture and adjustable for individual needs
	**Easy sport** Sportive, recreational, comfort bicycle. With the ergonomically shaped seat the user has an optimal support in the back. Technical and design in one bicycle which can be adapted to individual needs.

	**Double rider** Independent cycling with partner, child or friend. Easy get on and off. Comfortable seat posture and adjustable for individual needs
	**Easy rider** The easy rider is a modern shaped tricycle which has a comfort seat which supports the back of the user. The pedal movement is forward and has some of a sportive comfort bicycle.
	**Walking frame** Support user with walking longer distances. This walking frame is foldable and lightweight.
	**Maxi** This tricycle is easy to get on and maintain balance. This tricycle is comfortable and easy to add groceries at the back.
	**Husky** Tricycle for children who have problems with stability. The safety is important and the cranks are positioned straight under the seat so the child is pedaling in a straight line downwards.

Overview products Welzorg

	**Manual wheelchairs** • Manual wheelchair for inside with short turning circle • Sport wheelchairs with fixed frame which are lightweight. • Foldable wheelchairs which are compact and adjustable • Push wheelchairs for users who can't propel them self.
	**Electric wheelchair** For people who are not able to use physical strength and still would like to be independent. 3 types • inside • inside-outside • outside
	**Electric scooter** Practical solution for people who have problems with walking. Ideal for on the road to do independent groceries.
	**Bikes** Children, electric, tandems, tricycles for several people who like to be active and can't cycle independent.
	**Children support products** Move, play and investigate products for children which makes their life easier by support products.
	**House conveniences** For people who life independent and need products like stair elevator, chair for the bed or bath room etc.

Appendix C

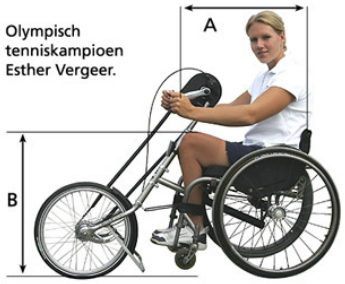
Competitors

The Dutch market of special bicycles is dominated by Dutch manufacturers. This is because they can adapt the products to the specific needs of the customers. The manufacturers have a better relation with revalidation centers and dealers. The bicycles are often very functional and basic because they have to fulfill the needs of the Dutch laws so the products can be subsidized. One direct competitor of Van Raam is Roam which not only sells similar products like wheelchair transporters, tandems, double riders but also several handbikes.

ROAM

Roam develop and produce in house handbikes, tricycles, tandems and wheelchair bikes, which makes them flexible. They deliver products to bicycle dealers and Welzorg. The advantage of this handbike manufacturer is that its design is back to basic and suits the WMO law of price and quality. Only for the eye it's not very appealing. In their assortment they have three types of handbikes:

Runner handbike



Runner handbike klickfix

Racer handbike

TNS Rijen, Freewheeler

This Dutch manufacturer of wheelchairs and handbikes is aiming for the improving the lifestyle of wheelchair users. They push their designs to the extreme and makes handbikes custom fit for every wheelchair.

Double performance, Tracker

Double performance is specialized in products for the individual wheelchair user. They sell high end sport wheelchairs and handbikes. They aim for the athlete and their product assortment is adapted to that goal. They have handbikes with bullhorn cranks, cardan transmission and easy adaptable mounting systems.

Speedy

Speedy Reha-Technik is a handbike manufacturer in Germany which has an unique mounting system and has a deep assortment of handbike variations.

Stricker

Stricker is also a German manufacturer of handbikes and the oldest in Europe. It's unique in its kind because its mounting system is attached to the front fork of the wheelchair and there is no adapter under the wheelchair.

Competence analysis of direct competitors

From the direct competitors speedy is the best handbike according the following company competence.

	Roam	Freewheeler	Tracker	speedy	Stricker
1. Product familiarity	+	-	+	+	+
2. Price/ quality	+/-	+/-	+	+	+
3. Innovation	-	-	+	+	-
4. Flexibility	+	+	+/-	+	+
5. Wide assortment	+	-	-	-	-
6. Deep assortment	-	-	+	+	+
7. In house production	+	+	+	+	+
8. Service	+	+	+	+	+

Other handbike manufacturers:

Alois praschberger

This manufacturer is located in Austria and produces handbikes suitable for in the mountains. These handbikes often use a derailleur. They don't have wide or deep assortment, but also produce winter sport product like sledges and monoskis for disabled people.

PFIFF

This manufacturer from Germany is a similar factory as Van Raam and produces also tricycles, tandems, bicycles and handbikes. They have high quality frames and have one handbike with three different mounting systems.

Pro activ Reha technik

This manufacturer from Germany produces handbikes and wheelchairs. They have one fur adult and one for kids. The design is cnc-designed, detailed, reliable and light weight.

Team hybrid

This manufacture from the UK is specialized in manual, power assist and powered handbikes.

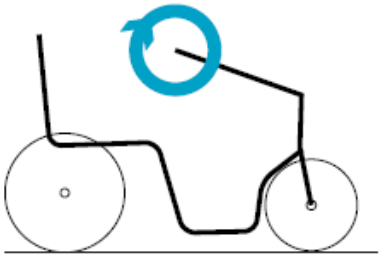
Rio mobility

This manufacturer from America delivers a handbike which is cheap (800 dollars) and need to be assembled by the users.

Appendix D

Handbike analysis

Handbike types



There are two main types of handbikes:

- Attachable "clamp on" handbike
- "Fixed frame handbike"

"Clamp on" handbike

The clamp on handbike is the most inexpensive way to get on the road and start riding. This design allows the user to clamp on the hand bike attachment, while staying seated in his chair, without assistance.

This design transforms the typical everyday wheelchair into a road-ready handbike. The attachment requires no tools and takes less space in storage then traditional hand bikes. The attachment lifts the caster, the front wheels of the wheelchair, slightly of the ground for easier pedalling.

However the everyday wheelchair is not made for long distance transportation and material problems can occur. The road holding will be worst and drag is bigger. Because of this and the high position of the gravity point the purpose of this handbike is for transport and light sport activities. The price is far too high compared with normal bicycles and the advantages of this design are mainly focused on user friendly attachment of the handbike.

"Fixed frame hand bike"

The fixed frame handbikes don't need an attachment to a wheelchair. They have an independent fixed frame with often three wheels. This hand tricycle is only used for sport activities. The design requirements are focussed on gaining high speed and are appropriate for long distance. Speeds up to 60 km an hour can be reached. The most important factor for the sport performance is the position of the user. For example when the user is sitting on his knees, he can also use his upper body to gain pedal force. In this way higher speeds can be gained compared with conventional sitting positions.

Paralympic handbike

For the serious sport handbikers a fixed frame bike is more suitable, because of the low lying position and speeds between 25 and 40 km/h can be reached.
The hand bike without a wheelchair has several riding positions: sitting, on the knees or lying.
For the Paralympics a customized handbike is made for Laura de Vaan by: Infinious, InnoSportNL, TU Delft, KNWU and NOC*NSF. Light weight materials from the aerospace industry are used to make this handbike superior.

Mountain trike

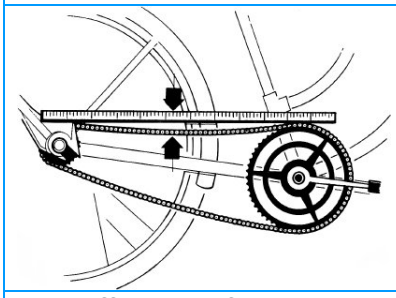
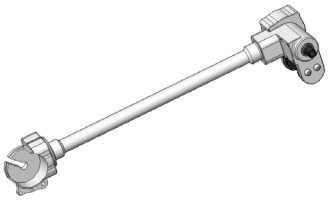
Another handbike type is the off-road handbike which has mountain wheels and a suitable name: mountaintrike.
The difference is that with this handbike the steering is done with two wheels.

Functionality

Handbikes can be used especially by people with a spinal chord lesion. If the person can use a manual wheelchair, riding a handbike is also possible. Even if people have trouble with the propulsion of a manual wheel chair, a handbike can be the solution for transport and exercise. A proper hand function is not necessary to use a handbike. There are several functions for the use of a handbike.

Transport	Training	Recreation
		
The small front wheel and straight cranks makes it possible to have a small turning radius and can be used in supermarkets and public areas.	A relative big wheel and bullhorn cranks makes it possible to have transfer more power with the trunk and higher speeds can be reached.	With the big wheel and derailleur and high sitting position this is the sport edition of the attachable handbikes.
Speed: 12-18 km/h	Speed: 15-25 km/h	Speed: 15-25 km/h

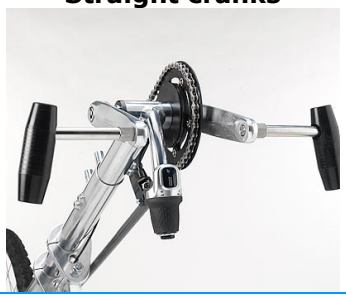
Drive systems

Chain drive	Cardan drive	Belt drive
		
Efficiency of 98,6%	Efficiency of 95 %	Efficiency 70-90%
Advantage	**Advantage**	**Advantage**
• High efficiency • Durable • Available at shops • Easy to replace	• Compactness • Ground clearance • Enclosed drive system • Safe for clothes • Cleanliness • Consistency of performance • Suitable longer drive train • Longevity so stable • Reduced maintenance and repair • Modern look	• No lubrication required • Smoother operation • Longer life then chain • Light weight system • Belt do not rust • More resistance to debris • Quieter than chain • No maintenance
Disadvantage	**Disadvantage**	**Disadvantage**
• Lubricant maintenance • Chain wear or stretch • Need weather protection • Greasy	• Power loss • Complexity • Cost • Gear range • Weight • Changing a flat	• Scarcer at shops then chain • Incorporate plastic components which wear out more quickly then metal • Derailleur can't be used • Can't retrofit to bike frames

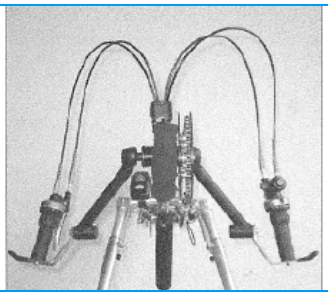
There is also a hydraulic drive possible or a direct gear chain drive system, however these systems are expensive for a handbike. For the most handbikes a chain drive is still the most common applied system because of the efficiency and widely common standard components which can be applied. However the look stays old fashion.

Cranks

The two most common crank styles are standard straight cranks and the bullhorn cranks.

Straight cranks	**Bullhorn cranks**
	
With the straight cranks the user pedals above his knees. In this the user can make sharper turns.	Bullhorn cranks are widely spread and are close to the upper legs. The position of the pedals is next to the upper legs. In this way the user can cycle faster, however with turns the cranks hit the legs faster. With this crank more trunk power can be used so more force can be generated during cycling.
High crank position, Speed: till 20 km/h	Low crank position, Speed: till 30 km/h

There are also V-cranks and U-cranks applied on some hand drive systems.

	
V-cranks	**U-cranks van Raam**

Pedals

Position

The pedals of the handbike are not opposite of each other like normal bicycles. They go up and down simultaneously. In this way more force can be transmitted to the front wheel and less shear force is generated. Also will the front wheel sway less.

Width

The width of the pedals should stand wider out of each other then normal bicycle pedals. This is because of the difference between the shoulder width and the width of the hips.

Straight or skew pedals

Skew pedals are more ergonomic then straight pedals because this prevents wrist injuries, so there is less force on the wrist joint.

Quad pedal
People with limited hand function control don't have enough force to hold the pedal. Here for there are several solution to fix the hand, by maintaining contact during cycling with the crank system.

Gears

The handbikes that are built for speed are using a derailleur system. For handbike that mainly have a transport function have a 7 speed internal hub.
This is because

- The attachable handbike need to pull from starting position and has the change to slip because of less traction between wheel and the ground. There is not enough weight on the front wheel which is been driven.
- With the user of a derailleur system the user need to change gear in front and with a hub gear this can be done in standing position.
- There is a coaster brake possible with the hub gear so the hands can stay on the pedals during cycling
- It is difficult to cycle backwards with a derailleur system.
- The internal hub gear is user friendly and need less maintenance.

Steer correction

The steering correction system prevents the handbike to sway and return to the middle straight position. This is very useful for long distance trips. However it is not very useful when used on handbikes which need to maneuver in small areas.

Freewheel

Just like on a normal bicycle there is a freewheel on the handbike. This means that when the bike is moving forward the pedals stay in the same position. In this way the user can use the wheelchair wheels to maneuver backwards.

Brake

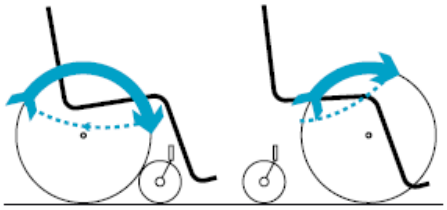
Because the user needs his hand to steer and pedal the most logic and user friendly solution is a coaster brake. The handbikes that are built for speed have a derailleur system so a coaster brake is not possible. A handbrake is mounted on the frame else where.

Materials

The most handbike frames are made from stainless steel tubes or aluminum tubes. One handbike producer "Pfiff freebee" use light-weight Aluminum designed in a multi chamber extrusion profile.

Appendix E

Wheelchair analysis

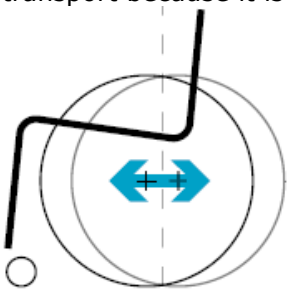


Wheelchair types

For all the different kind of sports with wheelchairs several adjustments are made. In principle there are 3 kinds of wheel chairs:

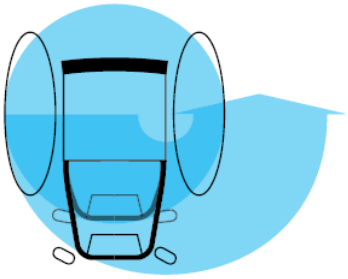
Passive wheelchair

The passive wheelchair is often used for daily used, not a lot of muscle power is needed and the wheelchair is very adaptable in size. It's easy to transport because it is foldable.



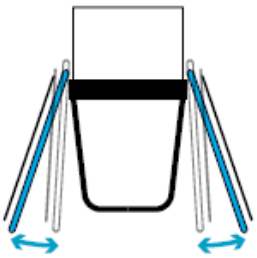
Active wheelchair

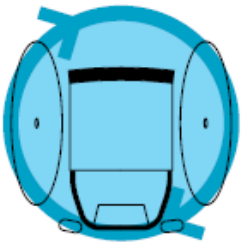
The active wheelchair is often a lightweight fixed frame and the user sits in an active position more to the front and the user can turn faster around the corner because of a shorter wheelbase.



Sport wheelchair

The sport wheelchairs the wheels are placed in a different angle so it's easier to turn fast. There is often also a small wheel at the back which prevents the user to fall backwards.





Wheelchair Components

① Front frame
② Seatmodule
③ Axle tube
④ Rear wheel
⑤ Backrest
⑥ Footrest
⑦ Front wheel

Frame

One of the biggest breakthroughs in wheelchair technology has been the development of new, lightweight materials for wheelchair frames. Whereas stainless steel used to be the only frame material available, wheelchair users today have their choice of stainless steel, chrome, aluminium, airplane aluminium, steel tubing, an alloy of chrome and lightweight materials, titanium, and other lightweight composite materials. The type of material used to construct the frame affects the weight of the frame, and therefore the overall weight of the wheelchair. The type of frame material also can affect the wheelchair's overall strength. The two most common types of frames currently available are rigid frame chairs (where the frame remains in one piece and the wheels are released for storage or travel), and the standard cross-brace frame (which enables the frame to fold for transport or storage).

Upholstery

Upholstery for wheelchairs must withstand daily use in all kinds of weather. Consequently, manufacturers provide a variety of options to users, ranging from cloth to new synthetic fabrics to leather. Many manufacturers also offer a selection of upholstery colours, ranging from black to neon, to allow for individual selection and differing tastes among consumers.

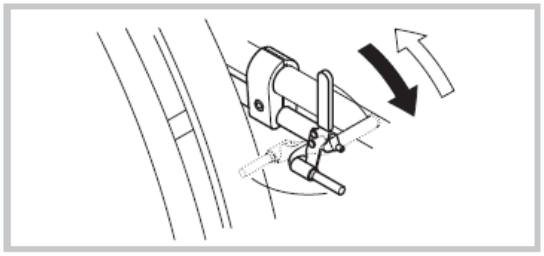
Seating System

Seating systems are sold separately from the wheelchairs themselves, as seating must be chosen on an individual basis. It is important when selecting a wheelchair or a seating system to ensure that the two components are compatible.

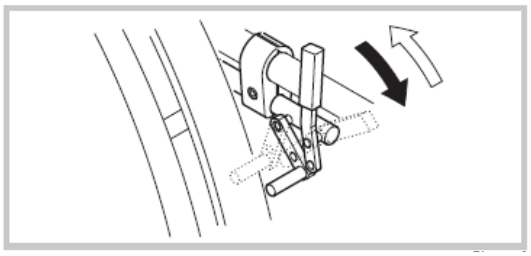
Brakes

"Braking" on a manual wheelchair in use is accomplished by applying the hands on the wheels. However, "parking brakes" (wheel locks) are available in several different designs, and can be mounted at various heights to maximize convenience to the user.

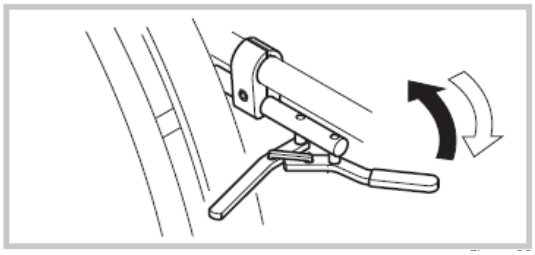
Performance brake



Standard brake



Active brake



Wheels/Tires

Most wheelchairs use four wheels, with two large wheels at the back and two smaller ones (casters) at the front. The standard tire used for the rear wheels on most wheelchairs is a pneumatic tire, for which the standard size is 24 inches. Smaller and larger sizes, however, also are available. Many manufacturers now also offer other types of tires such as solid tires, semi-pneumatic, or radial tires at extra cost. Mag wheels and off road wheels also are options on some chairs. Casters, too, vary in size (ranging from six to eight inches in diameter) and composition (pneumatic, solid rubber, plastic, or a combination of these).

Footrests

For rigid frame chairs, footrests usually are incorporated into the frame of the chair as part of the design. Cross-brace folding chairs often have footrests which swivel, flip up, and/or can be removed.

Armrests

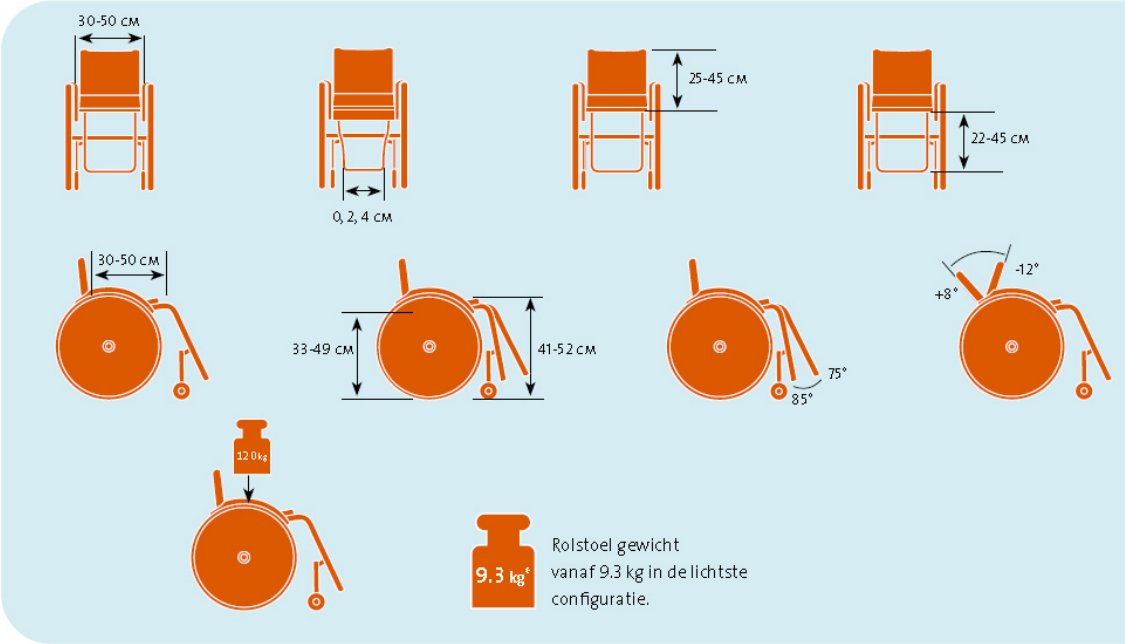
Many lightweight manual chairs are designed to be used without armrests. The absence of armrests makes it easier for the user to roll up to a desk or table, and many active wheelchair users prefer the streamlined look of a chair with no armrests. However, armrests are helpful if the user has difficulty with upper body balance while seated. Armrests come in a variety of styles including desk length (to allow the user closer access to desks and tables) or full length and both types may be flip-up, fixed, or detachable.

Cost of Manual Wheelchairs

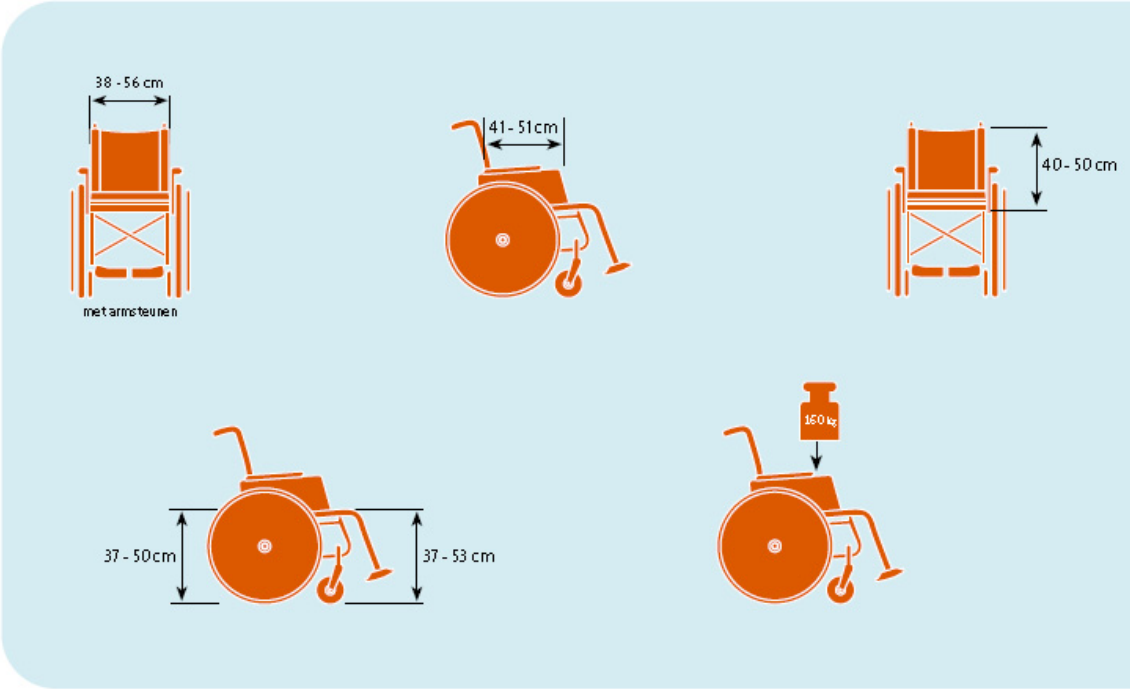
The cost of a manual wheelchair can go from approximately $500 for an institutional chair to more than $4,000 for a customized lightweight wheelchair with "all the trimmings." Most lightweight manual chairs, depending upon the manufacturer, are in the $1,800 to $2,800 range. These figures should not be used, however, to suggest an "appropriate price" for a wheelchair for any specific individual; special accessory needs or customization required to accommodate specific disabilities could put the actual purchase price much higher. Source [10]

Wheelchair dimension range

Fixed frame



Foldable frame



Important measurements

Width frame tube	300-560 mm
Seat height front	370-530 mm
Seat depth	300-510 mm
Tube sizes	18-35 mm

Appendix F

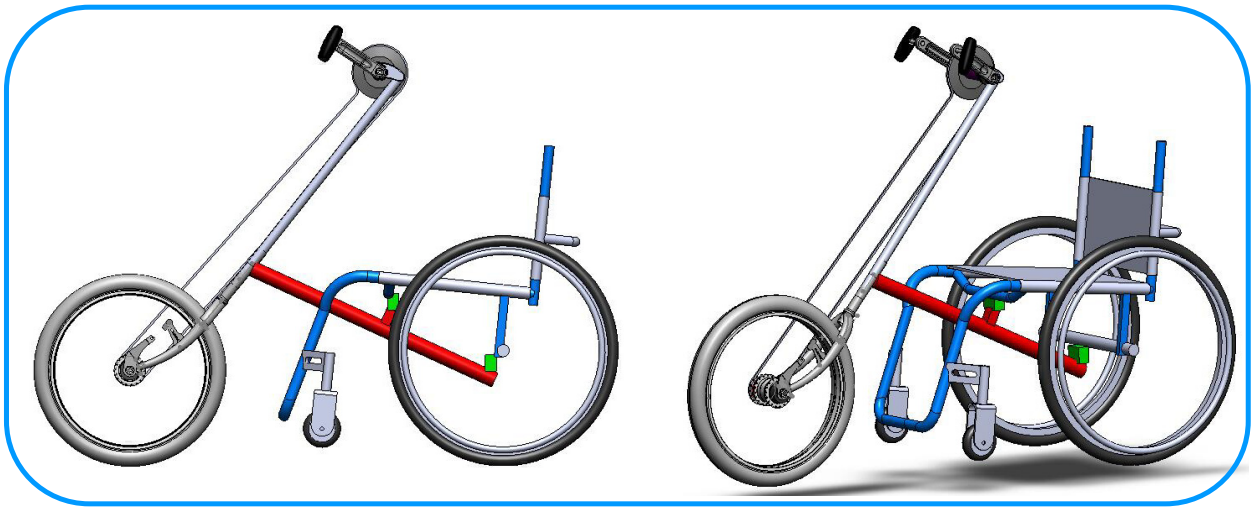
Mounting systems

From the 5 direct competitors from appendix D the mounting systems on the wheelchair are explained. These are also the most common mounting systems on the wheelchair. There are two main differences made for the fixed and foldable wheelchair.

Tracker, Double performance

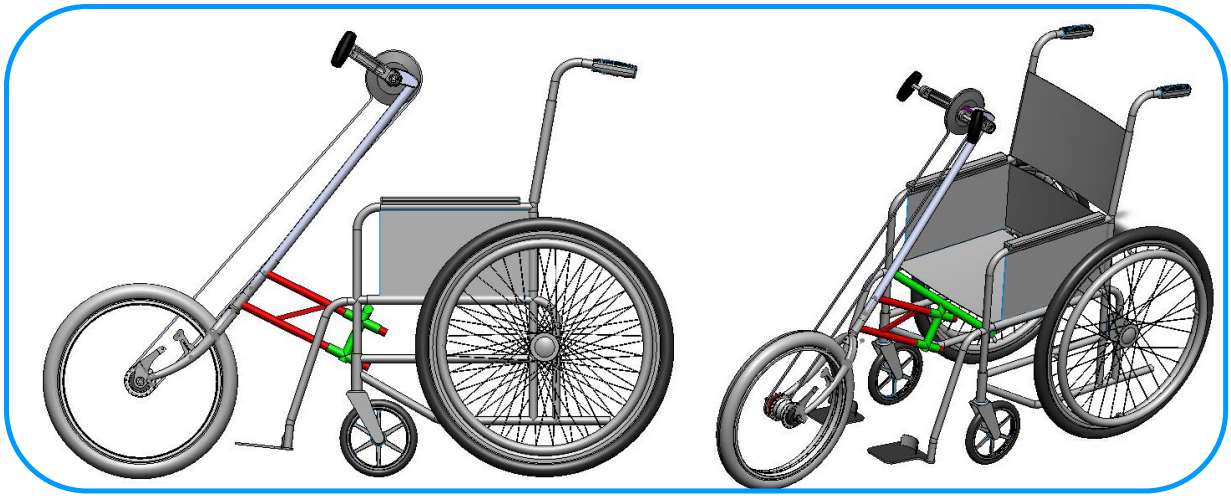
Tracker newest and most competitive system is the S6 mounting system. With this system there is no heavy adapter needed under the wheelchair and is easier to use. For the attachment of the coupling system people need to bring their wheelchair to double performance in Gouda. This s6 mounting system is patented and is mainly made for fixed frame wheelchairs. Tracker S6 mounting system is:

1. Simple
2. Solid
3. Safe
4. Small
5. Fast (snel)
6. Rigid (spellings vrij)



Speedy mounting system

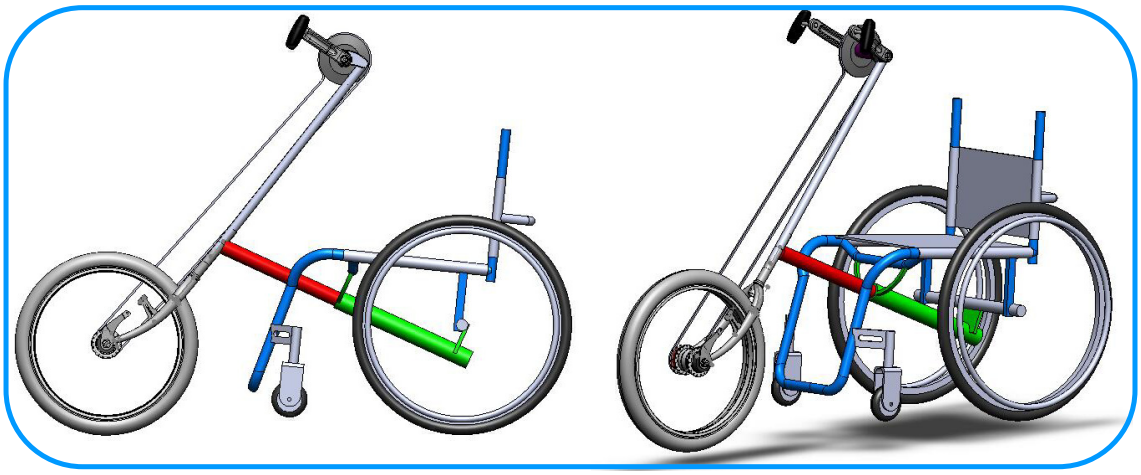
Speedy have got a mounting system which consist of two pins which are inserted in a docking station and fixed with a pin. The system use a lever to lift the handbike and the there is also a system with a spring to help the user. This system can be used on a fixed- and on a foldable wheelchair.



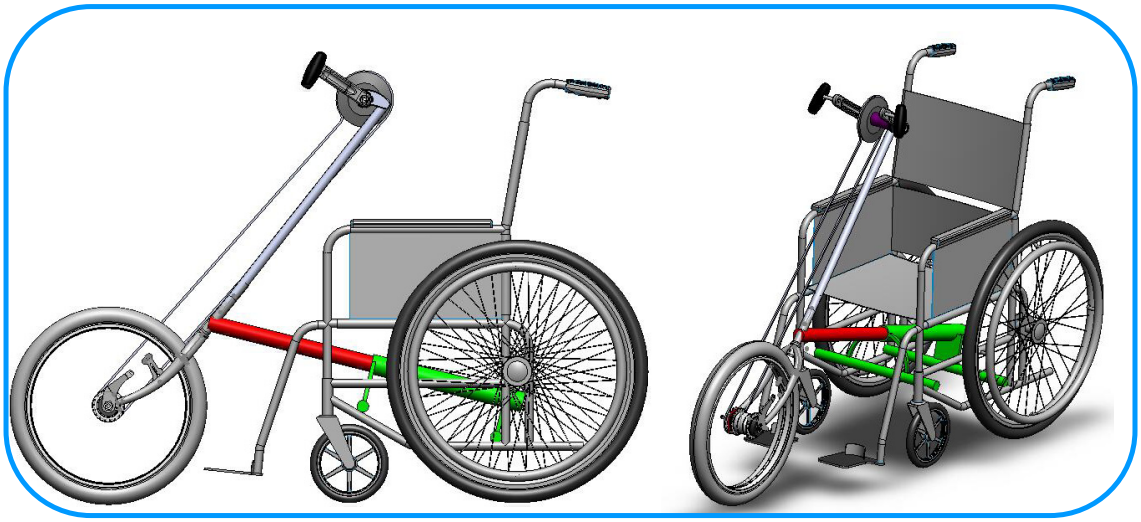
Roam mounting system

Roam actually have 3 mounting systems for several wheelchairs. However the standard system is a pin-hole system. This consists of a long tube which can be inserted in another tube and connected with a pull toggle clamp system. The advantage is that this system is solid and simple; however there stays a heavy tube under the wheelchair.

Pin-hole fixed wheelchair frame



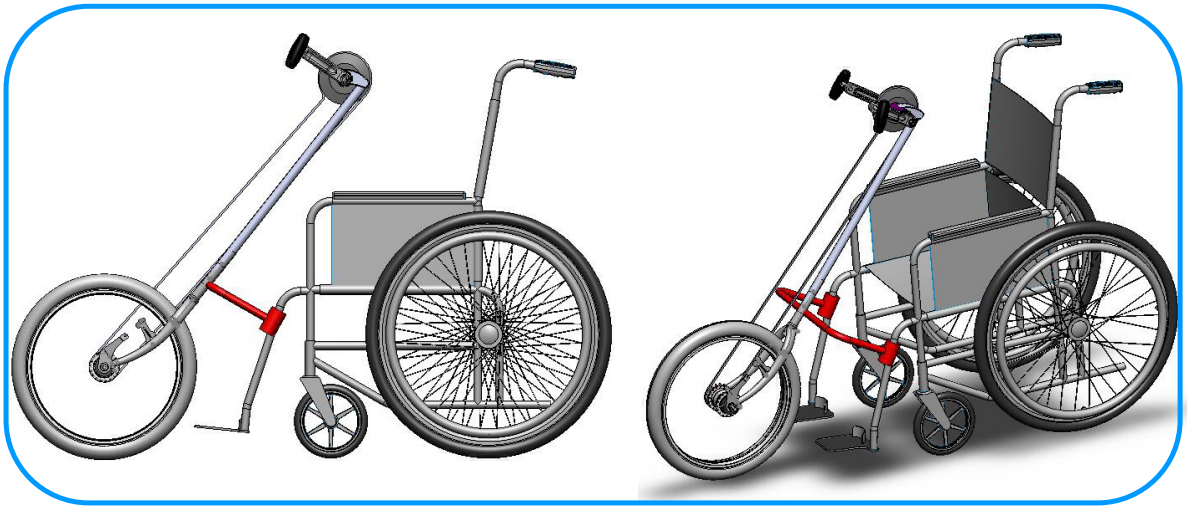
Pin-hole foldable wheelchair frame



The system is fixed on the bottom tubes of the wheelchair with two extra tubes which connect the main tube. However he docking station is hard to disconnect because it is low and 4 fixing points.

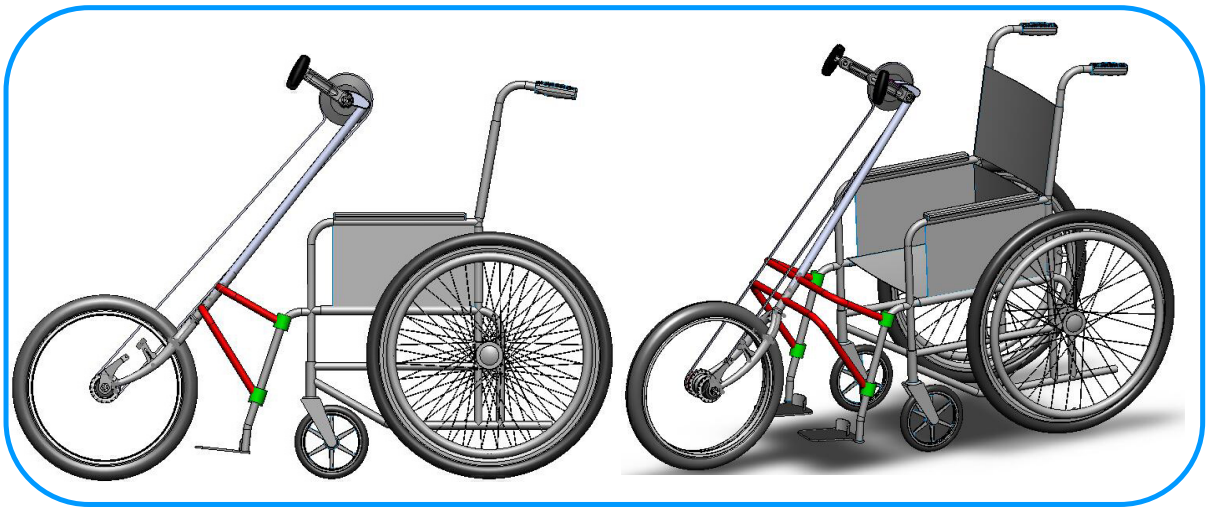
Stricker mounting system

The stricker mounting system can be clamped on the front fork of the wheelchair. In this way no parts on the wheelchair are left after attachment of the handbike. However there are a lot of small actions needed, turn a lever 7 times each side and open safety clamps.



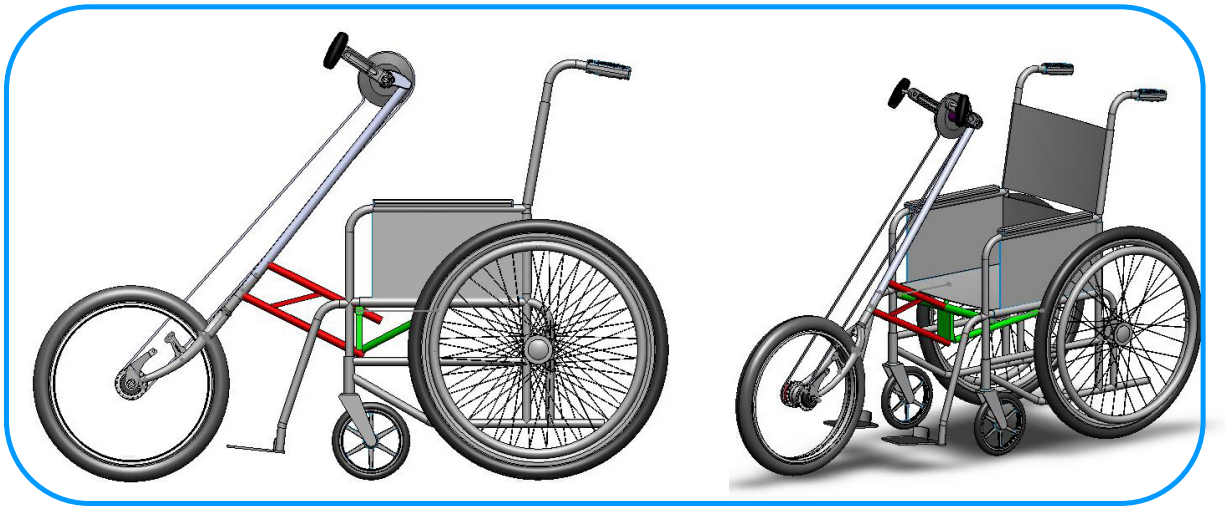
Freewheeler

The freewheeler mounting system is a custom made frame which is very quick to attach by a ball joint clamp mechanism. However the ball joint is drilled in the frame of the wheelchair so the light weight frame is damaged by big holes and weakened. But the system is easy to release with brake lever system. The 4 attachment joints are hard to outline because of small balls and some coordination is needed.



Praschberger

The Praschberger system is mounted on 4 spots on the wheelchair frame uses a lever to lift the wheelchair. The system is adjustable in width and light however is not easy to take of from the wheelchair. Also the appearance is very constructed with sheet metal and looks old fashioned.



Appendix G

Self exploration

Attaching handbikes on wheelchairs

Speedy

Pull, insert pin

Push handle

Ready to ride

Roam

Lift handbike

Male female connection

Secure system

Tracker

Lift handbike

Male female connection

Secure with lever

Stricker

Approach handbike

Clamp on front frame

Push handbike

Grade table Mounting systems

		Quick to attach	Steps to attach	Simplicity-understandable	Weight on wheelchair	Total points
1	Roam klick fix	2	2	4	5	13
2	Roam male-female	4	4	5	1	14
3	Tracker pull system	4	4	5	1	14
4	Tracker push system	5	5	5	4	19
5	Tracker clamp system	1	3	4	5	13
6	Stricker clamp system	2	1	2	5	10
7	Freewheeler custom fix	2	2	3	5	12
8	Speedy hinge	4	4	4	3	15
9	Speedy spring hinge	5	5	5	3	18
10	Praschberger fix	3	3	3	3	12
11	Berkelbike axe	4	5	5	2	16
12	Pfiff standard	4	4	4	2	14
13	Pfiff clamp	2	3	3	5	13
14	Pfiff HS middle	5	3	4	3	15
15	Dragonfly clamp	2	2	3	5	12
16	Adaptive docking	4	4	4	2	14
17	Cyclone axe	4	4	5	1	14
18	Fun bike clamp	1	3	4	5	13
19	Da vinci axe	4	4	5	1	14
20	Hybrid docking	4	4	5	1	14

Grade 1 to 5

- 1 worst
- 2 bad
- 3 normal
- 4 good
- 5 excellent

Drive test handbikes

By testing different handbikes the difference can be felt so the best points and problems can be noticed of the current handbikes. For this test 5 brands (roam, speedy, tracker, stricker and freewheeler) are tested.
The Roam with chain transmission was comfortable to ride. The front wheel had enough traction to gain speed and the angel of steering was fine to make sharp turns. The roam with bullhorn cranks the cranks needed to be held upside down while steering in corners. But the width of the cranks and height of propulsion more power could be generated.
The Roam cardan transmission was hard to start up because the front wheel was slipping a lot in the low gears. The gear on gear transmission was not as smooth as with a chain transmission. In this way shifting of gears was not as smooth as it supposes to be.

The speedy was comfortable to ride; this was because of the proper grip by the off-road tires. For straight roads the steering correction keeps the frame stable and straight.
The tracker cardan with bullhorn cranks had a short light frame and a lot of power could be generated. The transmission was not smooth, but there was enough traction still. The steering capabilities are like other bullhorn cranks, just need to anticipate on it.
The tracker with chain transmission had a long and heavy frame. It felt like a chopper bike. Steering in sharp corners was harder and to maintain traction on the road was harder.

Evaluation drive test

	Traction/ grip	Shift gear	Transmission smoothness	Steering control	Frame stiffness
Roam chain Standard crank	**+**	**+/-**	**+**	**+**	**+/-**
Roam chain Bullhorn crank	**+/-**	**+/-**	**+**	**+**	**+/-**
Roam cardan Standard crank	**-**	**+/-**	**-**	**+**	**+/-**
Speedy chain Standard crank	**+**	**+/-**	**+**	**+**	**+**
Tracker cardan bullhorn crank	**-**	**-**	**-**	**+/-**	**+**
Tracker chain standard crank	**+**	**-**	**+**	**+**	**+**
Stricker chain Standard crank	**+**	**+**	**+**	**+**	**+**
Freewheeler chain Standard crank	**+/-**	**+**	**+**	**-**	**-**

Appendix H

User interviews

Welzorg sport

Piet Hermans
Sales manager

Played for 10 years wheelchair tennis

Iwan van Breemen
Technical advisor

Fanatic wheeler and Paralympics marathon champion

Marcel Bierman
Technical advisor and sales

Played national rugby for 6 years on high level

User experience

Welzorg active has several experts which advise the end users for the appropriate handbike. However in their spare time they also use a handbike for transport in the city, training and leisure.

Technology handbikes

The mounting system is for every user different depending on their physical capabilities. The preference of a handbike is made for the type of use and type of wheelchair they own. At first the user need to get used to the handbike mounting system by some practice to see what suit him best.

Appearance current handbikes

According to the users the current models are too technical and are not attractive for the user. It doesn't suit the wheelchair design and are mainly focussed on function and adjustability and to show of the working principle of the technology.

Points for improvement

	Problems	Solution
Mounting system	➢ Heavy ➢ Technical appearance ➢ Fragile ➢ High coordination ➢ A lot of action needed ➢	➢ Lightweight ➢ Robust ➢ Self searching ➢ Less action
Mounting on the wheelchair	➢ Heavy ➢ Hard to dismount ➢ fragile	➢ Lightweight ➢ Quick release ➢ Stiff
Traction	➢ Front wheel traction is low because of weight on wheelchair	➢ More weight on front wheel ➢ Wider bigger tires ➢ Wheelchair wheels more to the back ➢ More pressure front wheel, gain 1,5km an hour more
Brakes	➢ Not safe brake mechanism on hill	➢ Disc hydraulic brake
Steer correction	➢ When users need to climb a hill they have to use their hoop to keep speed, here for the frame need to stay straight. Steering correction is necessary for this problem.	➢ Integrated steering plastic clamp in head tube.
Manoeuvring with cranks	➢ Bullhorn cranks hard to turn sharp corners ➢ Not every body can use trunk power to pedal	➢ Straight cranks ➢ High position crank

Double performance

Drs. Kees Van Breukelen
Technical director double performance
Wheelchair ergonomic expert

Kees van Breukelen studied human movement sciences and was first sport teacher for 10 years. Since 1980 he does practical research for wheelchair and handbike ergonomics. He was first 10 years active wheelchair racer and the last 10 years he is a competitive handcyclist. His opinion on improvement of handbikes is that real innovation comes from ergonomic improvements. For example the sitting position can influence the performance of the cyclist extremely. By using arm-trunk power more power can be used to gain speed and fewer injuries are the result.

With his company "double performance" he is "improving the efficiency of arm power" for wheelchairs and handbikes. By listening to individual needs and wishes of users he developed a popular attachable handbike "Tracker" which transform a wheelchair in an efficient handbike. This is ideal for transport, fitness, recreation and sport. This the most sophisticated and efficient product for independent transport on arm power.

He has experienced the whole process from the start of hand cycling and by trial and error he improved several methods and techniques. Even though chain propulsion is the most efficient he was the first who introduced a "Cardan drive" on an attachable handbike. Also "Bullhorn cranks" with a much lower propulsion position where applied, which makes it possible to decrease the force on the shoulder joint. Longer cranks (170 mm) make it possible to increase the propulsion circle which makes it possible to use more trunk power.

Appendix I

Ergonomic research

Ergonomic classification: Arm vs Trunk power (Kees van Breukelen)

Another point of innovation is the crank system where the height, the length and the width determine better ergonomic position for the user. In this way the user is able not only to use his arms but also his trunk.

There are two ways of propulsion for hand bikes: by power, generated via Arm-Power only (AP) or by power, generated by the combination of Arm-Power and upper body power (ATP).

	attachable handbike	fixed-frame handbike	
Arm-Power (AP)			
Arm-Trunk-Power (ATP)			

The difference between AP en ATP for attachable hand bikes is the crank/ handlebar position. AP hand bikes use standard cranks where the chain wheel must be correctly placed at a specific height above the knees. This standard crank of 17 cm must be able to rotate free above the knees. This means that the top half of the propulsion circle is situated in front of the chest and arms often reach above the shoulder. This means that only arm activity can be used in the form of pushing and pulling where the body stays in upright position. The use of 15 cm long cranks makes the propulsion-circle smaller and lower and is no real option because shorter cranks require more power because of the shorter moment arm and this is not desirable. This position can only be efficient when the backrest of the wheelchair is high enough to support the shoulder blades.
The effectiveness of an attachable hand bike type AP is sufficient enough for normal ADL use or recreation purposes, but improvements are still possible.
The AP hand bikes often have maintenance free gearboxes with 7 gears. This is an effective way for every day use and a speed of 20 km an hour can be reached. Companies like tracker, Speedy, Stricker, Roam and freewheeler deliver such AP hand bikes.

The noticeable difference for ATP hand bikes is the low position of the crank system. A lower crank position is only possible with bullhorn cranks (cranks in the shape of cow's horns). Bullhorn cranks makes it possible to lower the position of the propulsion chain wheel above the upper legs and knees of the hand biker while remaining the length of 17 cm. The upper torso can now work together with the arms in forward and downwards position. This can only be done by person where the stomach muscle functions. The stomach muscle support the upper body as it curves forwards while lower part is remaining contact with the backrest. Because the upper body is moving forward and slightly downward a high backrest is not needed here. The pull position is seen as a

highly slanted backwards direction. Because of the lower position of the propulsion system there is more tendency to be pushed more into the wheelchair then pulled out of it. The ATP system is more effective then the AP system because the pull and push phases are more effective and the output of the invested energy is greater.
The attachable hand bike type Arm-Trunk-Power has also a simple gearbox (7 inner gears) or a derailleur system (e.g. 3 x 8 = 24 outer gears).The speed that can be reached is about 30 km per hour. Examples of attachable hand bikes (Arm-Trunk-Power types) are Tracker 20 sport and the Praschberger challenger (both have bullhorn cranks).

With the development of the Bullhorn cranks a lower drive position is possible and the load for the shoulder joint will be reduced and multiple positions are possible. The lower position of the drive system is more efficient because the trunk can be used next to the arms.

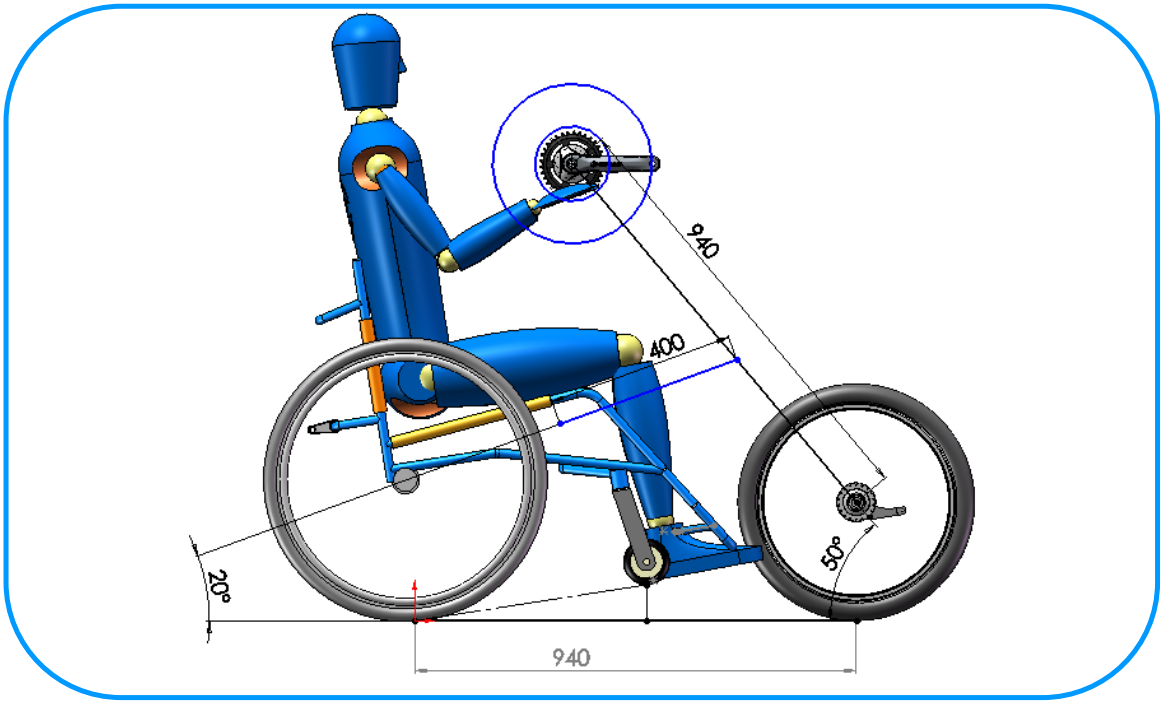
Appendix J

Starting points

Propulsion position

The position of propulsion is chosen for the wish of making an all-round standard handbike which also can be used by people who only can use their arms to propel and not their trunk. Also the height of propulsion determines the comfort for the rider and makes the difference between a recreational handbike and a training sport handbike.
Because this handbike purpose is more for recreational and city transportation the user need to enjoy the view and sit there for straight up and pedal higher.

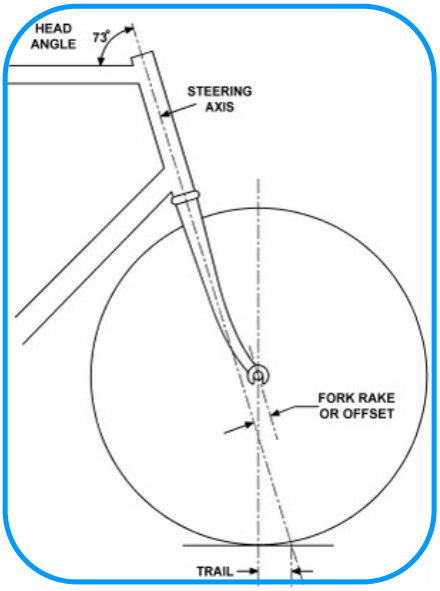
Global dimension



For the appropriate size of the handbike several test and explorations are done to notice which existing handbike fulfills the most comfortable ride.
The frame angle of current handbikes is between 40 degrees and 50 degrees. (Tracker – Roam) the difference here for is between the steering behavior. With a handbike of 40 degrees the front wheel is more to the front and is better for longer distances to maintain a straight path. The handbike with a frame of 50 degrees is maneuverable and more a city bike.
There is chosen for an angle of 50 degrees because of the needs of the users and where for they will apply their handbike. Also self exploration is done with several handbikes and the steering behavior was better with a frame which was under a bigger angle. This steering behavior depends a lot on the angle of the head tube where the wheel is turning about.

Steering frame angle

The geometry of the handbike frame determines the cycling behavior of steering in a straight line.



If the head angle is larger then 70 degrees the steering will be very nervous. If the angle will be smaller then 65 degree the steering will be better for longer distances to maintain a straight line.

For regular city bicycles the head angle is between 65 and 70 degree. The trail is the distance between the head angle line and the hart of the front wheel. This distance is for regular bicycles between 50 and 80 mm.

For hand bikes the steering behavior can differ a lot depending on the type of cranks, angle of the front tube and height of propulsion.
This is because with the bullhorn cranks it is harder to steer with the cranks down in sharp corners because they will interfere with the upper legs. If the head angle is too small the maneuverability will be less in small environments.

Another special attention point for handbikes is the place of the ball head or turning point. This is because the chain line can interfere in sharp corners with the tube that is connecting the handbike frame with the wheelchair.

The last point that is common on handbikes is a steering corrector which makes it possible to keep the handbike straight while propelling with the hoop of the wheelchair. This is often done by an elastic, rubber or spring.

If the angle of the ball head is too steep the maneuverability is high however it can also become a very nervous steering bike. Because of the trail the person doesn't have to steer constantly and the bike will continue in a straight line when it has reached a certain speed.
So for the head angle 60 degrees is chosen so the user doesn't have to correct his steering action a lot while pedaling. For the trail an average 60 mm is chosen for an optimal steering behavior.

Drive mechanism

For the choice of the drive mechanism the advantages and disadvantages are considered and possibilities combined.

Chain drive system

The most common drive system in the bicycle industry is with chain because this is the most efficient. However before a definite chose is made other alternatives where also considered. Here for several criteria are considered like, efficiency, weight, cost, flexibility to adjust length or add other components like derailleur, maintenance, design or appearance.

Belt drive system

Also a belt drive system is already tried on for example a Stricker city hand bike. A belt drive system is light and doesn't need a lot of maintenance; however a belt drive system doesn't have a great efficiency and are not able to combine with many parts from the traditional bicycle industry.

Cardan drive system

The cardan system is already a familiar system in the handbike industry and is applied for the Tracker hand bike by Double performance.
The advantages of the cardan system are:

- Clean appearance
- Low maintenance
- Simple to assemble

Double chain drive

A double chain drive is often used to create space for lower frame on bicycle so it becomes easier to step on or for the appearance.
One very innovative appliance is the Berkelbike where a small gear at the top is being used for hand propulsion and a bigger gear at the top of the fork for foot propulsion.

If a narrow integrated chain drive would like to be integrated in a tube a double chain drive would be the option. In this way two small gears can be used before a bigger gear is being used to transfer the power to the wheel. The advantage of a double chain is that compared with a cardan drive standard components still can be used and it is 1 kg lighter then a cardan.
The efficiency of both systems is almost even and is 4% less then a direct chain drive. Only the price of a cardan drive is more expensive then a chain drive however a double chain drive takes more time to assemble so the assembly cost are higher.
After comparing all the four possibilities of drive systems there is chosen for a direct chain drive, because of its flexibility to combine with standard bicycle components, it high efficiency, it low weight and it low price and it doesn't take extra time to assemble.

Wheel

City 20 inch or sport 24 inch

From the design guidelines a 20 inch wheel is required according to the standard version of a hand bike. This is comfortable for short distances in the city. However if a higher speed is preferred a 24 inch wheel is more efficient. For the design of the handbike a 20 inch wheel is chosen to compete with the other competitors and fulfill the requirement according to the WMO and PGB law. With this 20 inch wheel the user is able to accelerate faster, however for longer distances a 24 inch sport wheel would be preferred.

Big Apple balloon tire

Speed	Grip	Protection	Durability
▮▮▮▮▯	▮▮▮▮▮	▮▮▮▮▮	▮▮▮▮▯

The big balloon tire is chosen for its robust looks, excellent grip and proper speed and durability specifications.

Euroline aluminum rim

The aluminum hollow rims are selected for the lightweight, stiff rims and modern appearance.

Hub

For the choice of the hub there are several options of brands and specifications.
According to the design guidelines the minimal criteria are a coaster hub with 7 gears speed ratio. Brands like Shimano, Sram or Sturney archer could be applied and chosen. The quality doesn't differ a lot, however the users are accustomed to familiar brands like Shimano. Van Raam is also transferring al their hubs to Shimano in 2010 so this trend would also be suitable for the handbike. However there was a need from the users and welzorg to have an option to pedal in reverse. There for Sturney archer already had a hub with coaster brake and reversible pedaling function integrated. The disadvantage is it only had 5 gears and will be taken out of production.
Here for the best option is the shimano nexus 8 speed with coaster brake. The reversible function will be adapted to this hub by Van Raam.

Gear

To determine the amount of tooth necessary for a comfortable ride calculation is needed for optimal use. Depending on the chosen hub specifications and maximum speed, gears will be chosen for an optimum cycle condition of one cycle per second.
Depending on the wheel size and the shimano nexus hub gear ratio the sprocket (small gear) size and chain gear can be calculated. The speed that is preferred to achieve in the highest gear is 20 km/h (555cm/sec)

Wheel size	=20 inch		= 50,8 cm
Circumference 2*pi*r=	pi*r=	3,14*50,8	= 159,6 cm
Max speed	=20 km/h		= 555 cm/sec
Gear per rotation	= 555/159,6		= 3,477 cm/rotation

If the maximum size of the chain gear at the top will be a 38 tooth, the sprocket amount of tooth can be calculated. If a bigger chain gear like 40 teeth would be chosen a higher speed could be reached, however it would be big in the user view and not aesthetic.

If there would be no hub but a direct connection the sprocket had to have:
Amount of sprocket tooth: 38/3,477 = 10,93 = 11 tooth

However this would not fit on the shimano hub. A range between 16 and 23 would fit on it.

Shimano	gear	SG-8C31	**38/16**	speed		**38/18**	speed		**38/19**	speed	
			2,375	cm/sec	**km/h**	2,11	cm/sec	**km/h**	2	cm/sec	**km/h**
Gear Ratio 1	1	0,527	1,25	199,76	7,19	1,11	177,56	6,39	1,05	168,22	6,06
Gear Ratio 2	2	0,644	1,53	244,11	8,79	1,36	216,99	7,81	1,29	205,56	7,40
Gear Ratio 3	3	0,748	1,78	283,53	10,21	1,58	252,03	9,07	1,50	238,76	8,60
Gear Ratio 4	4	0,851	2,02	322,57	11,61	1,80	286,73	10,32	1,70	271,64	9,78
Gear Ratio 5	5	1	2,38	379,05	13,65	2,11	336,93	12,13	2,00	319,20	11,49
Gear Ratio 6	6	1,223	2,90	463,58	16,69	2,58	412,07	14,83	2,45	390,38	14,05
Gear Ratio 7	7	1,419	3,37	537,87	19,36	3,00	478,11	17,21	2,84	452,94	16,31
Gear Ratio 8	8	1,615	3,84	612,17	22,04	3,41	544,15	19,59	3,23	515,51	18,56

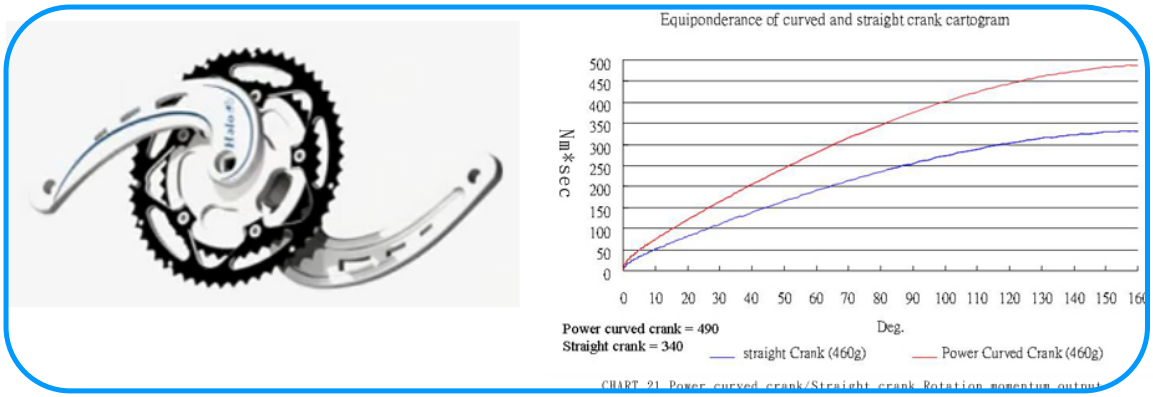
From this table can be concluded that if on the shimano hub a 16 tooth sprocket would be chosen the user would be able to reach a maximum speed of 22 km an hour in 8 gear. But in the lower gears the user need to pedal heavier.

If a sprocket of 19 or bigger tooth will be selected a maximum speed of 18,56 km an hour could be reached. For the user it would be too light in the first gear to pedal and not useful. So for a maximum speed of 19,59km/h so 20km an hour a sprocket with 18 teeth need to be placed and this would be the optimal range with an 38 gear chain disc.

Another option is also a mountain drive which gives extra gears in transmission, but is quit expensive.

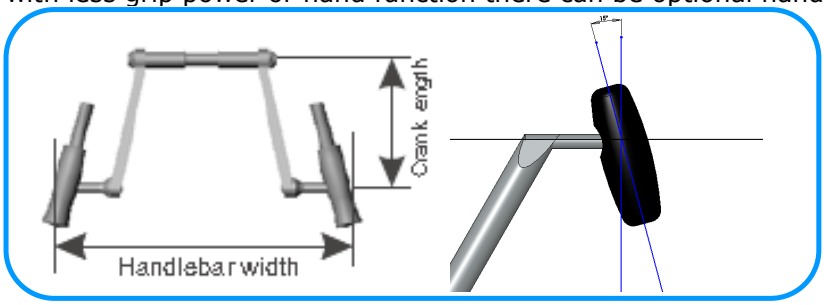
Crank

The handbike cranks can have different length which has influence on the pedaling behavior and efficiency of the handbike. The crank is a lever and determines the optimal pedal frequency for the rider. The standard crank from the bicycle industry with a length of 170 mm is the most convenient and efficient.
However if there is a need for a time race or climbing hills different lengths are more appropriate like 150mm and 190mm. Bullhorn cranks are not considered because the propulsion height is already determined and there is chosen for a high propulsion position. From the design guidelines 170 mm standard straight cranks are required. Here for "power curved cranks" are applied because of improved crank specifications and unique design shape.



Handlebar

The width of the handlebars is determined by the width of the shoulders of the user to have a comfortable ride. However not for every individual the size is necessary to adjust. The standard size handle bar width should be 40 cm. However other options like 45 cm and 50 cm are possible.
The angle of the handle bar should be 15 degree so the wrist is in rest position and in natural position. The most common standard pedal supports the thumb. But for people with less grip power or hand function there can be optional handlebar supports.



Reverse pedaling

For reverse pedaling there was a Sturney Archer 5 speed hub on the market which has an automatic reverse function. But the minimal requirements of the design guidelines are also a minimum of 7 speeds to be competitive with other competitors and user wishes. The Sturney Archer hub will be taken out of production and van Raam is also switches to Shimano nexus inter 8 speeds. Here for another solution had to be developed. This solution is inspired by a freewheel and react when the user stops pedaling or braking so a pin is pushed in a milled part so the reverse pedaling function is activated.

Power assist

Currently Van Raam is using Heinzmann electric hub engines. However due to lots of failure the new engines that will be applied are the Crystalyte bicycle engines.

Crystalyte engine
Weight 3,9 kg

- 20" rim = max speed 33 km/h by 24 V
- 24" rim =max speed 40 km/h by 24 V

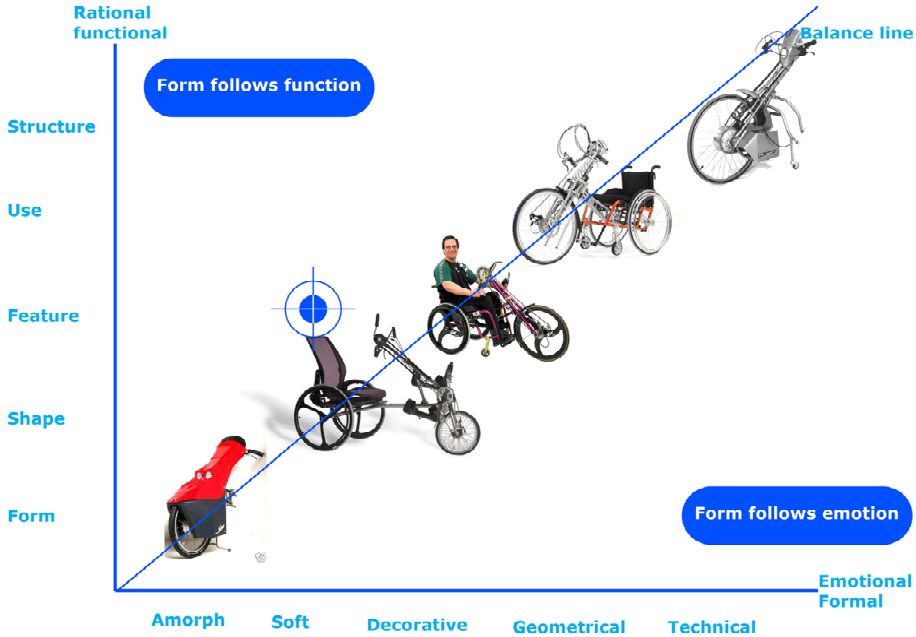
Indes Battery
Battery and controller on top integrated in luggage carrier.

- Lithium ion battery
- 6 km an hour without pedaling
- maximum of 25 km/h
- double pack battery
- 474 Wh (36 V-12,8 Ah)
- charge time 1 hour
- reach 60- 100 km
- weight 2x2,5 kg

Appearance, look and feel

Form follows function

In this graph the current handbikes are mapped according to their shape and looks.



Visual mapping

Visual mapping is a tool from Philips design to categories the current handbike products or other shapes according to their appearance were they would fit in time and in differentiation. With this graph can be determined in which section the style of the handbike should look like.

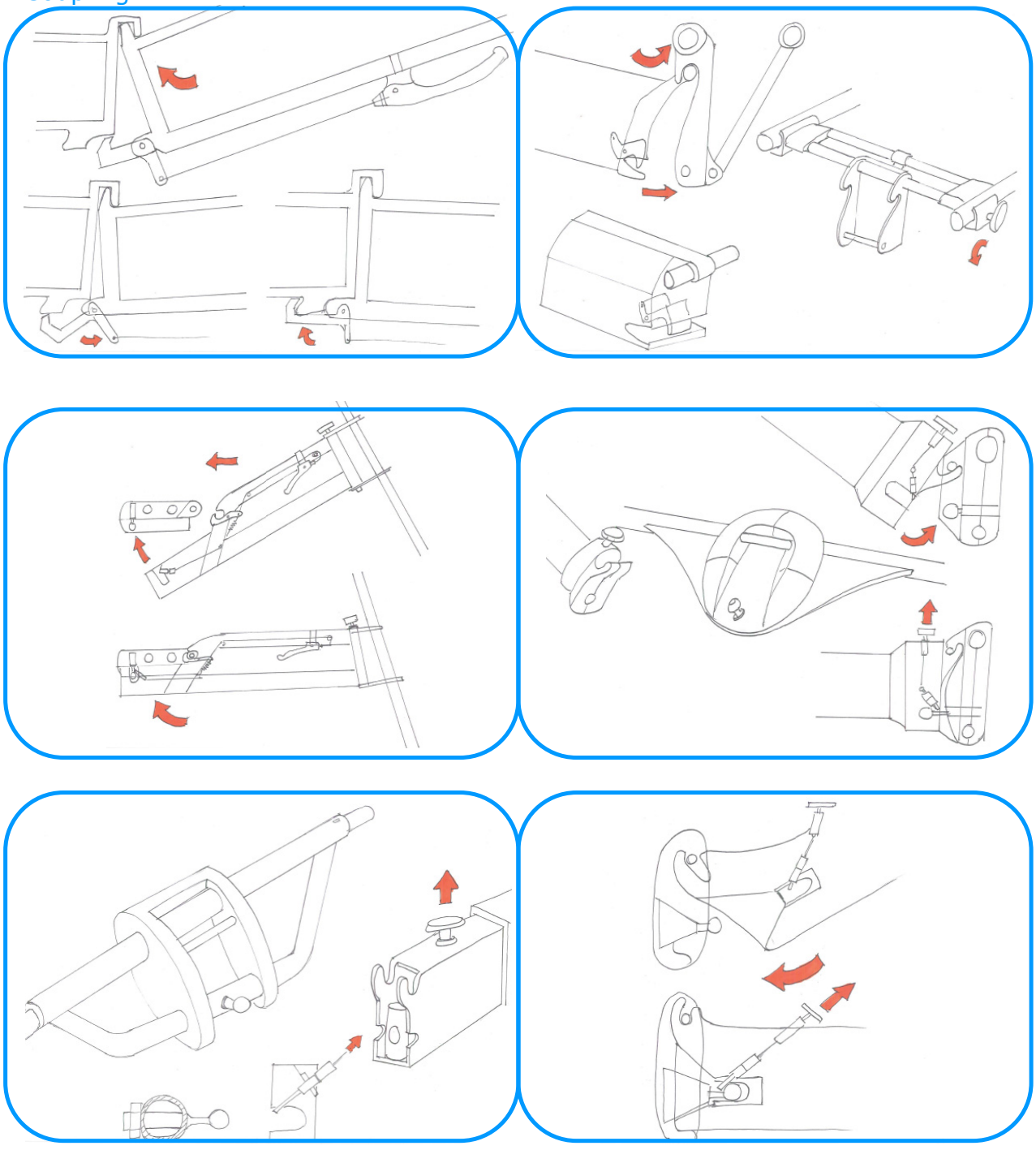
Visual brand

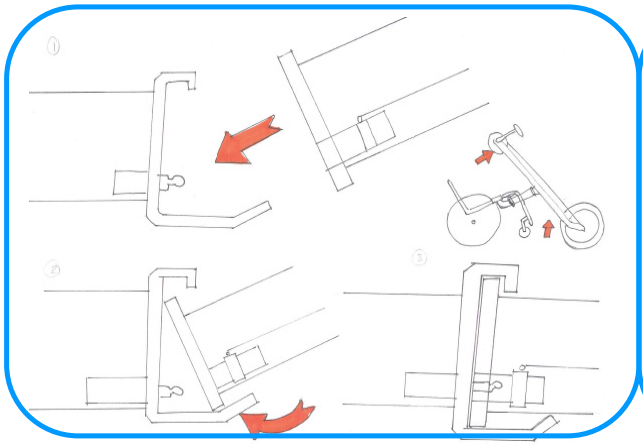
Visual brand is a tool from SCOPE design were a large amount of pictures is shown and which suit the brand of Van Raam for the future.

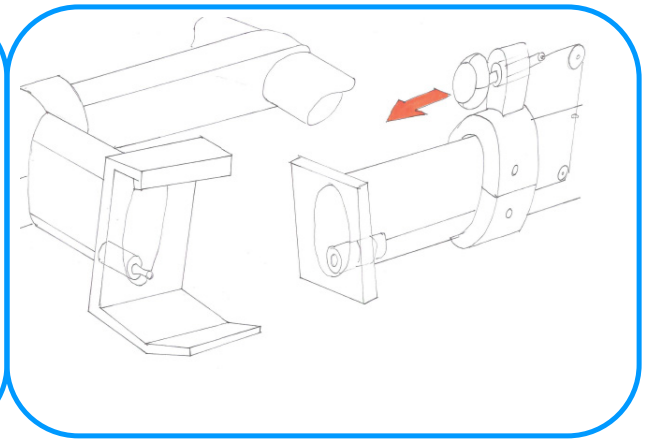
Appendix K

Sketches

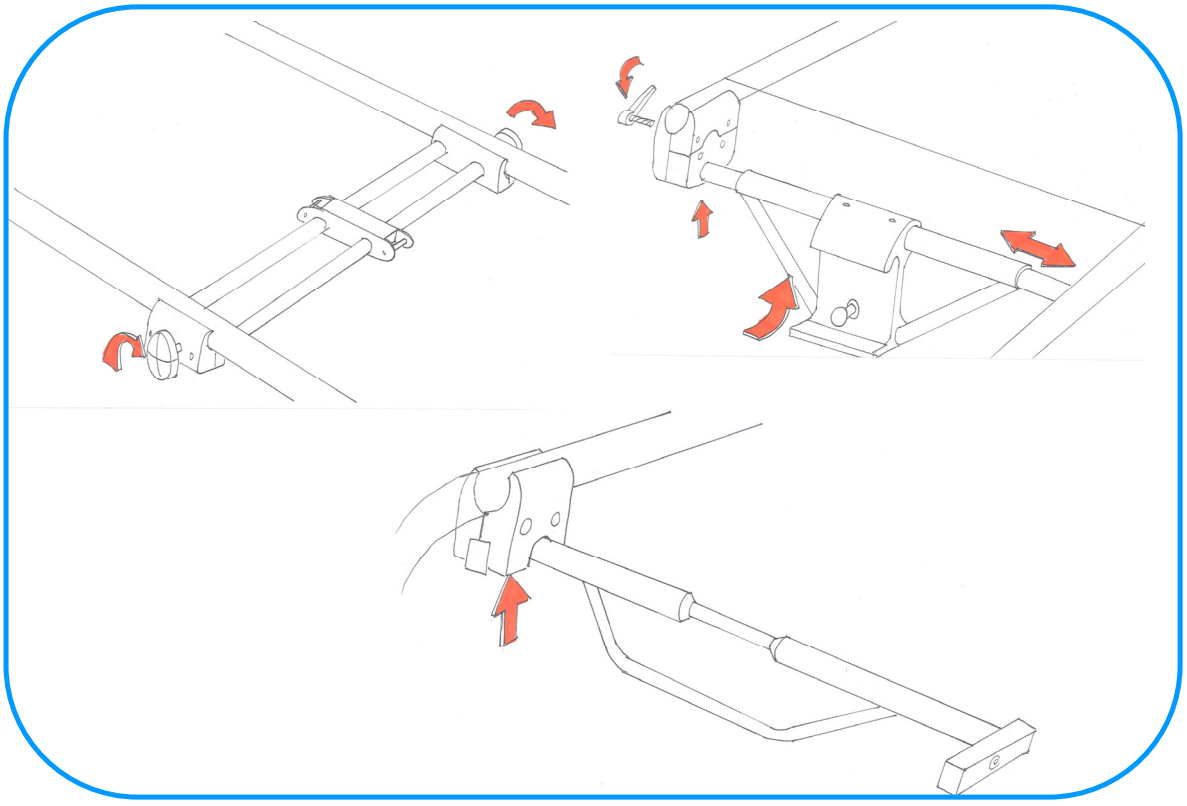
Coupling

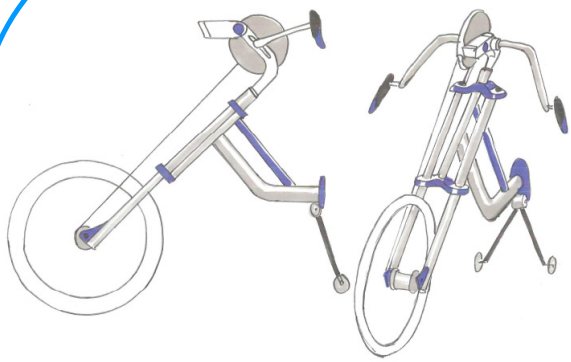




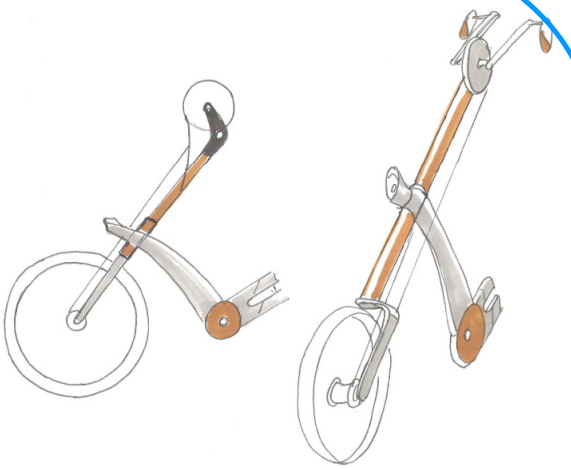


Wheelchair frame clamp

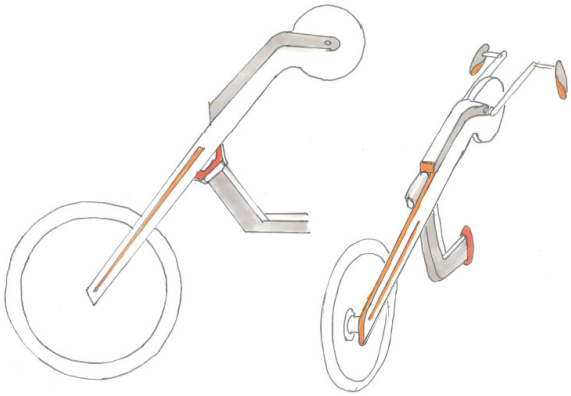




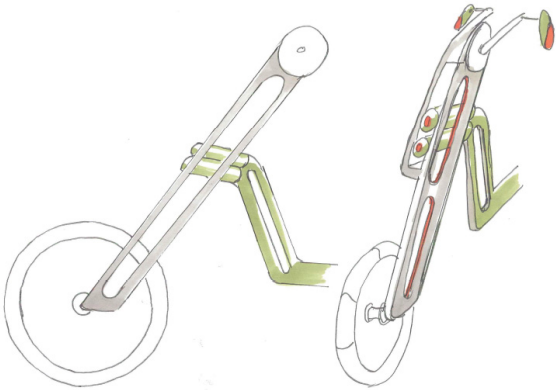
Double tube



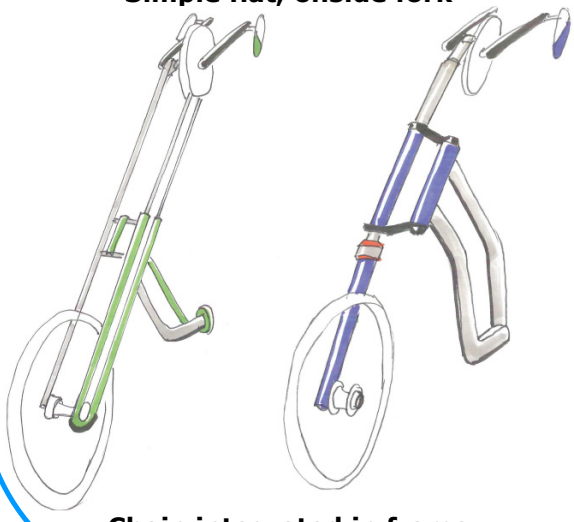
Integrated lamp tube



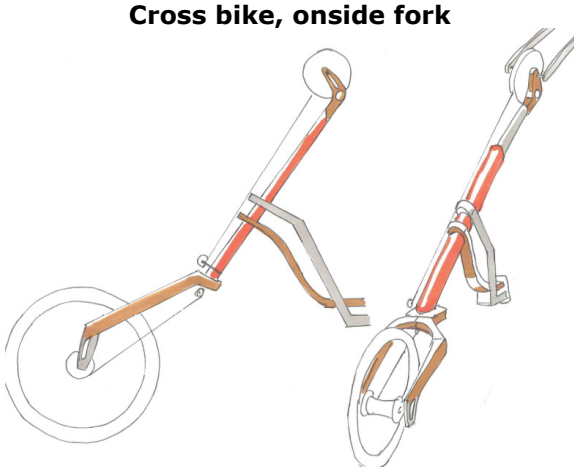
Simple flat, onside fork



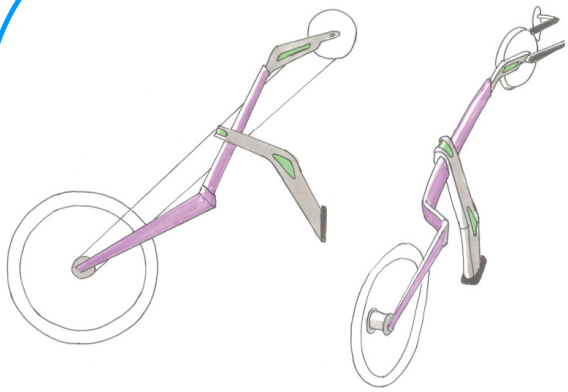
Cross bike, onside fork



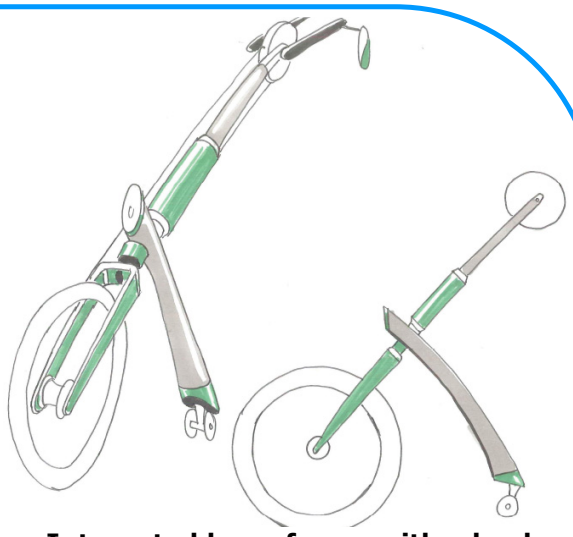
Chain integrated in frame



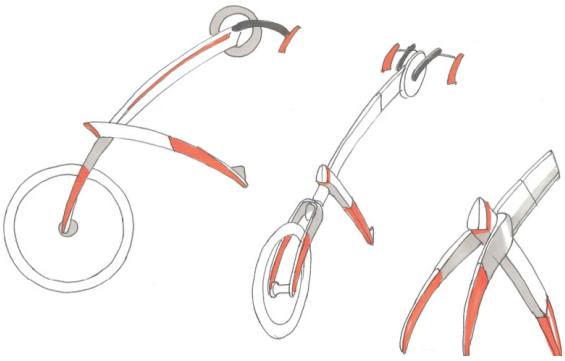
Chain bent



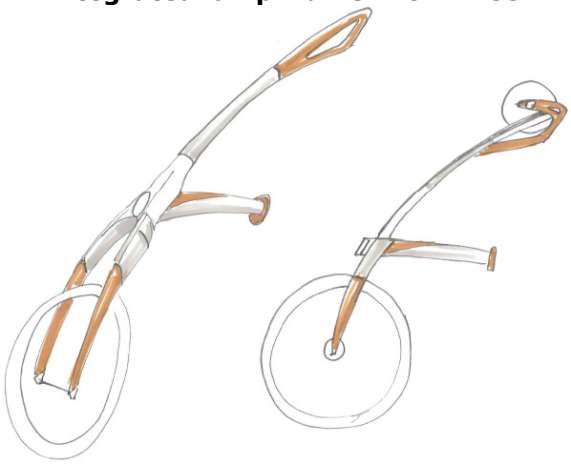
Single double curved frame



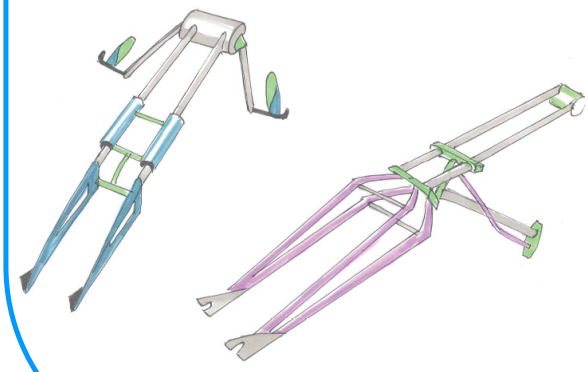
Integrated lamp frame with wheel



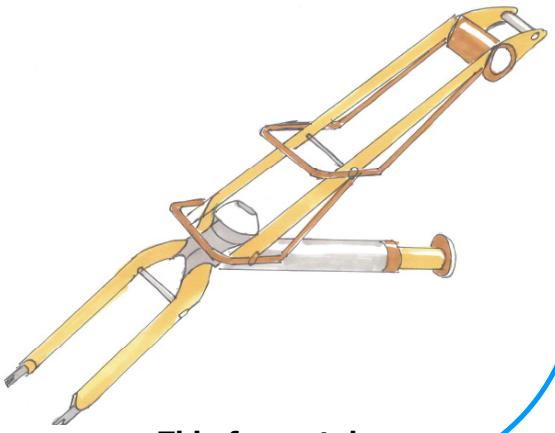
Simple elegant frame



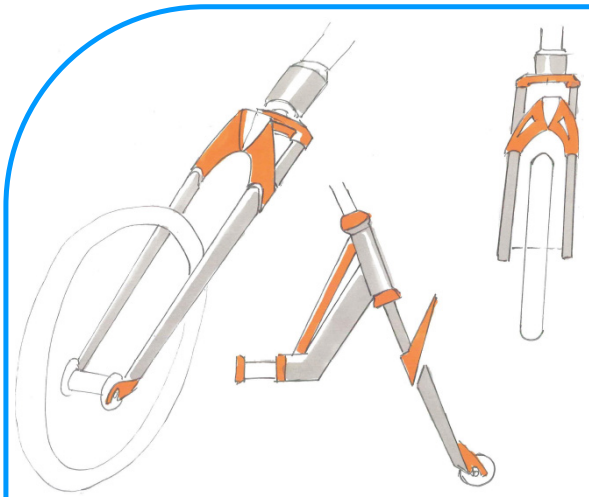
Organic frame



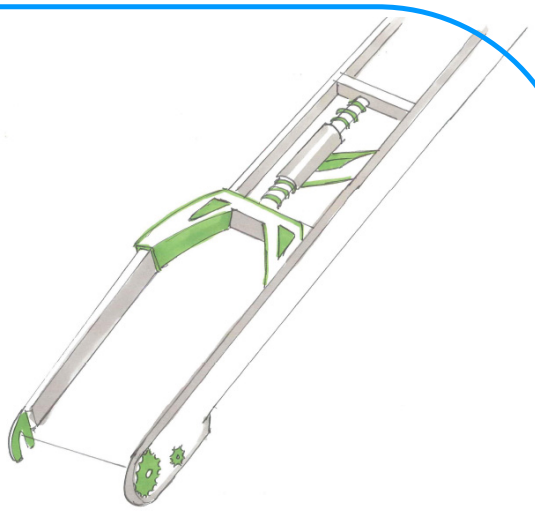
Thin tubes



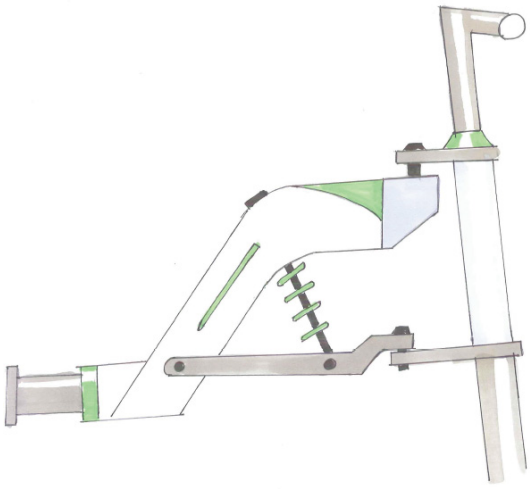
Thin frame tube



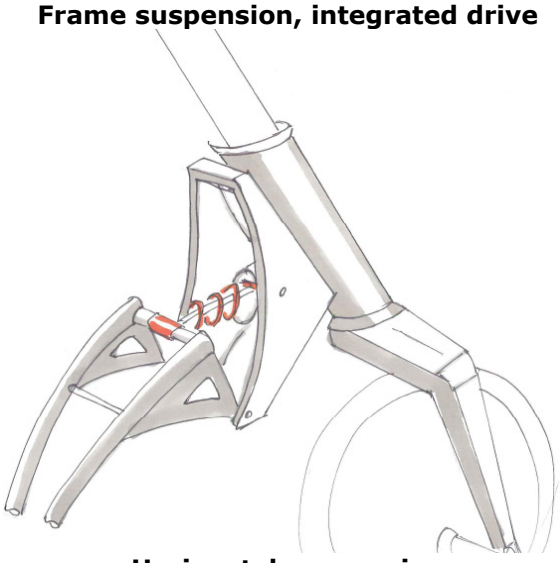
Fork suspension, integrated lamp



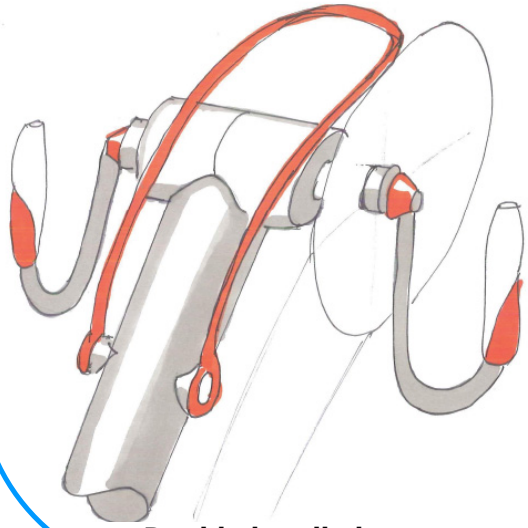
Frame suspension, integrated drive



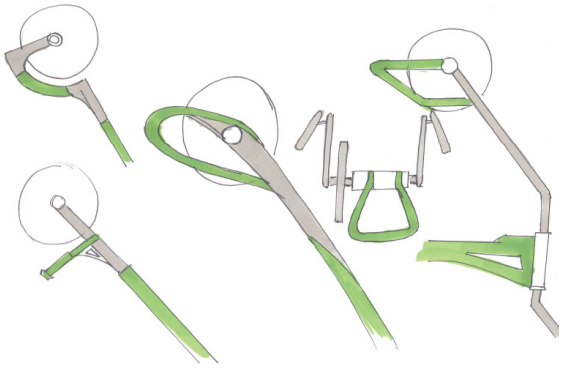
Vertical suspension



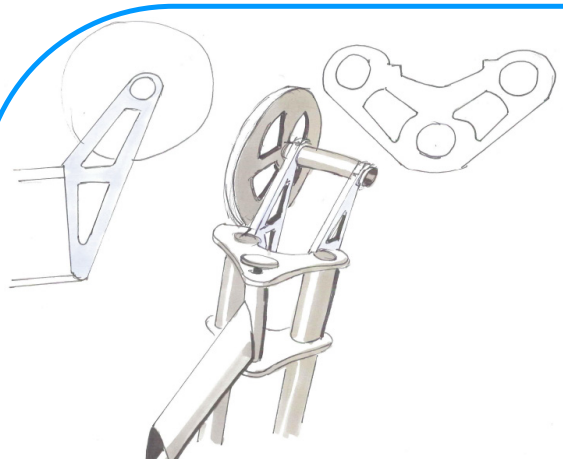
Horizontal suspension



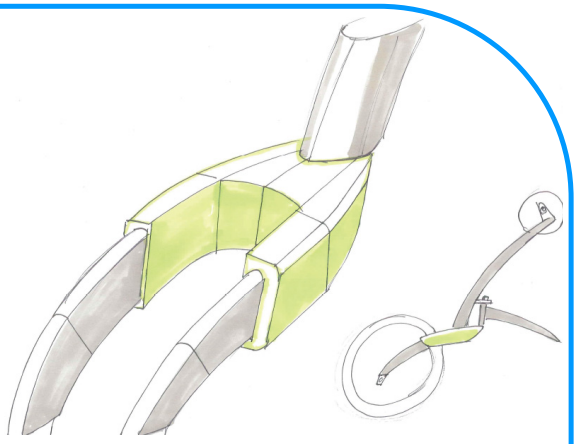
Double handle bar



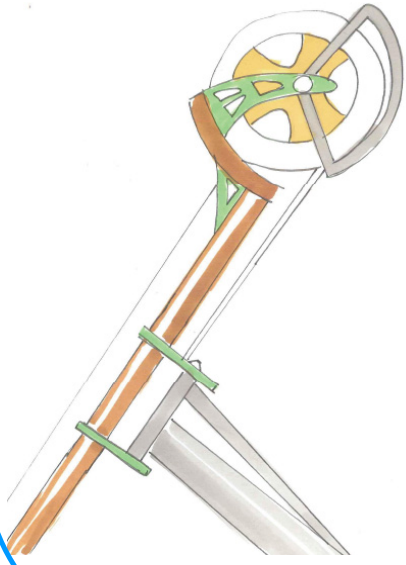
Single handle bar



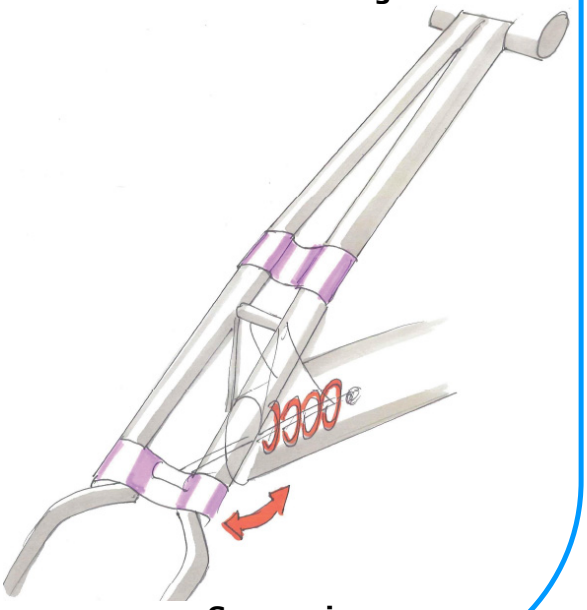
Steering head tube



Front fork design



Top part handbike

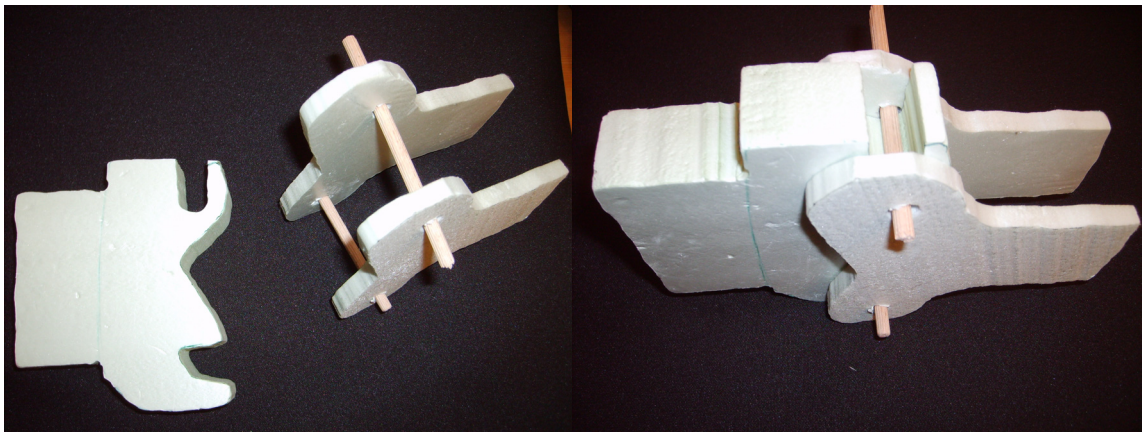


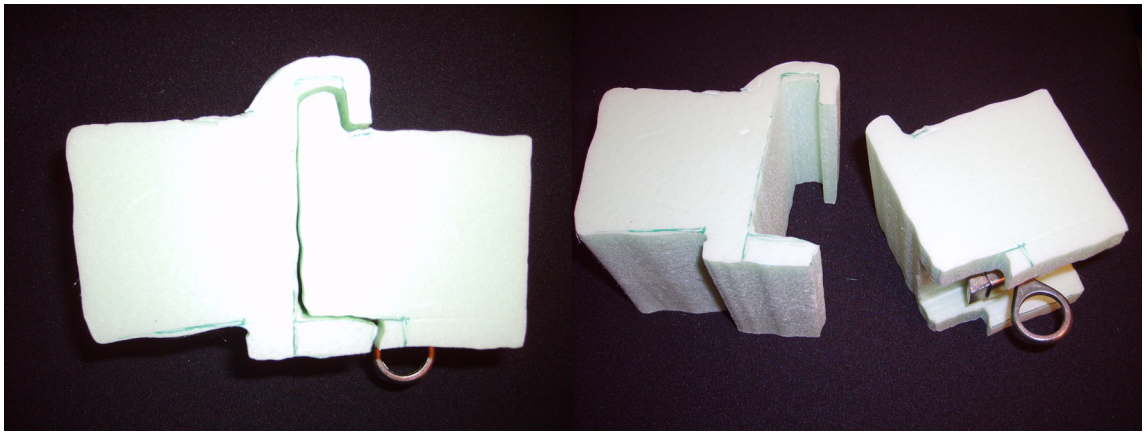
Suspension

Appendix L

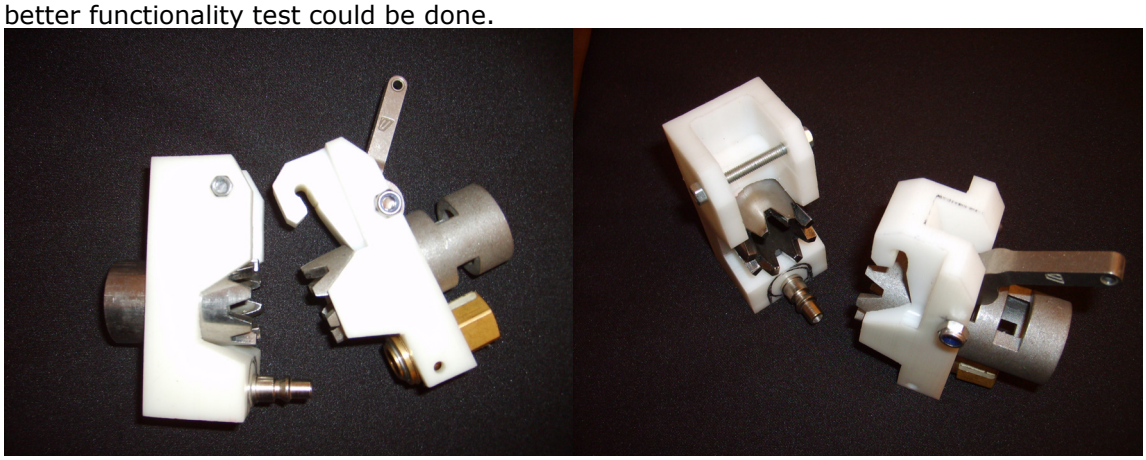
Mock up test

At the beginning of the conceptualization phase several mock ups are made from foam and standard parts.





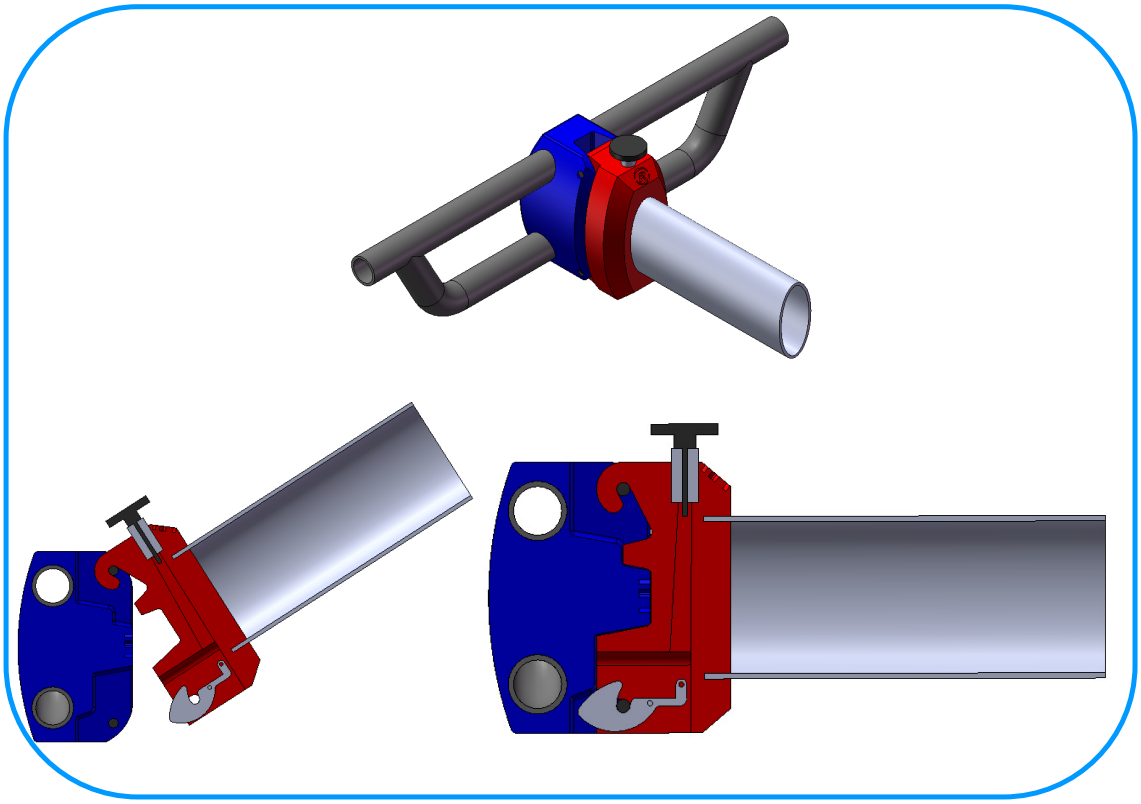
When the mock ups become more complicated the mock ups were milled from plastic so better functionality test could be done.



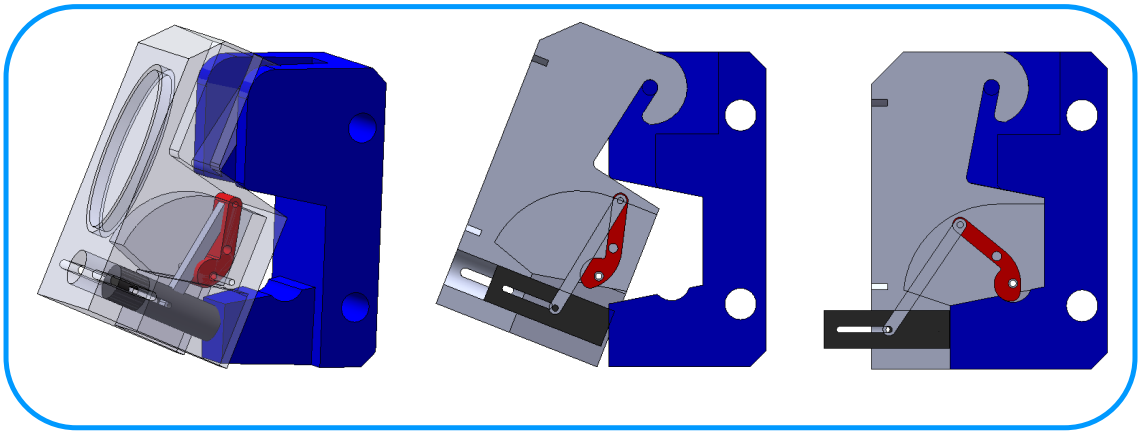
Appendix M

3D modelling coupling

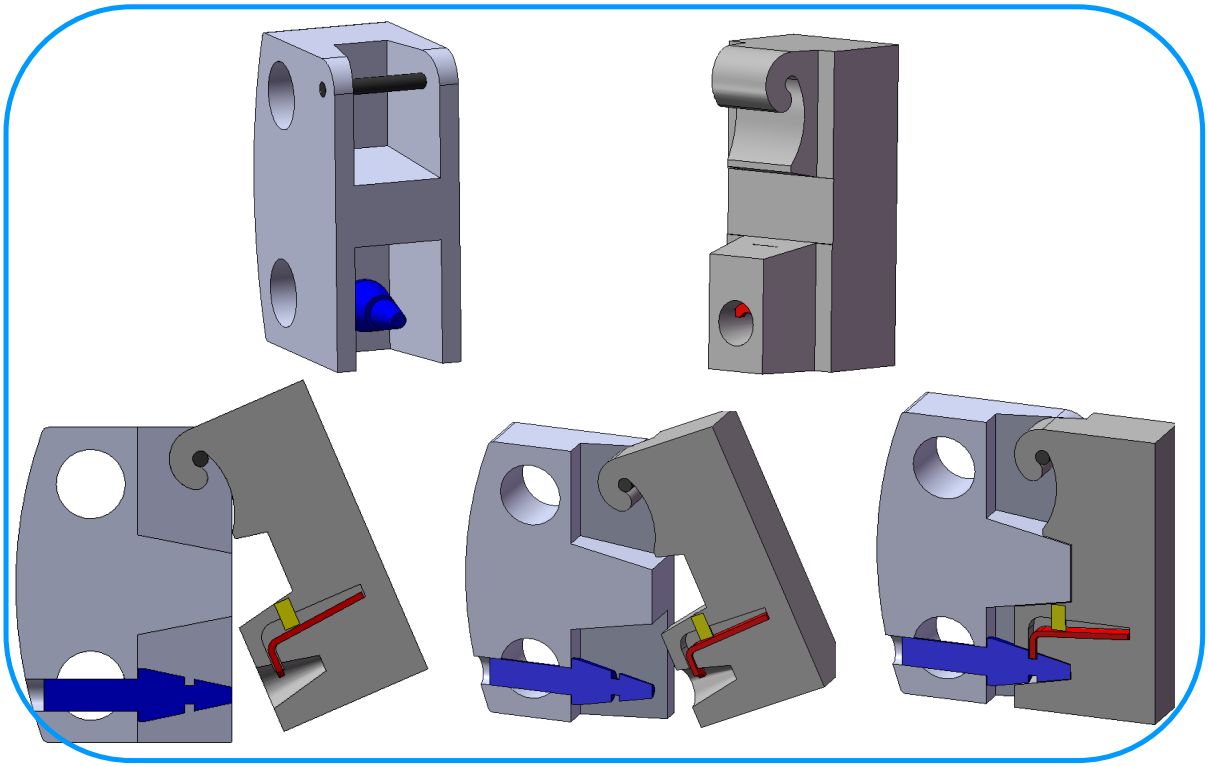
Coupling 1: hook lock with pull release



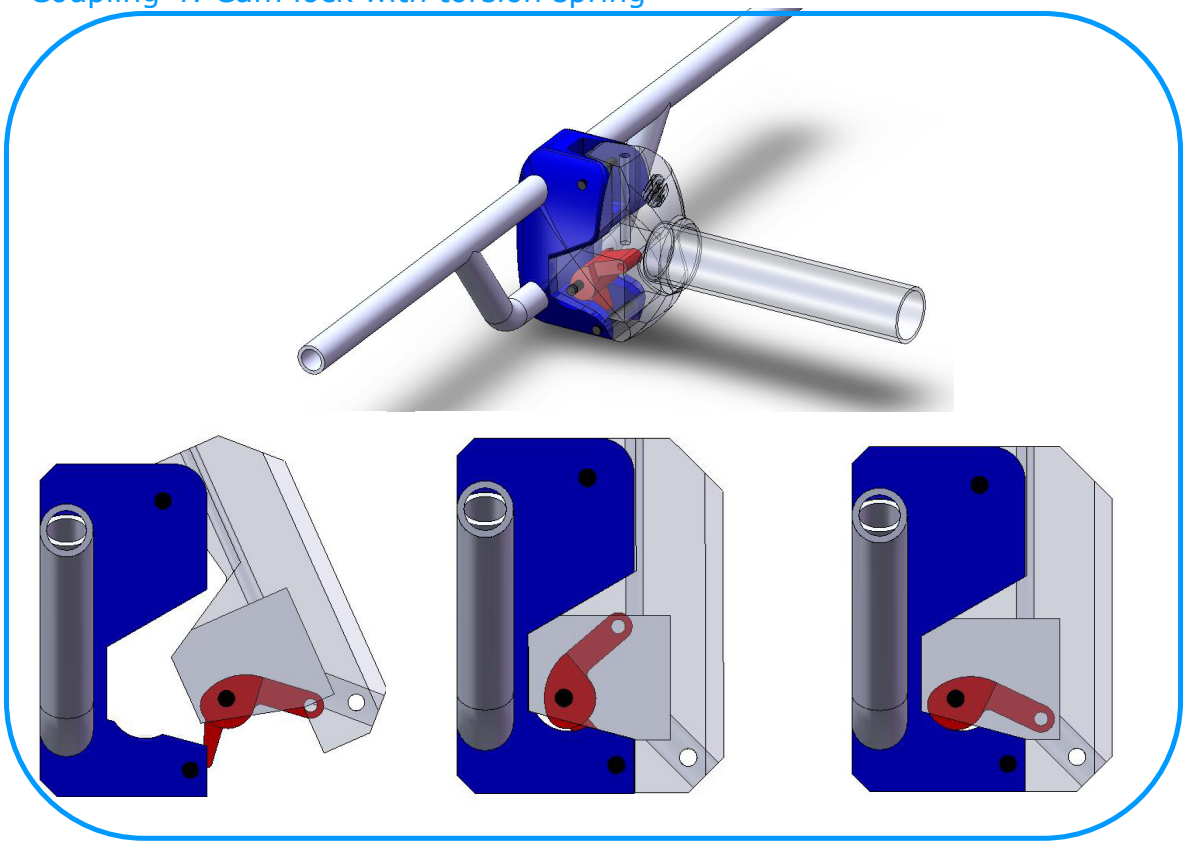
Coupling 2: push rod which fix cam lever



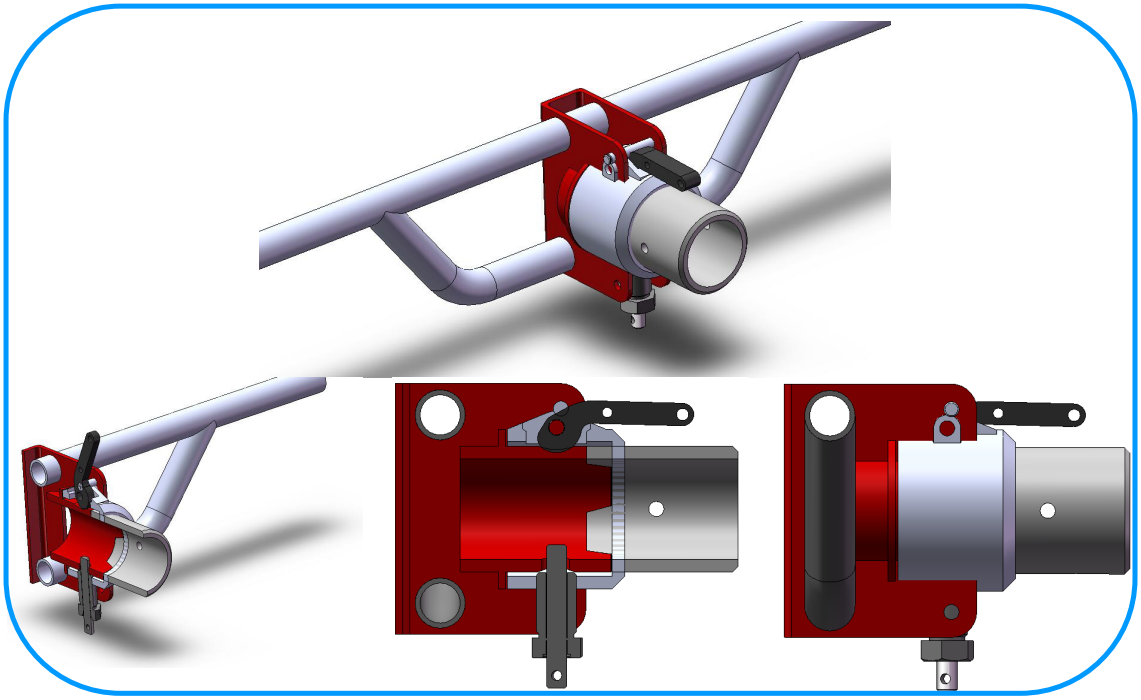
Coupling 3: conic pin with Basta lock principle (elastomer)



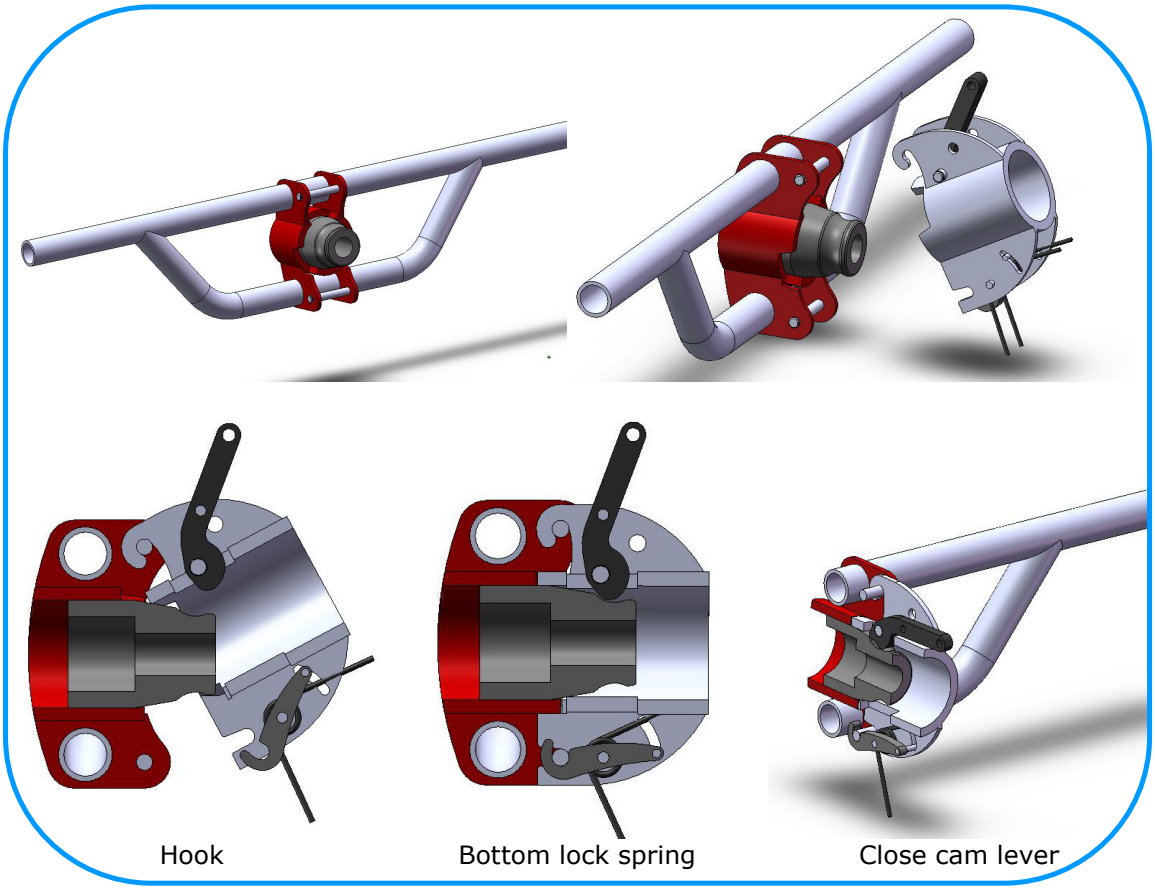
Coupling 4: Cam lock with torsion spring



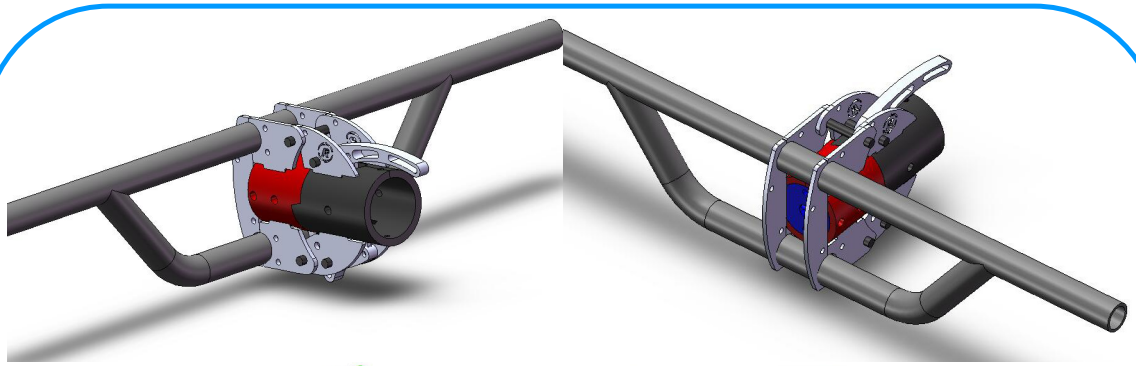
Coupling 5: pin spring lock with cam lever and 3 tooth

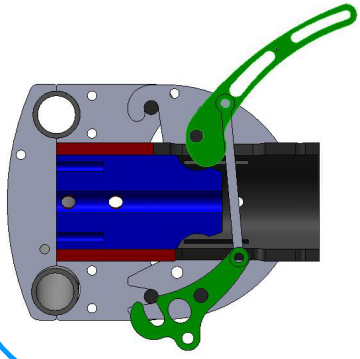


Coupling 6: hook lock with cam compression

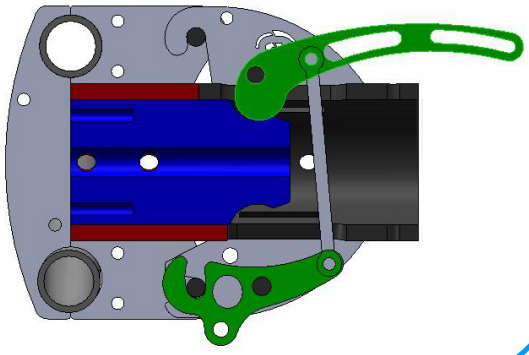


Coupling 7: detailed model coupling 6



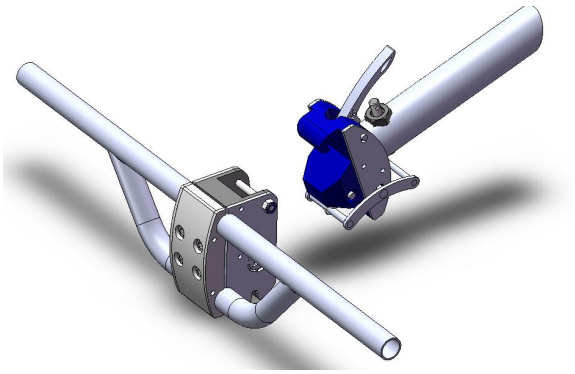


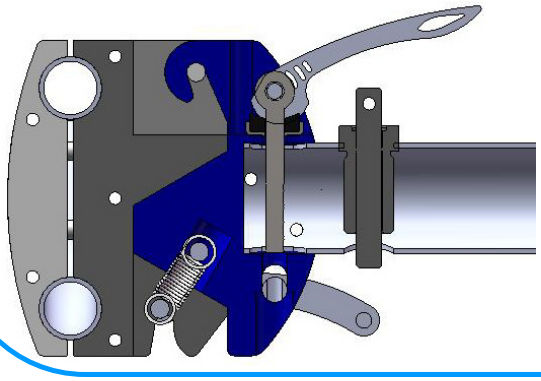
Bottom click system

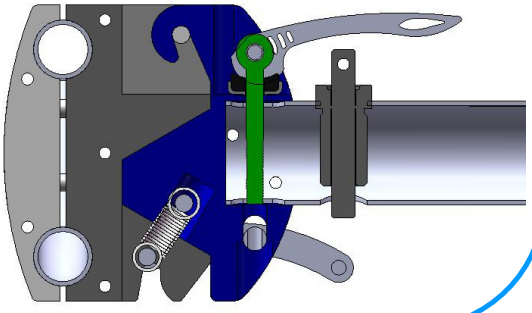


tension cam lever

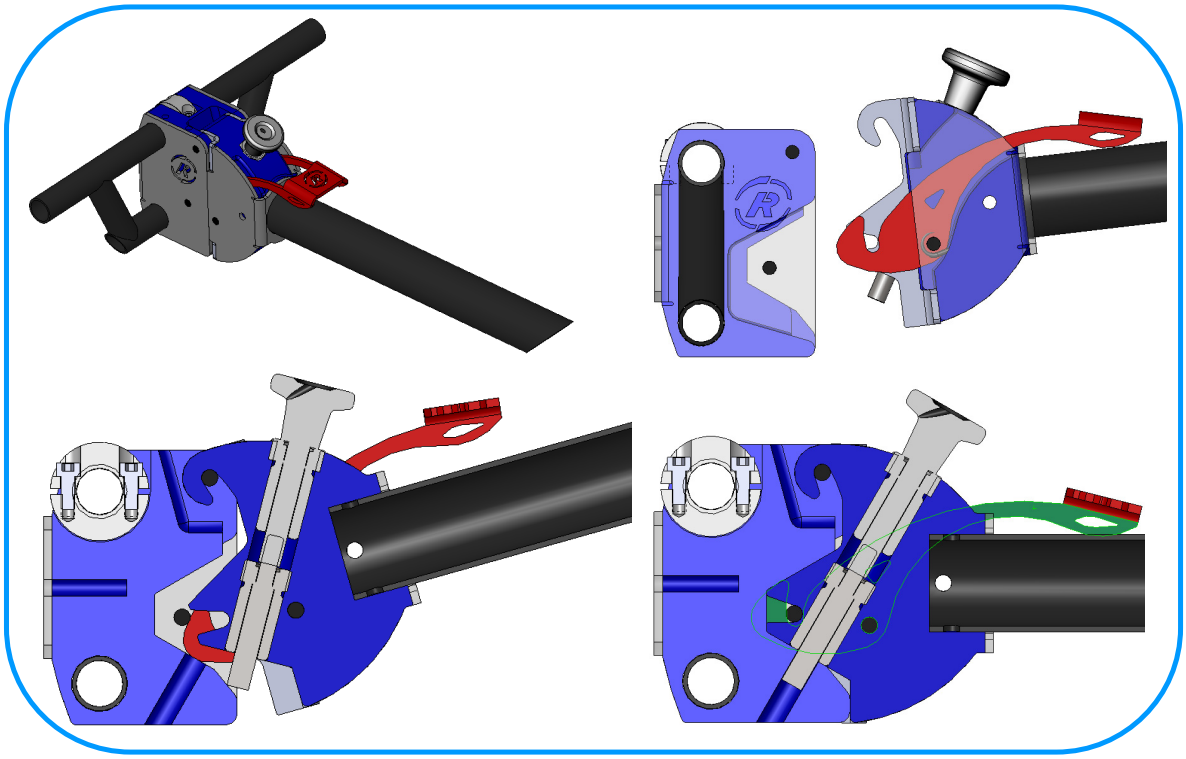
Coupling 8:rod lock with tension lever



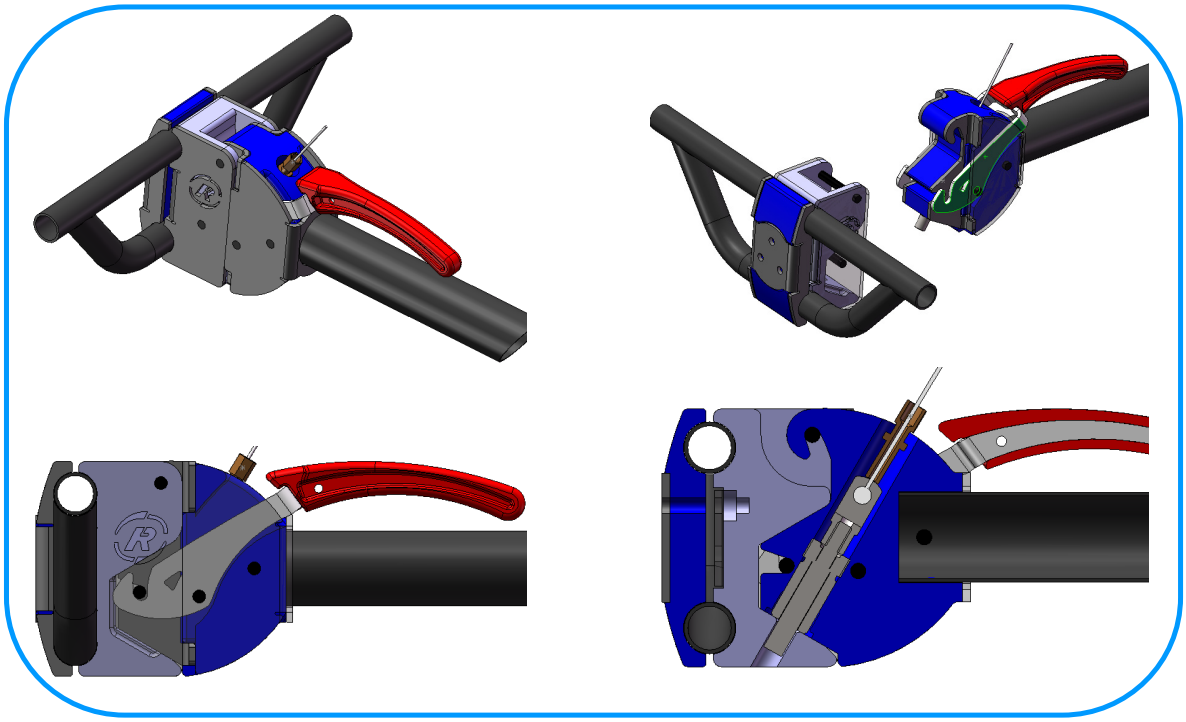




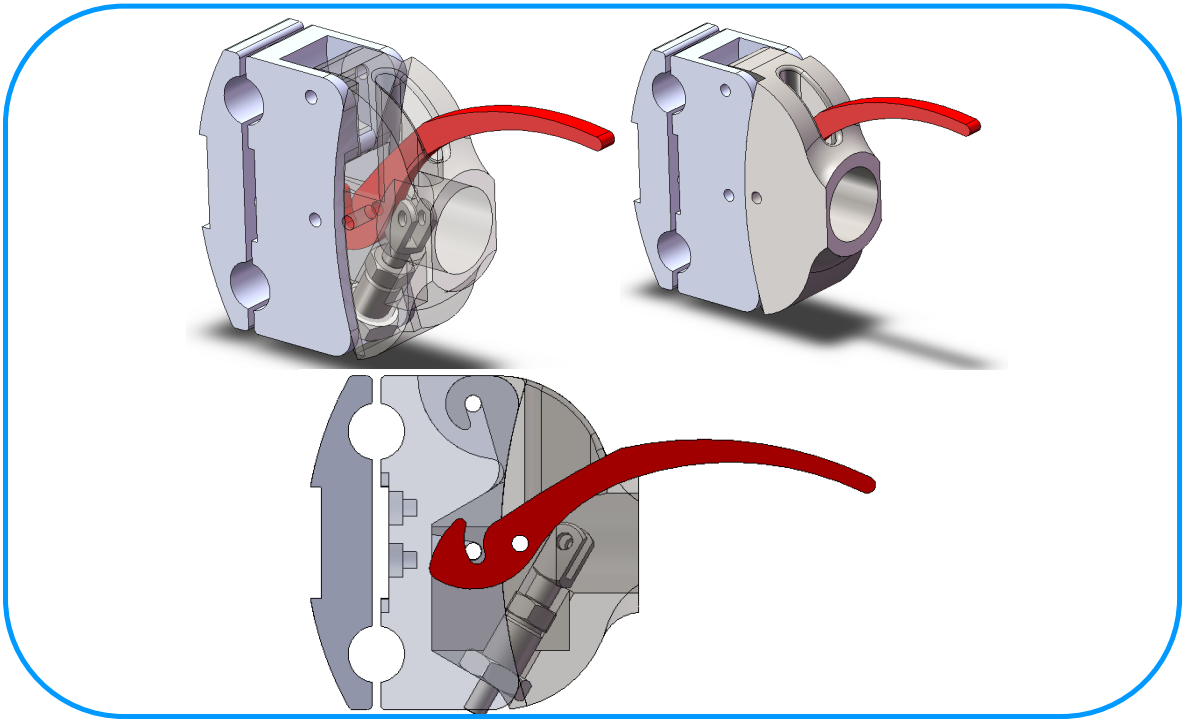
Coupling 9: quick pin lock and release, eccentric hook compression



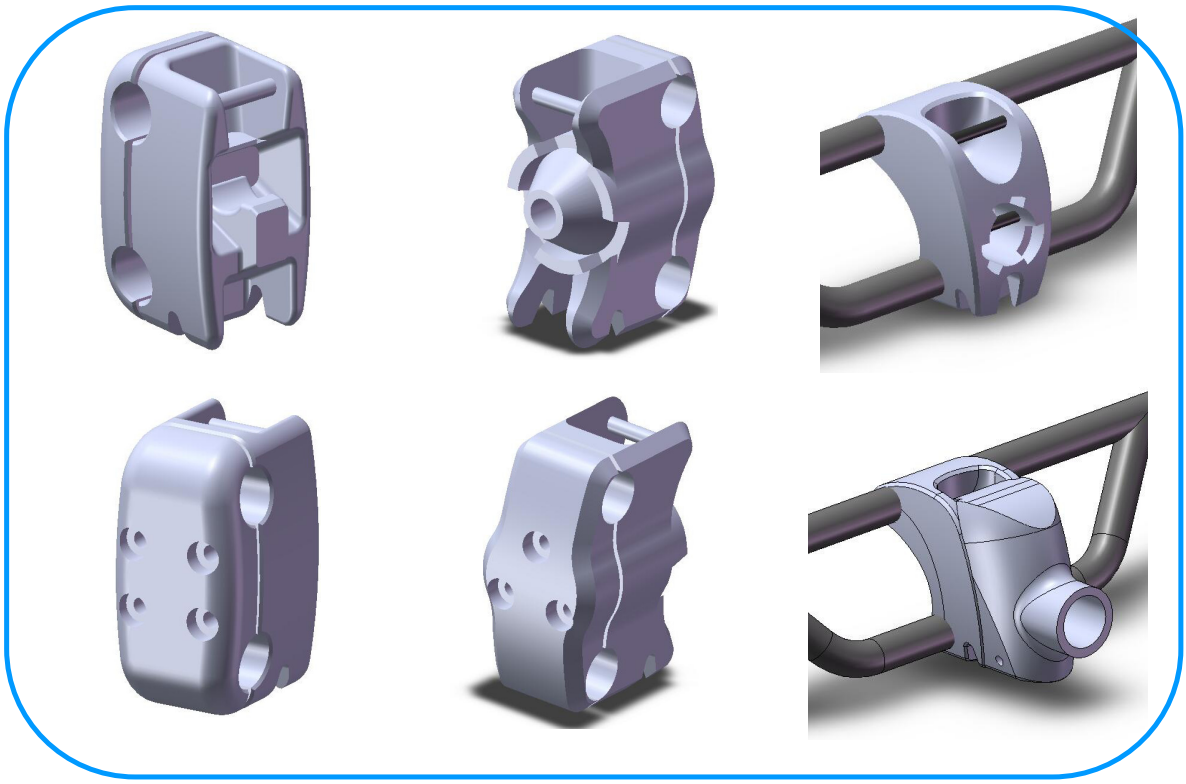
Coupling 10:pin lock with hook compression, one lever



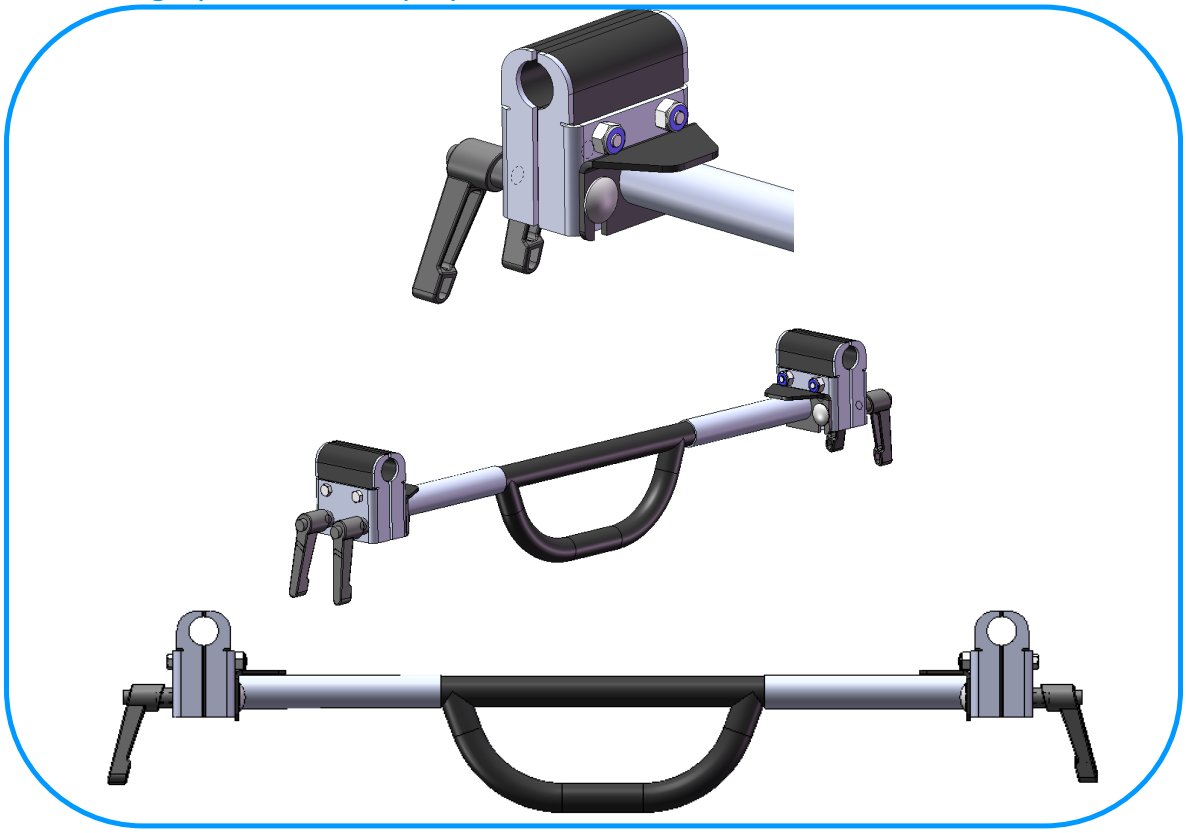
Coupling 11: one grip and hook compression with quick lock system



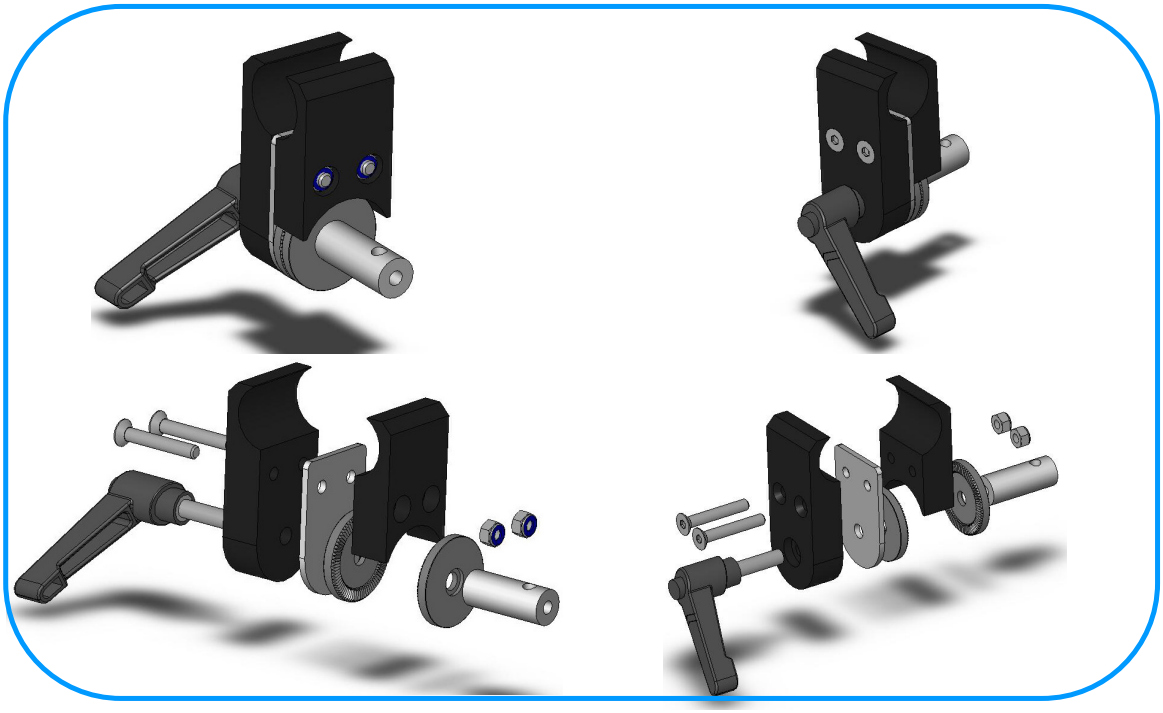
Rapid prototyping shapes:



Mounting system1: clamp system with sleeves to slide and fix frame



Mounting system 2: clamp mechanism with gears to adjust angle



Mounting system 3: conic pin and insert with sheet metal plastic clamps

Appendix N

Cost price calculation

For the handbike a specific calculation is made to estimate the cost price of the handbike for Van Raam. This is divided in production, assembly, outsource parts and hours to produce and assembly the handbike.

production	**specifications**	**amount**	**price**	
frame	mm		p/m	
material				
tube oval (rolling)	60x30x1,5	1	€ 2,79	€ 2,79
tube ellipse (rollin)	40x20x1	1	€ 5,98	€ 5,98
handle	22x1,5	0,3	€ 1,42	€ 0,43
wheelchair tube (bended)	22x1,5	0,5	€ 1,42	€ 0,71
kick stand tube	22x1,5	1	€ 1,42	€ 1,42
head tube	35x2,5	0,2	€ 5,23	€ 1,05
mounting tube	35x2,5	0,3	€ 5,23	€ 1,57
mounting tube	40x2,5	0,2	€ 2,65	€ 0,53
wheelchair tube	25,4x1,5	0,4	€ 1,57	€ 0,63
inner tube	25,4x1,5	0,3	€ 1,57	€ 0,47
bolt holder				
fork end plate		2	€ 2,70	€ 5,40
bracket shell		1	€ 2,95	€ 2,95
core house		2	€ 3,08	€ 6,16
steering border		1	€ 0,31	€ 0,31
seat bolt holder		4	€ 0,16	€ 0,64
bidon bus		2	€ 0,04	€ 0,08
total				€ 31,11

core house		1,24	€ 53,21	€ 65,98
production hours		2	€ 45,00	€ 90,00
powder coating		0,3	€ 55,00	€ 16,50
total				€ 203,59

Assembly parts		product	specifications	amount	price	
wheel	inside tire	40/62 406	20''	1	€ 1,00	€ 1,00
	tire	schwalbe big apple	20'' 406	1	€ 5,04	€ 5,04
	rim	euroline , 24H, 36H	20'' 406	1	€ 4,15	€ 4,15
	spokes			1	€ 7,00	€ 7,00
	hub	shimano SG-8C31	8-speed	1	€ 57,64	€ 57,64
	fender	plastic	20"	1	€ 2,65	€ 2,65
	fender bar			1	€ 0,35	€ 0,35
	sprocket		18T	1	€ 0,30	€ 0,30
	chain ring		38T	1	€ 1,00	€ 1,00
	chain			1	€ 2,05	€ 2,05
top	chain coat	chain glider	38T	1	€ 10,85	€ 10,85
	crank	straight	170 mm	2	€ 4,09	€ 8,18
	bracket		138mm	1	€ 3,00	€ 3,00
	shifter	shimano SL-8S20	8-speed	1	€ 5,35	€ 5,35
	grip	sram		2	€ 0,30	€ 0,60
	brake lever			1	€ 1,72	€ 1,72
	bearing			2	€ 2,81	€ 5,62
	crank insert			2	€ 3,11	€ 6,22
	secure ring		32mm	4	0,18	€ 0,72
	head set			1	1,2	€ 1,20
	insert head tube			2	€ 4,40	€ 8,80
	caps			2	€ 0,02	€ 0,03
	spanner			1	€ 3,80	€ 3,80
	bolts			10	€ 1,00	€ 10,00
						€ 0,00
kickstand	click			2	€ 1,88	€ 3,76
	insert caps			2	€ 0,02	€ 0,04
						€ 0,00
Coupling	quick snap lock			1		€ 0,00
	grip			1	€ 0,30	€ 0,30
	knob			2	€ 0,50	€ 1,00
	stem			2	€ 2,99	€ 5,98
	cable			1	€ 0,45	€ 0,45
	brake bent			1	€ 0,28	€ 0,28
						€ 0,00
accessories	lamp	smart accu lamp		1	€ 9,10	€ 9,10
		lamp holder		1	€ 1,01	€ 1,01
		km counter		1	€ 4,10	€ 4,10
		finger bell		1	€ 0,30	€ 0,30
	total					€ 173,59

outsource						
sheet metal	lasercut, bent			5	€ 5,00	€ 25,00
clamps	milling			4	€ 10,00	€ 40,00
conic pin	spinning			2	€ 10,00	€ 20,00
conic insert	spinning			2	€ 10,00	€ 20,00
POM blocks	milling			2	€ 20,00	€ 40,00
total						€ 145,00

Options				
reverse pedaling			€ 70,00	
power curved crank	170 mm		€ 61,75	
U crank				
Bullhorn crank				
V crank				
power assist				
battery			€ 320,00	
engine			€ 181,00	
carrier				
assembly hours		1	€ 45,00	€ 45,00
total normal				€ 522,18
with curved crank				€ 583,93
with c-crank reverse pedal				€ 653,93

Appendix O

User research

Protocol of user research handbike:

Introduction research

The researcher is showing the handbike prototype to the end user. A small introduction about the purpose of the project is explained and the purpose of this research to the user.

A. General questions

Before the test start the user is asked for general questions about his experience with handbiking.

1. User name
2. Age
3. Type of handbike
4. What kind of purpose
5. How often do they use it

B. Appearance

The user can look at the prototype and is asked for his opinion before the functional test can start.

1. What is you're first impression?
2. Which part attracts you the most and why?
3. What is you're opinion about coupling system?
4. What kind of subscription would suit this handbike?

Safe	Elegant	Boring
Sportive	Expensive	Recreation bike
Solid	Different	Modern
Not practical	Trendy	Comfortable
Technical	Fragile	Organic

5. Would you feel comfortable riding with this handbike?
6. Does this product fit with you're lifestyle?
7. Would you buy this handbike?
8. What are you're expectations of the handbike driving skills?

C. Functional test

The handbike coupling and functionality is explained and the user can try it.

1. Measurement, adjustability appropriate size?
2. Would it be easy and necessary to adjust it by your self?
3. What do you this of the adjustability for wheelchairs?

First the user adds the mounting on the wheelchair on and off, then attach the handbike on and of.

4. Is it easy to understand?
5. Does it take a lot of time?
6. Do you feel safe?
7. What kind of difference do you feel between the aluminum bottom hook compared with the plastic (POM) hook?
8. What do you think of the release mechanism?

What are you're opinion about:

- Crank length, height, width
- Grips pedals
- Stability
- Traction
- Cycling forward
- Reverse pedaling
- Switching gears
- Braking
- Turning, steering radius

D. Evaluation handbike

At the end a short evaluation is hold about the test.

1. Was it what you expected of the handbike
2. What kind of problems did occur?
3. Can you describe you're cycling experience?
4. What kind of suggestions, points for improvements do you recommend?
5. What kind of difference did you feel compared with you're own handbike?
6. What kind of grade would you give the handbike on a scale of 1 to 10.

Ending

Thank the user for his cooperation and is asked what he think about the research.

Result user research

A general information

- **Bart Peters**
- 18 years old
- Student TUDelft
- Use tracker handbike with bullhorn cranks and cardan transmission.
- Cycle every day to the university in Delft and keep the docking station under his wheelchair.

B Opinion

1. What is you're first impression?
Bart first impression is that the handbike looks sportive, trendy and liked that it's painted. Maybe it looks attractive because it's new and but it doesn't look different then other handbikes. His handbike is from stainless steel and looks boring compared with the painted handbike.

2.Which part attracts you the most and why?
The parts that attract him the most are the curved oval frame, curved cranks and the kickstand. He's used to bullhorn cranks so he wonders if this position will cycle comfortable.

3. What is you're opinion about coupling system?
His first opinion about the coupling mechanism is that there is still some movement in the mechanism which doesn't make it looks safe. But after looking on how it should work with the lever he would like to try it and wonder if it will be strong.

4. What kind of subscription would suit this handbike?
The handbike looks sportive, trendy and modern

5. Would you feel comfortable riding with this handbike?
Because the wheelchair that is used in the user test was not his own, he will have to get used to it and feel not as comfortable and safe as his own. He uses a cardan transmission and likes to cycle with a chain drive because it should be smoother.

6. Does this product fit with you're lifestyle?
Bart would not be ashamed to cycle with this handbike and show it of to his friends. But after a while it will get old and you don't keep showing of you're bike.

7. Would you buy this handbike?
Bart would by this bike if his own would not work again, but would like to have an option to add bullhorn cranks on it so he can maintain using arm trunk power.

8. What are you're expectations of the handbike driving skills?
Bart expects that the handbike will react quick, comfortable and smooth on his actions.

C functional

1. Measurement, adjustability appropriate size?
The measurements of the handbike are appropriate for him, only the wheelchair wheels are positioned too much to the front. The position of propulsion is higher than he is used and has to get used to it.

2. Would it be easy and necessary to adjust it by your self?
It would be easy to adjust and he always have a repair toolkit with him for his wheelchair and handbike

3. What do you think of the adjustability for wheelchairs?
It looks easy but he would not change it, because the fitting is done once for his wheelchair and he would leave it under his fixed frame wheelchair.

4. Is it easy to understand?
After two times of practice it is easy to understand the principle of attaching. The hook system was not working properly and the front wheel of the handbike had to be lifted from the ground. He was not used to this and this was also not the purpose.

5. Does it take a lot of time?
On and off coupling went is seconds and didn't consume any of time. It was easy when he hear a click that the system is locked. With the red lever to push was done naturally.

6. Do you feel safe?
The coupling system was not milled accurate so there was still some movement. Bart thought this was the purpose while cycling and didn't think is was not safe. He was although careful because he didn't want to break the prototype.

7. What kind of difference do you feel between the aluminum bottom hook compared with the plastic (POM) hook?
The difference for bart was that the lever of the plastic block was fixing much better. In this way cycling was with less movement and feels stiffer. For attaching the coupling system was not a lot of difference because the angle of approach was the same for him.

8. What do you think of the release mechanism?
The release mechanism didn't worked yet so this still had to be tested. However the principle was clear to release the top lever. But he didn't aspect to have a secure system in it. The double lock had to be explained first before both actions could be done in the proper order.

9. What is you're opinion about:

Crank length, height, width	good
Grips pedals	soft, prefer hard grips
Stability	good
Traction	average, wheelchair wheels need to go back
Cycling forward	good
Reverse pedaling	nice, but is used to use wheelchair rims
Switching gears	easy, but doesn't use it during pedaling
Braking	abrupt, didn't want to brake to hard
Turning, steering radius	not used to, used to take sharp corner

D Evaluation handbike

1. Was it what you expected of the handbike

The handbike is fine and is more advanced than he would expect.

2. What kind of problems did occur?

The coupling was still moving a bit, the steering angle need to be larger, the braking was abrupt.

3. Can you describe you're cycling experience?

If the small things would be improved it would be a handbike that is fine to use and has some advantages like the reverse pedaling, mounting on and off and switching gears while cycling. However, to all these he will have to get used to, because he has learned him self some habits with his own handbike.

4. What kind of suggestions, points for improvements do you recommend?

The lever of the coupling should not be red and attracts too much attention
The angle of approach for the coupling needs to be different so the wheel doesn't need to be lifted.
The aluminum block looks technical but he likes the appearance and gives his wheelchair more identity.

5. What kind of difference did you feel compared with you're own handbike?

Bart bike is another kind of handbike and this stands on its own. After some improvements it will be a pleasant bike to ride with.

6. What kind of grade would you give the handbike on a scale of 1 to 10.

He would give the handbike a 7,5

A General information

- **Marcel Bierman**
- Employee Welzorg
- Uses ROAM handbike with bullhorncranks and chain transmission
- Uses the handbike weekly basis to cycle in Amsterdam to do groceries

B Opinion

1. What is you're first impression?
Marcel first impression is that the handbike looks beautiful. Its different then what is already on the market.

2. Which part attracts you the most and why?
Marcel likes the cranks, the curve in the frame and thinks the handbike is unique.
He has no problems with the chain line because it is more efficient then a cardan transmission and the top cyclist all use chain transmission.

3. What is you're opinion about coupling system?
Attaching the system on the wheelchair would be no problem for him; it doesn't look to technical and fit the wheelchair. The weight can be reduced because current wheelchair weight 4 kg and if the mounting system weighs 2 kg this will be a disadvantage.
He wonders if the angle of the mounting system will remain if he would take a hill or bumps into something with his front wheel.

4. What kind of subscription would suit this handbike?
Sportive, different and modern

5. Would you feel comfortable riding with this handbike?
He would feel comfortable but has to experience it by himself.

6. Does this product fit with you're lifestyle?
Yes, I would use it as urban transport and suits my lifestyle, no problem.

7. Would you buy this handbike?
He already has a handbike but is enthusiastic about the design of this on.

8. What are you're expectations of the handbike driving skills?
I expect that the handbike will cycle comfortable, I doubt how strong the mounting system will be.

C functional

1. Measurement, adjustability appropriate size?
The size of the wheelchair it not totally appropriate and his arms need to be stretched out while pedaling. He would need more support in his back because he doesn't have a lot of trunk power.

2. Would it be easy and necessary to adjust it by your self?
Yes no problem

3. What do you think of the adjustability for wheelchairs?
Easy to adjust, and see the advantage of it for foldable wheelchair to transport but he would not use it by him self because he uses a fixed frame wheelchair

4. Is it easy to understand?
The principle is clear and easy but some practice is needed. Especially because the brakes from the wheelchair were removed and the wheels were too much to the front.

5. Does it take a lot of time?
After some practice it went faster.

6. Do you feel safe?
He didn't feel save with the off balance wheelchair but in combination with the handbike it was better.

7. What kind of difference do you feel between the aluminum bottom hook compared with the plastic (POM) hook?
-Not done in this research

8. What do you think of the release mechanism?
The idea is great to have a squeeze lever at top in sight and reach. And the double lock system makes it safe.

9. What is you're opinion about:

Crank length, height, width	good
Grips pedals	soft, prefer hard grips
Stability	average, need other wheelchair
Traction	average, wheelchair wheels need to go back
Cycling forward	good
Reverse pedaling	nice, would not use it
Switching gears	easy, but doesn't use it during pedaling
Braking	good
Turning, steering radius	not used to, used to take sharp corner

D Evaluation handbike

1. Was it what you expected of the handbike

The adjustment had to better for his needs, but that could be done by make it fit better to his needs. Cycling backwards was fun but he would not use it often

2. What kind of problems did occur?

The coupling orientation was hard to bring it in straight line to the docking station
Marcel trouser get trapped in the coupling mechanism, but this was because the wheelchair frame was narrow.
The steering angle was too small for him and he is used to turn quick in the city.

3. Can you describe you're cycling experience?

The handbike was reacting properly but the wheelchair was not suitable for his needs.
Turning the handbike could smaller and the steering correction was not applied yet.

4. What kind of suggestions, points for improvements do you recommend?

Orientation for the coupling mechanism
Angle of docking station need to be fixed or pinned properly
Steering corrector and angle
Harder durable grips

5. What kind of difference did you feel compared with you're own handbike?

He uses bullhorn cranks and a handbike which steer quicker and shorter. The handbike looks attractive and the weight could be reduces

6. What kind of grade would you give the handbike on a scale of 1 to 10?

He would give the handbike a 7

Appendix P

Reflection design guidelines

In this overview the design of the handbike is compared with the product requirements and list of wishes. If the demand is fulfilled it will be green and if not it will be red. If the demands are not fulfilled optimal it will receive a blue color.

Product requirements

1. Requirement according WMO Law (Wet Maatschappelijke Ondersteuning, social law support) and PGB (persoonsgebonden budget, personal budget) package for adult handbikes are:

Category 3: adults

- 20 inch front wheel
- 7-Speed Internal Hub gear
- lighting (battery/ unit behind wheelchair
- kilometer counter
- bell
- chain protection
- kick stand
- fender
- coaster brake (back pedal or foot brake)
- 170 mm crank standard position

Handbike use

2. The handbike crank propulsion should be in high position, so the user sit straight and use the handbike without trunk power
3. The cranks propulsion should be adjustable in height and length for users between 1,60 and 1,90m, without over stretching the arms of the users
4. The handbike steering mechanism must correct itself to steer straight
5. The handbike should be able to stand in neutral straight position without a wheelchair
6. The handbike steering should have a small turn radius and be limited to a maximum range of 45 degrees to the left and 45 degree to the right.
7. The handbike should weight less then 15 kg
8. The handbike user should be able to pedal and cycle in reverse direction
9. The handbike must have the possibility to transform into an electrical powered bike with little adjustments as possible
10. The installation of the handbike on the wheelchair must be done by a mechanic at the user home
11. Installing the handbike should be done with simple tools which are able too fit in a van
12. The handbike should be easy to use and maintain

Mounting mechanism

13. The mounting mechanism should be easy to understand for users
14. Quick to attach and easy to detach
15. Easy to attach, with little force for users with different disability levels
16. The mounting system on the wheelchair should be universal (adjustable) so it fit on most common fixed and foldable wheelchairs.
17. Their should be as less then 1 kg left on the wheelchair when the handbike is detached
18. The front wheels of the wheelchair should be elevated 5 cm of the ground (the rolling resistance will be reduced with 80%)
19. The connection with the wheelchair must be solid, safe and strong
20. The clamp on system on the wheelchair tubes must be strong and light as possible
21. The wheelchair frame should not be damage or weakened by the mounting mechanism

Design & shape

22. Form and design should be the right extension for recent wheelchairs
23. The appearance should be modern, attractive for users and fit current wheelchairs
24. The appearance should fit sportive, recreational, city bike users
25. The design has to differentiate itself from other handbikes on the market

Production and assembly

26. The frame of the handbike must be durable and stiff to transmit the human power to the wheel
27. The handbike frame should be weather resistant
28. The assembly should be as efficient as possible for serial production of 100 a year
29. Adjustment and customization should be easy to make
30. Standard bicycle components should be applied, so it is easy to adjust and customize components

Cost

31. The consumer selling price of the handbike must not be higher then 3000 euro for a standard handbike
32. The production cost should be less then 750 euro
33. A minimal profit of 29% should be considered for can Raam and 35% for Welzorg

List of wishes

User

It's desirable that the handbike user can:

- shift easily between speed gears
- easily brake fast and safe
- have smooth cranking propulsion and comfortable ride
- reduce the time of mounting the handbike on the wheelchair with less steps
- easily transport and store the handbike

Product

It's desirable that the handbike is made:

- from a modular system so conversion is possible and take less effort
- from standard bicycle tube dimensions so different accessories can be applied
- in the capabilities of van Raam production methods or else outsource parts