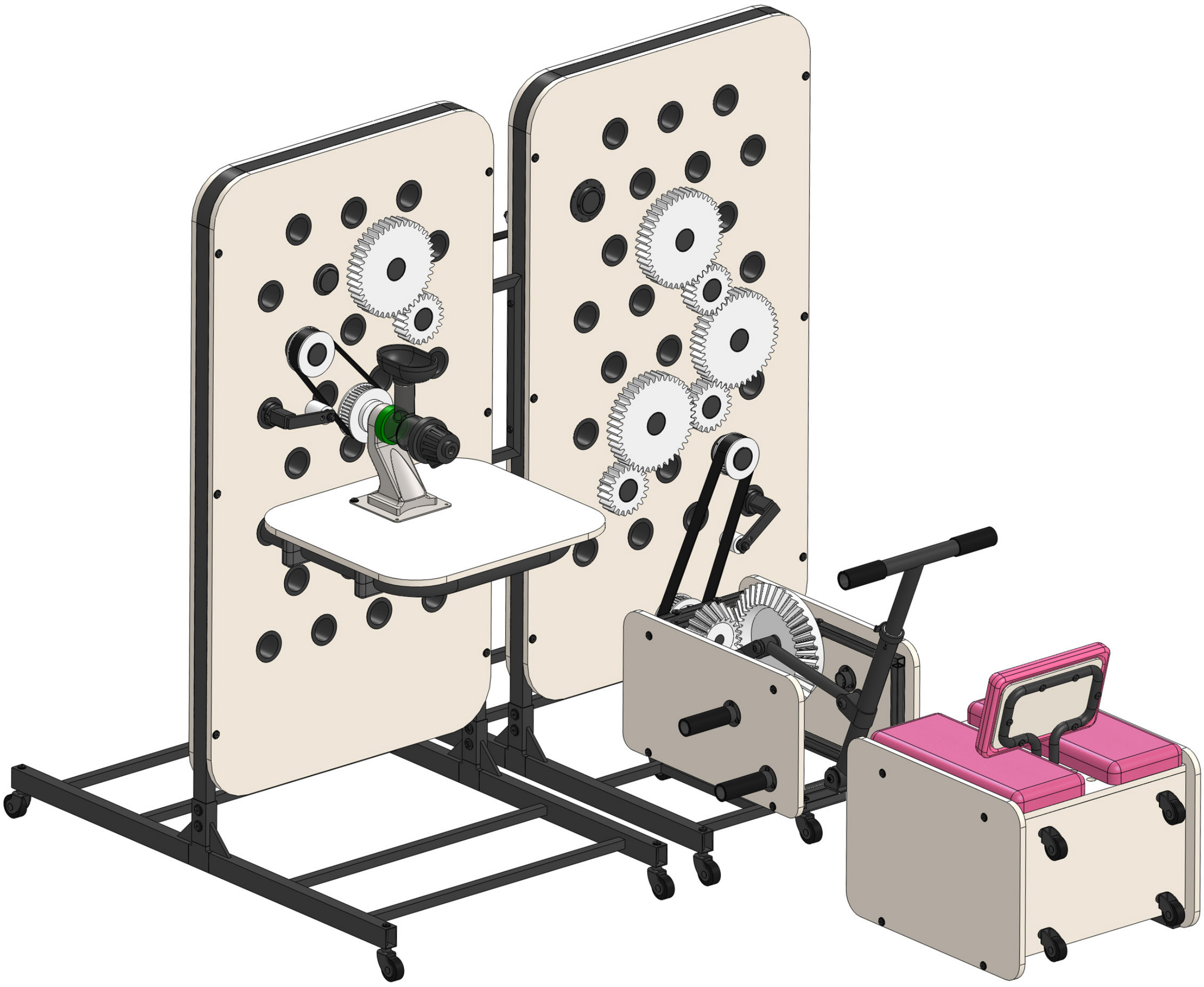
Design of a human-powered juicer device



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Type of project: Internship

UNIVERSITY OF TWENTE.

orange creatives 橙创

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Preface

This report is the result of my internship performed at Orange Creatives in Guanzhou, China. Performing this internship at Orange Creatives was a great experience. It also allowed me to experience China and its culture for five months. Although it seemed like a large challenge beforehand, I had the time of my life during those months. It left a large impression on me and I learned a lot, not only internship-related, but also a lot about myself.

I would therefore like to thank Boukje Koch, for giving me the opportunity for having this great experience. I also want to thank Maarten Boer, with whom I spend a lot of time working together in the office, but with whom I also had a lot of fun outside office hours. I want to thank my other Dutch and Chinese colleagues as well, especially Bob Wang and Rundy Chuang, who helped me a lot on the later phases of the project. And I want to thank my other newfound friends, who made the internship period so much fun and made it go by way too quickly!

Jarne

Abstract

This report describes an internship performed at Orange Creatives. The internship was part of a product development project performed for the client Vitatools. The project assignment was to develop a human-powered juicing device.

In the analysis phase information relevant to the internship was extracted from earlier results within the project, most importantly the design brief. This included information about the slowjuicer used in the device, the main principle of how the product functions and the requirements related to the technical design.

In the concept phase a user test was performed to further specify the requirements. Subsequently, a number of technical solutions were investigated for various aspects of the design, of which the results were combined into a morphological chart, as well as a combination matrix, to display the compatibility of using solutions together. Part of these solutions were then used in the designs of three concepts. Of these concepts, the client selected the plug & play panels concept.

After the selection by the client, the concept was further developed during the detailed concept phase. For each of the modules, technical solutions were chosen to fulfil their required functionality. In turn, these solutions were developed further to form the initial general design of the modules.

After the concept was finalized in the detailed concept phase, the next step was to fully design the product, up to a production ready state. This was done in the engineering phase, where the geometry, dimensions, material and production processes were designed and selected for all components. Calculations were used to verify dimensions or the component selection of functional components and important load-bearing parts. From the completed CAD-model technical drawings were made, which were used to source production, receive production cost quotations and to receive feedback on the design. Subsequently, this information was used to further improve the design, resulting in a complete design. At the end of the engineering phase, the design was ready for the production of the first prototype to be ordered.

The resulting design is a juicer wall, which allows its user to create a healthy juice through human power. It consists of a chair and, a movement input module, two wall segments supporting a system of gears and pulleys, and a table supporting a slowjuicer. The system starts with the movement input module, with which a user powers the system through a skelter rowing motion. The movement input is positioned on the foot of the right wall segment. Both wall segments combined form the wall. Along the wall, the gears and pulleys transfer the human input motion to the slowjuicer output. The slowjuicer is mounted on the table, which itself is supported by the left wall segment. During use of the product an assistant feeds ingredients into the slowjuicer.

Unfortunately, it was not possible to manufacture the prototype during the internship, so the design could not be evaluated within this period, but has to be evaluated afterwards instead. The internship was finalized with a project transfer, to transfer data on the progression of the project thus far to a new employee and to evaluate the project.

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1. Introduction

This report is the result of an internship performed at Orange Creatives, a Dutch design agency situated in Guangzhou, China. The internship had a duration of five months and was part of the master study mechanical engineering at the University of Twente. It had the objective of gaining work experience, as a practical addition to the courses followed at the university.

The internship was part of a design project performed on behalf of Orange Creatives' client Vitatools, a company that offers services for supporting a healthier lifestyle, food and physical exercise for employees. Vitatools desired a new product for promoting both exercise and a healthy diet. Therefore, the assignment of the project was to design a human-powered juicing device.

The structure of the report is similar to the structure of project phases used by Orange Creatives. Chapter 2 supplies background information on the project, describing the stakeholders involved and the scope of the internship within the project. Chapter 3 describes the analysis phase, in which information relevant to the internship was derived from work performed on the project prior to the start of the internship. Chapter 4 discusses the concept phase. In this phase a user test was performed, technical solutions to be used in the concepts were investigated and three concepts were presented. The chapter concludes with the concept selection. In chapter 5 the detailed concept phase is discussed, in which the chosen concept was developed further, resulting in a complete concept. In chapter 6 the engineering phase is discussed. In this phase the created concept was used to fully design and finalize the product, up to a production ready state. The chapter also describes how the internship itself was finalized. And chapter 7 discusses conclusions and recommendations on the project, as well as an evaluation of the internship.

2. Assignment background

In this chapter the context is described in which the internship assignment took place. The company where the internship took place is discussed, as well as the client for whom the project was performed. The chapter concludes with the scope of the internship assignment within the project.

2.1 Orange Creatives

Orange Creatives is a Dutch design agency, situated in Guangzhou, China. Their design work covers a broad range of consumer products. It is a relative small company, with at the time of the project 13 employees, a mix of Dutch and Chinese people. Originally the company started out as providing local design and development for western companies. For western companies, one of the biggest challenges of having production in China is communication with the Chinese suppliers and quality control of the products. By being situated in China and having Chinese employees, Orange Creatives bridges this gap between their western clients and Chinese manufacturing companies. Knowing the language and culture allows for better communication and being locally situated allows for visiting factories directly and thus quality control on site, quick feedback from production tests during development and a quick response to possible problems during production.

Over time, the company also grew into designing for Chinese companies, bringing the quality of Dutch designers into the Chinese product design market. Its design activities therefore cover the whole scope of new product development, from branding to concept design to detailed design for production and assembly.

Within the team of Orange Creatives, most of the work was performed in collaboration with Maarten Boer, who was the project manager, but who also functioned as the industrial designer of the project. While the internship focused on the technical functionality and construction of the product, his tasks encompassed all other aspects of the design. Later on, when the project focused more on detailed development, two of the Chinese engineers, Bob Wang and Rundy Chuang, became involved as well. Both provided feedback on technical design aspects and the first performed most of the communication with suppliers, sourcing the production of components for the prototype and providing feedback from manufacturers used in redesigns.

2.2 Vitatools

Vitatools is the client for which the project was performed. It is a Dutch company that focuses on supporting healthier lifestyle, food and physical exercise for employees. It does this by organising events and activities at companies that inform the employees about these aspects in an interactive way, such as providing tips on how to reduce stress and what kind of healthy food can improve their day at the office. One of the earlier products of Vitatools is their “fruitshakebike”, a bike modified to drive a blender through human power. This product, shown in figure 2.1, gives a fun way to promote both exercise and healthy food.

Nowadays, the fruitshakebike has become an independent commercial concept. Therefore, Vitatools wants a new product that promotes both exercise and a healthy diet, but with a concept that moves away from the idea of ‘a modified bike’ and towards a separate product in itself. This includes other types of exercise movements, a different type of juicer device, better technical functionality and overall a more unique design. In order to achieve this, they have asked Orange Creatives to create this new juicer.

Figure 2.1: Original fruitshakebike

2.3 Scope of internship within project

Before the internship started, the first few phases of the project were already finished. At the start of the project an initial assessment of the project was performed together with the client, resulting in a project brief. Next, a market research was performed, which was combined into a ‘product map’. Based on this product map and discussions with the client, a design brief was drawn up, composing of the desired direction of the concepts and the requirements. This design brief was the input for the concept phase.

The internship started during this initial concept phase, in which three concepts were being designed. After the client made its decision on the desired concept, the detailed concept phase was started, during which a complete concept of the product was designed. Again after feedback from the client the concept was finalized and further developed in the engineering phase. At the end of the engineering phase the production of components was sourced to manufacturers, whose feedback was used to finalize the first prototype. At the end of the internship the production of the prototype was about to be started.

3. Analysis phase

In this chapter information from the design brief relevant to the internship assignment is be discussed. This includes information about the slowjuicer used in the device, the main principle of how the product will function and the requirements related to the technical design.

3.1 Slowjuicer

The original fruitshakebike made shakes by powering a blender. For this new product Vitatools want to change the juicing device from a blender to a juicer, specifically a slowjuicer. Blenders are not suited for all fruits, nor can they process most vegetables. In contrast, juicers are suited for all these ingredients, and therefore offer more possibilities in making healthy juices. Most juicers are centrifugal juicers. A new trend, which the client wants to follow, is the use of slowjuicers. Instead of high speed centrifugal extraction, they use a low speed augur that breaks down and slowly squeezes all the juice of the pulp, resulting in a higher amount of juice from the same amount of fruit, and (supposedly) also resulting in a juice that contains more of the fruit's vitamins and minerals. A slowjuicer is also suited for vegetables with a low amount of juice, for instance carrots. Due to its high force it can even extract juice from seeds and nuts. Most of these slowjuicers are electrically powered, but they also exist as manual versions with a hand crank. Both of these slowjuicers are shown in figure 3.1. In the case of this project the client wanted to use a manual version, since it allows the user to actuate the slowjuicer directly, instead of generating electricity which in turn could be used to power the machine. This adds to a very visible mechanical functionality of the product.

Figure 3.1: Slowjuicers, manual (left) and electric (right)

While operating the slowjuicer, fruit and vegetables have to be continually fed into the machine from the top. This means that it is difficult for one person to operate the manual product, since the product needs to be powered by hand simultaneously. It is therefore better to use the manual product by two persons and split these tasks.

To avoid confusion, in the report the following terms are used: juicer refers to the whole product, while slowjuicer refers to the actual juicing device within the product.

3.2 Product principle

In this paragraph the principle behind the slowjuicer, as well as the modular approach of the concept design process are discussed. Based on market research and project brief the product was divided up into the three basic modules, as shown in figure 3.2, illustrated by Maarten Boer.

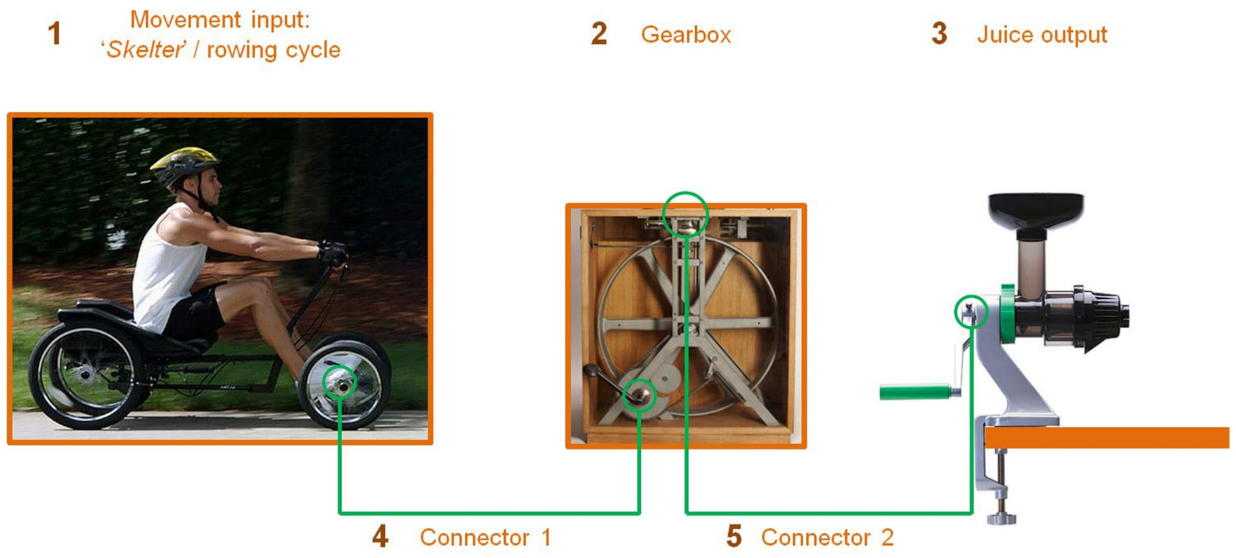

Figure 3.2: Main modular principle

Module 1 is the movement input, which the user uses to supply power to the product. Module 3 is the juice output, the hand-driven slowjuicer which uses the power of the user to produce juice. The gearbox in between, module 2, is used to supply the correct speed and/or power for the juicer. Each of these modules are combined with connectors in between them. Due to this modularity, the movement input can be changed while keeping the rest of the product the same.

3.3 Requirements

The requirements are based on the project brief and market research. To keep the requirements brief, some of the requirements not related to the mechanical design, such as style and aesthetic design style, are omitted from this list.

- The user should use the product for at least 1 minute before reaching the result of 250 ml of juice.
- The juicer should be operated by a combination of one instructor/helper and one user.
- The juicer should be transported and assembled on site by one person.
- During transport, the juicer should fit inside a station wagon.
- The juicer has to be adjustable, to accommodate the body dimensions representative of 90% of the population, from age six and up.
- The amount of adjustments needed for each new person have to be minimized.
- The usage and functionality of the juicer should be understandable by the same user group.
- The transmission from movement towards juicing should be visible.
- The transmission should have a very 'mechanical' feel to it.
- The device should power the Tribest Z-710 slowjuicer.
- The slowjuicer should be easy to mount and clean.
- Connector 1 should be able to connect to different types of movement input modules.
- Connector 2 should have the possibility to connect to different types of slowjuicers, as well as a generator, which are possibly added in a later stage.
- Speed should be displayed, to create a competition element.
- The production cost of the juicer should not exceed € 1.000,-, for an estimated first production series of 20 units.

4. Concept phase

In this chapter the concept phase is discussed. The chapter starts with discussing the performed user test, followed by the technical solutions which were investigated and combined into a morphological chart. Of these solutions the motion type to be used is discussed in more detail, after which the three concepts are presented. The chapter concludes with the concept selection.

4.1 User Test

Before designing solutions, it was decided to perform a short user test of the Z-710 slowjuicer with the normal hand crank. This was done to further specify the requirements. The most important factors were speed, effort and amount of juice (the requirement is that the user should use the device for at least 1 minute before reaching the result of 250 ml of juice). It was also meant to get a better understanding of which aspects of using the slowjuicer needed to be taken into account into the design, as well as possible problems during use.

A test subject used the hand crank while an assistant fed ingredients into the juicer. Four test subjects performed the tests and the ingredients ranged from soft and juicy oranges to hard carrots with little juice (All tests were performed four times, with the exception of the test with oranges, which was done only once at the highest possible speed, as an extreme scenario). The focus was on vegetables, since these were expected to be mostly used in the healthy drinks.

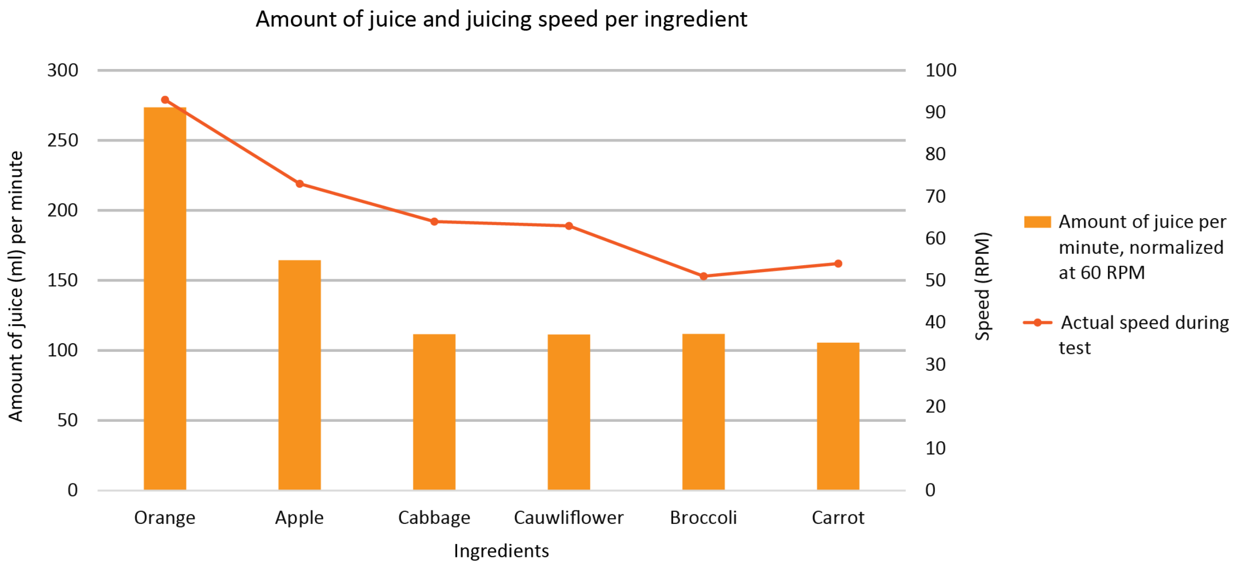

Figure 4.1: Results user test. Line graph shows speed, columns describe amount of juice at normalized speed

The test results for speed and amount of juice are shown in figure 4.1. The figure shows that there is a large difference in amount of juice and speed: between oranges and carrots there is a 1.7x difference in speed and, when normalized to the same speed, a 2.6x difference in amount of juice.

During actual use of the product a combination of fruits and vegetables are used. Figures 4.2 and 4.3 show the average amount of juice per minute and the average amount of time needed to reach 250 ml of juice, respectively. Both are plotted for a low user speed of 60 RPM and a high speed of 90 RPM, and for multiple possible gear ratios between user input and juicer output. With a 1:1 gear ratio the average time needed is below one minute. It was therefore decided to use a 4:3 gear ratio, as a balance between not finishing too fast but also not taking too long.

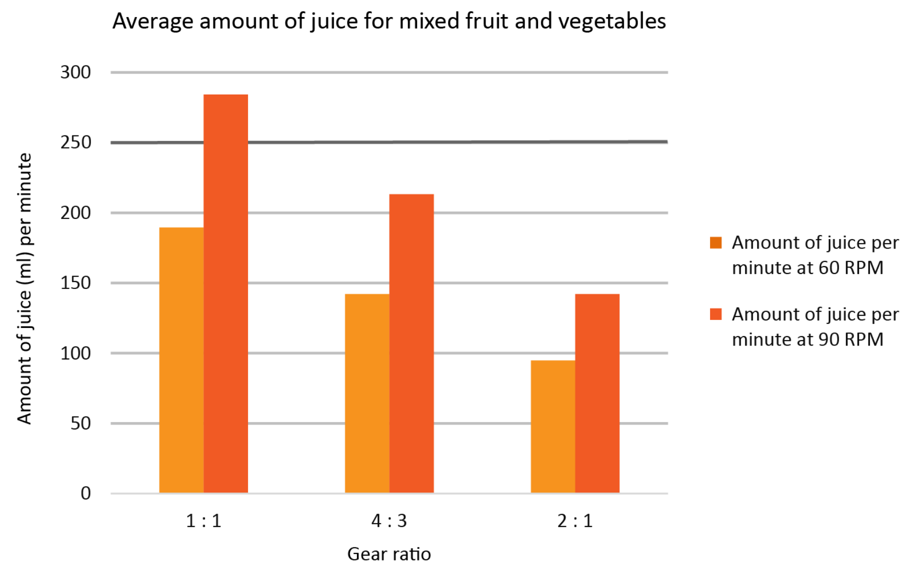

Figure 4.2: Results user test. Average amount of juice per minute

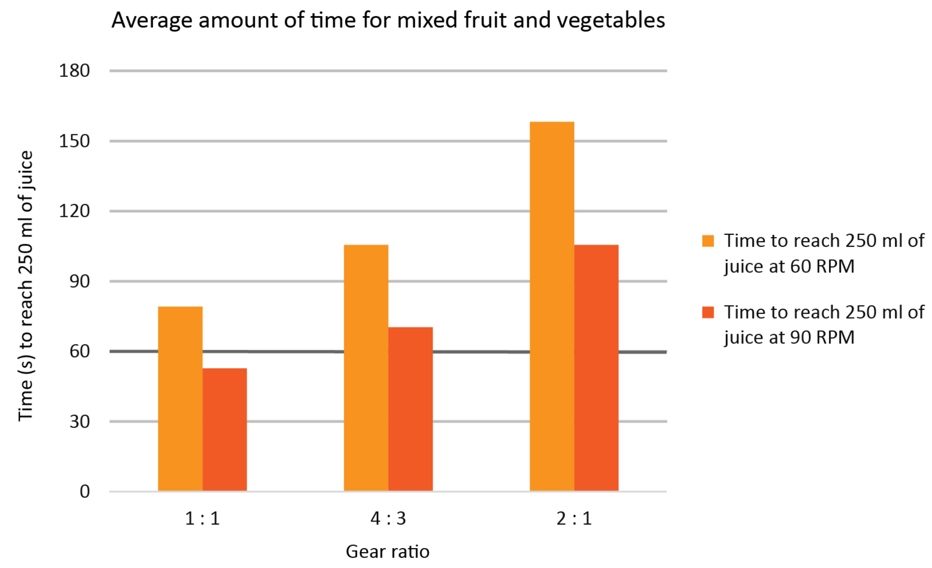

Figure 4.3: Results user test. Average amount of time needed for full glass

During the tests it was also noticed that the effort needed to juice each type of ingredient greatly varied. For the most part the responses about the effort needed corresponded to the speeds shown in figure 4.1, in the sense that more resistance resulted in a lower speed. The users found that especially the carrot was too hard to juice. And the test was conducted with adults, so if children have to be able to use the device as well, the required force needs to be reduced. The necessary force is already reduced due to the mentioned gear ratio, but on top of that the movement input needs to give the user an additional moment arm compared to the hand crank. On the other hand, making the product usable for children means that the device will be too light for the strongest users. Therefore it was decided that the device needs to have an adjustable resistance to provide a challenge for all types of users.

It was also noted that during the test the movement was very jerky. This is due to the manual feeding of ingredients into the machine, which makes the resistance felt at each given moment vary greatly. But it is expected that with a much larger chain of gears the system will have more inertia, making the movement more fluid. So this is not expected to be a problem. It was also noticed that the juicer gets dirty real quickly, as shown in figure 4.4, and it will take a few minutes each time to clean it. Therefore, if the device is to be continually used, it will need additional juicer components close at hand, which will in turn requires additional storage space to accommodate these components.

Figure 4.4: Slowjuicer after test

4.2 Morphological chart

During the concept phase a number of technical solutions were investigated for various aspects of the design. Some of these solutions were used in the three concepts presented in section 4.4. Others were investigated in advance for the detailed concept phase. All these solutions were combined into a morphological chart. A part of this chart is shown in figure 4.5.

The choice of solutions for the technical design depended heavily on the concept selection. Selecting a solution for each sub-problem also depended heavily on the other choices made. Therefore, the morphological chart was combined with a combination matrix, showing which solutions were compatible with each other. This combination matrix was also an interactive excel sheet, allowing the user to make some decisions and then see what the consequences are for the other solutions. A part of this decision matrix is shown in figure 4.6.

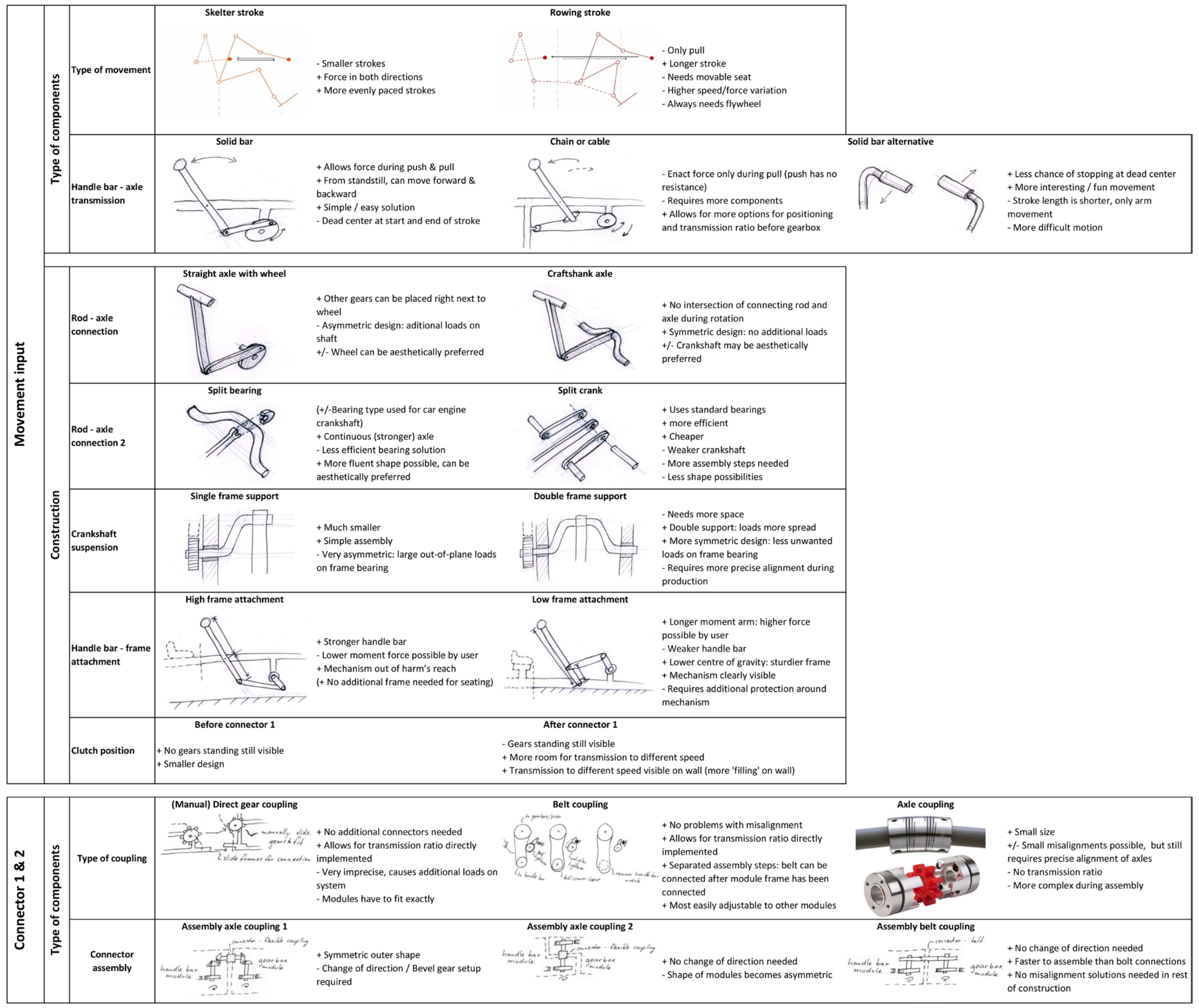

Figure 4.5: Part of morphological chart

(blank)	possible to use together
no	not possible to use together

				Movement input													
				Type of components						Construction							
				type of movement		Handle bar - axle transmission				Rod - axle connection		Rod - axle connection 2		crankshaft suspension		Handle bar attachment to	
				Skelter stroke	Rowing stroke	Solid bar	Chain or cable	Solid bar alternative	Chain / cable alternative	Straight axle with wheel	Craftshank axle	Split bearing	Split crank	Single frame support	Double frame support	High frame attachment	Low frame attachment
Movement input	Type of components	type of movement	Skelter stroke		no												
			Rowing stroke	no		no		no		no	no	no	no				
		Handle bar - axle transmission	Solid bar		no		no	no	no								
			Chain or cable			no		no	no	no	no	no	no				
			Solid bar alternative		no	no	no		no								
			Chain / cable alternative			no	no	no		no	no	no	no				
	Construction	Rod - axle connection	Straight axle with wheel		no		no		no		no	no			no		
			Craftshank axle		no		no		no	no							
		Rod - axle connection 2	Split bearing		no		no		no	no			no				
			Split crank		no		no		no			no					
		crankshaft suspension	Single frame support												no		
			Double frame support							no				no			
		Handle bar attachment	High frame attachment														no
			Low frame attachment													no	

Figure 4.6: Part of combination matrix

4.3 Movement input motion type

One of the more important decisions from the morphological chart used in designing the concepts, was the choice of motion used for the first movement input module. After the idea phase, it was decided to use a type of rowing motion as the first type of movement input module. Two possible sub-types of a rowing motion were considered: a complete rowing cycle and a skelter rowing cycle. These are shown in figure 4.7. With the skelter stroke the user stays in place. Here, the legs have a smaller role and a large part of the force is generated by the arms. The stroke is therefore much smaller, but it is possible to make a system in which the user enacts force in both the pulling and pushing stroke. The rowing stroke instead allows for much better use of the legs in generating force. But this also requires a movable seat. This motion has a much larger stroke, but only allows for pulling, while no force is enacted when moving back to the starting position.

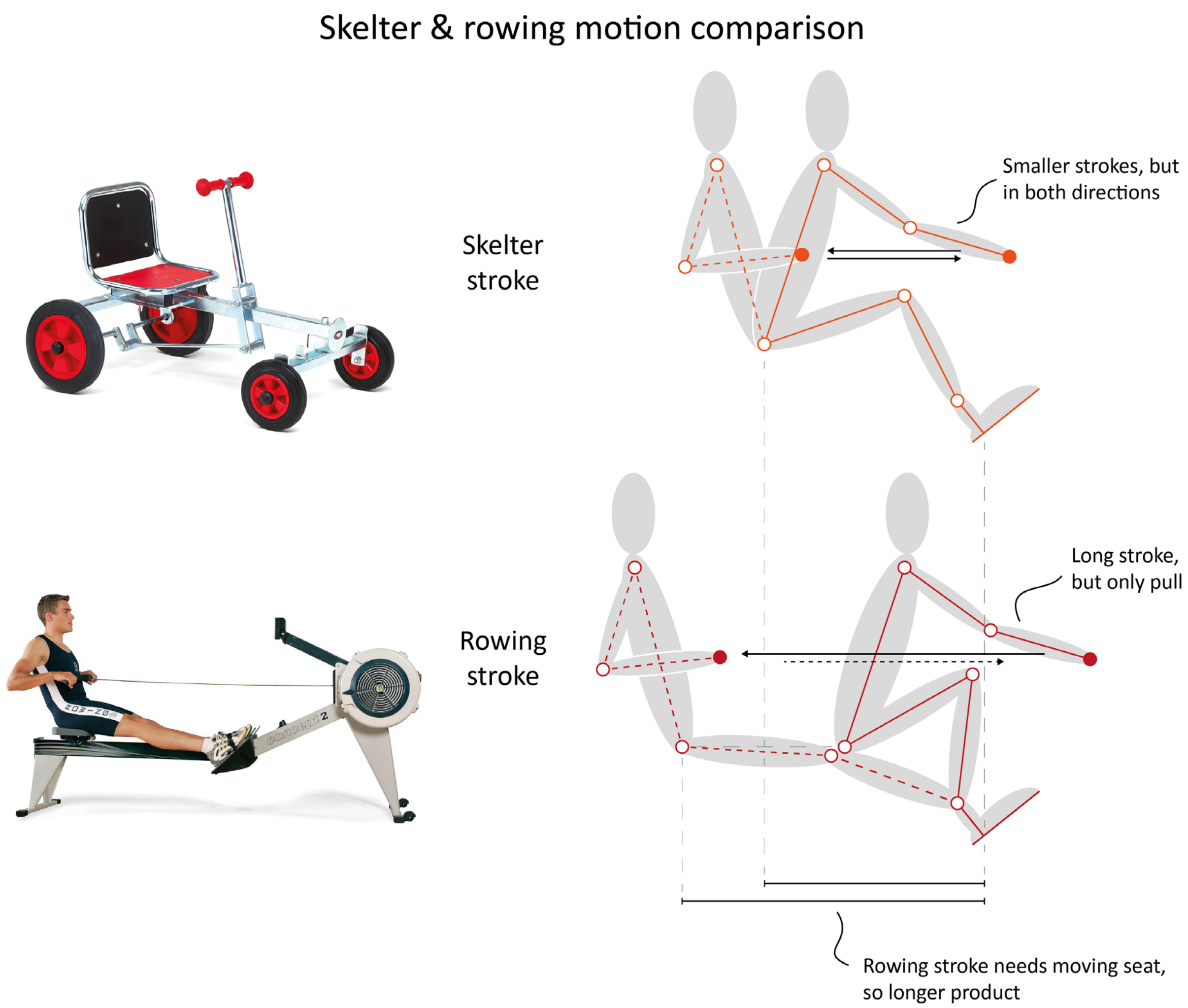

Figure 4.7: Comparison skelter & rowing motion. Left: examples. Right: schematic representation motion

The diagrams of figure 4.8 show a further comparison between both motions. The first diagram shows the situation when a fixed gear is used, while the second shows the situation when an overrunning clutch is used instead (one of the other decisions that had to be made for the concept). In both cases it is clear that the rowing stroke results in higher peaks in the juicing speed (with higher accelerations and thus higher forces on the system). It also shows that the rowing stroke has more variation in the juicing speed, while it is best to keep the speed for the slowjuicer as constant as possible. This can be compensated by using a flywheel, but that increases the price and adds weight to the product, which is undesirable for easy transport.

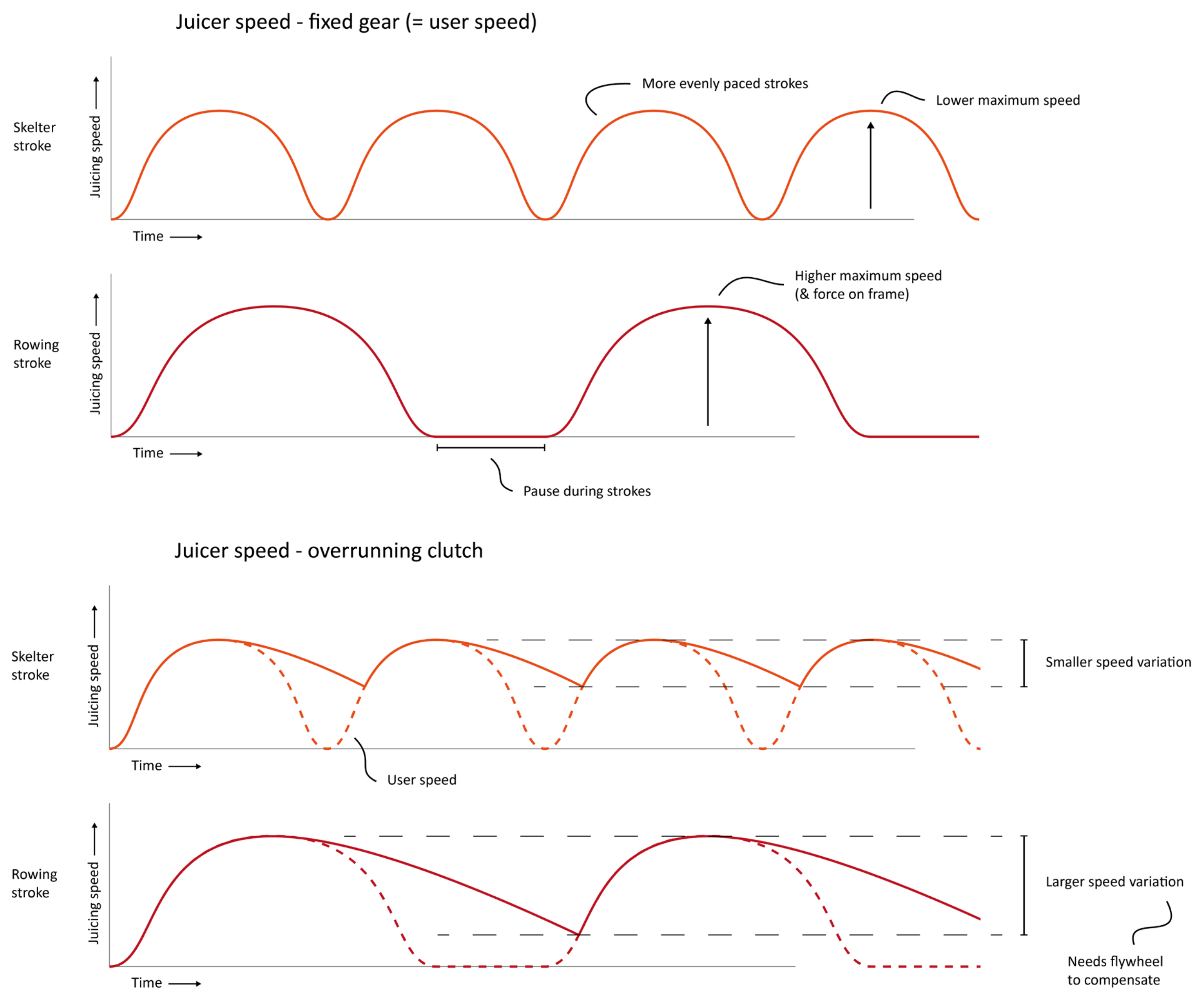

Figure 4.8: Comparison juicing speed skelter and rowing motion

Because of a better spread of forces on the system, less variation in the speed and a simpler design, it was decided to use the skelter stroke. Next to these technical arguments, one of the arguments for the client was that the rowing stroke had too much of an association with 'fitness equipment'.

4.4 Three Concepts

During the concept phase three concepts were generated by Maarten Boer. For completeness, these will be briefly mentioned in this paragraph.

Concept 1: Modular train

The modular train concept, shown in figure 4.9, is based on the idea that all kind of modules can be connected to each other and assembled on one rail system. It exists out of three main component blocks: a motion block, a gear/transmission block and a juicer block. The rail system allows for modules of different sizes and easy placement of these modules. The hexagon shape, built from a metal frame with wooden panels, allows for a sturdy construction, while still providing much space for the components and extra storage. The panels can also be made partially open, making the mechanical operation visible.

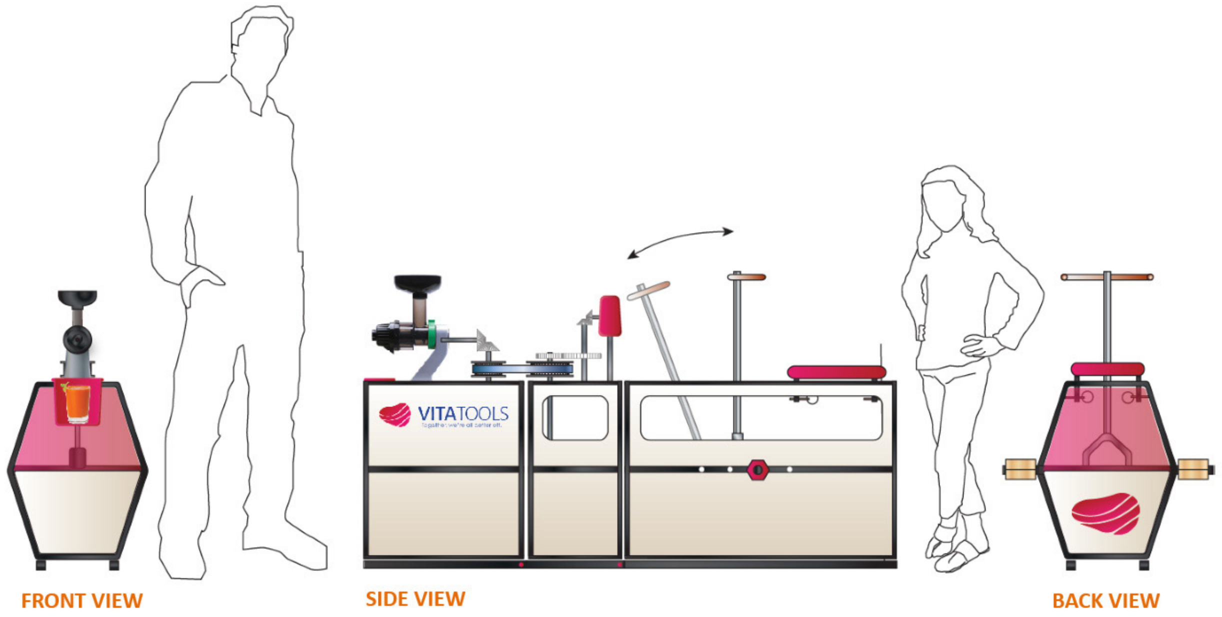

Figure 4.9: Concept 1

Concept 2: Sandwich
The sandwich concept, shown in figure 4.10, consists of side panels which house the other components in between. The modules are therefore closed on the sides, but the mechanical and functional components are still clearly visible from the top and front. The resulting design is much slimmer than concept 1, but there is also no storage space. The various modules do not have to be exactly the same, making it easier to design different modules. On the other hand this results in a less cohesive design. Due to the separate seat, the movement input module can be switched while still keeping the same seat. The gearbox and stand for the juicer are instead combined into one module. Each module contains a framed structure and bars on the ground for positioning and stability.

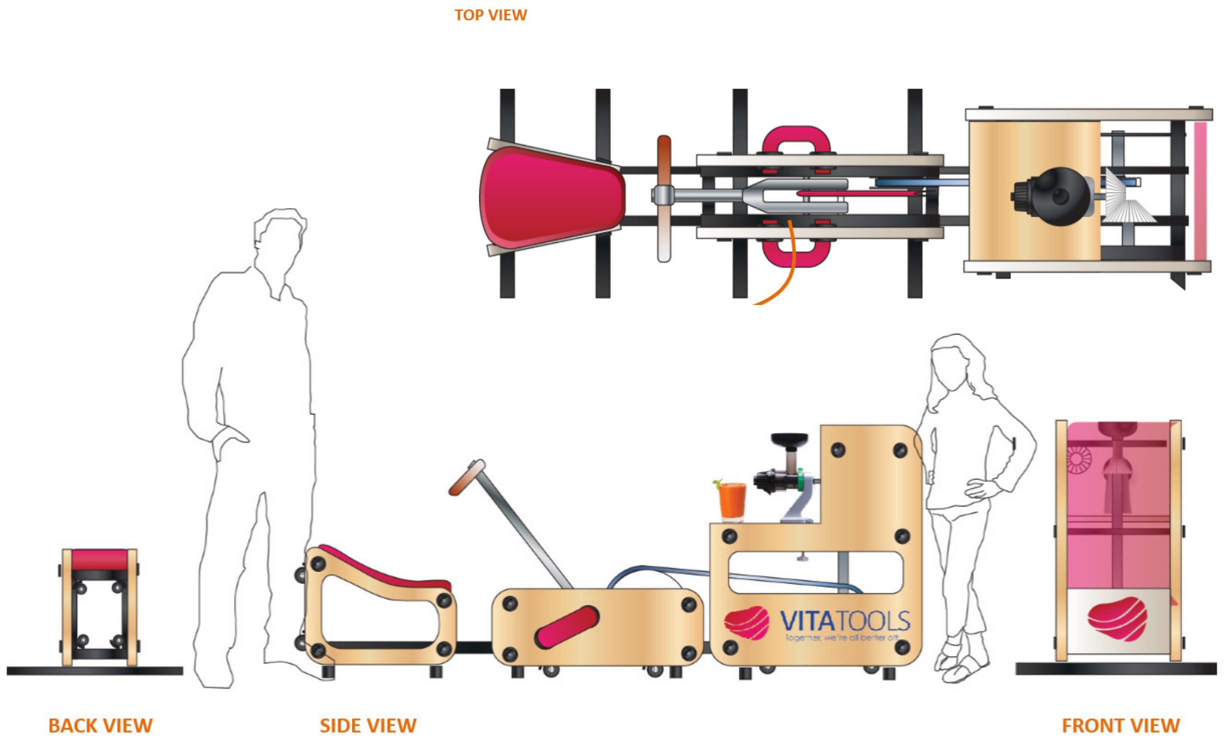

Figure 4.10: Concept 2

Concept 3: Plug & play panels
As the name suggests, the third concept is a wall with a plug and play system, shown in figure 4.11. All the components on the wall have a standard plug which fits everywhere on the wall. This way, the gears and belt drives can be changed into a different configuration each time, which adds a playful element to the design. The gears are overdimensioned for a playful and mechanical feel. The seat and motion element are formed from one sheet of metal. The seat is elongated, so it does not need to be adjusted for different users. Compared to the other concepts the plug & play panels are much larger. This results in a product which draws more attention and which has a lot of space for promotion (such as company logo's). On the other hand, the product becomes more difficult to transport and assemble.

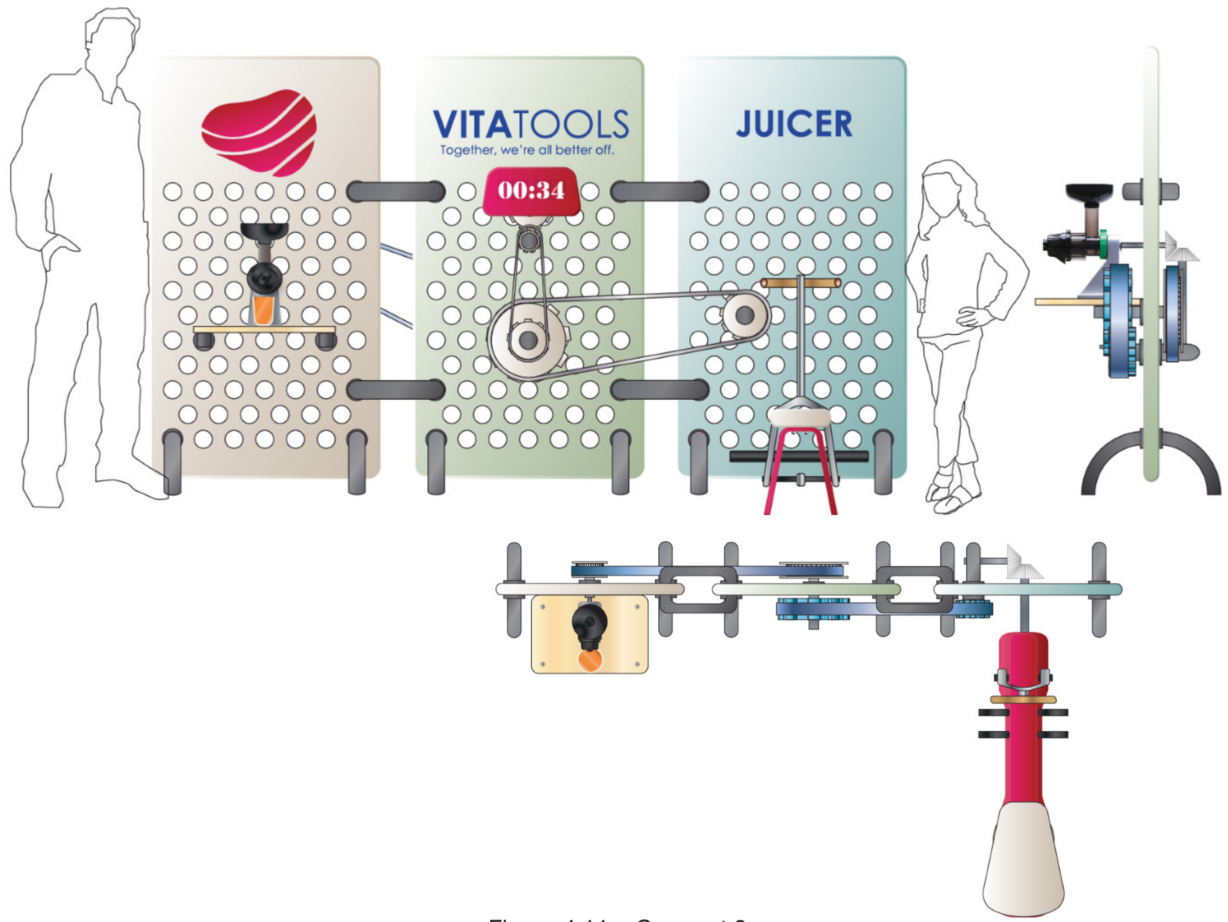

Figure 4.11: Concept 3

4.5 Chosen concept

In the end, the client was most interested in concept 3, because it is playful, draws attention, and allows for a lot of space for promotion. But the client favoured the movement input from concept 2. Therefore it was decided to further develop concept 3, combined with the movement input design of concept 2. This detailed concept is be discussed in chapter 5.

5. Detailed concept phase

In this chapter the detailed concept is discussed. This is be done by discussing the development process of some aspects of the design. The most important aspects of the design on which the author has worked in this phase are the construction of the movement input, the wall and the gear transmission.

5.1 Movement input

5.1.1 Mechanism

As mentioned in section 4.3, the first movement input module will function with a skelter rowing cycle. This is in fact a variation on a crank-rocker mechanism, shown in figure 5.1. Using the right length ratios in this four bar linkage, the front-and-back motion is turned into a continually rotating motion, in which the handlebar functions as the rocker and the crank is connected to an output shaft.

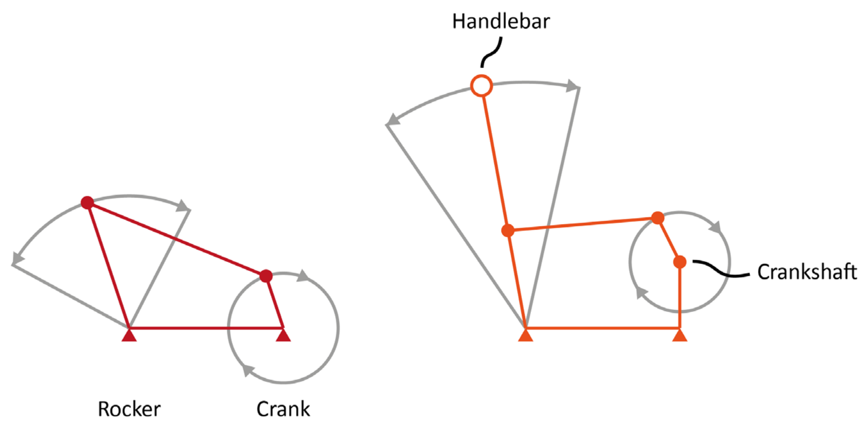

Figure 5.1: Standard crank-rocker mechanism (left) and adjusted design for movement input (right)

On top of the rocker the handlebar is mounted for the user. The output crankshaft is connected to a set of bevel gears, in order to make the direction of movement parallel to the wall. This is shown in figure 5.2. The second bevel gear is connected to connector 1. Connector 1 is a set of pulleys connected by a belt drive, of which the first pulley is mounted on the movement input and the second mounted on the wall. The belt drive allows for quick assembly and allows for some misalignment when connecting the modules. It also makes it easier to connect different types of movement input modules (with different dimensions) to the wall.

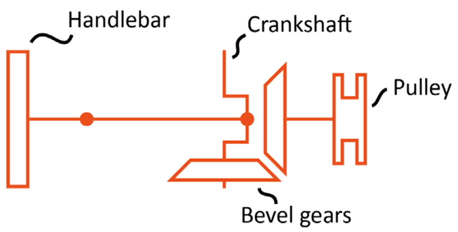

Figure 5.2: Top view functional mechanism

The functional components are supported with a rectangular metal frame, with the side panels on both sides. The top of the frame is not covered, which allows all components of the actuation to be clearly seen. Later on it still has to be decided whether the open gears are safe enough for the user, or if a (semi-)transparent plastic hood needs to be placed above the gears. The functional components are placed in the centre, as symmetrically as possible, to reduce uneven forces on the frame. On the sides of this frame there will be footrests, where the user can place his feet during use. Wheels are added to the bottom for transportation.

5.1.2 Construction

After the functional mechanism was decided upon, various concepts were designed on how the mechanism would be constructed, which included the kind of components to be used, as well as the type of connections and the supporting frame. Figure 5.3 shows two sketches of the handle bar rod and its connections to the rest of the mechanism and the frame. In the end it was decided to use the design with a single straight tube. Here (and in the other design choices) the focus was on using a simple design with as much standardized components as possible, in order to keep the production cost down.

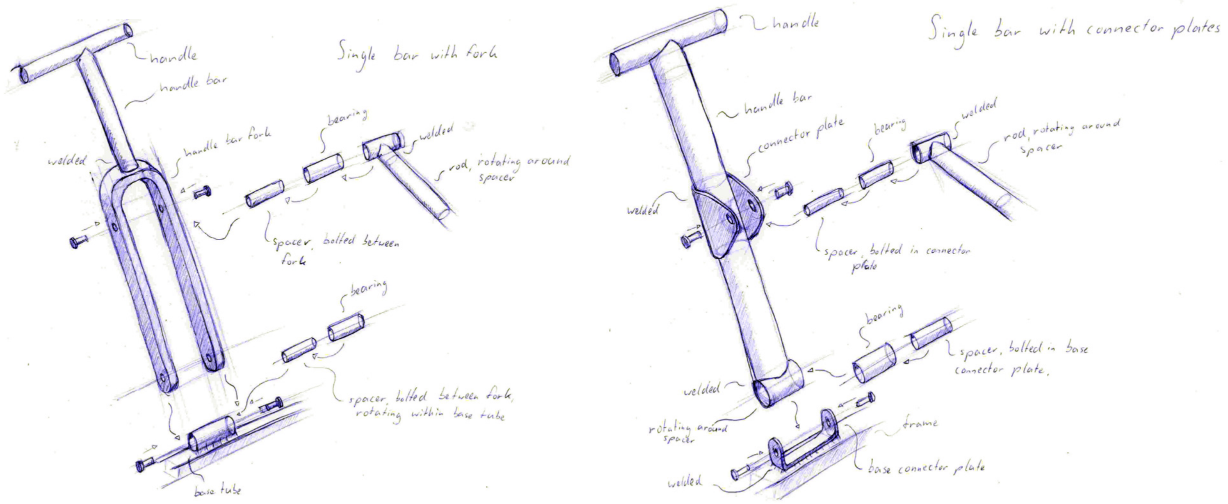

Figure 5.3: Two sketches of the handle bar rod

After these construction decisions, the design was completed by determining its dimensions. The movement input dimensions were based on human dimensions from DINED (adults and children), as well as an initial static analysis (by hand) of the resulting moment force.

5.1.3 Result

The detailed concept which resulted from this process is shown in figure 5.4, as illustrated by Maarten Boer. Here, the pink tubes on the sides are the foot supports.

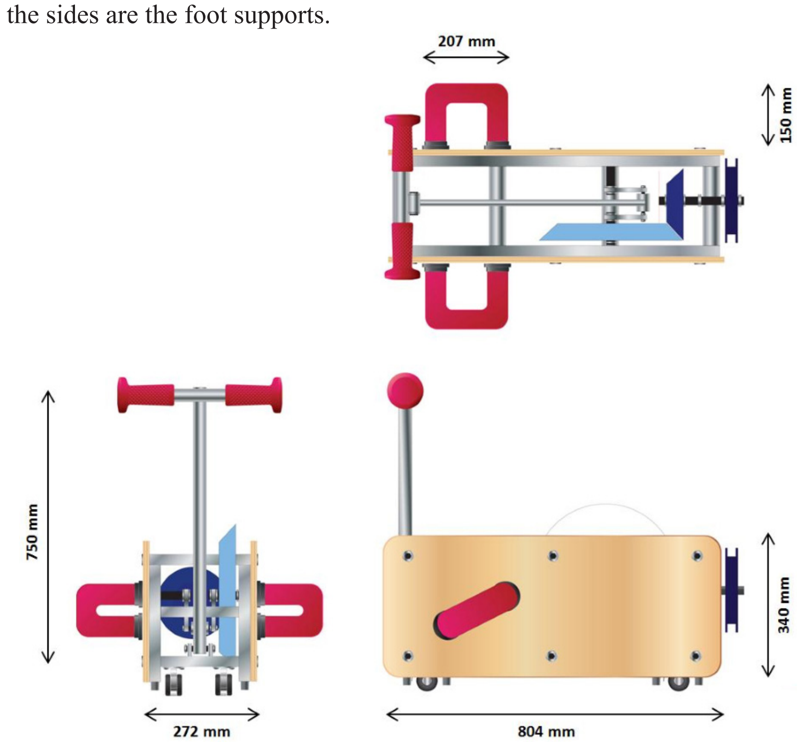

Figure 5.4: Front, side and top view of movement input module

5.2 Wall segment

5.2.1 Wall panels

The wall consists of multiple segments next to each other. Each segment consists of panels mounted on a frame. All the components are plugged into holes on these panels. For the proper strength, the full height of the panels are supported by a metal frame on the back. For the wall it was decided to use a sandwich structure as well, as shown in figure 5.5.

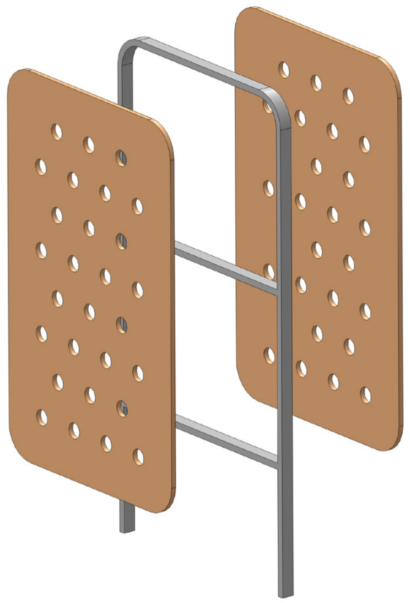

Figure 5.5: Sandwich structure wall segment

This had three reasons. Firstly for its aesthetics, because the juicer wall would be placed in the centre of a room, and panel on the backside would hide the frame. Secondly, this way the back could be used for gears as well. And thirdly, this way the forces would be better absorbed by the panels. See figure 5.6. With a single (thick) panel, the gear on the front and back would excite a moment on the wall. With two separate panels, there is still a moment working on each of the panels, but it is much smaller and the forces are much more in line with the panels themselves.

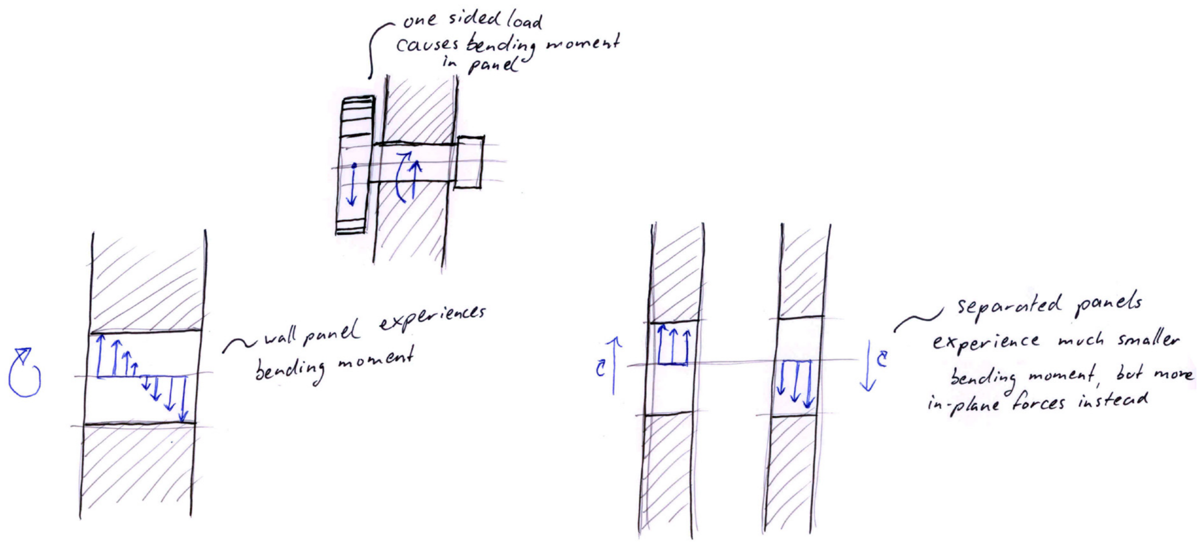

Figure 5.6: Force distribution in sandwich structure

5.2.2 Wall foot

For the foot of the wall various supports were designed, as shown in figure 5.7. The client was interested in a design with rounded shapes, such as the sketch mid-bottom, but this would require more expensive bending. Therefore it was decided to use a simple straight design with as much standard components as possible, as illustrated by Maarten Boer and shown in figure 5.8.

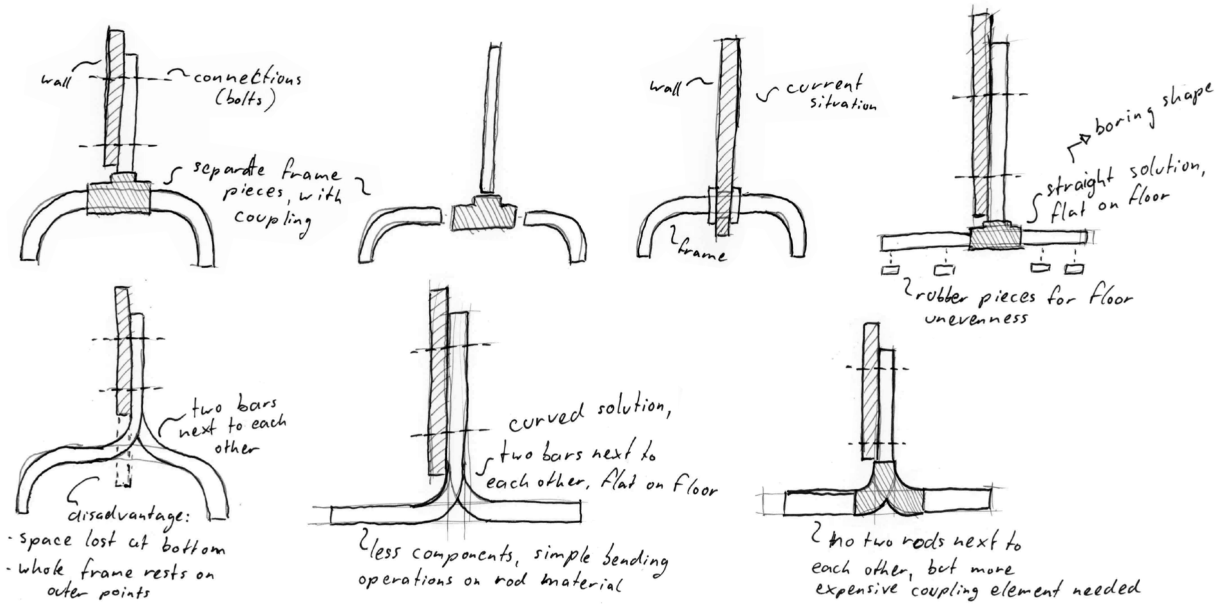

Figure 5.7: Wall support variations

For transportation, the frame is split between the foot and the standing frame. This way the wall can be removed from the foot, greatly reducing its size during transport. Wheels are also added to the bottom of the wall foot. This way, the wall of the juicer can be assembled outside of the car, and then moved into the building as a whole, instead of moving all parts into the building separately. The different wall segments are connected to each other with braces, connecting the frame elements at half their height. This is visible in figure 5.8 as well.

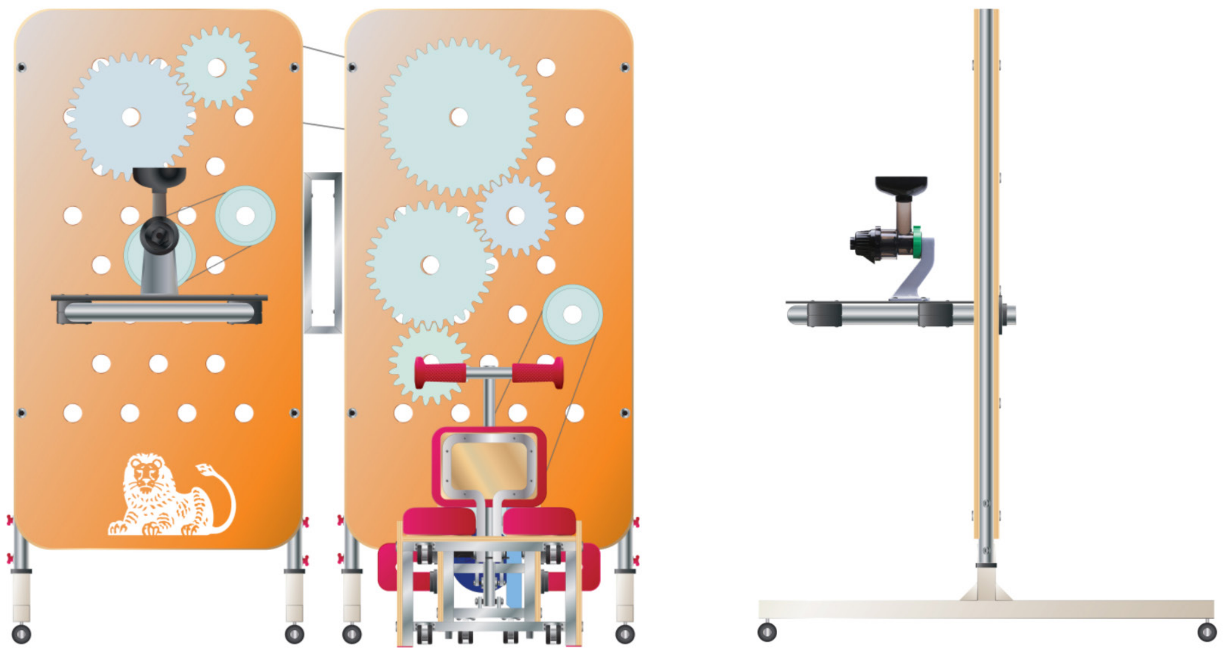

Figure 5.8: Wall foot and connection between wall segments

5.3 Gears and pulleys

5.3.1 Gears and pulleys

In order to give the product a playful and mechanical feel, large, oversized gears and pulleys are selected for the design. Gears of varying sizes are used for aesthetic reasons and to vary the speeds of the gears on the wall to fast and slow rotating gears. Although it seems like the wall is plug & play, meaning that the gears can be used anywhere on the wall, the gears in fact have a fixed configuration. It was found that otherwise it is difficult to spread the gears evenly over the wall segment, while maintaining the correct total gear ratio at the end for the slowjuicer.

Pulleys and belts are used to connect the movement input module to the wall and to cross the distances between the wall segments. Because of the large gears is was aesthetically desired to make the gear shafts large as well. To prevent them from becoming too heavy, it was decided to used hollow shafts, which restricted the mounting possibilities. In the end it was decided to use set screws for the gears and pulleys. The layout of the gears and pulleys is shown in figure 5.9. The figure also shows a rotary air damper. This damper, similar to ones used in indoor rowing devices, was added to the concept as an adjustable resistance. An adjustable resistance is needed, since the product has to be used by children, but also needs to stay challenging for user with more strength. How much added resistance is actually needed depends on user tests. Therefore it was decided wait with further development of the rotary air damper until after the initial prototype.

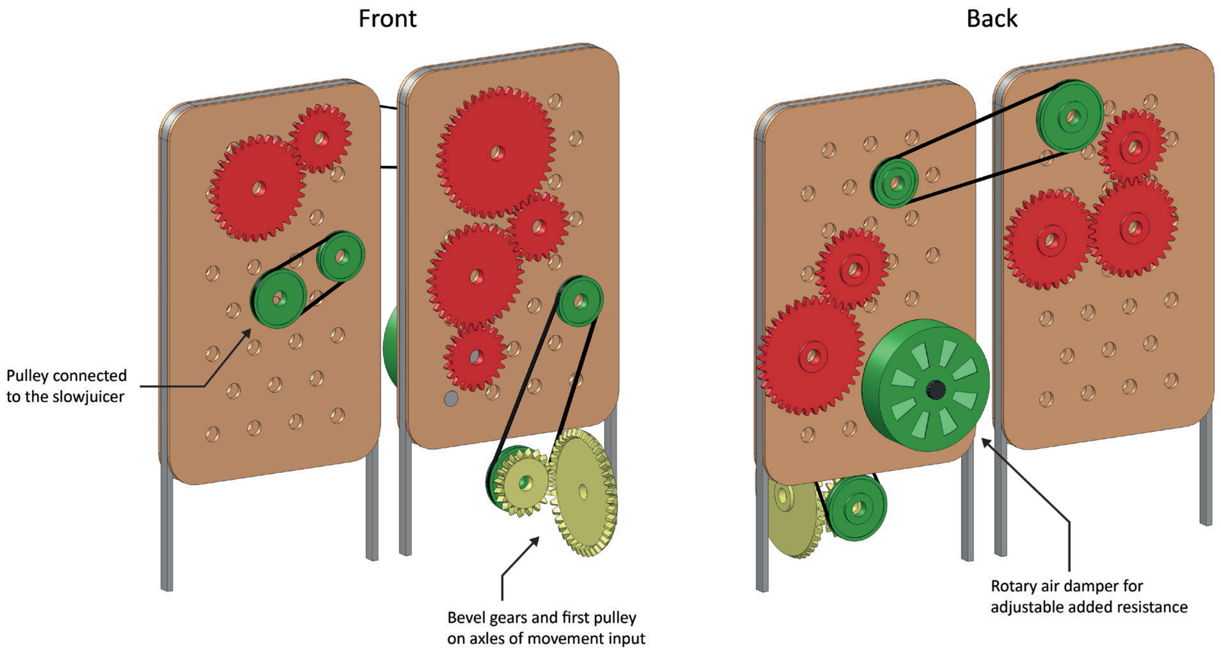

Figure 5.9: Gear composition on wall panels

5.3.2 Panel holes

The wall panels have a hole pattern in which the gears/pulleys and their shafts can be mounted. In order to give the wall the plug & play feel, it would need a large amount of holes. Various patterns were tried, until the alternating pattern with equal spacing between all holes was selected, as previously shown in figures 5.5, 5.8 and 5.9. In order for the holes to properly support the gear shafts, a setup was designed for mounting the gears on the wall. Figure 5.10 illustrates the steps of this setup in cross sections a cross section of one of these holes.

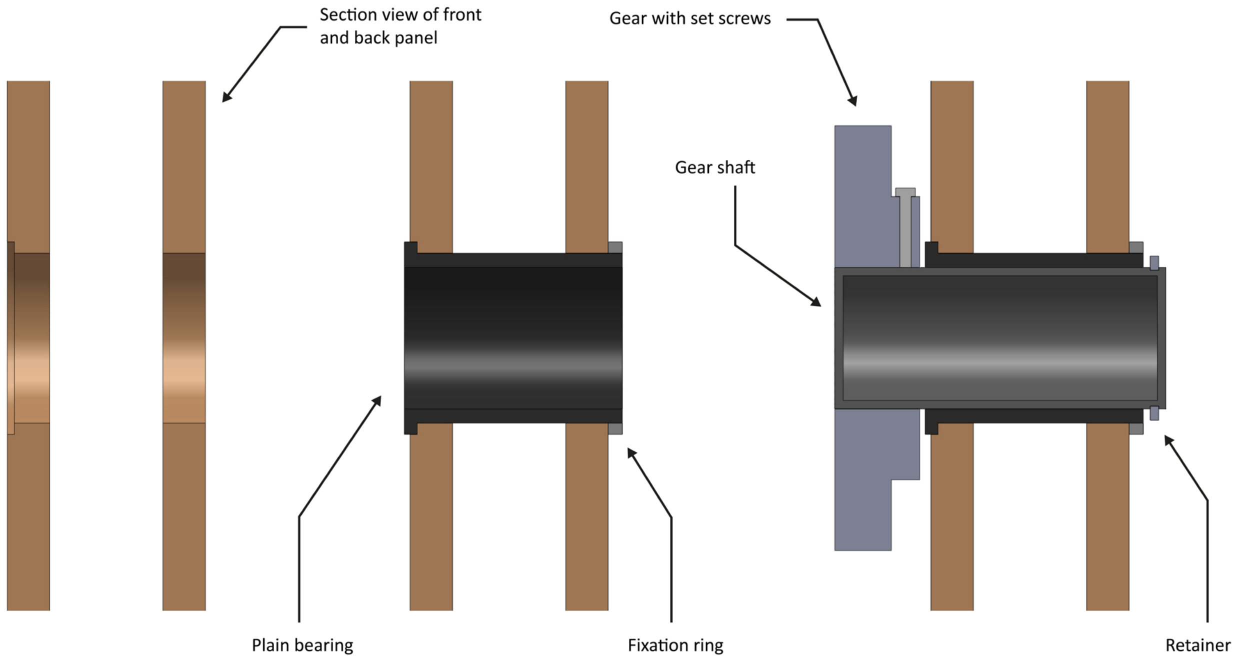

Figure 5.10: Setup for mounting gears in panel holes

To the left of figure 5.10, two aligned holes of the front and back panels are shown, both mounted on the wall frame. A plain bearing is inserted through both holes, as shown in the middle. The bearing has a flange at the front and a ring will be screwed on the back to fix it in place. The bearing functions both as a spacer connecting the holes at the front and back and dividing the loads on both panels, and functions as a bearing for the gear shaft. These were initially a separate spacer and bearing, but for the current dimensions both components needed to be custom made, so it was decided to combine both into one component. This bearing is also placed in the holes which will not contain a gear shaft. In this case, it solely functions as a spacer, to hide the space in between the panels. The spacers and bearings stay fixed after the first assembly. The gear shafts are mounted again each time the juicer is used and dismounted for transport. As shown on the right, the gears are mounted on the shafts using set screws and sequentially placed inside the bearing, with a retainer at the back.

6. Engineering phase

After the concept was finalized in the detailed concept phase, the next step was to fully design the whole product, up to a production ready state. This engineering phase is discussed in the current chapter. So far, the engineering solutions used in each part of the design had been decided upon in broad strokes, and some parts important to the feasibility of the concept had more detailed solutions. In the engineering phase these decisions on solutions in the design were finalized. The geometry, dimensions, material and production processes were designed and selected for all components. For functional components and important load-bearing parts, calculations were used to verify the dimensions, or to verify the component selection in the case of off-the-shelve components. These results were used in the creation of the whole CAD-model. After the CAD-model was completed, drawings were made of each of the custom made components. These were used by a colleague for sourcing the components at suppliers, in order to source production of the components and to receive production cost quotations, as well as receiving feedback on the design. Both quotations and feedback were used to further optimize the design.

The focus was on designing for the initial production series of 20 units. But before the actual production one or more prototypes were needed to review and optimize the design. Therefore engineering the product focused on both single unit and 20 unit production. Since 20 units is still a very small production series, the production methods are the same in both cases, with the only difference being the production cost. The production cost is also an important aspect of the requirements, and had therefore a leading role in optimizing the design. Prototyping had its own separate budget in the development costs, which had to be kept in check.

The final model resulting from this phase is very large. It consists of 94 unique parts, and 669 parts in total. Keep therefore in mind that this chapter discusses only part of the work performed in this phase and that not all aspects of the design process are discussed.

6.1 Movement input

The final design of the movement input module is shown in figure 6.1. Since its functionality is important, it had already received a lot of focus in the detailed concept phase, part of which has been discussed in section 5.1.

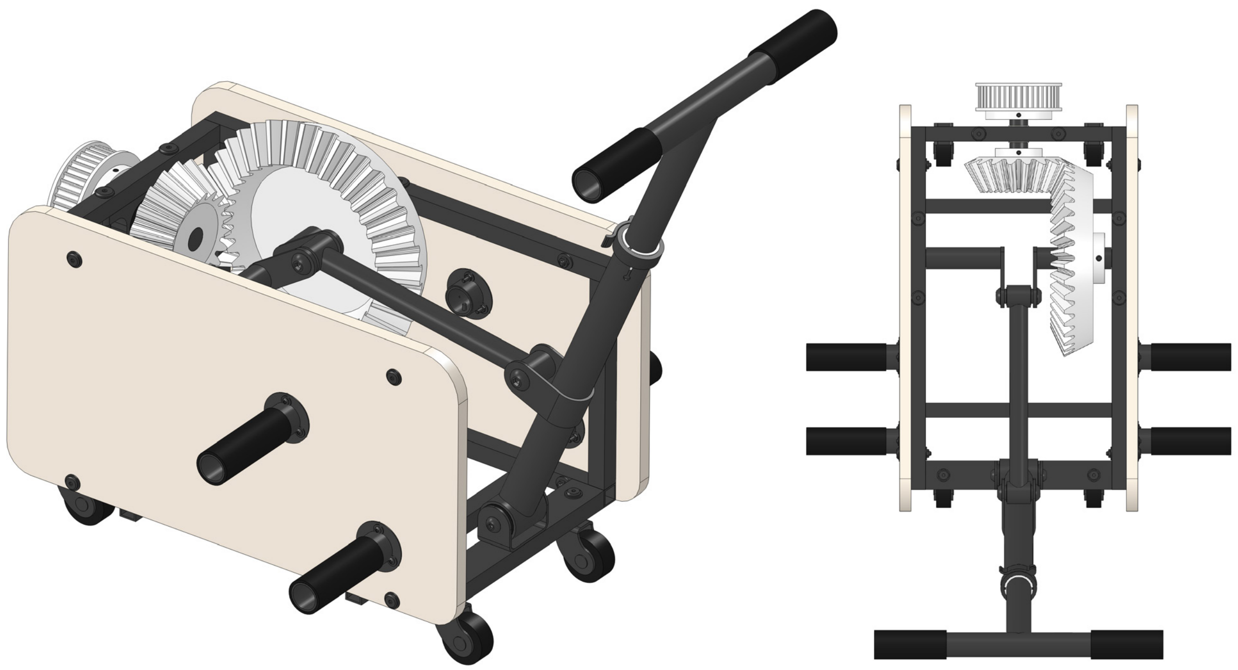

Figure 6.1: Final design of movement input module

For the frame steel is used. Aluminium would have been a lighter material, but it is also more expensive. Aluminium is also more difficult to weld, which in turn also makes processing it more expensive. Therefore it is only used in parts where weight was important. Weight is not a problem for the movement input module, therefore the cheaper option of steel is used. But it must be noted that a lighter aluminium frame could be an option for later production series, if a lower weight is desired. For the functional components of the movement input steel is used as well. The side panels are made of high pressure laminated (HPL) plywood. The plastic top layer improves the strength of the wood, and creates a water-proof and scratch-resistant surface. Some of the more expensive HPL's allow for full colour print imbedded into the layer, allowing for not only uniform colour, but also custom prints, such as logo's or other promotional content. Wheels are added to the bottom for transport. But since the movement input module needs stay in place during use, it can also be lifted and fixed in position on the wall foot of the wall segment, which will be discussed in section 6.3. An exploded view of the frame construction is shown in figure 6.2.

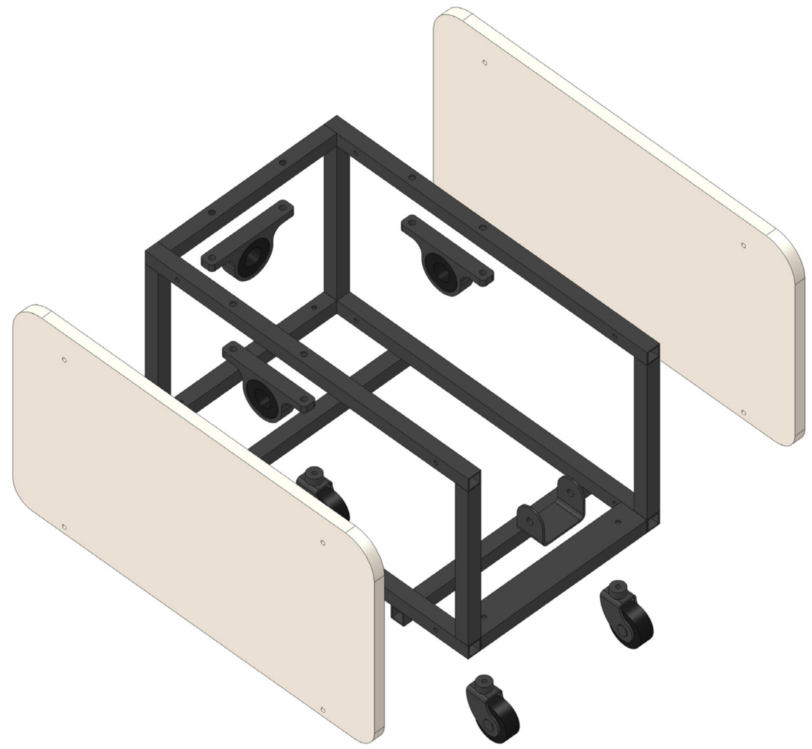

Figure 6.2: Exploded view frame movement input module

Next to selecting the materials, some calculations had to be made as well, to determine the dimensions of the components. Instead of performing all calculations by hand, MITCalc software was used[1]. MITCalc, which stands for 'Mechanical, Industrial and Technical Calculations', is an Excel plug-in that allows routine calculations to be performed much easier and quicker. Examples are static and dynamic loads on beams, shafts, bolt connections and weld connections. In the case of the frame, the beams which supported the functional components directly were analysed. After these dimensions were known, it was decided to use standard tubing of the same dimensions on the rest of the frame to keep the production simple. In the case of the functional components, the calculations of all the components, as well as their connections were performed separately. Figure 6.3 shows an exploded view of all the functional components. The calculations of the bevel gears and the pulley are discussed separately, in section 6.4.

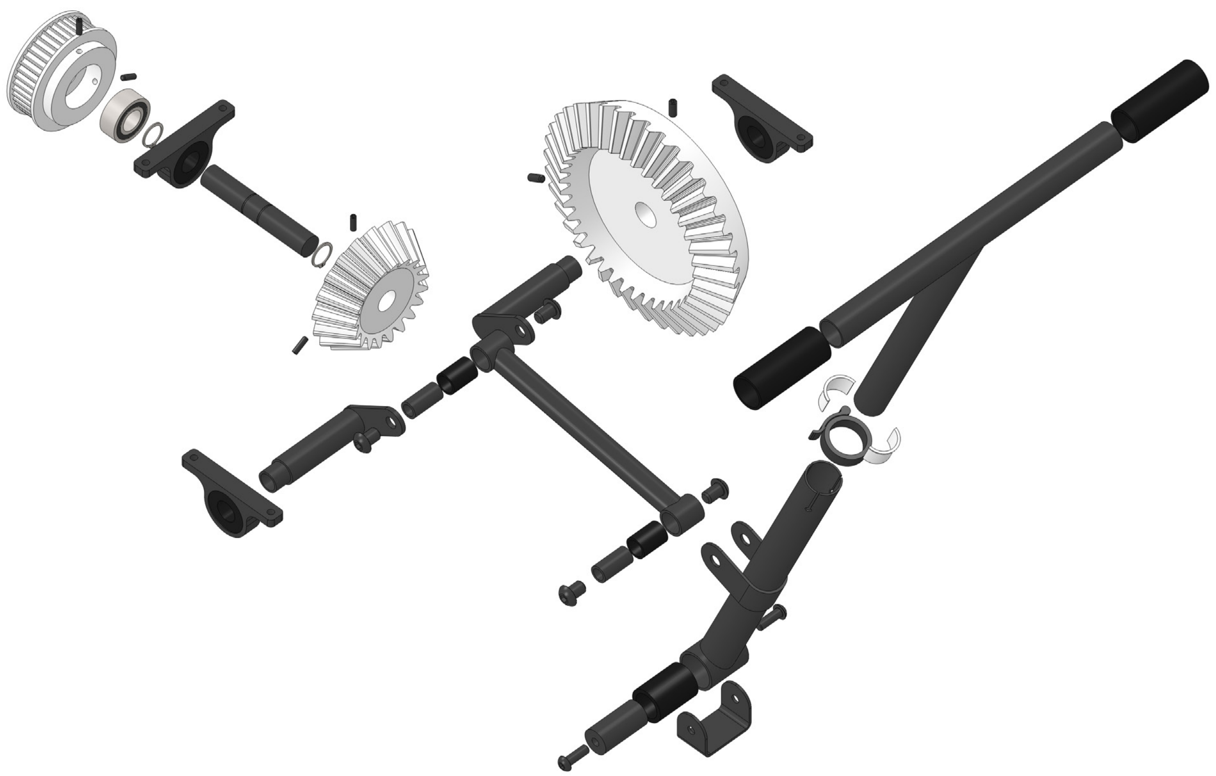

Figure 6.3: Exploded view functional components movement input module

Although the main functional components already received attention in the concept phase, other aspects of the movement input still had to be designed in the engineering phase. For example, the dimensions of the handle bar motion were based on DINED dimensions for adults and children. But so far, only the averages were used. In order for 90% of the population to use the product, it was determined that the handle bar rod had to be adjustable in height. Since it should be adjusted quickly, it was decided to use a quick release clamp, commonly used in foldable bikes. The adjustable handle bar rod is visible to the right in figure 6.3.

Another example is the footrests. In the concept design these were presented as a single U-bend tube. But the aesthetic design of the footrests are of less importance in the overall design. Therefore it was decided to use two separate footrests instead, with a simpler production and assembly. The footrests are fastened on the side panels using flange supports on both sides of the panel. An exploded view of this construction is shown in figure 6.4. The exact location of the foot rests was a bit more difficult to determine, since it is more difficult to determine a comfortable position of the legs in advance. Therefore the selected locations are a first estimate, which have to be tested with the different user groups.

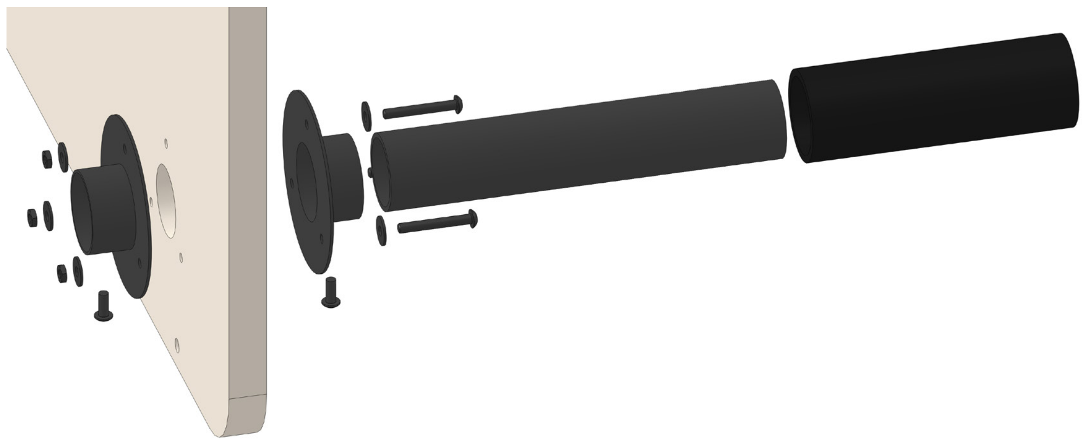

Figure 6.4: Exploded view footrest movement input module

6.2 Chair

The final result of the chair is shown on the left and middle in figure 6.5. To accommodate users of various sizes, the design still has an elongated seat cushion on the top, as described in concept 3 of section 4.4. But it was determined that it was preferable if the user had a backrest as well. Therefore a backrest was designed, whose position can be adjusted by inserting it into different holes along the top of the chair. Since the chair has to stay in place, the wheels are positioned on the back of the chair. During transportation the chair is flipped on its backside, as shown on the right in figure 6.5. This figure also shows that the front side has no panel. This way, the chair becomes a storage compartment during transport. The chair is constructed from a rectangular frame with panels on all sides (except the front), similar to the movement input design. It was decided to use the same type of tubing and panels here as used in the movement input, to reduce cost of construction and to create more aesthetic unity in the design.

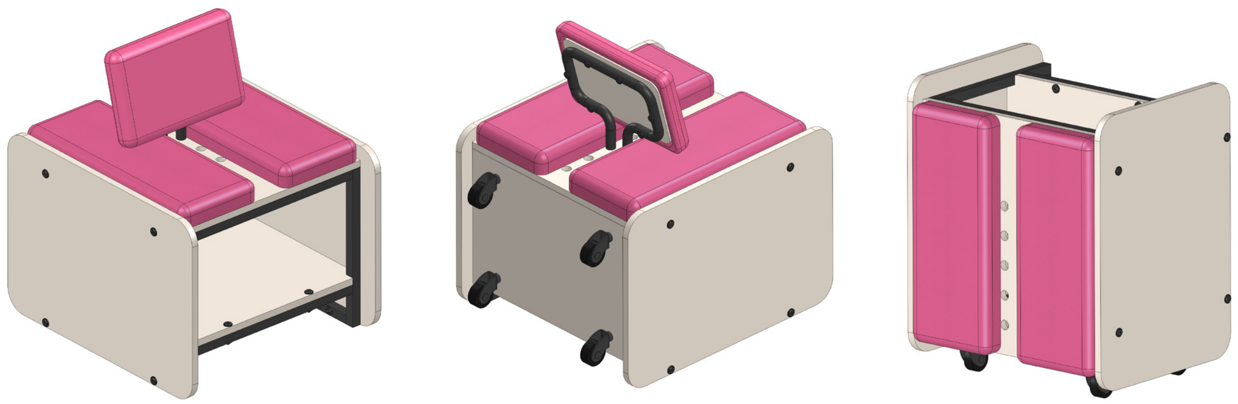

Figure 6.5: Final design of chair (in vitatools colours)

6.3 Wall segment

The general design of the wall segment has remained the same as shown in chapter 5. In the case of selecting the material for the wall segment, the choice did fell on an aluminium frame. This was because weight becomes more of an issue. If the frame would have been made of steel, the carrying weight of the wall segment would be above Dutch health and safety legislation limits. The dimensions of the frame and bolt connections were determined again using calculations made in MITCalc. The panels are again made of the same HPL plywood. It was desired by the client that the wall would have a sturdy look. Therefore the thickness of the panels was chosen such, that it gives the wall a sturdy aesthetic. An exploded view of the wall segment is shown in figure 6.6.

The wall foot has added cross-beams in the final design. In the case of the right wall segment (the version shown in figure 6.6), the beams at the front have a shape such, that the movement input module can be positioned exactly in between these beams, fixing it in place for both transport and use. On the front of the left wall segment, the chair can be placed for transport and on the back of both wall panels there is room for boxes of supplies, such as ingredients.

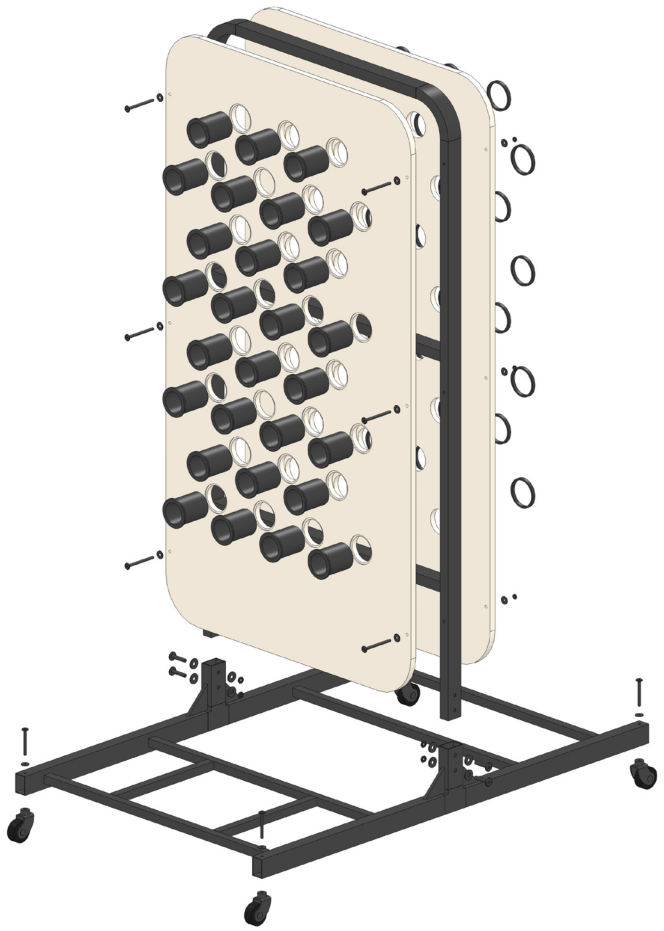

Figure 6.6: Exploded view of right wall segment

6.4 Gears and pulleys

In the engineering phase the composition of the gears has changed, as shown in figure 6.7. Quotations from suppliers on the original gears showed that these were too expensive in production. This was solved in two ways: firstly, the maximum size of the gears was reduced. It was found that with a pattern of smaller gears the wall segments were still aesthetically adequately filled. Secondly, the variation in gear sizes was reduced to only two types of spur gears (next to the two bevel gears).

The gears are made of PA plastic. PA is selected for its low price in combination with self-lubricating properties, while still having acceptable mechanical properties for the current application[2]. The gears are not in a closed gearbox, but out in the open and visible to users. The gears also have to be put in their places by hand each time the product is assembled. Therefore it is undesired to use normal lubrication, and self-lubricating material is used instead. For the same reason the plain bearings in the holes on the wall are also made of PA.

Performing calculations on plastic gears initially proved more difficult than expected. There is a lot of in-depth information available for calculations on metal gears. This is not the case for plastic gears however. Due to their flexibility and plasticity, it is much more difficult to get reliable results for plastic gears. A guideline is offered by the VDI2545 standard, but its calculation is highly inaccurate if not combined with adequate testing[3]. Determining the right gears would have been less of a problem in the case of standardized off-the-shelve gears. These have been tested by their suppliers, who also offer calculation methods specifically for their own products[4]. But there are no standardized plastic gears available in the sizes required for the product. Therefore the gears have to be custom made, which in turn requires a more accurate determination of all the dimensions (this service could have been supplied by western manufacturers, but that would be too expensive, especially for the current production numbers).

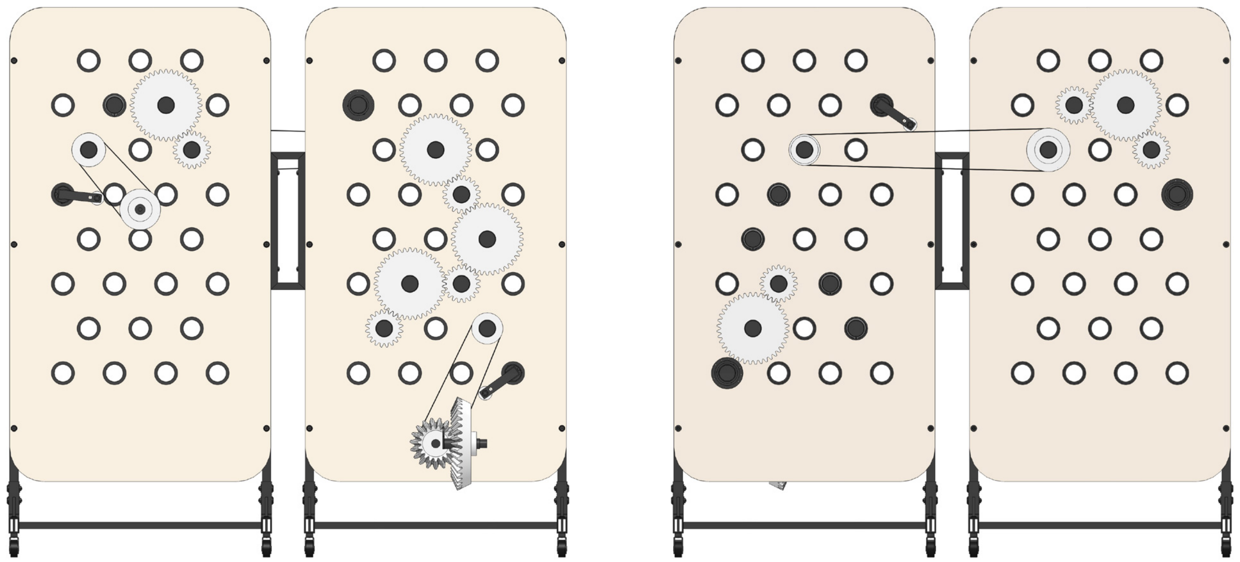

Figure 6.7: New gear composition

A solution was found in the software of KISSsoft[3]. This company has collaborated with the manufacturer SABIC, to calibrate the gear calculations of their software for a wide variety of plastics[5]. Therefore using their software is expected to result in a more reliable design of the gearbox. This software was used to perform calculations on the first set of spur gears (which have the heaviest loads in the design). The resulting gears seem very thick, but this is due to the fact that the machine is human powered, resulting in low speeds but very high moment forces, compared to gearboxes used in other applications. The KISSsoft software was also used in determining the dimensions of the bevel gears in the movement input module. With these bevel gears not only the loads played a role, but also leaving enough space for the other moving components. The dimensions of the bevel gears in relation to these other components is visible in figure 6.3.

For the belts, timing belts are used, of which an example is shown in figure 6.8. These belts are more suited for low speed, high torque applications and also require lower belt tension, as is the case in the current product. The rounded HTD belt profile is used because it is also used in other human-powered devices, such as bicycles with belt drives.

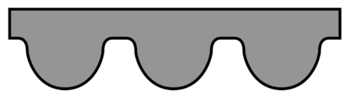

Figure 6.8: HTD belt profile

In contrast to the gears, the required belt and pulleys did fall into the range of standardized products. This had the advantage that the selection could be based on a standard selection method offered by a manufacturer. Unfortunately this service is not provided by Orange Creatives' Chinese suppliers. Therefore, the selection was based on a selection method and corresponding tables from a western supplier[6]. It is expected that if an error margin is used, the resulting selection still applies to products from a different manufacturer.

The pulleys are connected to the shafts using set screws, just as the gears. One exception to this is the first pulley, on the movement input module. This pulley is not directly mounted on the shaft. Instead, a clutch is mounted between the pulley and the shaft. This overrunning clutch has two functions. Firstly, the actuation of the user is not constant. Compared to a fixed drive train, the clutch smooths out the actuation for the rest of the gear chain and the slowjuicer. This difference is visible in the comparison of motion types in figure 4.6. Secondly, it allows the user to stop moving the handle bar, while the components on the wall keep continuing to rotate. With a fixed drive train the inertia of the gear chain would force the handle bar to keep moving until the whole system stops, which is expected to be unpleasant for the user.

The belts and pulleys are mounted each time the device is used. After the belt is mounted around its pulleys, it needs to be pulled tight by a belt tensioner for it to properly function. A pivoting tensioner is used, pushing the belt inward with an idler by rotating. For the tensioner an off-the-shelve industrial belt tensioner is used, mounted on a custom shaft to fit in one of the holes of the wall, as shown in figure 6.9. Since the tensioner uses torsion, it is fixed on the panel on the back of the wall to prevent it from rotating. Selection of the tensioner was based on the required size of the idler, since at this size the tensioner was already capable of handling more force than required for its current application. The force exerted by the tensioner on the belt depends how its starting angle and how far it is 'wound up' during use. The tensioner should apply enough force on the belt for it to function properly, but the belt is mounted by hand, which means that the force should also be low enough for the user to push the tensioner aside during assembly. Therefore user tests with the prototype should determine at which angle each of the tensioners needs to be fixed in place.

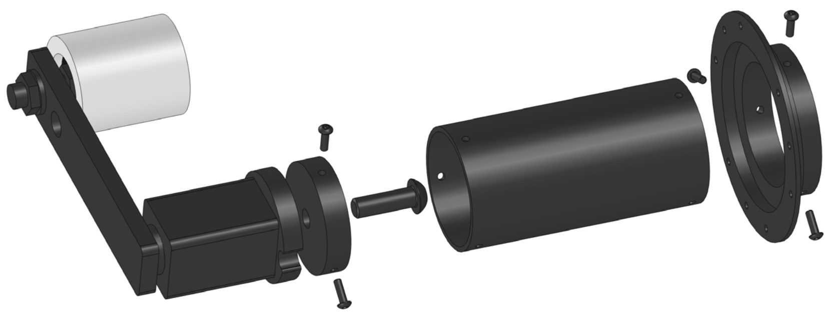

Figure 6.9: Exploded view of belt tensioner with custom mounting shaft

6.5 Table

The table which holds the slowjuicer is shown in figure 6.10. It consists of a aluminium U-bend tube with an HPL plywood panel mounted on top. The waterproof and scratch resistance properties of HPL are especially important for the tabletop. Both ends of the U-bend fit exactly through two of the holes on the wall and rings are screwed on the back of both ends to fix the table in place.

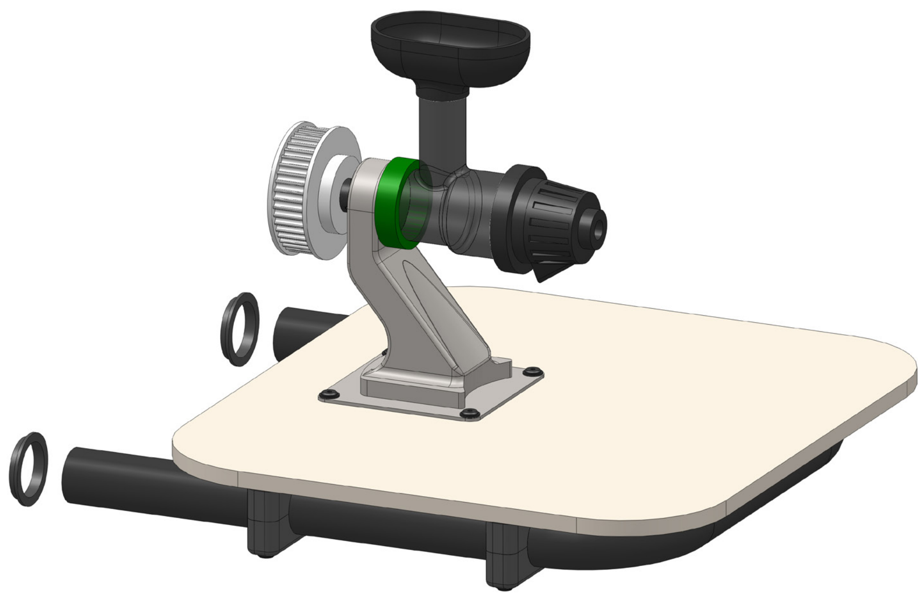

Figure 6.10: Table

Early on, in the user tests it became apparent that the table clamp normally supplied with the slowjuicer does not provide a stable fixation for the slowjuicer. Therefore a different solution was found: the base of the slowjuicer stays fixed on the table (in contrast to the rest of the slowjuicer, which is mounted on the base with each use). The base is welded on top of a bottom plate. The plate is then mounted on the tabletop with multiple bolts, resulting in a much sturdier connection.

6.6 Complete design

When all the modules are assembled, they can be combined to form the complete product. The front and rear view of the complete product are shown in figure 6.11.

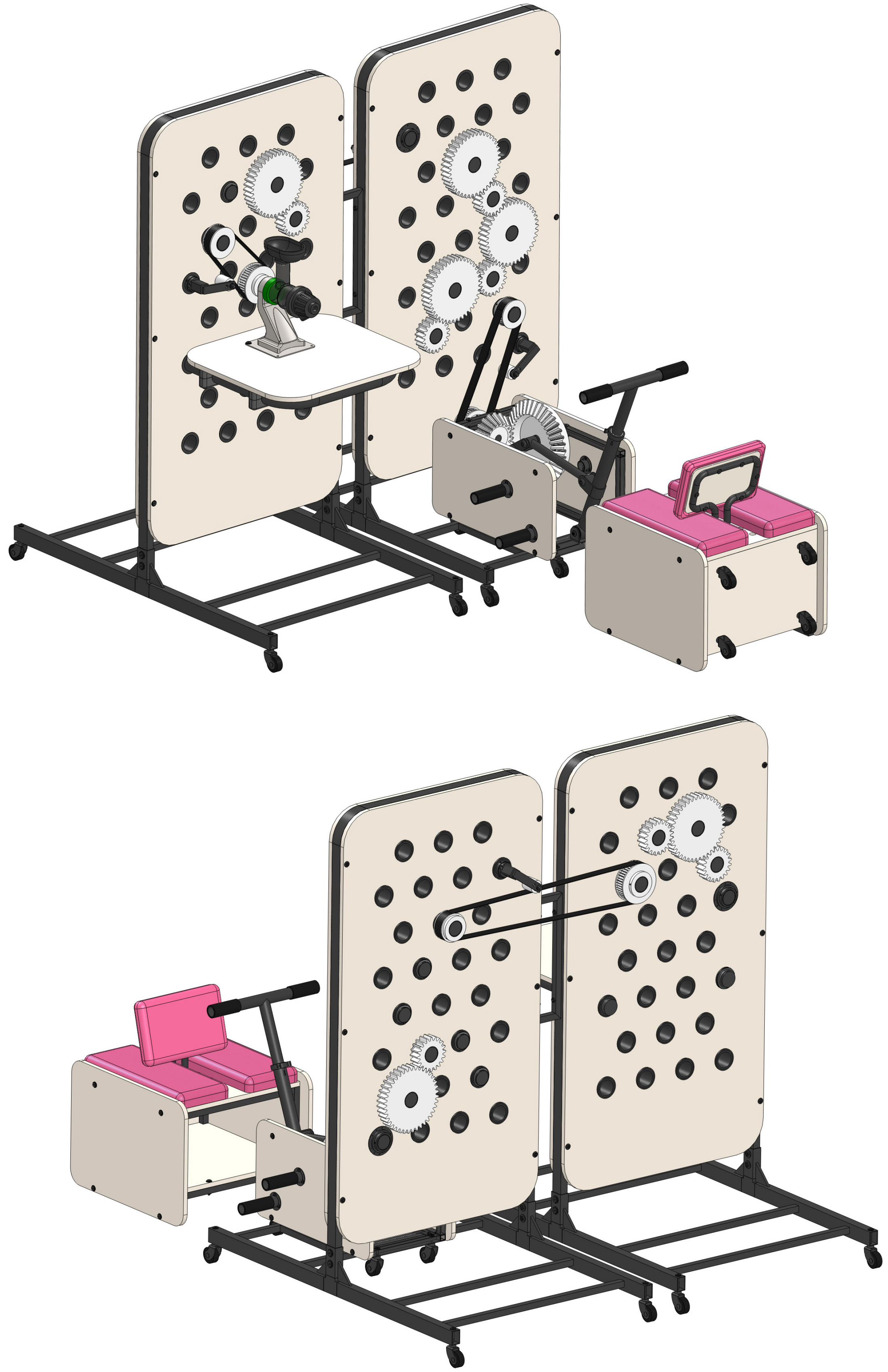

Figure 6.11: Front and rear view of complete model

6.7 Transport

The juicer will be moved to a different location (almost) each time it is used, which is why transportation requires additional attention. Transporting the juicer to a new location is done in two steps. Starting from the situation shown in figure 6.11, where the product is fully assembled and displayed inside a building, the chair is positioned on the wall foot cross beams below the table. Other equipment and ingredients are stacked in boxes on the cross-beams on the back of the wall. This way the whole product can be moved outside of the building as a single 'train'. There, the table and gears are removed from the wall, the wall segments themselves are separated at the wall foot and all parts are loaded into a transport vehicle. One of the requirement was that during transport the device should fit inside a station wagon. It is difficult to prove that the juicer will fit in every station wagon. Therefore, as an initial indication, the model was tested to fit inside a Skoda Octavia[7]. This is shown in figure 6.12 and 6.13. Note that only the large modules are shown. It is expected that enough room is left for (more flexibly placed) boxes with gears and ingredients. After the juicer is moved to its new location, the exact opposite steps take place. The juicer is assembled just outside of the car and is moved inside as a single unit, where it is positioned as shown in figure 6.11.

Figure 6.12: Juicer modules stacked inside a station wagon

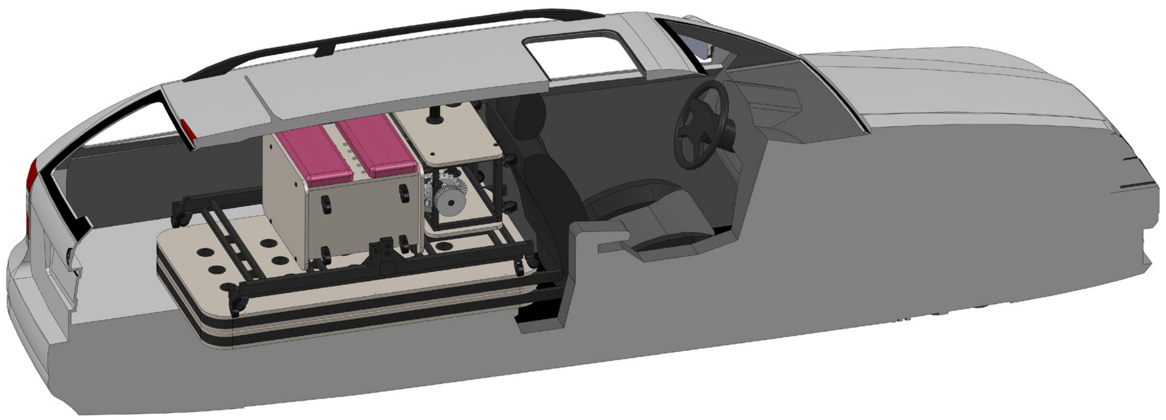

Figure 6.13: Cross-section of the station wagon with better view of stacked juicer modules

6.8 Conclusion engineering phase

In this chapter an overview is given of the fully engineered product. All the dimensions have been determined, the materials have been selected, technical drawings have been prepared, suppliers have been found and production costs are known. The design is therefore ready to order the production of the first prototype.

With this design completed, the internship period also came to an end. Involvement in the project was finalized with a project transfer. Maarten Boer was involved with the project and would stay involved, but another (new Dutch) employee would take over the engineering tasks in the project. Therefore information on the project thus far had to be transferred to him. Orange Creatives uses a standardized file system for project files. This way, the files used in the project, such as the CAD-model and documentation on calculations, can be easily found by someone outside of the project, or in this case by a new team member. Additionally, a project transfer document was composed for him to take over these tasks. The document contains a description of the tasks performed in the project thus far. It also contains a detailed list design choices and other aspects of the design which require additional attention during prototype testing, as well as a list with points of attention and recommendations for the design process after prototype testing. Additionally, it contained an evaluation of the project process itself. This evaluation can be used by Orange Creatives to improve their design process in subsequent projects.

7. Conclusions

7.1 Conclusions

This report described the development of a product during an internship at Orange Creatives. The internship was part of a project performed for Orange Creatives' client Vitatools. The assignment of the project was to develop a human-powered juicing device.

During the analysis phase information relevant to the internship was extracted from earlier results within the project, of which the design brief was the most important source. The extracted information included information about the slowjuicer used in the device, the main principle of how the product functions and the requirements related to the technical design.

In the concept phase a user test was performed, in order to further specify the requirements. Subsequently, a number of technical solutions were investigated for various aspects of the design, of which the results were combined into a morphological chart, as well as a combination matrix, to display the compatibility of using solutions together. Part of these solutions were then used in the designs of three concepts. Of these concepts, the client selected the concept with the plug & play wall panels.

The selected concept was further developed during the detailed concept phase. Technical solutions were selected to fulfil the required functionality of each of the modules. These initial solutions were then developed further to form the initial general design of the modules.

After the concept was finalized in the detailed concept phase, the following step was to fully design the whole product, up to a production ready state. This was done in the engineering phase, during which the geometry, dimensions, material and production processes were designed and selected for all components. In the case of functional components and important load-bearing parts, calculations were used to verify dimensions or the component selection. The design of all the components culminated into a full CAD-model of the product. Based on the model, technical drawings were made of all custom parts, which in turn were used to source production, receive production cost quotations and to receive feedback on the design. Subsequently, this information was used to further improve the design, resulting in a complete design, consisting of 94 unique parts, and 669 parts in total. At the end of the engineering phase, the design was ready for the first prototype to be ordered.

The resulting design is a juicer wall, which allows its user to create a healthy juice through human power. It consists of a chair and, a movement input module, two wall segments supporting a system of gears and pulleys, and a table supporting a slowjuicer. The system starts with the movement input module, with which a user powers the system through a skelter rowing motion. The movement input is positioned on the foot of the right wall segment. Both wall segments combined form the wall. Along the wall, the gears and pulleys transfer the human input motion to the slowjuicer output. The slowjuicer is mounted on the table, which itself is supported by the left wall segment. During use of the product an assistant feeds ingredients into the slowjuicer.

Unfortunately, it was not possible to manufacture the prototype within the period of the internship, so the design could not be evaluated within this period, but has to be evaluated afterwards instead. The internship was finalized with a project transfer, to transfer data on the progression of the project thus far to a new employee and to evaluate the project.

7.2 Recommendations

Part of the project transfer was a project transfer document. The document contained a description of the tasks performed in the project thus far. But it also contained recommendations for the rest of the project. The list of recommendations is too detailed to fully describe, therefore only a few examples are described in this section.

The types of recommendations were two-fold. The first type was recommendations in the form of aspects of the design which require additional attention during prototype testing. For example, the dimensions of the movement

input and the chair are based on DINED dimensions. It should therefore be possible for the specified user groups to use the device. But prototype testing should determine whether it is actually a comfortable position for the user to exert force on the juicer. The exact position of the footrests must be determined this way as well.

Another example is transportability. For transport, the product can be divided such, that a single user can assemble and disassemble the product on site. Although the weight of each part complies with Dutch health and safety legislation limits, tests should determine whether larger parts such as the wall segments can be moved and placed into a car dexterously by a single person. And all the gears and pulleys also have to be removed every time the juicer is transported, which is a lot of work. Tests have to determine whether this is acceptable, if (part of) the gears can stay in place during transport, or if a different solution is needed altogether.

The second type was recommendations on the tasks which need to be done after prototype testing. For instance, in section 5.3.1 it is discussed that the concept has an adjustable rotary air damper (which is shown in figure 5.9). Since the juicer needs to be able to be used by children, this damper is needed to keep the exercise challenging for adults. The damper was not further developed during the engineering phase. Instead, tests with the prototype should determine how much added resistance is actually needed and thus what kind of damper needs to be designed after prototype testing.

Another example is promotional banners. In the current design the wall is 1,60 m high. This is below the average eye level of Dutch adults. It would therefore be preferable if the wall was higher, since that would draw more attention to it. But increasing the height would make the wall segment heavier than allowed by Dutch health and safety legislation limits. It was therefore decided that separate banners were to be placed horizontally atop the wall. This allows for more room for promotional content and would make the product more noticeable, while only marginally increasing weight and costs. This was a detail of less importance for the first prototype, but still has to be designed before the product goes into production.

7.3 Internship evaluation

Living in China for five months taught me a lot about Chinese culture. It showed the differences between Chinese and western culture, but also showed that there were more similarities than I had expected beforehand. Although the internship was performed in China, Orange Creatives itself is of Dutch origin. The company culture in the office was therefore still very familiar. The language used in the office was English, which made it much easier to communicate with my Chinese colleagues. But while collaborating in-depth on a project, cultural differences and language difficulties still emerged.

For instance, the colleague with whom I collaborated the most in the engineering phase had a rudimentary knowledge of English used in normal conversations, but this was not enough when discussing manufacturing details. These meetings therefore required a third attendant functioning as a translator, adding more interpretation errors. Another example is the difference in culture when dealing with design freedom. For some components it was cheaper to use off-the-shelve components instead of custom manufacturing them. These components had one or two important dimensions, while the other dimensions could be chosen freely, depending on what was available at the supplier. Dealing with this design freedom proved more difficult for Chinese colleagues than initially expected. However, in the end all these types of interpretation errors were resolved. They just required more time and effort, compared to collaboration with Dutch colleagues.

Most of the time I was working together with Maarten Boer, who functioned as the project leader and the industrial design engineer. Before starting my master study in mechanical engineering, I obtained a bachelor's degree in industrial design engineering myself. Being the mechanical engineer on the team and leaving the design tasks to Maarten was therefore an interesting division of labour. On the other hand, my industrial design skills still proved to be useful on the project. This was the case for experience on the new product development process in general, but also specifically in the concept phase, where my tasks not only focused on the mechanical construction, but also on ergonomic use of the product and partially the aesthetic design.

When comparing the internship to the master itself, a large difference I noticed was that the master is very theoretical, while the internship was very applied. In that sense the internship is a great addition to the master study, but this also resulted in that I used more competencies from the bachelor rather than the master courses. An important thing I learned during the internship, is how important the development budget itself is. In the case of the current project, the estimated production series are very low, which results in the fact that the development costs are a large part of the product cost price. This means that it is sometimes more desirable to end up with an acceptable solution quickly, rather than spending much more time trying to find the ideal solution. This became apparent for instance in the concept phase, were much time was spent to find multiple alternative solutions to technical problems. The client was pleased with this additional effort, but would also have been content with a simple initial solutions if this would have meant that the design process would elapse faster.

This was also noticeable in the engineering phase. Most of the master courses followed by me are useful for optimizing a design. But in the case of this project there was no time budget to completely optimize the design, which meant that a part of knowledge from the master study was not applicable during the internship. But it is expected that this knowledge would have been more useful in the case of larger production series.

On the other hand, some courses did prove to be useful. For instance, in the design of the product there were a lot of situation where a balance needed to be found or a trade-off needed to be made between material, production and design. The experience gained in the course 'Design, Production and Materials' was very useful in these situation (whose name coincidentally contains the stated problem situation). And the course 'Surface Technology' provided relevant information on types of surface degradation, combined with types of surface treatment which can be used to prevent this degradation and create a durable product instead.

The project described in this report was the main project I worked on while I was at Orange Creatives. Although the plan at first was that I would be involved in at least two projects, in the end I almost completely focused on one project, which turned out to be much larger than expected. The second project on the other hand had much delays, which is why I was no longer needed for that project. I did perform some work for two other projects. I visited factories for quality control of manufactured parts. In one of these occasions, new problems emerged in a product, which required me to do some troubleshooting on the design with technical solutions that could be implemented in the current production process. Compared to the main project these were minor tasks. But it was a nice experience to visit these factories, which included receiving full tours of the facilities. It was also a useful experience to work under pressure and having to find solutions quickly for the mentioned manufacturing problems. Next to these projects, I also joined my Chinese colleagues on trips to trade fairs, functioning as a representative at our exhibition booth on these fairs. These trips showed me some new insights into how Chinese corporate culture works.

All in all, I must say that the internship was a very educational experience, both personal and as an addition to the master study.

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Figure 6.12 and figure 6.13

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Figure 2.1

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Figure 3.1

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Figure 4.5

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