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Applying the Wayfaring Model in Product Development: Case Study "Tile/Grout Cleaner"

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Assignment description

NTNU - NORWEGIAN UNIVERSITY
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AND MATERIALS

MASTER THESIS SPRING 2016
FOR
STUD.TECHN. GINA LIMSETH

Applying the wayfaring model in product development: case study "tile/grout cleaner"

- run through entire engineering design process from early need finding to concrete product concept(s)
- in collaboration with Pontificia Universidad Javeriana, Cali, Colombia, Prof. Juan Pablo García Cifuentes
- applying the concepts and tools of the wayfaring model in product development (Gerstenberg et al.2015)
- development of (final) product prototype(s)
- also, it is encouraged to contribute to one or more scientific publications or grant proposal submissions during the master

Formal requirements:

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (https://www.ntnu.edu/web/ipm/master-thesis). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.
The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.
The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.
The contact person in Columbia is Prof. Juan Pablo Garcia Cifuentes and Prof. Martin Steinert and Stephanie Balters at NTNU.

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Preface

This Master's Thesis is the result of the course TMM4901 - Engineering Design, Calculation and Manufacture during the spring of 2016 at the Department of Engineering Design and Materials, Norwegian University of Science and Technology (NTNU) in Trondheim.

The thesis is a continuation of my pre-master project "Need Finding in Colombia" carried out during the fall of 2015.

I would like to thank my supervisor Martin Steinert for his guidance, feedback and inspiring discussions throughout the entire duration of the thesis project. Besides my advisor, I want to thank PhD candidate Stephanie Balters for her valuable input and motivation, and Karen Alejandra Cuesta Vinasco for the excellent teamwork.

My sincere thanks go to Mr. Stefan Strathmann and Henkel AG & Co. KGaA Duesseldorf for their continuous support.

Trondheim, June of 2016

Gina Limseth

Abstract

The wayfaring model is a product development approach that uses continuous exploration, ideation, prototyping and testing to reach a final destination. This thesis describes the wayfaring journey of the development of a tile and grout-cleaning tool for Henkel AG & Company, KGaA. The aim was to create one or more prototypes for testing and presentation of the concept.

The journey started with gaining as much knowledge as possible about the problem and solution space through benchmarking, bathroom dirt research and early stage cleaning experiments. This led to a divergent ideation phase where several concepts were rapidly prototyped and tested before the convergent evaluation phase resulted in the chosen concept: *Manual cleaning "iron"*. The next part of the journey included the development of the design of the tool, the ergonomics of the handle and the mechanical brush function solution. This was realized by combining different tools such as hand drawing, 3D-modelling and printing, as well as mechanical machining. The result was two prototypes, one *proof of design*, and one *proof of function* prototype. The functional prototype was tested concerning the handle ergonomics, hand and wrist posture, force transmission, visual result feedback and user satisfaction. The results were encouraging, and some were even better than those of an pre-existing competing tool.

The entire process is well documented, and improvement suggestions for further development are included in the thesis to facilitate a continuation of the project by Henkel.

Sammendrag

Wayfaring-modellen er en produktutviklingsmodell hvor man gjennom kontinuerlig utforsking, idéskaping, prototyping og testing når et mål. Denne masteroppgaven beskriver wayfaring-reisen for utviklingen av en flise- og fugevasker for Henkel AG & Company, KGaA. Målet var å lage en eller flere prototyper for testing og presentasjon av konsept.

Reisen startet med å samle så mye kunnskap som mulig om problem- og løsningsrommet gjennom benchmarking, undersøkelser av hvilke typer skitt som finnes i et baderom og innledende rengjøringseksperimenter. Dette ledet videre til den divergerende idéskapningsfasen, hvor flere konsepter ble utviklet og testet, før den konvergente fasen førte til at *Manuelt vaske "strykejern"* konseptet ble valgt for videre utvikling. Den neste delen av reisen omfattet utviklingen av det totale designet, ergonomien til håndtaket og mekanismen for børstefunksjonen. Dette ble realisert ved å kombinere forskjellige metoder som håndskissering, 3D-modellering og – printing, i tillegg til mekanisk arbeid. Resultatet var to prototyper; en funksjonell og en visuell. Den funksjonelle prototypen ble testet i forhold til ergonomi, hånd- og armstilling, kraftoverføring, visuelt rengjøringsresultat og brukertilfredshet. Resultatene var lovende, og enkelte var til og med bedre enn for en eksisterende, konkurrerende flise- og fugevasker.

Hele prosessen er veldokumentert, og forbedringsforslag for videre utvikling er inkludert i oppgaven for å tilrettelegge for at Henkel skal kunne overta prosjektet.

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Abbreviations

ABS	Acrylonitrile Butadiene Styrene
ADC	Analog to Digital Converter
AHP	Analytical Hierarchy Process
CAD	Computer-Aided Design
DANE	Departamento Administrativo Nacional de Estadística
DNP	Departamento Nacional de planeación
FARC	Revolutionary Armed Forces of Colombia
FRS	Force Sensing Resistor
GFCI	Ground Fault Circuit Interrupter
GMA	General Morphological Analysis
HWE	Hot Water Extraction
IKW	German Cosmetic, Toiletry, Perfumery and Detergent Association (Industrieverband Koerperpflege- und Waschmittel)
MPI	Multidimensional Poverty Index
NTNU	Norwegian University of Science and Technology
PE	Polyethylene
PHWE	Pressurized Hot Water Extraction
PUJ	Pontificia Universidad Javeriana
RM	Rapid Manufacturing
RP	Rapid Prototyping
RT	Rapid Tooling
SHS	Selective Heat Sintering
ZCR	Zones of Convenient Reach

1 Introduction

1.1 Background

This master's thesis has been part of a longer cooperation between TrollLABS at NTNU and the German company Henkel AG & Company, KGaA. Henkel is a multinational company with products within laundry and homecare, beauty care and adhesive technology (Henkel AG & Co. KGaA, n.d.). In 2014, Andreas Wulvik travelled to India to conduct his pre-master project "Photography - a new tool in Need Finding" with the aim to do innovative product development based on theory and methods from Design Thinking and Need Finding (Wulvik, Balters, Steinert, & others, 2015). In the end, Henkel decided not to introduce any products to the Indian market, but they were interested in the design process and the results so they decided to do a second "Need Finding" project, only this time in Colombia. Henkel already had several products on the Colombian market, such as Schwarzkopf (beauty care), Persil (laundry detergent) and Loctite (adhesive), but they wanted to increase their market share within laundry and homecare, particularly focusing on bathroom products.

In September of 2015, I stayed one month in Colombia to gain knowledge for my "Need Finding in Colombia" pre-master project. I learned to speak and write fluent Spanish while I lived in Buenos Aires, Argentina, during my exchange program in 2013/2014 and during my many travels in Latin America. This gave me a huge advantage as there were no communication problems, in addition to my knowledge and understanding of the Latin culture. In Colombia I collaborated with with industrial engineering student Karen Alejandra Cuesta Vinasco and electrical engineering student José Luis Ariza Cabrera at La Pontificia Universidad Javeriana Cali (PUJ) in Cali. Juan Pablo Garcia Cifuentes was our supervisor and contact person at the university. We had access to *The loft*, a workspace intended for the Stanford ME310 Design Innovation course, so we had access to several whiteboards and some basic materials to build prototypes (cardboard, color pens, tape e.g.). In addition to Cali, which is a highly developed and large city in Colombia, I also travelled to the poorest department of Colombia, Chocó, to gain a better insight of the different extreme users and environments in Colombia.

1.2 The approach – applying wayfaring in product development

The wayfaring model in product development is described as a development journey where rapid learning cycles, probing ideas and prototyping drives the development process and continuously shapes the outcome. The model was inspired by Kwon (1998) and Ingold (2007) and first described by Martin Steinert and Larry J. Leifer (2012), and further developed and applied by Achim Gerstenberg et al. (2015) and Kittil K. Leikanger et al. (2016). Figure 1-1 describes an example of how such a journey could evolve. Point *A* is the starting point for the project and point *V*, with its uncertainty magnitude represented as a three-dimensional coordinate system, is the envisaged result. The uncertainty is caused by the conflict of predicting a result when doing something that has never been done before. As new knowledge and understanding is gained through pragmatic exploration, the envisaged result will change from V to V', V' to V'' and so on until the wayfaring ends at the result V^x, "the really big idea" (Gerstenberg et al., 2015; Steinert & Leifer, 2012).

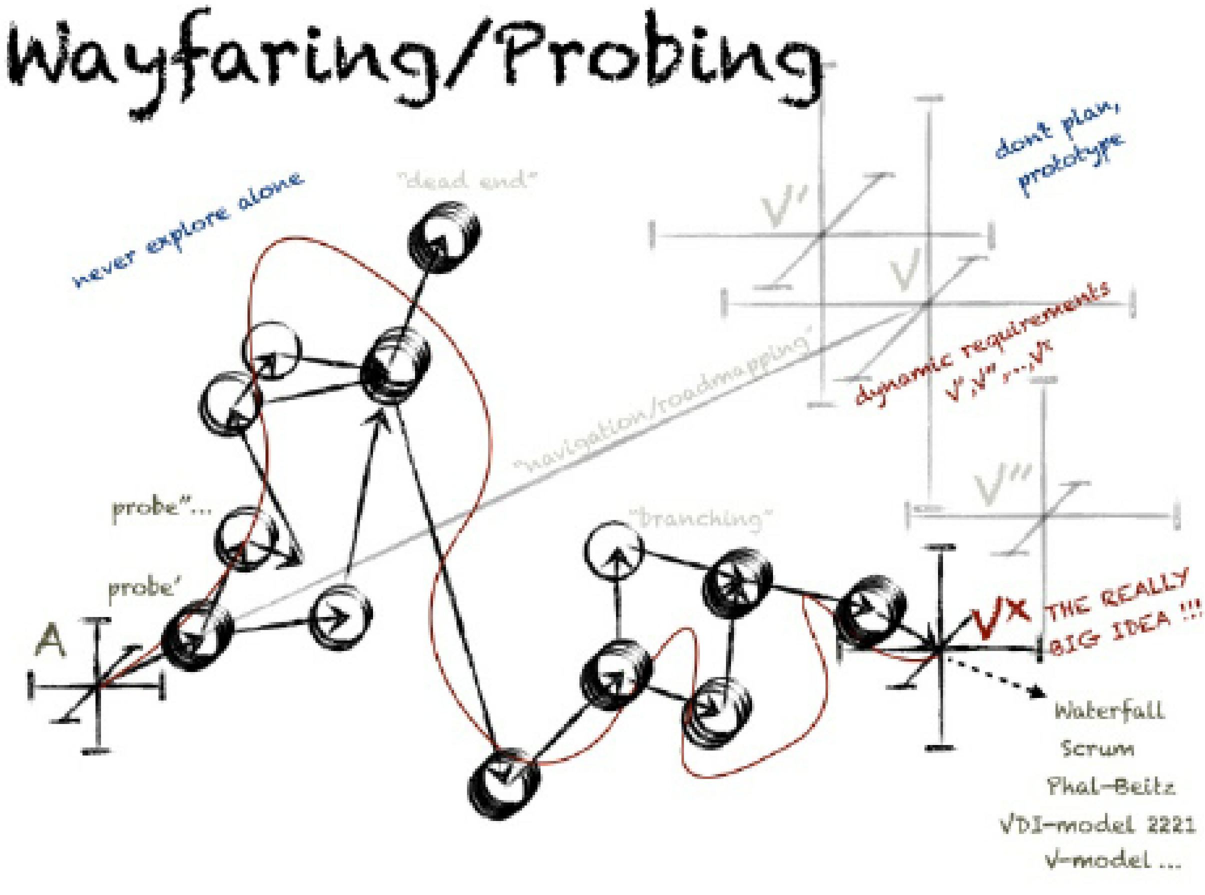


Figure 1-1: The wayfaring model in product development (Gerstenberg et al., 2015)

The wayfaring path is continuously explored through probing ideas, where the aim is to focus on the most critical functions in the beginning, leaving *nice to have* features for later. The concept of probing is described in Figure 1-2. Each probing cycle is initiated by a divergent thinking phase where the aim is to come up with as many ideas as possible, and then these ideas are prototyped and tested. The low resolution prototyping enables the possibility to test quantitatively at a low cost. This encourages the concept of safe failure; test and fail as early as possible to learn, correct the path and minimize the wasted time and resources wayfaring into a *dead end* (Figure 1-1). After each probing cycle follows a convergent phase where the best ideas are selected and the new understanding of the process is taken to the next probe (Gerstenberg et al., 2015). The approach also points out that components from different technical disciplines should be merged and tested together as early as possible to discover interdependencies. By testing the system as a whole early in the process, relevant knowledge can be exchanged between disciplines and possible requirement-related conflicts may be avoided (Gerstenberg et al., 2015; Leikanger et al., 2016).

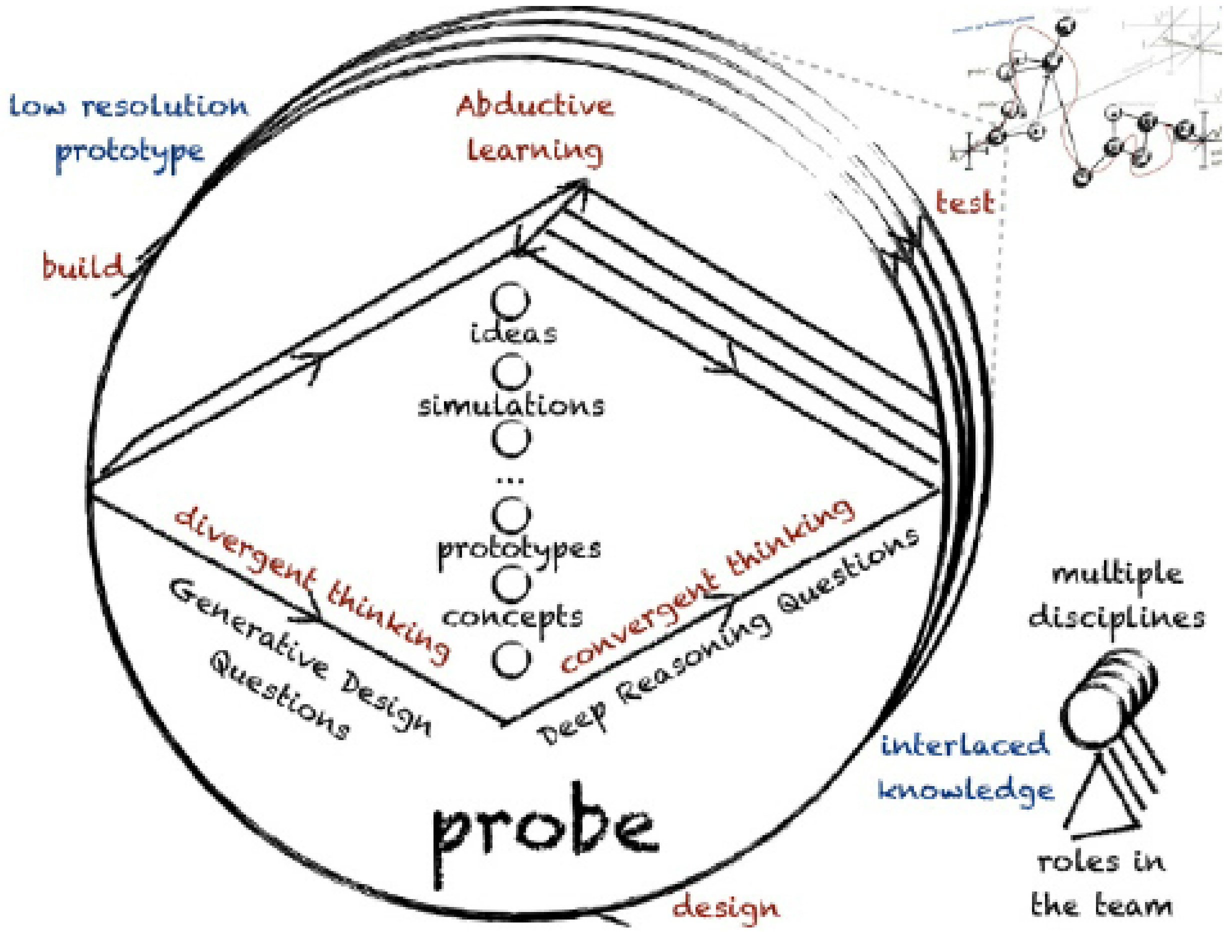


Figure 1-2: Probing cycles (Gerstenberg et al., 2015)

The wayfaring model has its most potential when it is applied to a project with a high level of uncertainty in the development process, a high degree of intended innovation and freedom in the solution space and a limited amount of time (Gerstenberg et al., 2015). Based on these criteria, we believe there is a great advantage and benefit of applying the wayfaring model to the product development process of this master's thesis.

1.3 Project vision

The pre-master project resulted in a lot of user knowledge and different pain points, which are the starting points *A* for the master's thesis project. The challenge is to convert the problem areas and the needs found into a specific product development project. The vision for this master's thesis, our envisaged result *V*, is to create a prototype for a new cleaning tool that will simplify the removal of dirt and grime from tiles and grouts as well as reduce the time spent cleaning. Cleaning the grouts is a big challenge because some stains, especially mold, are extremely difficult to remove and tend to return in a relatively short time. The need finding, user observation and market research we did during the pre-master project supports that this is a pain point worth exploring and that there is an international market potential. There are products on the market today that aim to clean tiles and grouts, however a user survey reveals that more than 90% of the participants still use a cloth or an old toothbrush to clean their grouts. By working with Henkel AG & Co. KGaA Duesseldorf and with the guidance of Martin Steinert and Stephanie Balters at NTNU this vision will be realized by June 10th 2016.

A useful tool to visualize how the vision will be reached is to use the *Change Paths* method by Carleton et al. (2013) to outline some tangible milestones (see Figure 1-3).

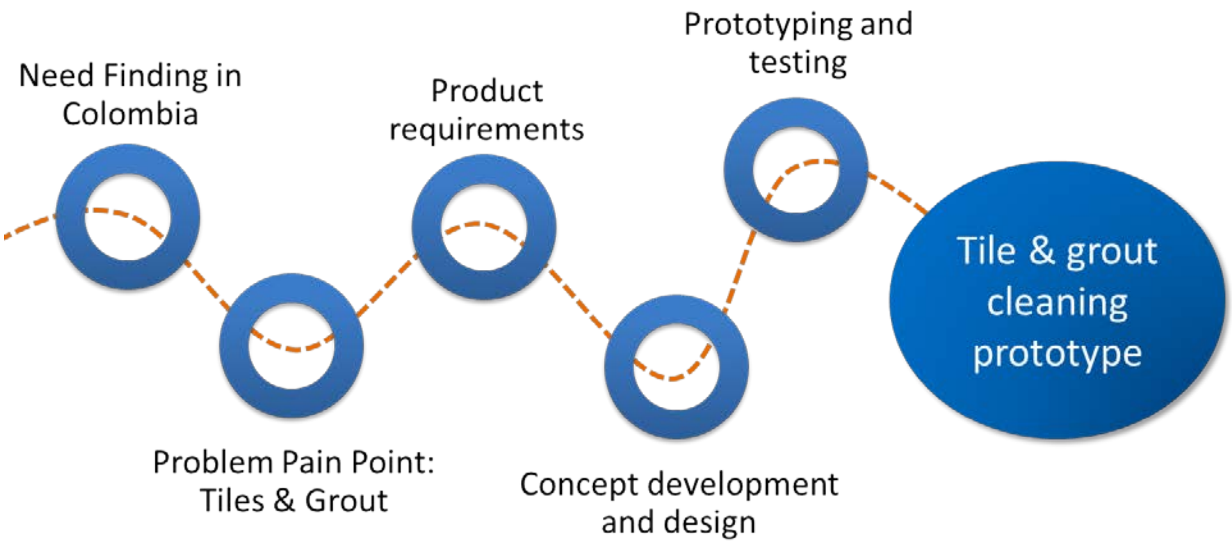


Figure 1-3: Change Paths diagram

1.4 Structure

This master's thesis is written in chronological order, following the wayfaring path towards a final solution. The different main phases, milestones and events are illustrated in the journey map in Figure 1-4. The journey map can be described as a more detailed change paths diagram. The journey map was continually updated and used during the process to plan the next step and get an overview of which phases or milestones might influence the direction of the development process. It was also used to present the progress during the meetings with Henkel and lastly it is used to communicate the complete wayfaring (Plattner, 2009).

The main pain points and knowledge gained from the pre-master project "Need Finding in Colombia" are presented in section *2 Introduction to Colombia* and *3 Need finding in Colombia.* Section *4 Product requirements*, *5 Benchmarking* and *6 Bathroom dirt and grime*, include detailed descriptions of the different product requirements, what environments it must be designed for and also a benchmarking part to identify possible existing products and competitors. The next sections of the thesis, section *7 Tile wall prototype*, *8 Early concept development*, *9 Ideation and concept workshop at NTNU and 10 Further concept development* can collectively be described as a divergent phase where more than ten different concepts were probed. The main convergent phase is described in section *11 Concept evaluation*. During these phases there were also smaller divergent/convergent thinking processes so the grouping of these sections is only intended to give a main overarching structure. Section *12 Design*, *13 Ergonomics*, *14 Function*, *15 Assembly of the prototype* and *16 Testing and evaluation* describe the further exploration of the chosen concept, and the testing of the features aforementioned. The last part of the thesis includes section *17 Improvements – the beta prototype* and *18 Conclusion,* as well as references and appendices.

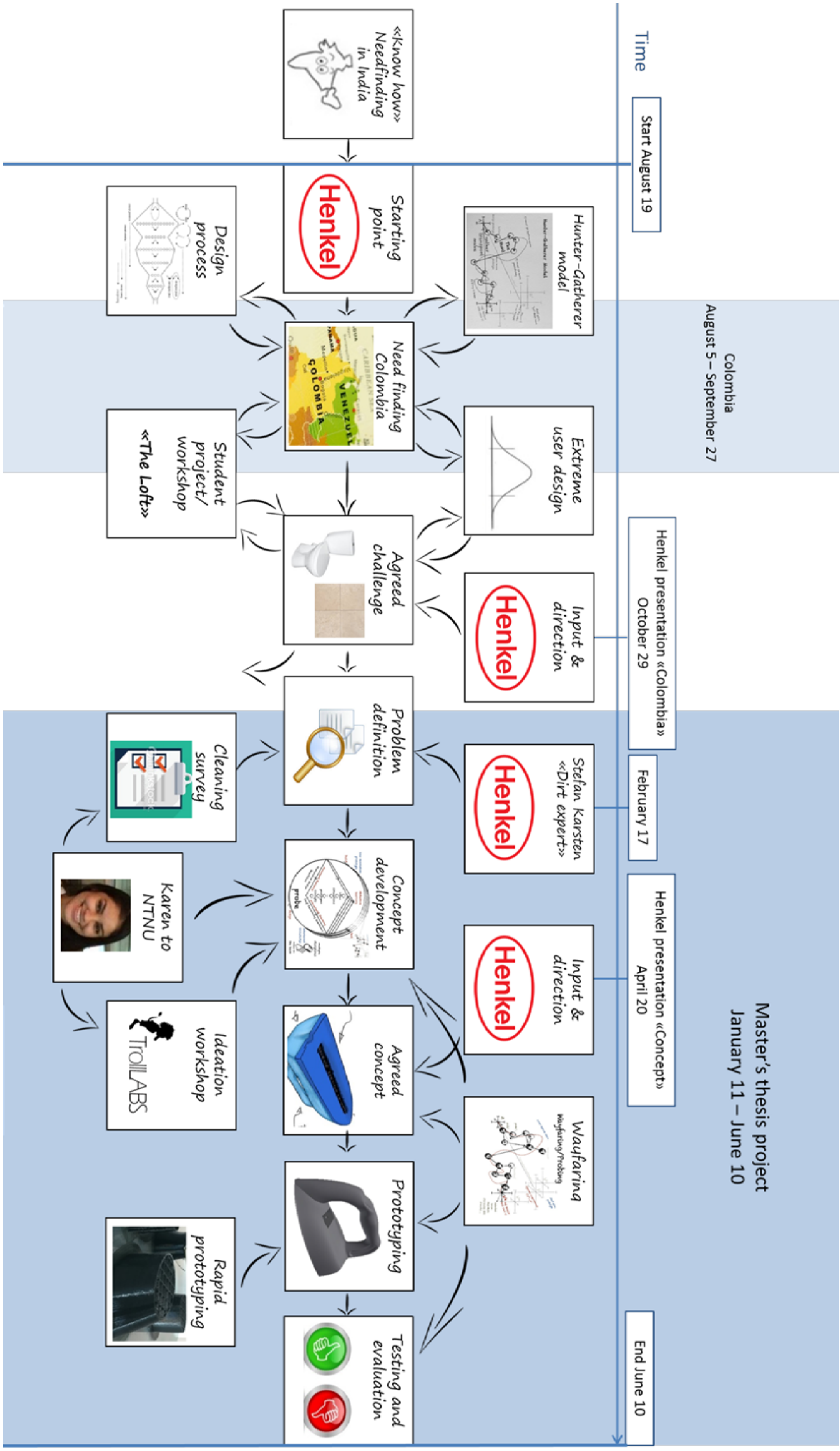


Figure 1-4: Project roadmap and timeline

2 Introduction to Colombia

Figure 2-1: Map of Colombia (Entorno inteligente, 2015)

Colombia is located in the northern part of South America. It borders the North Pacific Ocean and the Caribbean Sea, as well as the countries Panama, Venezuela, Brazil, Peru and Ecuador. The official language of Colombia is Spanish, the capital is Bogotá and 90% of the population are Roman Catholics. The two main ethnical groups are Mestizo (descendants of mixed European and Amerindian ancestry), white (84,2%) and Afro-Colombian (10,4%). The total area is 1,138,910 km2, which is approximately equivalent to Germany, United Kingdom and France combined. The population is 46 736 728 (est. July 2015) where 74,4% (est. 2015) are considered urban (Central Intelligence Agency, 2016). The National department of planning (NDP) of Colombia has defined an urban area as the area within the limits of a municipal capital, see Figure 2-2. The area that is not urban is defined as rural (Carranza Tresoldi, 2013).

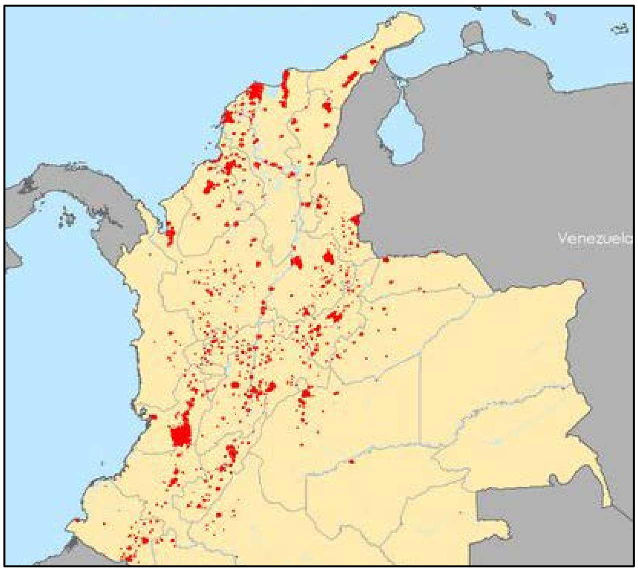


Figure 2-2: Urban areas in Colombia (Colombia University, 2009)

2.1 Economy

Colombia is the world's fourth largest exporter of coal and Latin America's fourth largest producer of oil. They also export emeralds, coffee, nickel, cut flowers, bananas and clothing, mainly to the US, China, Panama, Spain and India (2014 est.). The poor infrastructure, narcotics trafficking, inequality and corruption are some of the challenges that hinder further economic development. The unemployment rate reached its absolute lowest at 8,9% in March 2015 (Moss, 2015), which is one of the lowest rates in Latin America (Central Intelligence Agency, 2016).

There are two official ways of calculating poverty in Colombia. The first method, income poverty, is calculated from household income and is based on a household income survey from 1984/85. Extreme poverty is defined as the minimum income needed to buy the essential goods and services to survive. The poverty line is twice the extreme poverty line in urban areas, while only 1,5 times in rural areas (Bustamante, 2013; Dávila, 2002).

The other method, the Multidimensional Poverty Index (MPI), was implemented in 2001. It was developed by Alkire and Foster at Oxford University, and adapted for Colombia by the Departamento Nacional de planeación (NDP). The multidimensional poverty consists of five conditions: education, formative conditions, health, employment and living conditions (Bustamante, 2013). Both methods and poverty numbers for the year 2012 can be found in Figure 2-3.

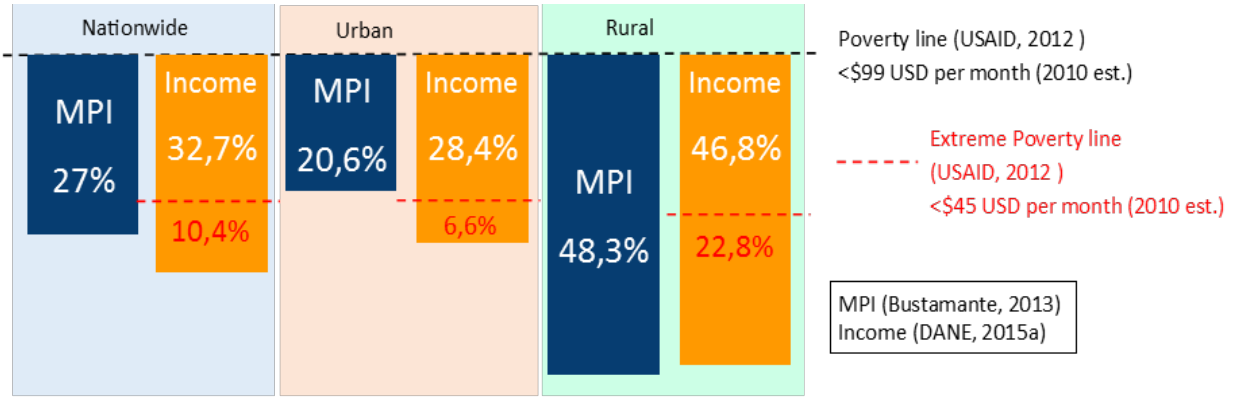


Figure 2-3: MPI poverty and Income poverty in 2012

2.2 Urban vs. Rural

During my stay in Colombia I stayed ten days in the urban city Cali (black pin on the map in Figure 2-2), before I travelled to Chocó region (area within the red lines) and visited Quibdó (red pin) and Bahia Solano on the Pacific coast (green pin), where I spent a week in total. The aim was to get a wide range of observations and be able to compare the urban vs. the rural situation. A video from my travels can be found on www.youtube.com[1] and additional photos of my observations can be found in *Appendix B: Photos from Colombia*.

Figure 2-4: Cali (black pin), Chocó (red pin) and Bahia Solano (black pin) (adapted from Google maps, 2015)

There is a huge difference between poor and rich in Colombia, which is the tenth most unequal country in the world. The poverty rate is much higher in rural areas than in urban (Central Intelligence Agency, 2016). For example, 27,2% (2013 est.) of the population lives below the poverty line (of which 7,1% are below the extreme poverty line) in Cali while in Chocó 63,1% (2013 est.) of the population lives below the poverty line, of which 35,6% are below the extreme poverty line (Departamento Administrativo Nacional de Estadística (DANE), 2015a).

[1] Colombia: https://youtu.be/5JtkoOPvbMQ

3 Need finding in Colombia

Need finding is a development tool used to explore user needs and values in consistency with design thinking methodology. In traditional product development, a set of initial requirements and specifications drive the innovation towards a final product. The weakness of this approach is that market and customer needs and requirements often change during the development process, leaving the development team with a product of low customer satisfaction or a costly re-design process needed (Leifer & Steinert, 2014).

Need finding consists of several efficient tools to observe, explore and obtain knowledge and insight about the user and how to use this knowledge to develop a concept through wayfaring. Some frequently used tools are interviews, fly-on-the-wall observation (observation without engaging with the user) and photography (Plattner, 2009; Wulvik et al., 2015). Design thinking also includes organizational tools to collect, organize and visualize the gathered information such as extreme user design (see section *3.1 Extreme user design*) and personas (section *3.2 Personas*) (Leifer & Steinert, 2014; Plattner, 2009).

3.1 Extreme user design

The purpose of extreme user design is to uncover extreme needs. The population on the edges of the curve will often have needs that are amplified compared to the mean user, and focusing on these needs could result in some creative ideas and meaningful insights (Plattner, 2009). In theory, if the extreme needs are met, the solution will also fit the mean user.

Based on observations we believe that the main variation within the bathroom product user group in Colombia is based on household finances and their purchasing power. All households in Colombia are divided into a six grade strata system; 1=lowest income, 2=low-middle class, 3=middle class, 4=upper-middle class, 5=upper class and 6=wealthy. According to the strata definition strata 1, 2 and 3 are considered poor, stratum 4 is the middle class and strata 5 and 6 are rich. The aim was to help the population in the lower strata with subsidies to pay for utilities, but the division is based on housing conditions such as garage, front yard and neighbourhood, and not on the household income, so today rich people tend to buy houses with a low stratum to avoid government fees (Hudson & Bushnell, 2010).

Hudson and Bushnell (2010) stated that 89% of the population lives in stratum 1, 2 and 3, 6,5% in stratum 4, 1,9% in stratum 5 and 1,5% in stratum 6. Due to the lack of more specific numbers, I have chosen to combine the strata definition with income poverty (Table 3-1) to create an extreme user chart for the population of Colombia, see Figure 3-1.

Table 3-1: Extreme user division

Stratum	Defined by	Percentage of population
1: Lowest income	Extreme poverty line (DANE, 2015b)	10,4%
2: Low-middle class	Poverty line (DANE, 2015b) *Not including the population in stratum 1*	22,3%
3: Middle class	*The remaining to reach 100%*	57,4%
4: Upper-middle class	(Hudson & Bushnell, 2010)	6,5%
5: Upper class	(Hudson & Bushnell, 2010)	1,9%
6: Wealthy	(Hudson & Bushnell, 2010)	1,5%

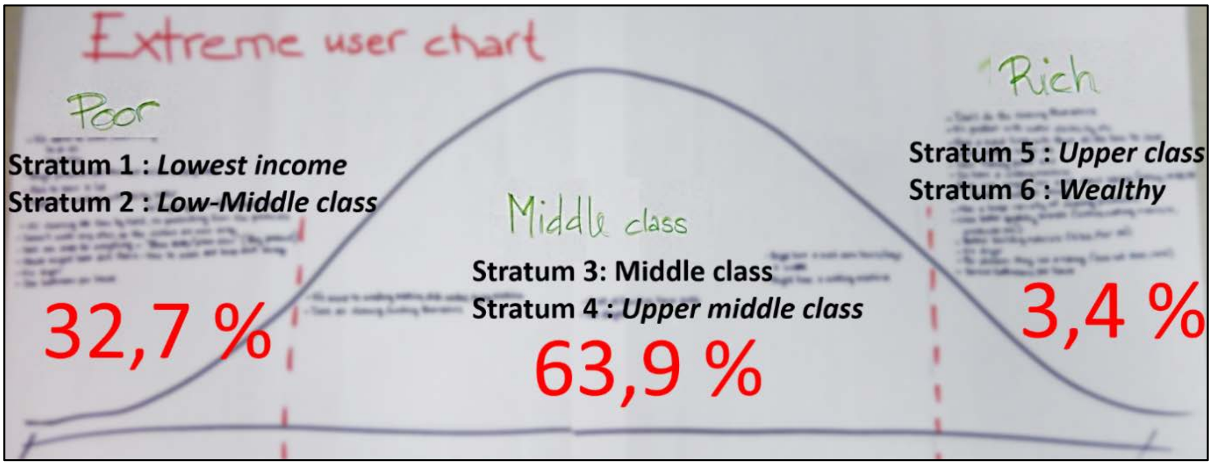


Figure 3-1: Extreme user chart Colombia

Some characteristics associated with the different extreme user groups are listed in Table 3-2.

Table 3-2: Extreme user characteristics

Extreme user	Characteristics
Poor *Strata 1&2*	– Buys products on a day-to-day basis (single-portion packages) – All cleaning done by hand – Uses one soap for everything, *Jabón Azul* – Does not wash clothes often, so they are dirtier – Partly, or no access to water and electricity – Uses rivers, rainwater etc. for drinking water and cleaning. – Houses have a low standard (dirt floor, curtain doors etc.)
Middle class *Strata 3&4*	– Buys normal size products, but price is important – Most upper-middle class households have a house cleaner and a washing machine, while stratum 3 does not.
Rich *Strata 5&6*	– Has a house cleaner – Buys the products that the house cleaner uses – Has a washing machine, but no dryer – Variety of cleaning products – Uses better quality brands – Houses have a high standard (building materials, several bathrooms etc.) – No problem with water, electricity etc. – Cares a lot about saving (use refills, big size packages etc.), part of culture

3.2 Personas

Creating different personas, or character profiles, is a good way to categorize a complex user group. Each persona represents a user sub group with similar tendencies or patterns (Plattner, 2009). For this project, the personas are based on their strata and cleaning habits, and resulted in four personas: Javier, Maria, Luz Marina and Marisol. Personas are also a good communication tool when discussing target users later in the development process.

Figure 3-2: The four personas. From the left: Javier Gomez Lopez (AleCastillo92, 2009), María Garcia (Dembner, 2013), Luz Marina Gutierrez (Jaramillo Otoya, 2013) and Marisol Rodriguez (Román, 2011)

3.2.1 Javier Gomez Lopez

Javier is 21 years old, he studies industrial engineering and he lives alone in a small apartment close to the University. Javier does all the cleaning himself, which is really boring and even though he has his favorites he does not like to spend a lot of money on cleaning products. Javier's parents are from the upper-middle class and pay the rent for the apartment.

3.2.2 María Garcia

Maria is 35 years old. She is married, has two daughters and a dog and lives with her family in a big house in the suburbs of Cali. María and her husband work a lot, so she has a woman that comes to her house every day to help with cleaning and cooking. María buys the cleaning products that she wants the house cleaner to use.

3.2.3 Luz Marina Gutierrez

Luz Marina is 55 years old, and she lives with her husband and her son in an apartment in the north of Cali. She works as a house cleaner for a family so she spends a lot of time at work. When she is home, she likes to prepare dinner and gather her family. Luz Marina buys all the cleaning products for her own use, and price is the deciding factor.

3.2.4 Marisol Rodriguez

Marisol is 26 years old and lives in a small village near Quibdó. She does not have a job so she takes care of her siblings and other children in the village to help her family. She also does a lot of cleaning and cooking. The family does not have indoor plumbing so she has to clean the clothes in the river. Most of the times she has to buys a small portion of detergent to fit the «day-to-day» budget.

3.3 Need finding workshop at PUJ

Once I arrived in Cali, Karen, José Luis and I arranged a priming workshop at PUJ with participants from the ME310 Stanford Design Innovation course. The aim for us was to gather a base knowledge of the cleaning situation today, and get some ideas and early stage prototypes to use as inspiration. As a priming tool, we showed them a video[2] we made of different bathrooms around the world and clips from different futuristic movies.

[2] Priming video: https://youtu.be/wF3P61W8J_E

We divided the workshop into three rounds of interaction: first a round with need finding and problem statement, then two rounds of prototyping. Between each round, the groups would present their ideas and get feedback from the other groups. The results from the workshop were categorized, merged with the rest of the need finding and the main pain points are presented in section *3.4 Summary – pain points*.

3.4 Summary – pain points

The aim with the trip to Colombia was to observe the current situation, explore the solution space, gain insight about the problem and find room for improvement and innovation. As a result, the need finding in Colombia and the need finding workshop can be summarized into nine pain points:

1. *Tiles:* They are time consuming and tedious to keep clean. Most houses have tiles on the floor, and they also wear their shoes on indoors.
2. *Large sized packages and product refills*: Colombians are concerned about saving as much as possible, and therefore they want their products as cheap as possible.
3. *Cleaning staff*: Most upper-middle class and wealthy population have a house cleaner to do their cleaning and cooking. In general, this means that they do not care as much about functionality of a product as if they were using them themselves.
4. *Smell/odor*: A cleaning product must have a significant, perfume-scented smell to be efficient.
5. *Lack of water*: For areas without indoor plumbing or during water restrictions in cities due to extreme heat.
6. *River cleaning*: People in rural areas wash their clothes in the river.
7. *Drying clothes*: High humidity in some regions or lack of space and no access to dryer in small city apartments makes it hard to dry clothes.
8. *Transport/logistics*: It is complicated to transport goods in parts of Colombia due to road conditions and the Revolutionary Armed Forces of Colombia (FARC) (anti-government insurgent group that controls certain countryside areas where they attack civilians and run their drug trading to finance their activities) (Central Intelligence Agency, 2016).
9. *Clean water*: Lack of improved drinking water source and clean rivers.

In mid-December we had a meeting again with Henkel, where we discussed the pain points and the direction of where we want to continue the project. We filtered out *tiles* and *smell* as the possible gold nuggets. The smell, and the delivery of the smell, is a very important aspect of any possible product, as Colombians are under the impression that no matter how efficient and effective a product might be; "if it does not smell nice, it does not work".

Regarding tiles, the focus was on the cleaning of the grouts as this turned out to be a problem, not only in Colombia, but in Europe as well. As a conclusion we decided that a tool for this purpose, possibly combined with a cleaning/mold preventive soap, was a interesting development project and it would be the project that could possibly create the most value for Henkel.

4 Product requirements

4.1 Context map

The 3 main user groups, described by the personas Javier, María and Luz Marina (see section *3.2 Personas*), were established to understand the users. To better understand their needs and the different dimensions of the needs, a context map was created to identify and illustrate the perfect cleaning tool, see Figure 4-1. According to the *Playbook for Strategic Foresight and Innovation* (Carleton et al., 2013) a context map is an efficient method to identify the main dimensions of a problem or opportunity space.

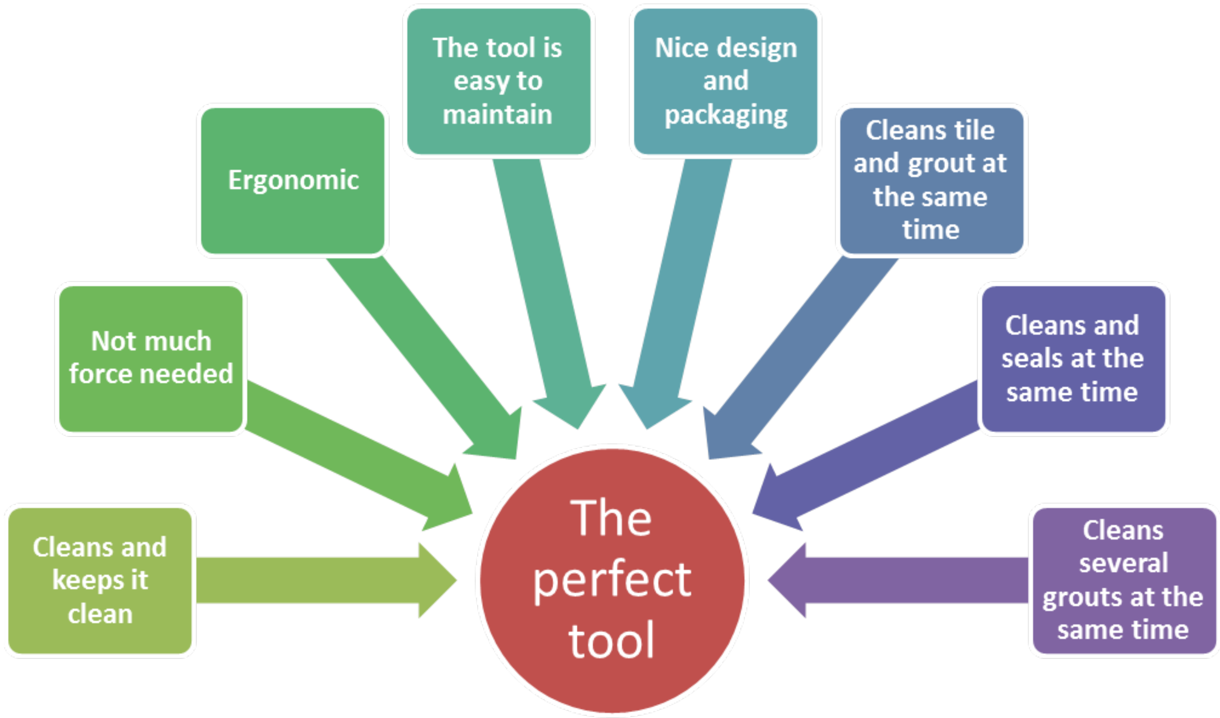


Figure 4-1: Context map of the perfect tool

The ideal cleaning tool does not only clean the grouts, but the tiles as well at the same time. It should be able to clean more than one grout simultaneously and have a function that keeps the surface clean for a long time. It should also be able to clean and seal, so that only one tool is needed. Another important feature for the ideal cleaning tool is that the user should not need to apply much force while using it. The tool itself must be easy to clean and maintain, it must have a nice ergonomic design and an appealing packaging.

4.2 Design and performance

The product requirements related to design and performance are summarized in Table 4-1. At this point in the development process, most of the requirements are still unknown and difficult to describe, but they portray the values the tool should have. A comparison of the importance of the different requirements (as well as some other inputs) can be found in section *4.4 Analytic Hierarchy Process*.

Table 4-1: Design and performance requirements

Product requirement	Description	Reference section
Price	The price of the tool must be compatible with similar tools on the market: ~100-300NOK	
Weight	<1,1 kg	0
Material	Housing in polyethylene (PE), metal parts in a corrosion-resistant, lightweight material	0
Color	The tool should have an elegant color that reflects cleanliness	0
Efficiency	The tool must be easy to use and clean efficiently	4.3
Speed	The tool must be able to fulfill its task as quickly as possible	
Reliability	The tool must always be in working condition when needed	
Portability	The tool must be easy to carry. If motorized, this also applies to batteries/cord	
Reusability	The tool itself must be reusable with brush/soap refills	
Set-up time	The tool should be ready to use. For a motorized option, a simple charging system must be developed	

4.3 Functionality

The main focus for this tool is the cleaning of the grouts. There are two main classifications of grout: cement based and epoxy based. The cementitious grouts can either be sanded, for grout joints between 4-15mm, or non-sanded, for joints of 4mm or smaller. The epoxy-based grout has lower water absorption, higher compressive strength, is more resistant to mold and staining and easier to maintain, but it is also more expensive and more difficult to apply than cement grout. It is mostly used in restaurants, hospitals and other buildings where hygiene is important. Caulk, or silicone filling, is used in corners or between different materials where there might exist small movements, which could cause cracking in a regular cement or epoxy grout (Good industry practices, n.d.). The tool must be designed in such a way that it cleans cement and epoxy grouts as well as the caulk filling in the corners (Figure 4-2), without damaging any of the mentioned. This is a challenge for the caulk, in particular as it is much softer than the two others.

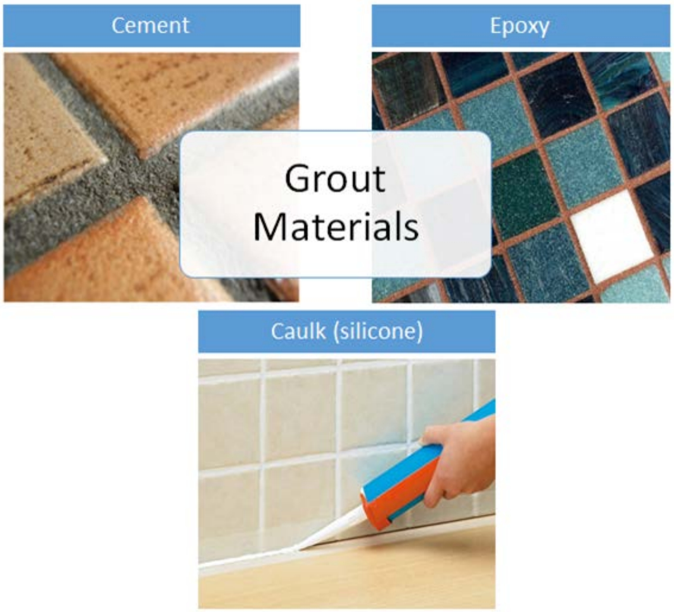


Figure 4-2: Grout materials; cement (Floorvinyl, 2014), epoxy (Vadodara, 2015), caulk (Alibaba, n.d)

The tool must also effectively clean different types of tiles such as porcelain, ceramic, as well as glazed and un-glazed tiles (Figure 4-3). Both porcelain and ceramic tiles are made out of clay that has been baked, but porcelain is fired at a higher temperature. The main difference is that ceramic tile has a higher density, it is often extruded and rectified (mechanically cut and ground down to correct size) and it must have a water absorption rate of 0,5% or less. Both porcelain and ceramic tiles can be glazed, which means that an additional layer of glass is added during a second firing process, leaving a smoother surface (Wallender, 2016).

Figure 4-3: Tiles; Porcelain (John tiling, n.d), Ceramics (Margret, 2015), Glazed/un-glazed (Eagle Brand Tiles, 2015; Homedepot, n.d)

For this problem scenario there is no need to differentiate too much between different tile materials, they are all harder and smoother than the grout so no material possibly chosen for the grout cleaning will be able to damage the tiles. However, a very soft sponge, for example, might be worn down and leave traces of fabric on a very rough un-glazed tile surface.

As described in section *6 Bathroom dirt and grime,* the most common types of dirt in a bathroom are mold, limescale and calcium soap, and other types of stains. Rust is also a big problem in Eastern European countries (Stefan Karsten, 2016). The tool together with a suitable detergent must be able to remove any of these types of dirt (Figure 4-4).

Figure 4-4: Dirt; stains (Sys teco, n.d), mold (Jaka, 2015), limescale/calcium soap (Knoji, 2013)

The design of the geometry of the tool must be in such a way that it reaches all corners, nooks and crannies and other problem areas (Figure 4-5) in the bathroom, for example behind the toilet. It must also be able to reach into the concavity of the grouts.

Figure 4-5: Problem areas; hard to reach areas (UPCA, n.d), corners (Flora, 2015), between different materials (Petersik, 2008), grout (Floorvinyl, 2014)

The tool can either be manually powered or powered by a motor, engine or compressor, including high pressure vapor (Figure 4-6).

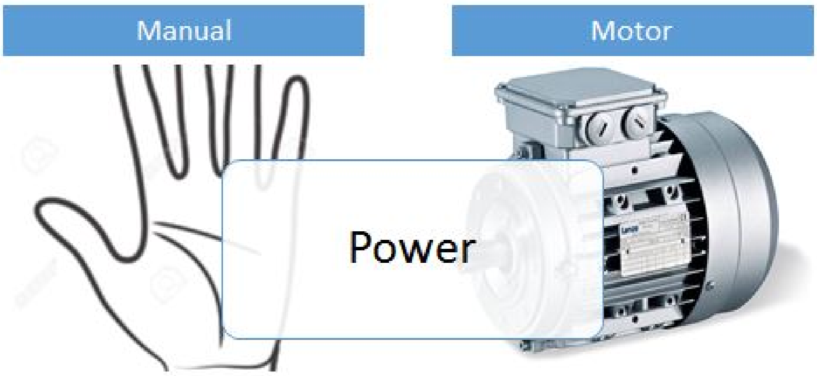


Figure 4-6: Power; manual (Nikolae, n.d), motor (Pixbam, n.d)

4.4 Analytic Hierarchy Process

An Analytical Hierarchy Process (AHP) is a tool to help decision making considering a problem with several options and selection criteria. The method uses pair-wise comparisons between two and two criteria (Table 4-2) and finally shows the resulting weight and rank in the result table as shown in Figure 4-7. The Excel template was downloaded from Klaus D. Goepel's business performance management blog about the AHP (Goepel, 2015b).

Table 4-2: AHP Criteria comparison table (Goepel, 2015a)

		Criteria		more important ?	Scale
i	j	A	B	A or B	(1-9)
1	2	Design	Performance	B	7
1	3		Price	B	2
1	4		Set-up time	A	6
1	5		Adaptability	B	8
1	6		Weight	A	3
1	7				
1	8				
2	3	Performance	Price	A	5
2	4		Set-up time	A	9
2	5		Adaptability	A	2
2	6		Weight	A	5
2	7				
2	8				
3	4	Price	Set-up time	A	3
3	5		Adaptability	B	5
3	6		Weight	A	3
3	7				
3	8				
4	5	Set-up time	Adaptability	B	7
4	6		Weight	B	3
4	7				
4	8				
5	6	Adaptability	Weight	A	7
5	7				
5	8				

As the table explains for each criterion pair either A or B must be chosen, then each choice is given a value from 1-9 (Table 4-3) describing how much more important the chosen criterion is compared to the other. The numbers 2, 4, 6 and 8 are the intermediate values between the corresponding definitions; e.g. 2 is the intermediate value between equal and moderate importance.

Table 4-3: Comparison scale (Goepel, 2013)

Intensity	Definition
1	Equal importance
3	Moderate importance
5	Strong Importance
7	Very strong importance
9	Extreme importance

AHP Analytic Hierarchy Process (EVM multiple inputs)

K. D. Goepel Version 07.06.2015 Free web based AHP software on: http://bpmsg.com

Only input data in the light green fields and worksheets!

n=	6	Number of criteria (2 to 10)	Scale:	1	Linear
N=	1	Number of Participants (1 to 20)	α:	0,1	Consensus: n/a
p=	1	selected Participant (0=consol.)	13	7	Gina Limseth

Objective Calculate weights for different product requirements

Author Gina Limseth

Date 16-Mar-16 Thresh: 1E-07 Iterations: 6 EVM check: 2,0E-08

Table

	Criterion	Comment	Weights	Rk
1	Design	Ergonomics, color, shape	8,3%	4
2	Performance	Efficiency, reliability, usability, speed	40,3%	1
3	Price	Tool price, refill/maintainance	9,8%	3
4	Set-up time	Charging	2,8%	6
5	Adaptability	Flexibility, portability, reusability, fits all materials	33,9%	2
6	Weight		4,9%	5
7			0,0%	
8			0,0%	
9		for 9&10 unprotect the input sheets and expand the	0,0%	
10		question section ("+" in row 66)	0,0%	

Result

Eigenvalue		lambda:	6,578
Consistency Ratio	0,37 GCI: 0,34	CR:	9,2%

Figure 4-7: AHP product requirements results (Goepel, 2015a)

Figure 4-7 shows that performance, which includes efficiency, reliability, usability and speed/operation time, is the highest ranked criterion, closely followed by adaptability, which is defined as flexibility, portability, reusability and that it fits all materials. Set-up time, understood as charging time and time spent on preparing the tool before the actual activity, got the lowest ranking. This can be interpreted as if the tool has a high performance the user will not mind a longer charging or preparation time. The result table also gives a visual representation of which criteria are worth some extra attention. The complete AHP calculation results can be found in *Appendix G: Concept AHP calculation results*.

5 Benchmarking

Before the development of any concept it is important to be aware of other similar products on the market and whether there are any protected patents that must be taken into consideration.

At this point of the project the user needs and the product requirements were defined. Google search and Google patents were used to do research on existing projects and products focused on tile and grout cleaning, and the most important ones are described in the next sections.

5.1 Existing products

The Grout Gator (Figure 5-1) is a manual grout-cleaning tool that fits all tiles up to 33cm in width. Additional brushes can be added, as well as an extension pole to make it easier to clean floor grouts. The price is approximately 30USD (Grout Gator, n.d.).

Figure 5-1: Grout gator (Grout Gator, n.d.)

The Shower Shimmy (Figure 5-2) is an all-in-one cleaning tool consisting of replaceable bristle and sponge components, an integrated detergent compartment and a squeegee. The project was funded through kickstarter.com, an online crowdfunding community (Lewis Call, n.d.).

Figure 5-2: Shower Shimmy (Lewis Call, n.d.)

The Scotch-Brite™ Grout Scrubber (Figure 5-3) is a light-weight and efficient grout-cleaning scrubber with a comfortable handle (Scotch-Brite, n.d.).

Figure 5-3: Scotch-Brite ™ Grout Scrubber (Scotch-Brite, n.d.)

The Tub N' Tile Power Scrubber (Figure 5-4) is an electric tool to clean tubs and tiles. It comes with two different brushes; one large scrubbing brush for larger areas, and a smaller stiffer one for corners and grout, as well as an extendable 53cm long aluminum handle (Quickie, n.d.).

Figure 5-4: Tub N' Tile Power Scrubber (Quickie, n.d.)

5.2 Active patents

5.2.1 Tool for cleaning tile and grout – patent US 8028366B2

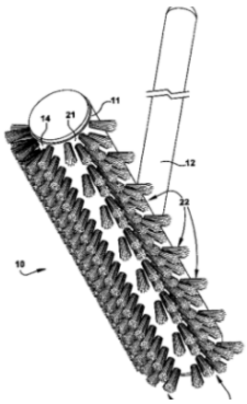


Figure 5-5: Tool for cleaning tile and grout (Grabowski, 2011)

"A tile and grout cleaning tool that can be turned over to place either a first series of bristle bundles projecting from the head of the tool in position to clean tile surfaces or a second series of bristle bundles spaced from the first series in position to clean the grout between tiles, the second series of bristle bundles comprising bristles that can be pressed into the grout channels and have ends of different lengths that form rough cleaning surface"(Grabowski, 2011)

Legal status: active, expires 2029-10-10 (Grabowski, 2011)

5.2.2 Grout cleaning apparatus – application US 20080229530A1

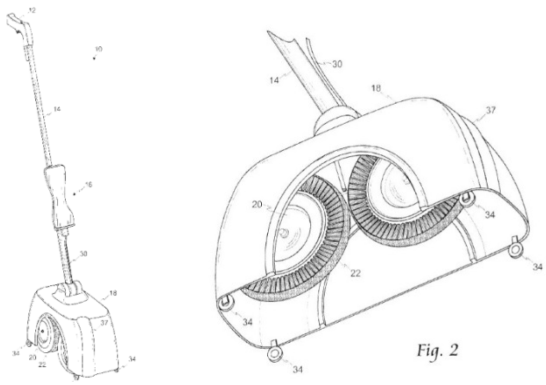


Figure 5-6: Grout cleaning apparatus (Kordick, 2008)

"An improved grout cleaning apparatus has in line cleaning wheels positioned within a housing, at the terminus of a shaft...a drive motor supplies power to the in line cleaning wheels... A cleaning fluid dispenser may also provided on the shaft, to permit the dispensing of fluid proximate the cleaning wheels during operation" (Kordick, 2008)

Legal status: pending (Kordick, 2008)

5.3 Expired patents

5.3.1 Tile grout scrubber – patent US 5412829A

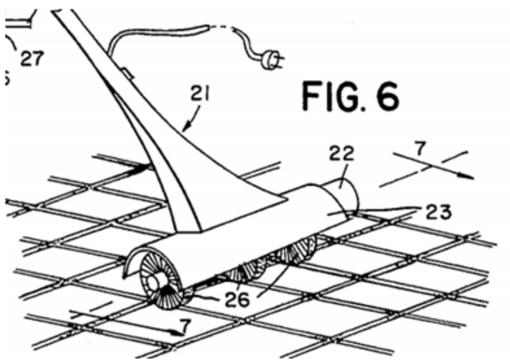


Figure 5-7: Tile grout scrubber (Hefner, 1995)

"To scrub adjacent parallel grout lines on a tile floor simultaneously... Two or more long narrow scrubbing elements are adjustably mounted on the base ...They are spaced apart to correspond to the spacing between tiles... the scrubbing effort is directed to the grout lines which tend to accumulate dirt more than the elevated, impervious tile surface. The scrubbing elements may be bristle brushes, foam or fibrous scrubbing material. An electric motor driven embodiment is shown with rotary brushes adjustably mounted on a rotary shaft" (Hefner, 1995)

Legal status: expired - fee related (Hefner, 1995)

5.3.2 Apparatus for cleaning tile grout joints – patent US 6059475A

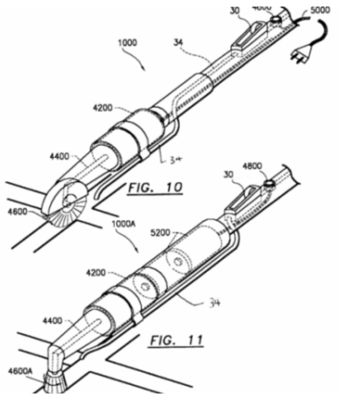


Figure 5-8: Apparatus for cleaning tile grout joints (Jafarmadar, 2000)

"An apparatus for cleaning grout joints formed between adjacent ceramic and clay floor and wall tiles. The apparatus includes a liquid container mounted on a handle and containing liquid grout cleaner, a manual flow control valve, and a liquid dispensing head... A scrubbing brush is removably connected to the liquid dispensing head for allowing the user to scrub the grout joint thereby removing dirt, mold, mildew, and other unwanted debris therefrom... The scrubbing brush may be rotatably connected to, and powered by, an electric motor" (Jafarmadar, 2000)

Legal status: expired - fee related (Jafarmadar, 2000)

5.4 Discussion

Most grout and tile cleaning related patents are expired due to expiration of their term or fee-related expirations. The search resulted in three active patents that are relevant to this project, but apart from those there are few patents restricting the solution space. There are also several similarities between some of the expired patents and existing products, such as the *Tile grout scrubber* (Figure 5-7) and the *Grout Gator* (Figure 5-1), as well as the *Apparatus for cleaning tile grout joints* Figure 5-8 and the *Tub N' Tile Power Scrubber* (Figure 5-4).

6 Bathroom dirt and grime

The humid environment in many bathrooms is a suitable growth environment for many types of mold and grime. Not only does it make the bathroom look dirty, but exposure to several of these bacteria and mold is a health risk. A study done in Tokyo, Japan, showed that the main composition of dirt collected from bathroom walls were fatty acids, triacylglycerols, surface active agents, calcium soap and dust as shown in Figure 6-1 (Hisanaga, Yamada, Tsutsui, & Tanizawa, 2008).

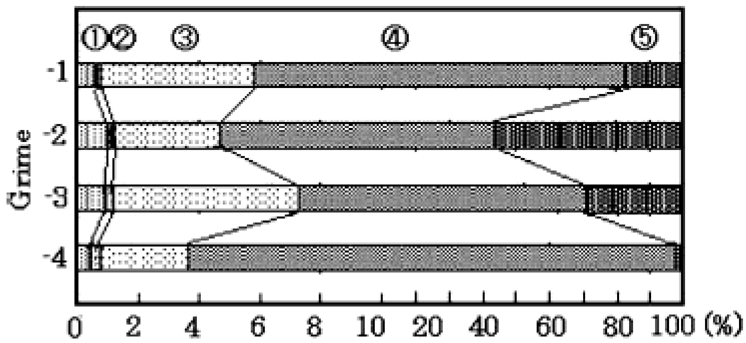


Figure 6-1: Composition of grime collected from bathroom walls in Japan: fatty acids (1), triacylglycerols (2), surface active agents (3), calcium soap (4) and dust (5) (Hisanaga et al., 2008)

The study showed that the fatty acids were mostly derived from human sebum, and only a small amount from bath products (Hisanaga et al., 2008). Fatty acids are nonpolar molecules consisting of a long carbon chain, with hydrogen, oxygen and a hydroxyl group (-OH), as shown in Figure 6-2 (University of Washington, u.d) .

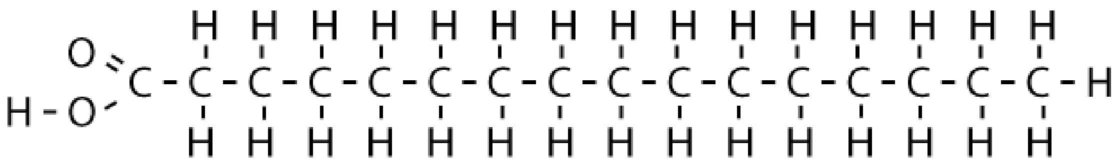


Figure 6-2: Saturated fatty acid (University of Washington, u.d)

It also suggests that these acyl groups adhere to the tiles where they react with calcium cations from the tap water and form calcium soap (Hisanaga et al., 2008). A similar product from hard water is limescale, which is mainly calcium but also magnesium ion deposits that are left whenever hard water evaporates (Stefan Karsten, 2016). There were also 0,5% or less triacylglycerols detected in the sample (Hisanaga et al., 2008). Triacylglycerols are three fatty acids coupled with a glycerol molecule that stores energy in our body. It is popularly called body fat, but there is also a large amount of triacylglycerols in skin oils (University of Washington, u.d). A surface active agent, or a surfactant, as it is also called, is an organic chemical that changes the interfacial properties of a liquid. The surfactant might have a positive or negative charge, hence it changes the surface tension in the liquid. It is a common element in detergents and bath products (Llenado & Neubecker, 2002).

Even though the amount of fatty acid and triacylglycerols is small compared to the amount of surfactants, calcium soap and dust, Hisanaga et al. (2008) and their research strongly suggest that they play an important role in the accumulation and growth of bathroom grime.

6.1 Mold

Molds are fungi that can be found both indoors and outdoors year round. They thrive in warm, damp, shady and humid environments, or in decomposing materials such as leaves or rotten planks. Unlike plants, molds do not use photosynthesis to grow, but consume the material they grow on. In nature this means that they clean up decaying organic substance, but in a house they can cause great damage. Mold can typically be found in the bathroom, basements or attics, around windows or other areas with condensate or rot. Mold grows in colonies that consist of a main body, the mycelium, and numerous connected multicellular fibers called hyphae. The hyphae releases enzymes that break down the material. They also produce the spores that spread the mold, similar to how plants spread seeds. The spores can survive in any environmental condition, even in dry places where mold normally would not grow. Molds or spores can be brought into houses with the wind, or they attach to clothing, shoes or pets and are carried indoors, where they will create new colonies (blackmold.awarespace.com, n.d.; National Center for Environmental Health, 2014). It is important to remember that even if the visible, typically black, mold spots are removed, the mycelium and the colony still exists inside the material (e.g., behind tiles and inside grout) and the mold will regrow if the environmental conditions are not changed (Stefan Karsten, 2016).

Some of the most common indoor molds are Cladosporium, Alternaria, Penicillium, Aspergillus, Fusarium, Paecilomyces, Strachybotrys and Trichoderma, of which the last six are known as toxic molds because they release mycotoxins that affect humans and animals (blackmold.awarespace.com, n.d.; National Center for Environmental Health, 2014). Besides the visible damage mold can cause by staining the surface, toxic mold can also cause health problems. Some symptoms are nasal stuffiness, wheezing and eye and skin irritation, but for people with asthma or allergies it may cause fever and even chronic lung illnesses due to long-term exposure (National Center for Environmental Health, 2014).

7 Tile wall prototype

To be able to explore and test in a controlled environment a tile wall prototype was constructed, including corners, glazed and un-glazed tiles as well as cement and caulk grout fillings.

In a real bathroom, mortar is used to attach the tiles to the wall, but as neither the strength nor the waterproofness was needed for this project the tiles were glued to a large wooden board with a glue gun. Real grout filling and tiles were used as they were the target for the experiments.

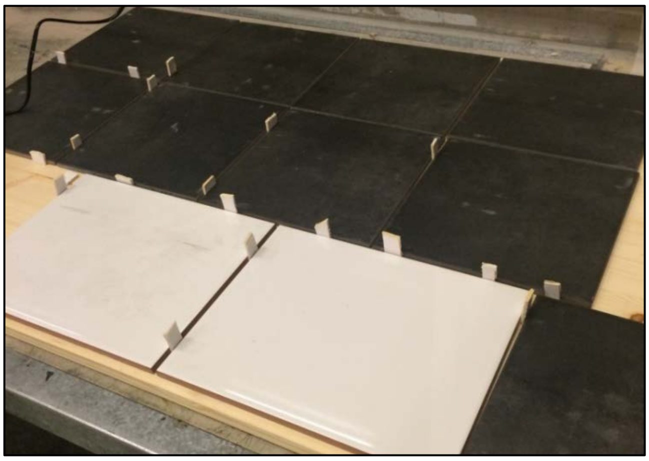


Figure 7-1: Tile layout strategy and spacing

The first step was to plan the tile layout to cover the wooden board, and cardboard spacers were used to ensure the same grout width across the whole board, see Figure 7-1. Next, the tiles were glued to the board (Figure 7-2) and then the gaps were filled with grout filling. After about 5-7 minutes the filling had solidified enough to remove the excess remains (Figure 7-3).

Figure 7-2: Adding glue to the tile and placing it to the wood board

Figure 7-3: Applying grout filler and cleaning off the excess

Once the prototype was finished, the clear need for a corner was obvious, which meant adding walls (Figure 7-4). This made it possible to test the geometry of the tool prototypes to ensure they could handle a corner. The corners were sealed with caulk because of the possible movement between the different surfaces (wall-wall, wall-floor or different materials), which might have led to a cement grout filling to crack. This also covered two of the three grout materials mentioned in section *4.3 Functionality.*

Figure 7-4: Finished tile prototype with walls and corner

7.1 Tile wall experiment

There are several standard tests for chemical cleaning and brushing (Stefan Karsten, 2016). One of them is the German Cosmetic, Toiletry, Perfumery and Detergent Association (IKW, Industrieverband Koerperpflege- und Waschmittel) recommendation for the Quality Assessment of the Product

Performance of All-Purpose Cleaners 2014 (German Cosmetic, Toiletry, Perfumery and Detergent Association, 2015), which describes a test set-up where test soil is applied to a tile and weighed, then the test cleaner is applied and lastly it is run through an atomized scrubbing process. The result is evaluated based on the weight difference of the tile and visual assessment scales. However, this test is intended to test the chemical cleaner and not the scrubbing brush which means that a different scrubbing apparatus must be developed to give any valuable results for this project. Among other, a pressure control system to ensure equal pressure from the brushes onto the tiles must be included. The soil is supposed to represent mold, as no real mold is allowed in testing due to health issues (except in special labs). Which is why Henkel has a program for real-life testing of their products, where they contact customers who might have a bathroom dirt problem and perform the testing in private houses (Stefan Karsten, 2016).

Because of the complexity of the IKW test, building the test apparatus and the fact that the cleanliness preference of the user most of all will be visual inspection, a simpler, but satisfactory, test set-up was preferred.

The aim of the experiment was to test different brushes and how well they remove dirt, but also to find “dirt” reminiscent of real bathroom dirt and mold. In order to do this, the tile wall prototype was covered in coffee, Coca-Cola, beetroot juice, hair conditioner, shaving gel, hair wax, soap bar scum, Vaseline and toothpaste, as shown in Figure 7-5, and left over the weekend so that it would really bind to the wall.

Figure 7-5: Dirt and cleaning tool experiment

Some of the cleaning tools tested in the experiment can be found in Figure 7-6. Additionally, a toothbrush and a regular cloth were also tested. No soap or detergent was used during the test, as the effectiveness of each brush/sponge was the important factor.

Figure 7-6: Some of the brushes used in dirt cleaning experiment

The coffee, Coca-Cola and beetroot stains were definitely the most difficult ones to remove and therefore were considered to be the best mold substitutes. The beetroot juice was selected because of its color, which made it easy to determine whether the grout was clean or not.

The different cleaning tools were tested on the prototype wall, but also with real dirt and mold in a private bathroom. The horse brush was the only tool that cleaned off any mold due to the stiff bristles, but the brush was too wide to get into the grout and it was not efficient on the tiles as it only moved the dirt around. It also did not work well with the greasy stains in the tile experiment. The slim brush worked similarly to the horse brush, but the bristles were too soft and too long and they bent when pressure was applied.

The tire cleaner was comfortable to use, but the bristles were too soft and even though the yellow sponge was able to retain a lot of water, which helped the cleaning, it also left some fluff on the rough surface of the grout. The (manual) toothbrush had a good reach into the grouts, but it did not remove the beetroot, Coca-Cola or coffee stains completely. The sponge was definitely the best tool for the tiles, and also worked well on the grouts when it was bent to fit the concavity. A big disfavor for the sponge is that the users must be is in contact with the water and the soap, or even bleach and other harsh chemicals. The cloth needed a lot of force from the user to clean anything, and in the same way as the sponge, the user is in contact with the cleaning detergent.

8 Early concept development

8.1 Morphological analysis

The General Morphological Analysis (GMA) was developed by Fritz Zwicky in the sixties as a tool to analyze multi-dimensional, non-quantifiable problems (Ritchey, 1998), which makes it a valuable tool for product development. Table 8-1 shows the different parameters, which represent the critical functions for the cleaning tool with the corresponding solution options.

Table 8-1: Morphological analysis

Solution / Parameter	1	2	3	4	5
Power	Manual	Electrical	Compressor		
Tool for cleaning	Brush	Sponge	Cloth	Vapor	
Movement	Vibration	Rotation	Pulsation	Rubbing (manual)	
Working Conditions	Wet	Humid	Dry		
Tile Material	Ceramics	Porcelain	Glazed	Un-glazed	Combined
Grout Material	Cement	Epoxy	Caulk	Combined	
Handle design	Round #joystick"	Hole in the middle (iron)	Pistol grip		
Shape	"Iron"	Square	Circle	Triangle	
Material	Plastic	Rubber	Wood	Metal	
Weight	<1 kg	1-2kg	>2kg		
Maintenance	Refill	Disposable	Washable	Combined	
Soap	Build-in	Special soap	Universal	No soap	

8.1.1 Discussion

At this point in the development process the different parameters and options in the morphology table must be explored further to find the optimal solution, but the early testing and need finding had already given some important insights (see the red circles in Table 8-1).

A manual tool is probably the best solution for the everyday cleaning scenario, because it does not need any preparation before use; there are no batteries that must be charged or any cables that must be plugged in. However, the tile wall cleaning experiment (section *7.1 Tile wall experiment*) showed that it was difficult to remove mold with a manual tool, so if this is the objective a motorized tool should be considered. A compressor is generally large, heavy and noisy and is therefore not the first choice for a power source.

The tool must be designed for all types of tile and grout materials and it must work in both humid and wet environments. Depending on the final design, a sponge or alternatives parts should be replaceable or washable. There could also be some sort of refillable soap chamber. The other parameters such as movement, handle design, shape, material and weight must be evaluated further.

Other additional functions that might be incorporated are:

- Vacuum cleaner: if a tool is developed for dry conditions (mechanical erosion of the grout) a vacuum cleaner inlet should be added so the dust is not spread.
- Water hose: to keep a constant water flow to the cleaning surface, a water hose could be integrated. It could also be combined with a soap dispensing system.
- Wheels: to keep the tool steady while cleaning the grouts and to keep a constant pressure on the cleaning surface, the tool could have wheels.
- Extension pole for floor cleaning: add-on component to ensure a better posture while cleaning the floor or out of reach areas.
- Add-on to existing tool/broom: the solution could have a universal mounting system so that it can easily be attached to existing cleaning tools, brushes or brooms.

8.2 Bathroom cleaning survey

To get a better understanding of the main challenges considering bathroom cleaning a survey was conducted among students at NTNU. The complete questionnaire can be found in *Appendix C: Bathroom cleaning survey a*nd the results in *Appendix D: Bathroom cleaning survey results.* Out of the 28 participants 15 were male (54%). All the participants cleaned their own bathroom every week, and most spent around 15-30 minutes cleaning the whole bathroom.

4. What's the worst thing of cleaning the bathroom? Rank them from 1 to 4, where 4 is the worst.

   a. Shower ☐
   b. Sink ☐
   c. Bathroom floor ☐
   d. Toilet ☐

Figure 8-1: Question 4

Question 4, "What is the worst thing about cleaning the bathroom?" can be found in Figure 8-1 and the total sum of all the responses can be found in Figure 8-2. From the graph it can be seen that the shower is the worst part about cleaning, closely followed by the toilet. The majority of the females found the toilet to be the worst, while the males meant it was the shower. However, in the next questions about which part is the most difficult and what takes the most time 72% answered the shower, compared to the toilet:21%, sink:3,5% and floor:3,5%. The main reasons for this were cleaning the drain, that is was difficult to remove all stains and that it takes a long time.

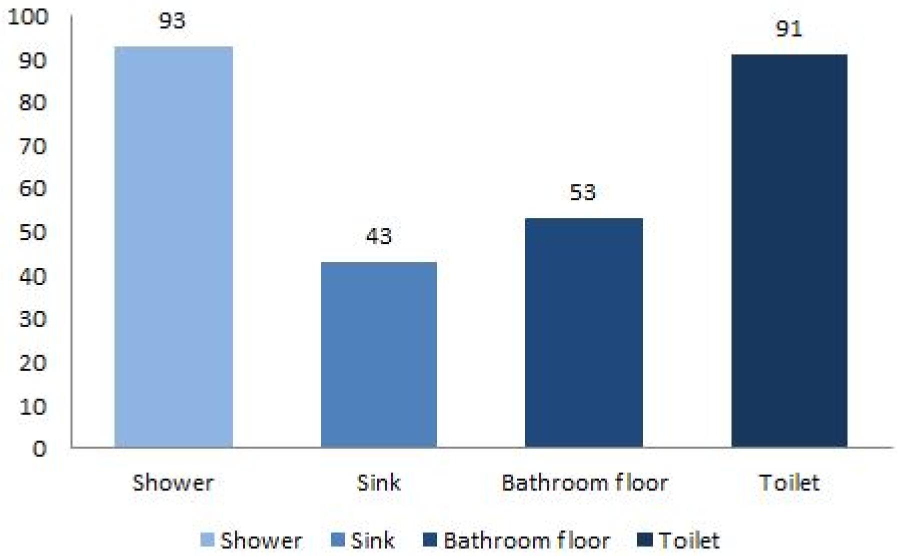


Figure 8-2: Results to question 4, see Figure 8-1

In the next part of the survey the participants answered how they cleaned the shower, floor, sink and toilet. The most common answer for all the different areas was a cloth and a suitable detergent (e.g. toilet detergent for the toilet and so on). The only specialized tool anyone mentioned to use was the toilet brush and a squeegee to clean the glass doors in the shower.

8.3 Early concepts

During the three first weeks of January, while Karen was visiting NTNU, we wanted to do a lot of mind storming and creative solution space exploration. Keeping in mind the context map (Figure 4-1) from section *4 Product requirements* and the morphology table, we came up with several good solutions.

The first concept is geometrically shaped like an iron, because we wanted the tool to be able to reach into all nooks and crannies, in the same way an iron irons a shirt. The tool consists of two main parts; a sponge or a softer brush to clean the tiles and a harder brush to clean the grouts. The idea is that the tool cleans both the tiles and the grouts, so that no second tool or cloth is needed. When the user wants to clean the grout the middle brush is in a down position (out of the tool), as shown in Figure 8-3, and while cleaning the tiles the brush is in an up position. The tip in front and the cavity in the back make it easy for the user to aim the tool at the grout. When the user wants to clean the tiles the brush is in an up position (inside the tool) making it easy to clean even large areas in a short time.

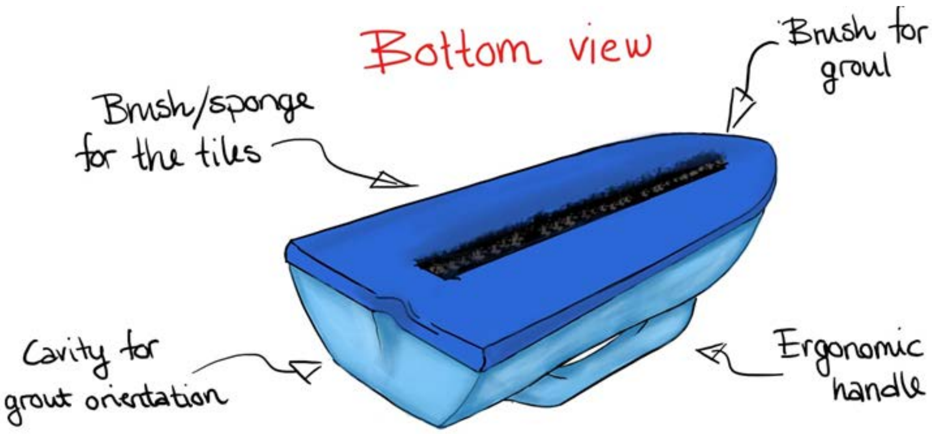


Figure 8-3: Manual cleaning "iron"

The advantage of a manual tool is that it will always be ready when needed, there is no need to charge it or use a cord and minimal cleaning and maintenance of the tool is needed. Considering Colombia, according to our need finding, a manual tool is the most desirable solution. However the small, but growing user group that lives alone and does their own cleaning, represented by Javier (see section *3.2 Personas*), might find a motorized solution interesting.

We started to explore electrically driven solutions. Taking inspiration from an angle grinder we came up with the solution illustrated in Figure 8-4. The brush is angled straight at the wall so it follows the grouts, in the same way as an angle grinder would have been used to cut the grout. The brush is changeable, and different brush thicknesses ensure that the brush reaches into the cavity of the grout and avoids unnecessary wear on the tiles. Depending on the amount and type of dirt, there are brushes with different hardness and the velocity of the tool is also adjustable.

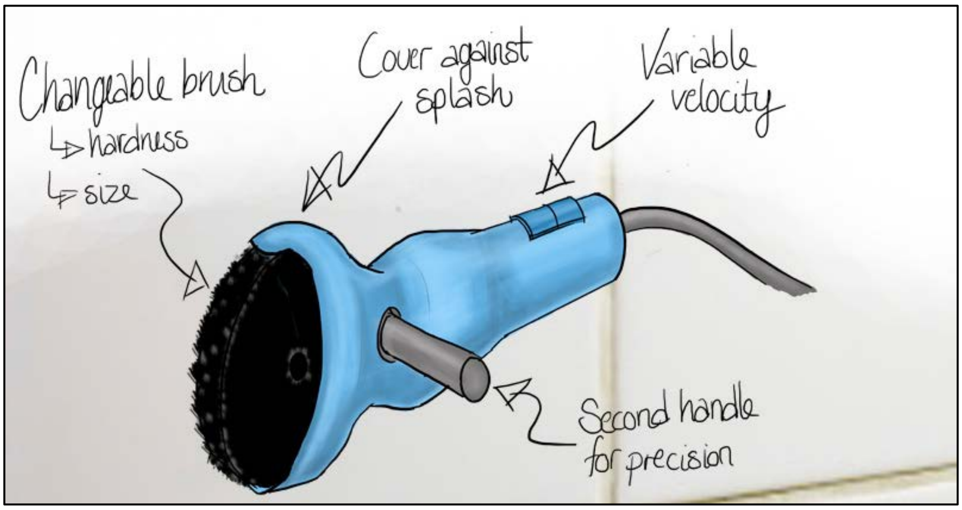


Figure 8-4: Angle grinder inspired electric brush

The second handle, intended to add stability and precision while using the tool, can either be mounted to the left as shown in Figure 8-4 or in any of the three other directions (right, under or over). This is meant to make it more comfortable for the user to clean both horizontal and vertical grouts as well as areas close to the ceiling or floor.

Lastly, the tool can either be powered through a cord or it can be battery driven. The inconvenience of using a cord is that the user is dependent on having a ground fault circuit interrupter (GFCI) electrical outlet close to the shower or an equivalent extension cord. By adding a battery to the tool this problem is avoided, however, extra weight is added. Another well-known problem with battery-driven tools is that the batteries are often depleted when the tool is needed, which in worst case could lead to the tool staying unused. To prevent this problem with power tools it is common to have two sets of batteries, so that one can be charged while the other is in use. However, most of these are either too expensive or heavy for a tile and grout-cleaner. There is predicted an imminent power revolution when it comes to batteries due to the high demand from big technology companies from the mobile and car industry, amongst others. There already exists high-tech batteries that can charge in few minutes (Edwards, 2016). These batteries are obviously too expensive, but maybe in a couple of year the situation will be different, and new applications like a tile and grout-cleaning tool might be possible.

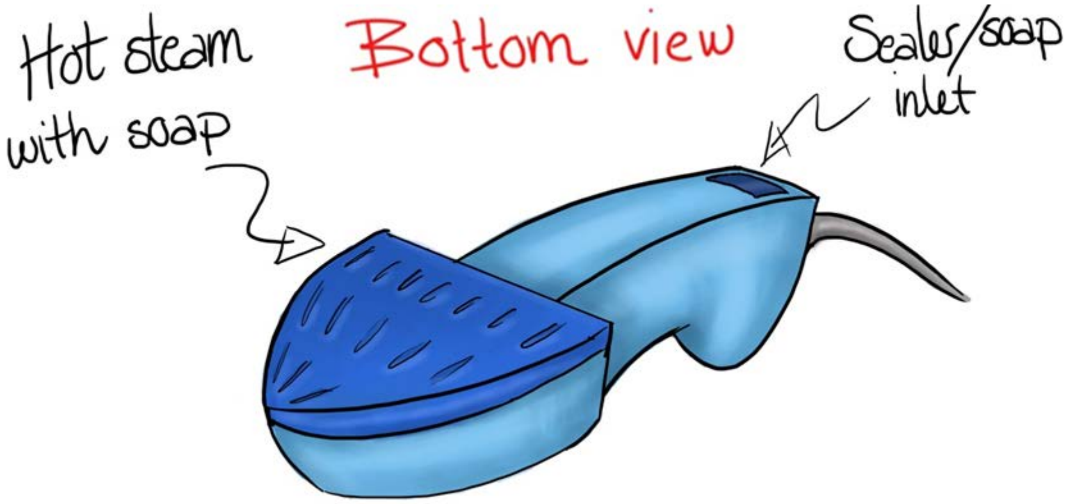


Figure 8-5: Hot water extraction cleaner

The next concept (see Figure 8-5) uses a sponge with hot steam to dissolve and clean off the dirt. The idea is that the user can fill the tool with the accompanying soap and it will automatically mix it with the steam, with the correct mixing ratio. After cleaning the tiles and the grouts, the tool can be used to apply a sealer in the same way, only with a different compartment for the sealer.

The disadvantage is that the tool must be attached to a hot water extraction (HWE) machine or some kind of compressor if pressurized hot water extraction (PHWE) is wanted (Swegle, 2016).

While discussing the possibility of adding the sealing function to the hot steam cleaner, we came up with a spin-off concept, illustrated in Figure 8-6. According to our research on grout sealing the pain point turned out to be applying the sealer without wasting a lot by spraying it on the tiles as well. We came up with a simple clip-on sealer applicator hose that is compatible with any standard spray can or bottle. The nozzle is shaped to create a thin jet in the longitudinal direction of the grout, and by rotating it 90 degrees the can will be in the upright position, spraying both the vertical and the horizontal grouts.

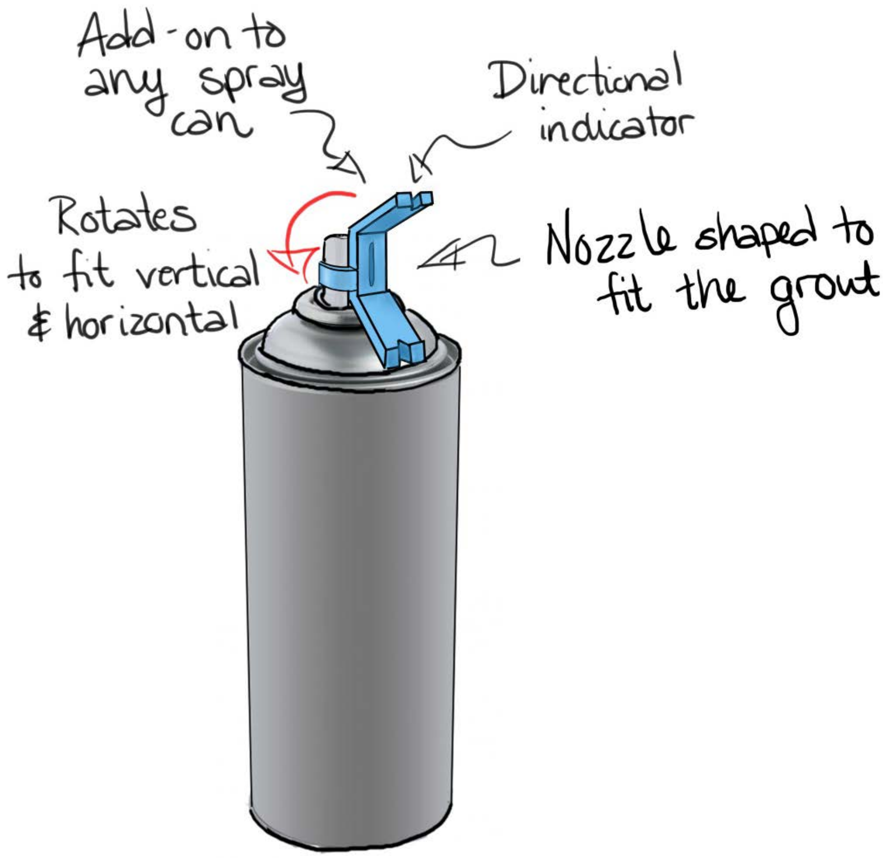


Figure 8-6: Add-on sealer applicator

9 Ideation and concept workshop at NTNU

From the need finding in Colombia and the insight gained through the pre-master project, the user needs and problem areas were well defined. The next step was early prototyping, ideation and concept exploration. Due to the good results we got from the priming workshop at PUJ, we decided to arrange a second workshop at NTNU during the period Karen was visiting. At this point we had clear boundaries and constraints regarding the problem scenario, but we still wanted the participants to start with an open mind so we showed them a priming video[3]. We found a commercial for a professional tile cleaning company that explained how complicated it is to get off all dirt and mold, and that the only solution is to hire their company. Then we ended it with the recording: "What? Can't we make a tool for that?"

The participants were fellow master students or 4th grade students from the course Fuzzy Front End with Martin Steinert as the lecturer. The main criterion was that the participants had some experience with prototyping and *Design Thinking*.

This method of including others in early prototyping is a great way to enhance creativity and get a kick-start to the concept development phase. In the collection of *Design Thinking* methods *Bootcamp Bootleg Design Thinking* Plattner (2009) describes prototyping as a valuable tool to make ideas tangible so that people can interact with them. Prototypes can be used to get a better understanding of the design space, so-called empathy gaining, they can be used for exploration of solution options, for testing and for inspiration. During the workshop we observed that the groups created prototypes that covered all of the mentioned uses. Carleton et al. (2013) also sheds light on the importance of using prototypes in the early phases of a development process to better understand the innovation concept, to communicate new proposals and to use paper mockups to ensure rapid feedback and learning cycles.

[3] Ideation Priming video: https://youtu.be/5N6K02cGC0I

9.1 Task and procedure

Figure 9-1: Creative participants, L-R: Øystein Bjelland, Anders Bredesen, Øystein Blix Walderhaug and Ferdinand Oddsønn Solvang

The workshop was divided into three interactions. During the first interaction each group of three participants did their own need finding and problem exploration. For the second interaction they were given clear constraints for materials, geometry, power etc. visualized by the pictures further described in section *4.3 Functionality.* The participants also had access to a variety of prototyping materials, different "dirt" and the test tile wall to experiment with, and the dedication to the task was tremendous. Before the third and last interaction, the groups were told to focus on wall tiles since they were considered to be the biggest challenge and many of the groups were only focusing on the floor tiles.

9.2 Results and concepts

Figure 9-2: Floor cleaner tool with water/soap dispenser

The concept of an automatic water and soap dispenser is interesting in terms of adding the correct amount of detergent during cleaning to get the best result. This concept also allows for a starter kit including the tool and the soap, as well as refill soap. Minimum consideration is done to the geometry and function of the brush.

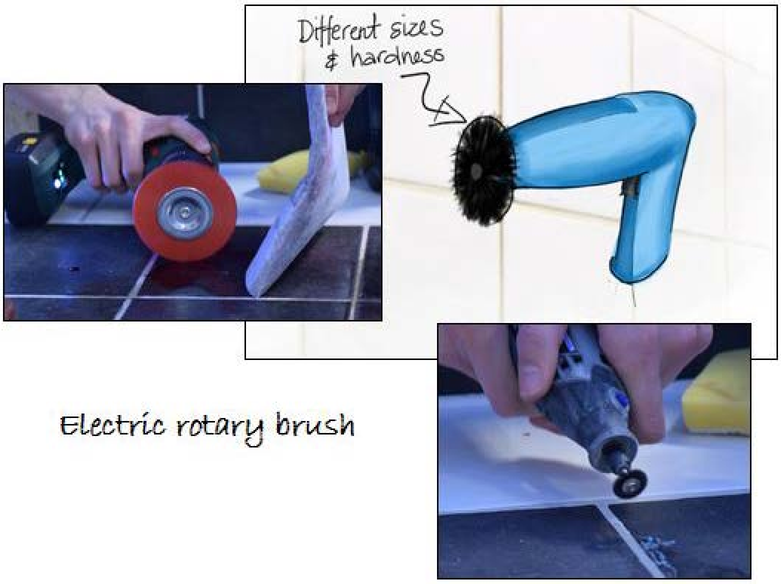


Figure 9-3: Electric rotary brush

This is a concept that was also explored during the early concept development phase, see section *5 Benchmarking*. The idea of using a rotary force turned out to be effective in removing dirt, and it was also more fun than other methods, according to the participants exploring this concept. However, the prototype splashed water and dirt all over, which would be a problem if you had to clean the entire bathroom after cleaning the shower, so some sort of dirt casing would be needed.

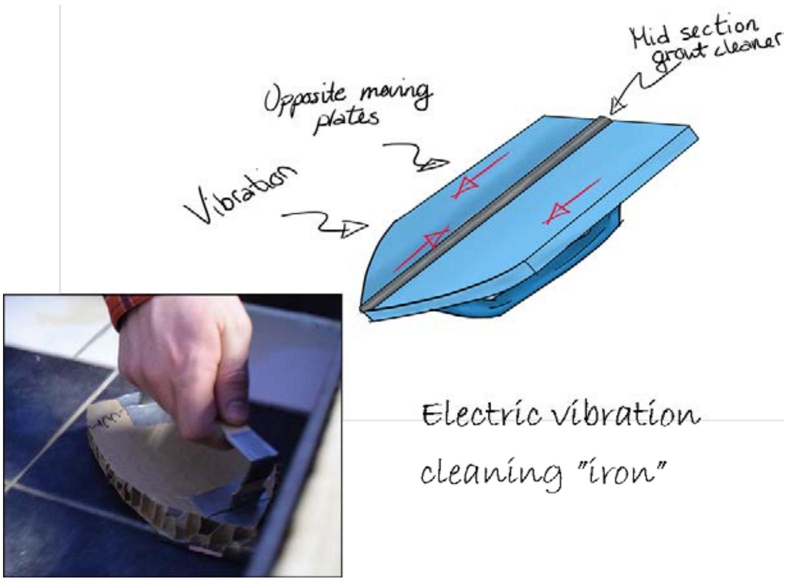


Figure 9-4: Electric vibration cleaning "iron"

The geometry of this tool is similar to one of the concepts from the early concept development phase. This strengthens the approach that an iron-looking shape is a logical choice to reach all nooks and crannies. The opposite moving and vibrating plates between the tiles and the grout are intended to lower the force needed to be applied by the user. This concept, combined with the electric rotary brush concept were the inspiration for the exploration of the electric toothbrush concept, see section *10.1 Electric toothbrush.*

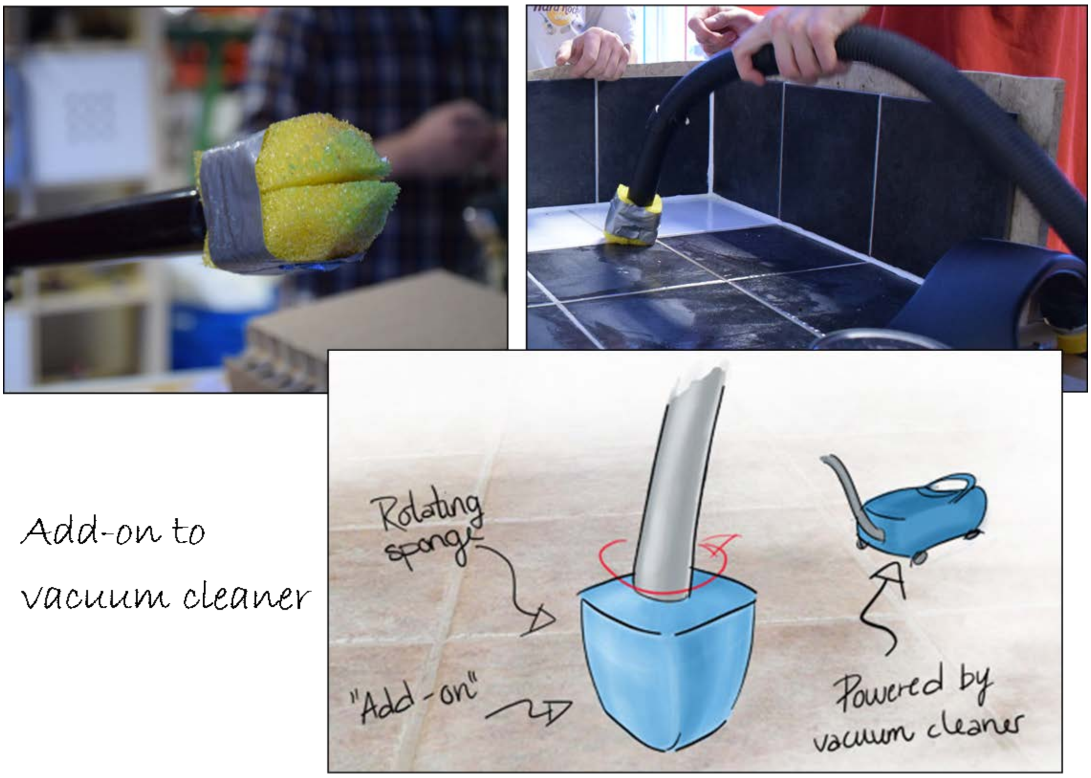


Figure 9-5: Rotary add-on to vacuum cleaner

The idea is to use a vacuum cleaner as the power source for this rotary add-on tool and vacuum away all dirt and excess water at once. However, it is essential that the vacuum cleaner is designed for water, which is normally only the case with more expensive industrial vacuum cleaners. The need finding in Colombia showed that few Colombians have a vacuum cleaner, which means that even less have a water-compatible one.

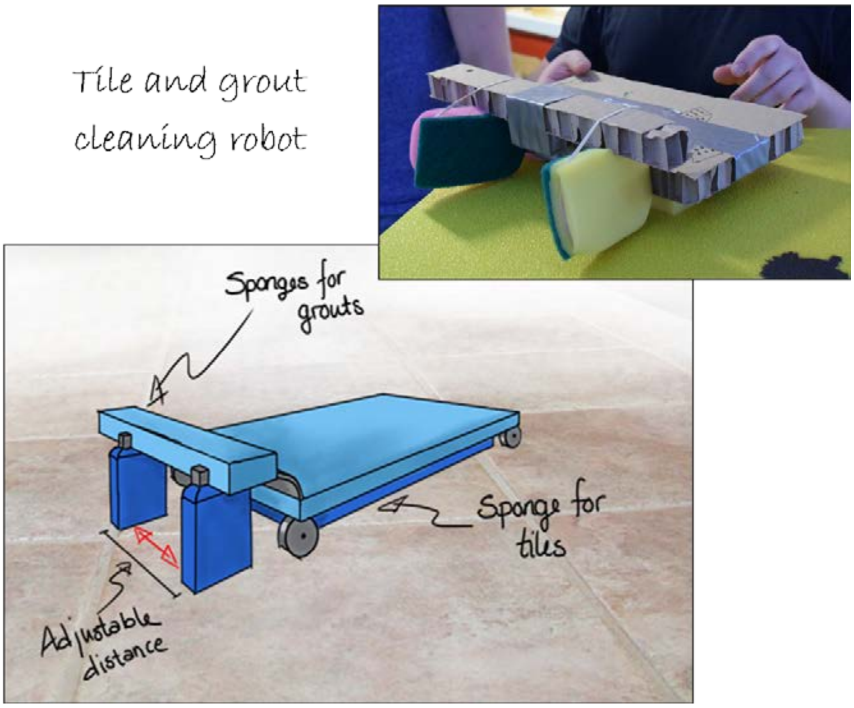


Figure 9-6: Tile and grout cleaning robot

The tile and grout-cleaning robot has many similarities with a vacuum cleaner robot. It moves around in the same way using different sensors, and has several programmable settings. The robot has two sponges/brushes in front to clean the grouts and a bigger softer sponge underneath to clean the tiles (Figure 9-6). The distance between the two grout sponges is adjustable to fit any tile floor, and it also applies soap and water automatically.

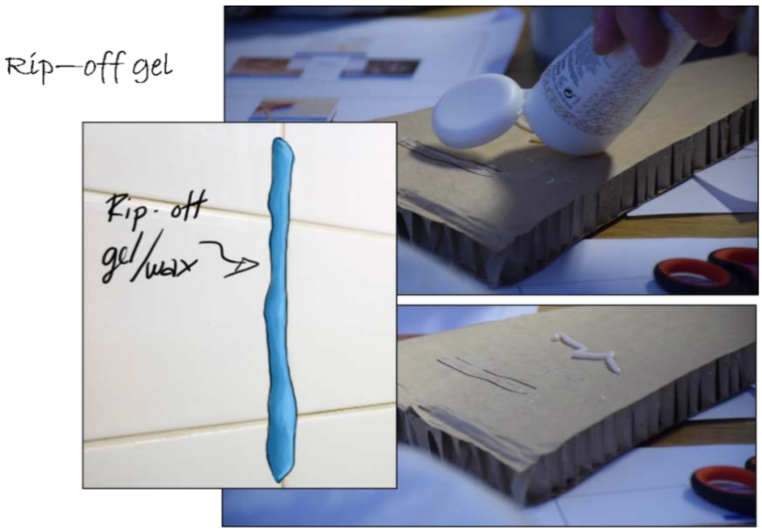


Figure 9-7: Rip–off gel/wax

The rip-off gel concept (Figure 9-7) is quite simple in theory; create a wax or gel that solidifies when applied to the grout and can be peeled off with all dirt and mold attached, much like a facial peeling mask.

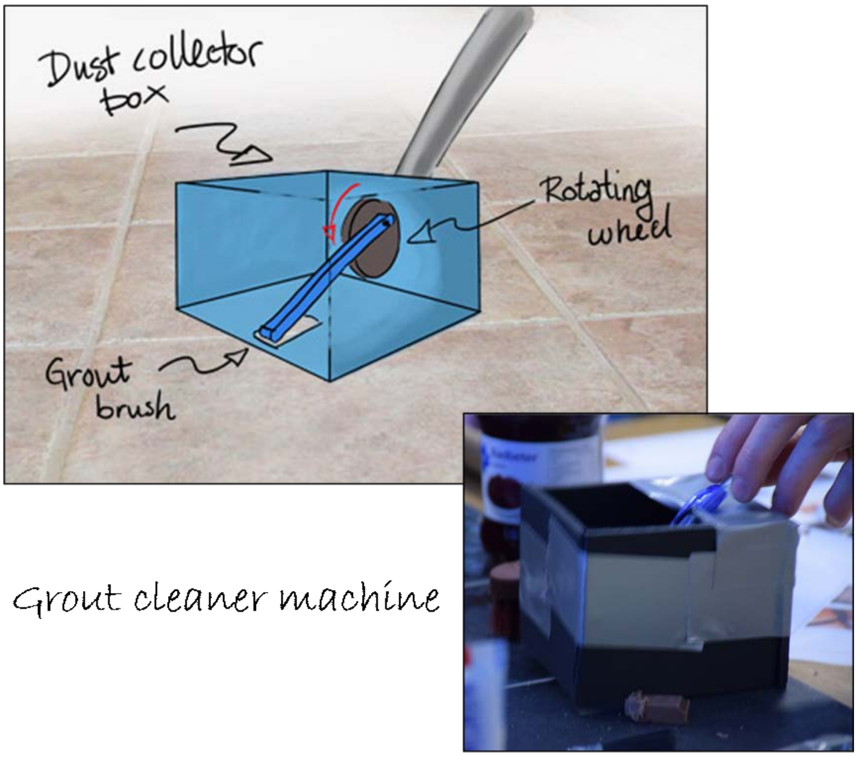


Figure 9-8: Grout cleaner machine

The grout brush moves up and down as the wheel rotates (the same movement as an engine cylinder) and the box traps the dirt and has a water flow inside to assist the cleaning, see Figure 9-8.This concept is mainly for floor cleaning.

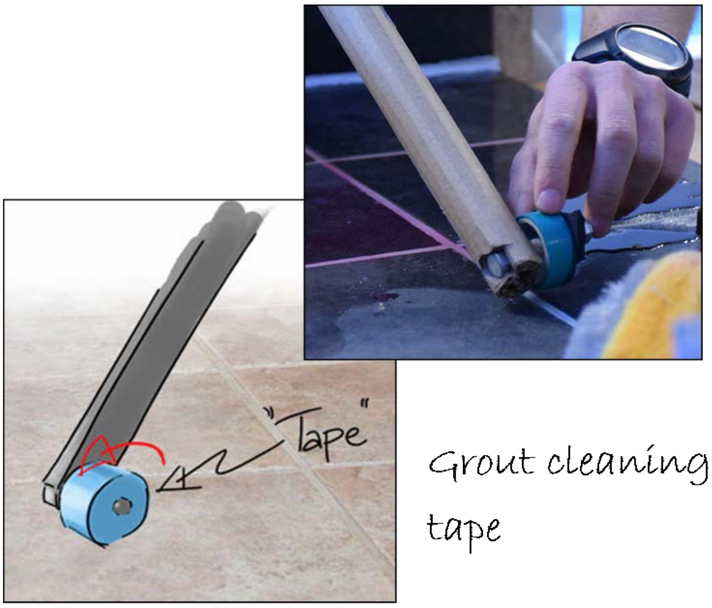


Figure 9-9: Grout-cleaning tape

Inspired by the lint roller for fabrics, the grout-cleaning tape (Figure 9-9) works in the same way with dirt; the dirt get stuck to the tape and rolled off.

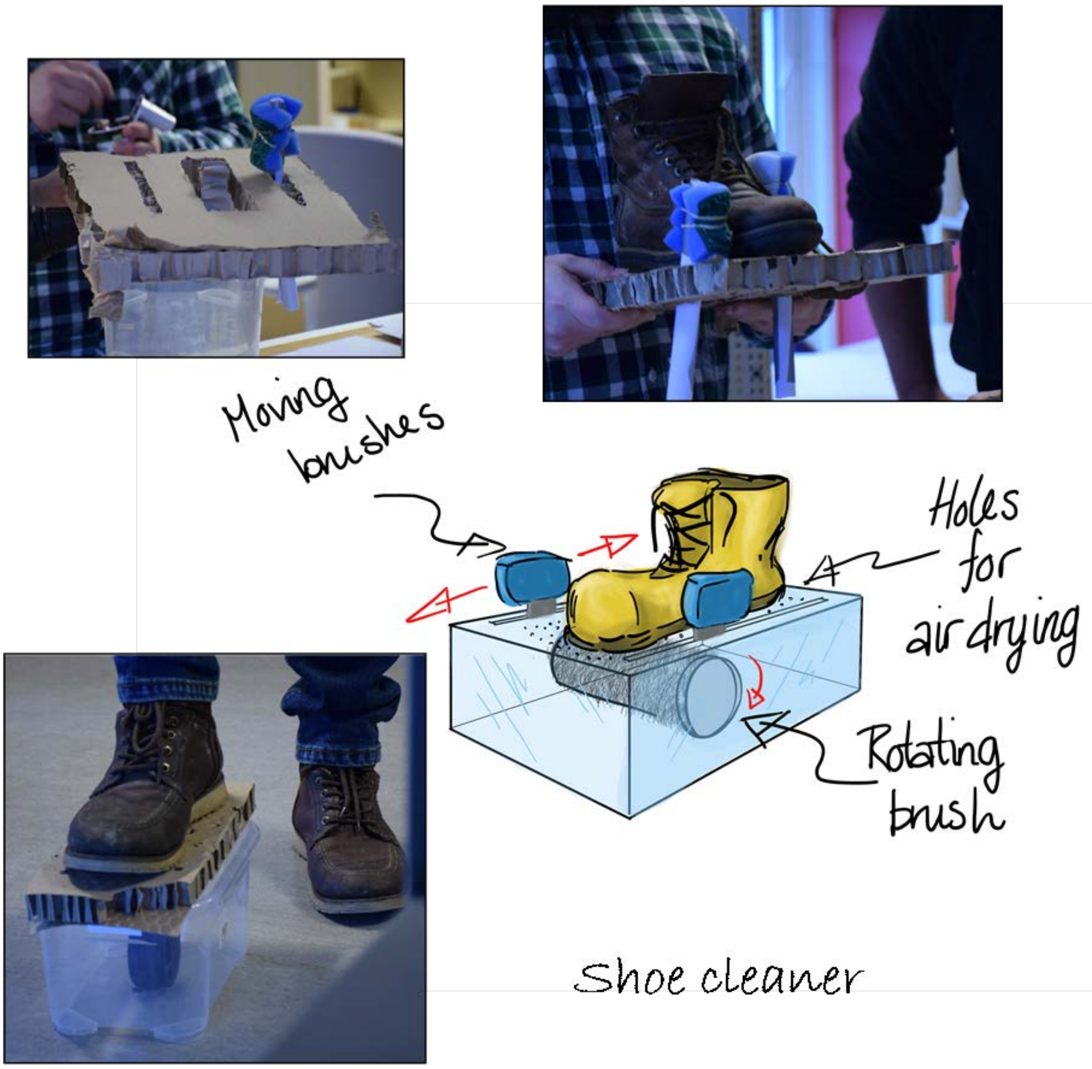


Figure 9-10: Shoe cleaner robot

A different approach, and the answer to "Colombians always wear their shoes indoors", is the shoe cleaner robot, as shown in Figure 9-10. Instead of focusing in how to clean, this group focused on how to prevent the floors from getting dirty in the first place. This robot dries the shoes and cleans off dirt so that the person will not drag dirt around the house.

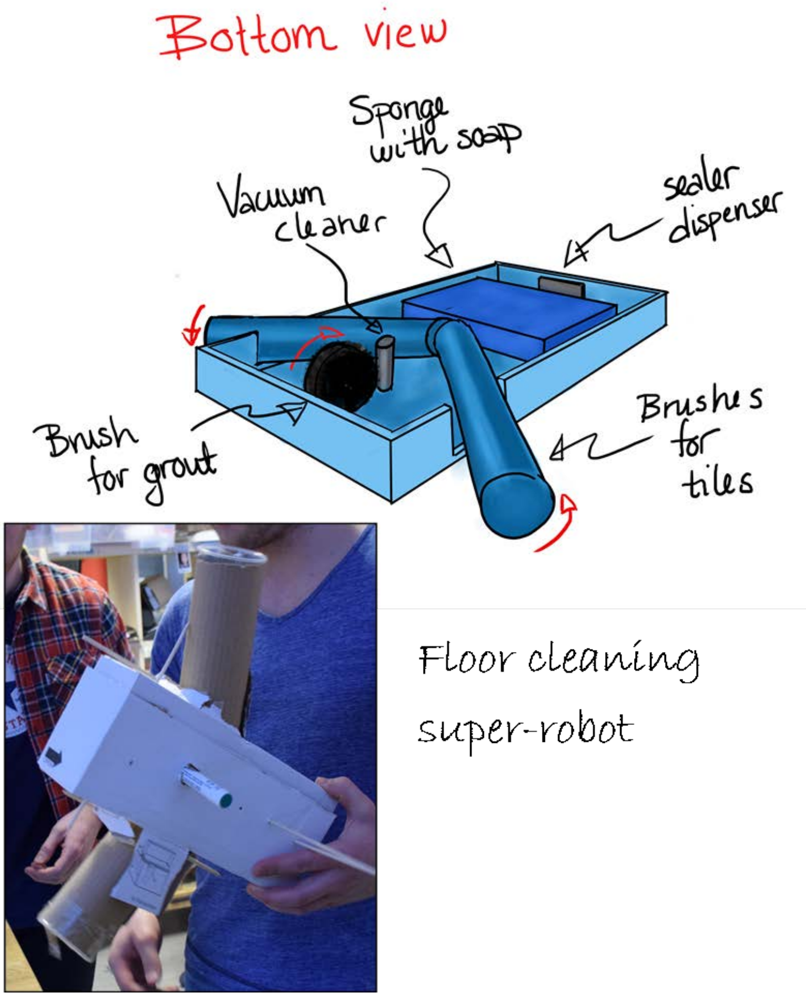


Figure 9-11: Floor cleaning super robot

This concept is a robot that "does-it-all"; the first black wheel (in the drawing in Figure 9-11) cleans the grout, the two softer brush wheels on each side cleans the tiles and the vacuum cleaner inlet then sucks it away. Next is a sponge with soap to clean away whatever the brushes were not able to get off and lastly a sealer is applied to impregnate the floor and keep it clean.

10 Further concept development

10.1 Electric toothbrush

The idea to test an electric toothbrush as a grout cleaner came partly from the workshop concept *electric vibration cleaning "iron"*, see Figure 9-4, and the observations done in Colombia showing that old manual toothbrushes were used to clean the grouts.

The tile prototype was used to set up the experiment. Beetroot juice was used to simulate a resisting stain, as for example mold, see Figure 10-1. The stain was left over the weekend to properly bind with the grout. The advantage of using the beetroot is firstly the color, which makes it easy to evaluate the effectiveness of the cleaning; secondly it is difficult to remove as soon as it has dried. Two different electric toothbrushes with different cleaning technology were tested, the Oral B Pro 5000 and the Philips Sonicare DiamondClean.

Figure 10-1: Tile prototype with beetroot stain

The Philips (Philips, 2016) uses a patented sonic technology with up to 31 000 brush strokes/min that drives fluid between the teeth and along the gumline. The Oral B (Oral B, n.d) oscillates, rotates and pulsates to achieve a 3D cleaning result. Both brushes have different cleaning modes; daily clean, gum care, whitening and sensitive. Additionally, the Philips has a polish mode. The test was done with hot water only, no detergent was used.

Figure 10-2: Testing the Oral B Pro 5000

In Figure 10-2 the splashing and droplets from the Oral B can be seen. The splashing is mostly in the parallel plane with the wall. Table 10-1 summarizes the test.

Table 10-1: Philips Sonicare DiamondClean vs. Oral B Pro 5000

Mode	Philips Sonicare DiamondClean	Oral B Pro 5000
Daily clean	– Hand feels numb after a while. – Good result, not as noisy as the Oral B. – Feels less effective than the Oral B, but it cleans well. – Splashes a lot.	– Cleans well. – Makes a lot of noise. – Splashes a lot, both during use and when lifted from the tiles. – Difficult to keep the brush on the grout as it tended to drag to either of the sides toward the smoother tiles.
Gum care	– Good result. – More comfortable to hold than the daily clean mode.	– Better control on the brush, however not as effective as the daily clean mode.
Whitening	– Does not remove stain.	– Red light and auto stop (too much pressure applied) was enabled very easily. – Good and quick result
Sensitive	– Same effect as the gum care mode, however not as effective.	– Splashes the most – Created foam, but did not remove stain well.

Polish	– Does not even get the stains off the smooth surface of the tiles.	X
Summary	– The brush splashes a lot during use in contact with the tiles, however not such a big problem when lifted. – The brush stops when too much pressure is applied. A better result might be achievable if this feature is deactivated. – The sonic vibration feels strange, and especially after a while on the daily cleaning mode the hand felt almost numb. – Makes less noise than the Oral B – Takes a long time to achieve a good result.	– The brush splashes a lot, especially if lifted up from the tiles while it is still on. – A red light is turned on and the brush stops when too much pressure is applied. A better result might be achievable if this feature is deactivated. – The result is good for several modes, but it takes a long time. – Difficult to keep the brush on the grout as it tends to pull to the smoother surface of the tiles.

The result can be seen in Figure 10-3. There are greater differences in the result for the Philips toothbrush, where the daily cleaning and gum care modes were the only ones that were able to remove the stain completely. All the modes for Oral B removed the stain, except the sensitive mode. Considering user experience and cleanness, the Philips toothbrush using the gum care mode yielded the best results.

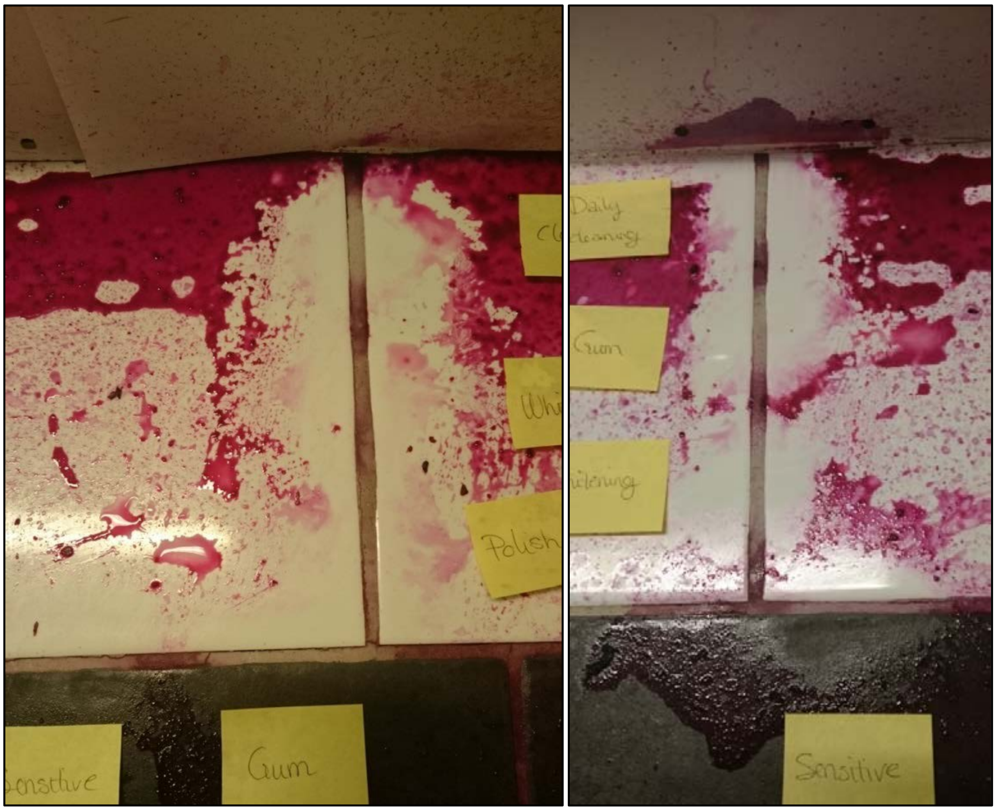


Figure 10-3: Results; left: Philips and right: Oral B

Looking further into the electric toothbrush idea and doing some more selected benchmarking, a tool based on the same concept was found, the Sonic Scrubber (Figure 10-4). In many ways it is an enlarged and strengthened electric toothbrush with different replaceable scrubber stems powered by induction charged batteries (Sonic Scrubbers, 2013).

Figure 10-4: Sonic Scrubber (Expert Verdict, n.d.)

The Sonic Scrubber won the Tomorrow Cleaning Awards 2013 and has been recommended by the Arthritis Foundation and the American Institute of Cleaning Sciences (Sonic Scrubbers, 2013) as a marked-leading cleaning tool. The tool is protected by the patent US8533886, which includes the elongated handle housing the motor, the drive shaft as well as the assembly of the brush head:

"A cleaning apparatus includes an elongated housing bounding a chamber with a motor disposed therein. A drive shaft is at least partially disposed within the chamber of the housing, the drive shaft being coupled with the motor such that during selective operation of the motor the drive shaft is rotated. A head assembly includes an elongated head housing having a head drive shaft and a brush head mounted thereon. The head assembly is adapted to be selectively coupled with the body assembly so that the body drive shaft is coupled with the head drive shaft" (Cobabe, Meyers, Goff, Thiess, & Jackson Zhao, 2013).

The patent expires December 29th 2030 (Cobabe et al., 2013); however, a different assembly of the brush head, drive shaft and motor should not be prevented by this patent. The Sonic Scrubber supports the success of integrating the electric toothbrush concept into the tool.

11 Concept evaluation

11.1 Analytic Hierarchy Process

The AHP method was again used to compare the different concepts against each other. The concepts were divided into ten groups to fit the software (Figure 11-1). The *Floor cleaner tool with soap dispenser* (Figure 9-2) was not included because a soap dispenser is a feature that can be incorporated in several of the other concepts. The *Shoe cleaner robot* (Figure 9-10) was not included because even if the idea is good it is not a direct answer to our grout and tile cleaning problem. The result table can be found in Figure 11-2 and the complete calculation result in *Appendix G: Concept AHP calculation results*.

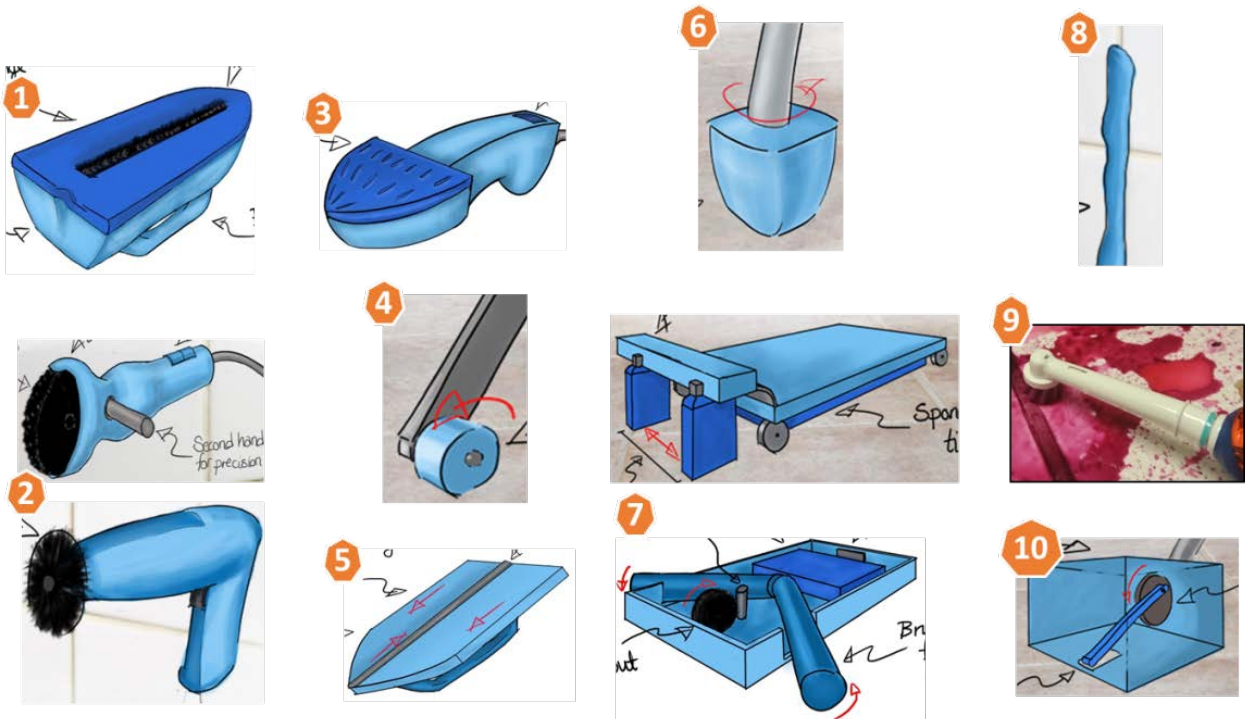


Figure 11-1: AHP concept criteria

Table	Criterion	Comment	Weights	Rk
1	Manual iron	Manual cleaning "iron"	29,1%	1
2	Electric rotary brus	Electrical rotary brush/angle grider inspired	15,1%	4
3	Hot steam	Hot water extraction cleaner	4,3%	6
4	Tape	Grout cleaning tape	1,3%	10
5	Electric vibration ir	Electric vibration cleaning "iron"	19,5%	2
6	Vacuum add-on	Vacuum cleaner add-on	3,0%	7
7	Floor robot	Floor cleaning robot/super robot	5,0%	5
8	Rip-off gel	Rip-off gel	1,7%	9
9	Electric toothbrush	Electric toothbrush	19,2%	3
10	Grout machine	Grout cleqaning machine	1,8%	8

Result				
Eigenvalue			lambda:	11,203
Consistency Ratio	0,37	GCI: 0,32	CR:	9,0%

Figure 11-2: AHP concept results (Goepel, 2015a)

11.2 Chosen concept – Manual cleaning "iron"

After some thorough evaluation based on the need finding, the concept AHP, the experimental testing and the concept presentation video conference in April with Stefan Strathmann Ulf Timmann from Henkel, the manual cleaning "iron" (Figure 11-3) from section *8 Early concept development* was chosen for further development.

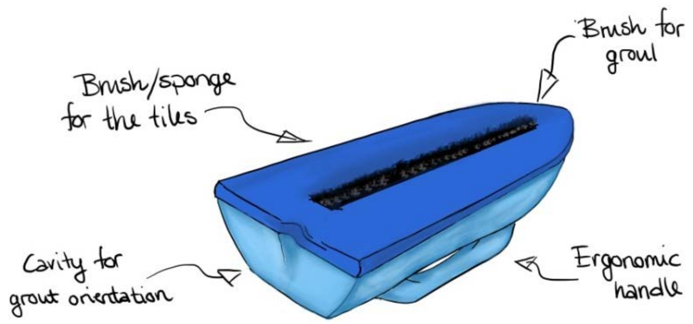


Figure 11-3: The chosen concept for further development

A deciding factor for why the manual cleaning "iron" concept was chosen was that it is manually driven, which does not exclude any user groups. It also follows Henkel's vision to provide simple, efficient cleaning tools at a low cost. The geometry of the tool is also similar to the electric vibration cleaning "iron" from the ideation and concept workshop, section *9 Ideation and concept workshop at NTNU*, which supports this design as a good starting point. However, the concept can easily be adapted to support an electric rotary/pulsing grout brush, so this will also be considered as a secondary tool option. These chosen concepts correspond to the four criteria with the highest rank in the concept AHP, see Figure 11-2.

12 Design

To get an overall idea of what the tool should look like, and also to establish space restrictions for the brush function, a finished design sketch was made. The design is strongly inspired by modern clothing irons, both when it comes to shape and size, due to the similarities in movement and level of precision needed. The estimated length of the tool is 20-25cm, and the rest of the tool should be designed accordingly. The tool housing will be made of polyethylene (PE). This is a common, strong, tough, light-weighted and inexpensive plastic, which is also resistant to acids, alkalis and many organic solvents. It can be exposed to temperatures up to 82°C without being affected, and its low thermal conductivity is important when the tool is used with hot water to avoid burning the user (Porex Corporation, n.d.). The sketch also shows the area where a layer of silicone overmolding is added to improve the grip on the tool. The overmolding also has an embedded pattern to further improve the grip even when the tool is wet and soapy.

Figure 12-1: Finished design sketch

The color of the tool is blue because it associates with water, cleanliness and symbolizes order and reliability. As mentioned in the description of the manual cleaning "iron" in section *8 Early concept development* this design will also include a tile cleaning sponge on the large area on the bottom of the tool and a grout-cleaning brush in the middle that can be lifted and lowered in and out of the housing. Any metal parts will be aluminum due to its low weight, corrosion resistance and price.

A competitive feature of the tool is the ergonomically designed handle that efficiently transfers the force from the user onto the wall. Another advantage of design is that the user is seldom in direct contact with the cleaning detergent unlike when, as an example, using a regular sponge. The next section describes the approach to achieve such a handle and tool design.

13 Ergonomics

13.1 Design analysis

Some criteria to be considered during the ergonomic work analysis are (adapted from Table 1 Criteria of a systematic analysis of the work task, (Strasser, 2007); p5):

- Work resistance: 0 torque, the contact forces transmitted to the palm during use should not exceed 10kg/cm^2 (EHS Today, 2005).
- Work movements are dynamic in a cyclic translational movement of approximately 30cm mainly in the frontal (wall) and the transverse (floor) plane (see Figure 13-1). For the grouts the movement is mainly in straight, vertical and horizontal lines, while cleaning the tiles the movement is freer.
- The precision requirement for the tool is intermediate-low, but it is not classified as a precision tool. Grout guiding will be included in the design (tip of the tool in front and cavity or similar in back).
- The total time needed to perform the entire task depends on the size of the surface to be cleaned, the dirtiness and the physical condition of the user. However, different grips, positions and postures can be used to ease the work.
- The result feedback is primarily visual (sight), but also olfactory (smell) and very slightly tactile (touch). Intervisibility with the work is hindered by the tool (and secondarily by the hand), so the tool must be moved to get visual result feedback.
- Environmental factors: the soap and water will cause the handle to be more slippery and the user might want to use rubber gloves so this must also be included in the design.
- Vibration and sound: The motorized tool option will also exert vibration and noise on the user. Vibration can cause white hand syndrome, which means that the blood flow to the hand and fingers is reduced. Over a longer period this may lead to a loss of sensory feedback and decreased performance. Vibrations between 40-130Hz are within the critical range and should be avoided. Materials, design and reducing the force can all contribute to reducing the vibrations. The noise limit value for an eight-hour dose is 87dB, and the peak value is 140 dB, and hearing protectors should be used from 80 dB and 135 dB accordingly.
- The main work safety concern for the tool is the contact with chemicals on the skin and clothes.

Additionally, any tool to be held and supported by the user should not exceed 2,3kg, but the recommended weight is only about 1,1kg. The center of gravity of the tool should be as close to the wrist as possible (Strasser, 2007).

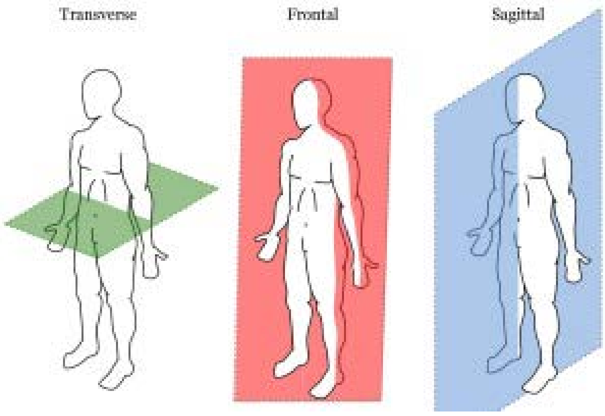


Figure 13-1: Planes of motion (Xrcise Expert, 2014)

According to Helmut Strasser (2007) the design analysis of the ergonomics of a hand held tool can be visualized as a flow chart, see Figure 13-2.

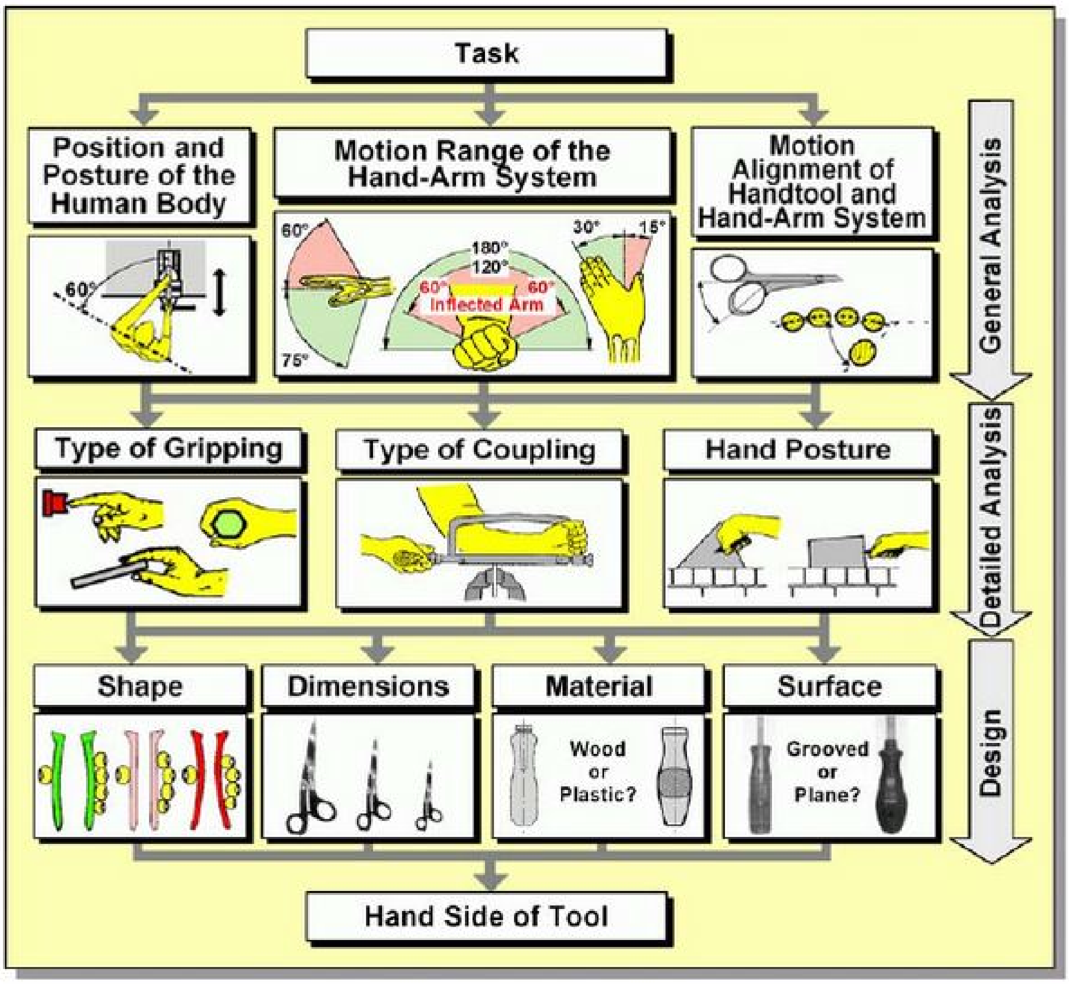


Figure 13-2: Ergonomics design flow chart of a hand held tool (Strasser, 2007)

The posture of the body is both standing and sitting, but they both meet the 60 degree angle between the frontal plane and the work direction. The type of gripping is a power grip, where the palm and the fingers are in contact with the handle, distributing the pressure evenly to maximize the force (green handle in Figure 13-2). Two or three finger pinch grips are more suited for precision tools (Strasser, 2007).

13.2 Handle design

Figure 13-3 shows how it is normal to grip any regular clothing iron.

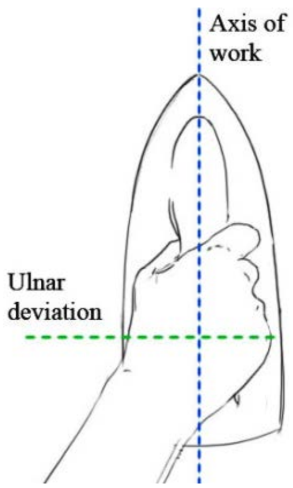


Figure 13-3: Regular "iron" power grip

From Figure 13-3 it is easy to see that the wrist is in a ulnar deviation posture (Figure 13-4), this could result in ailments and tendovaginitis (inflammation in the wrist area) (Strasser, 2007). This is not crucial when using an iron because most of the weight is on the ironing board, but since the user will lift the grout and tile cleaning tool, a different handle must be developed.

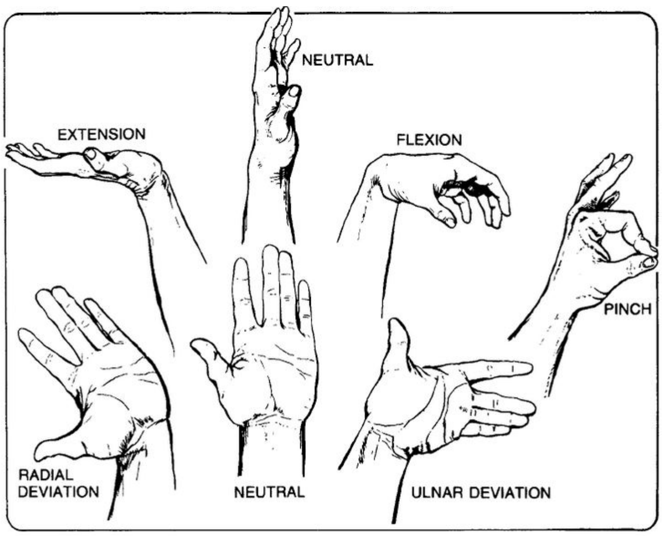


Figure 13-4: Hand and wrist postures (Pheasant, 2014)

One option is to improve the angle between the length of the handle and the arm/wrist posture (the green line should follow the arm) as shown in Figure 13-5. The disadvantage with this design is that the handle needs to be mirrored for left-handed users.

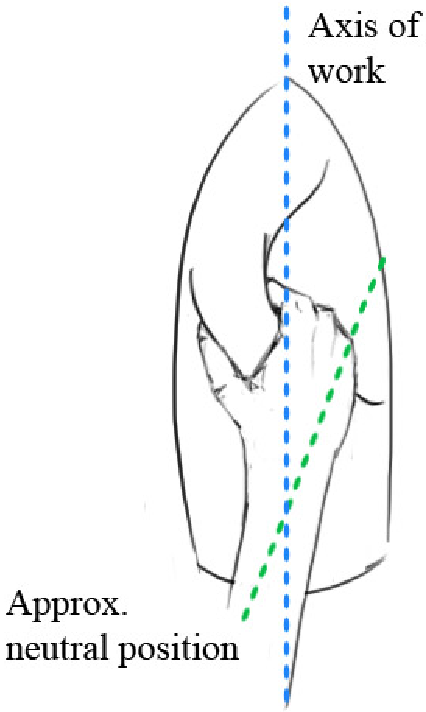


Figure 13-5: Improved ergonomic grip

The alignment of tool and hand-arm system should make a 100-110 °degree angle between the neutral posture of the wrist (Figure 13-4) and the axis of grip, as shown in Figure 13-6 (Strasser, 2007).

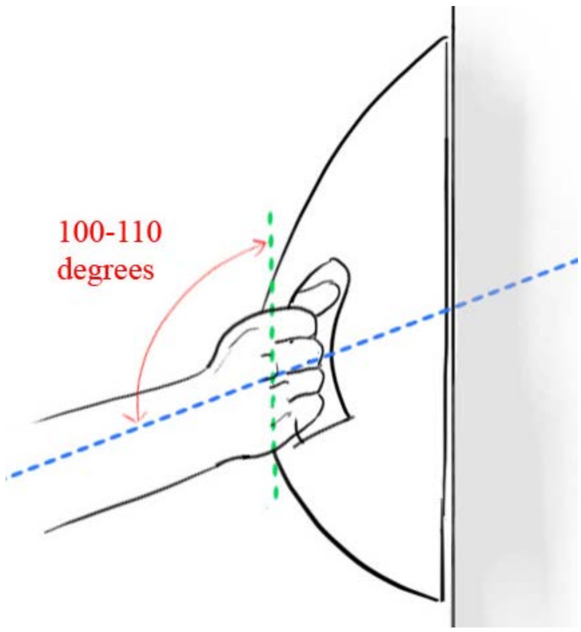


Figure 13-6: Positive coupling grip with neutral wrist posture

This type of power grip is called positive coupling, where all the force is directly transferred to the work surface with a moderate involvement of the palm and finger musculature (Strasser, 2007). A different handle design is the pistol grip, see Figure 13-7. The weakness of this design is that the center of gravity of the weight of the tool is far away from the wrist, which will cause unnecessary strain on the arm (Strasser, 2007). However, the pistol grip permits the wrist to remain in a neutral posture.

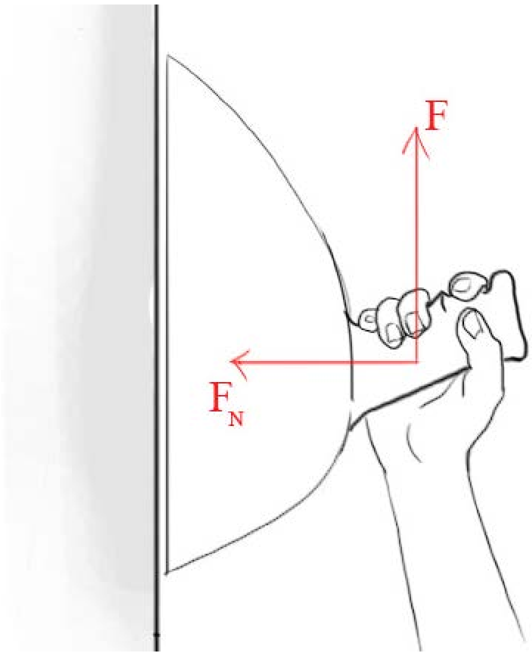


Figure 13-7: Pistol grip

Another important factor to consider is that the user might need to reach areas outside of the zones of convenient reach (ZCR), especially below knee height (see Figure 13-8).

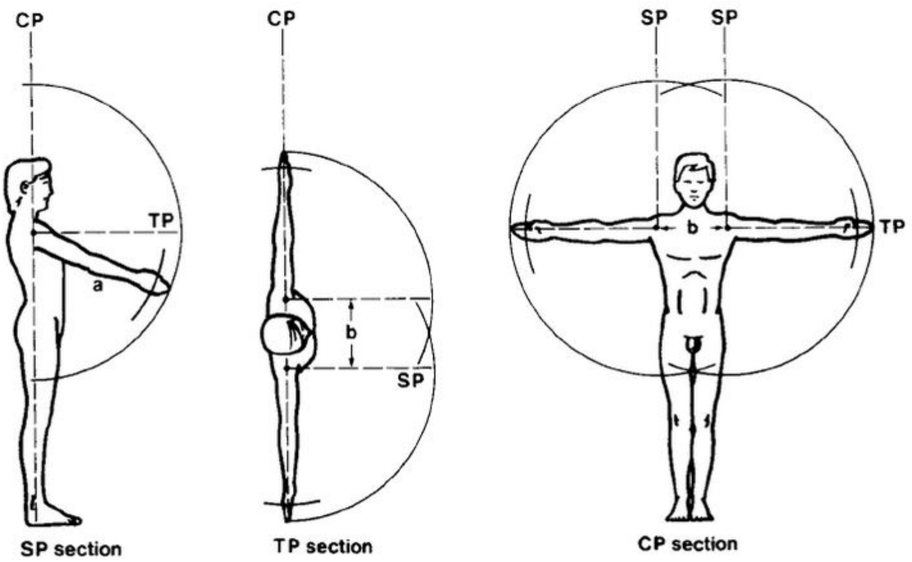


Figure 13-8: Zones of convenient reach (Pheasant, 2014)

One possible solution to this is to design the handle as a round "joystick", Figure 13-9. This design has no orientation limitations and the user can vary the grip to avoid repetitive movements. This also offers an advantage when the user is sitting down or bending to reach areas below knee height because the tool can be turned around without affecting the grip. However, when applying force on the tool, the wrist will have an extension posture which is close to the limitation of 60 degrees (Figure 13-2). There is also a high involvement of finger musculature while moving the tool in the frontal plane and keeping the orientation along the grouts.

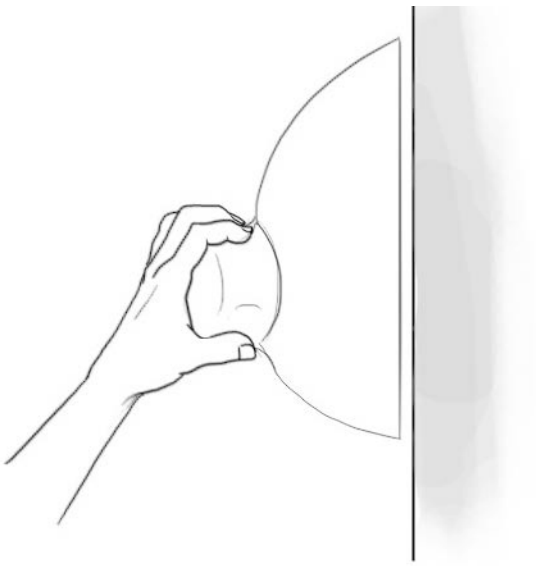


Figure 13-9: Round "joystick" handle

As a conclusion the positive coupling grip (Figure 13-6) is believed to be the best fit, design wise. This is based on the way the force is transmitted as well as the directional control this type of handle gives, which makes it easier for the user to keep the tool aligned with the grouts. To reduce the out-of-reach zones, hence reducing the need for a tool design specialized for these areas, the user should use a stool to either sit down on or stand on to reach higher areas. A further improvement would be to combine this design with the diagonal left-right handed design, but to produce two different designs or develop a complex design with the possibility to switch between the two handle positions would result in a much higher production cost.

13.2.1 Dimensions

The tool will be used by both male and female users so the design and its dimensions must be adapted to fit both. Table 13-1 and Figure 13-10 gives the anthropometric estimates for the male and female hand.

Table 13-1: Anthropometric estimates for the hand [mm] (Pheasant, 2014)

	Men				Women			
Dimension	5th %ile	50th %ile	95th %ile	SD	5th %ile	50th %ile	95th %ile	SD
1. Hand length	173	189	205	10	159	174	189	9
2. Palm length	98	107	116	6	89	97	105	5
3. Thumb length	44	51	58	4	40	47	53	4
4. Index finger length	64	72	79	5	60	67	74	4
5. Middle finger length	76	83	90	5	69	77	84	5
6. Ring finger length	65	72	80	4	59	66	73	4
7. Little finger length	48	55	63	4	43	50	57	4
8. Thumb breadth (IPJ)[a]	20	23	26	2	17	19	21	2
9. Thumb thickness (IPJ)	19	22	24	2	15	18	20	2
10. Index finger breadth (PIPJ)[b]	19	21	23	1	16	18	20	1
11. Index finger thickness (PIPJ)	17	19	21	1	14	16	18	1
12. Hand breadth (metacarpal)	78	87	95	5	69	76	83	4
13. Hand breadth (across thumb)	97	105	114	5	84	92	99	5
14. Hand breadth (minimum)[c]	71	81	91	6	63	71	79	5
15. Hand thickness (metacarpal)	27	33	38	3	24	28	33	3
16. Hand thickness (including thumb)	44	51	58	4	40	45	50	3
17. Maximum grip diameter[d]	45	52	59	4	43	48	53	3
18. Maximum spread	178	206	234	17	165	190	215	15
19. Maximum functional spread[e]	122	142	162	12	109	127	145	11
20. Minimum square access[f]	56	66	76	6	50	58	67	5

0

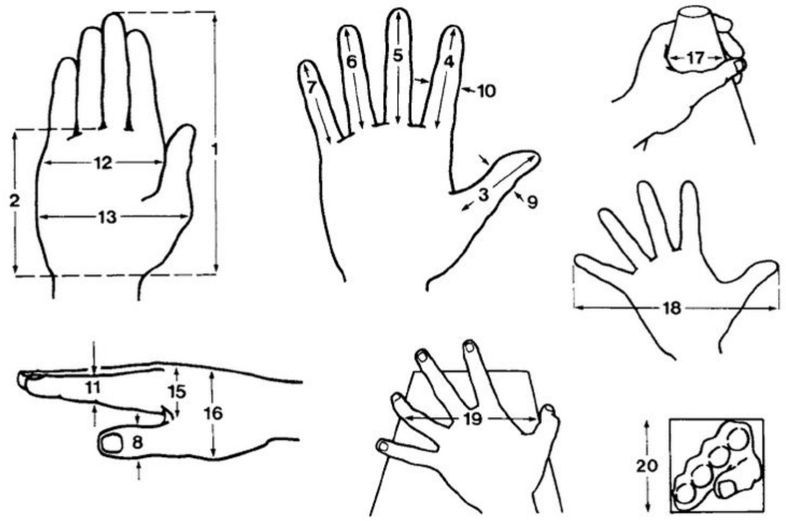


Figure 13-10: Anthropometry of the hand, as described in Table 13-1 (Pheasant, 2014)

According to Stephen Pheasant (2014), any aperture where the hand (without the thumb) is going to pass through should have minimum dimensions of 115 mm x50 mm. Strasser (2007) recommends the length of a handle to be 100-125mm for a positive force transmission for a medium size hand. Correspondingly, if the center diameter (D_v in Figure 13-11) be 38-41mm, the end diameters should be 28-30mm (Strasser, 2007).

It is important to attain a favorable longitudinal design of the handle to ensure the contact of all fingers in order to achieve an ergonomic grip and maximize the force transmitted, also over time. A rounded trapeziform cross-section of the handle compared to a circular one, will reduce the pinch force required by the fingers to keep the tool steady. The longitudinal design should also be different according to the difference of the palm from the thumb to the little finger (Strasser, 2007). Pheasant (2014) and Strasser (2007) points out that finger shaped handles should be avoided unless they are highly customized, since a wrong fit can easily lead to high point pressure and/or blisters.

The base dimensions for the handle were compiled from several examples from Strasser (2007), including trowels, screwdrivers and a hacksaw. The mid-section of the handle is designed for as much contact with the palm as possible, narrowing towards the end to fit the smaller circumferential grip of the little finger. The green rectangle in Figure 13-11 shows the recommended palm aperture.

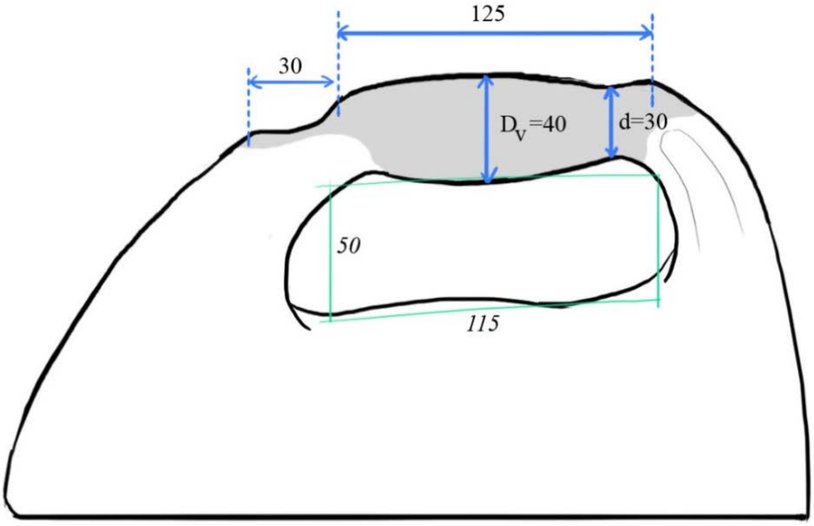


Figure 13-11: Side view

In the front there is a cavity to fit the thumb, to improve control of the tool when extra precision is needed. According to Table 13-1, the thumb breadth for 95% of men is 23mm and the thumb length is 51mm. A smaller thumb will still fit the cavity without losing functionality, so the breadth was decided to be 24mm and the length 30mm (the distal phalanx of the thumb is approximately half the total length). The cross-section of the handle was given an elongated trapeziform shape as shown in Figure 13-12, to reduce the pinch forces needed to keep the correct orientation of the tool. A small cavity on both sides of the back of the tool (Figure 13-11) is designed to give an extra grip to the fingertips when holding the back of the tool, e.g. when reaching high areas.

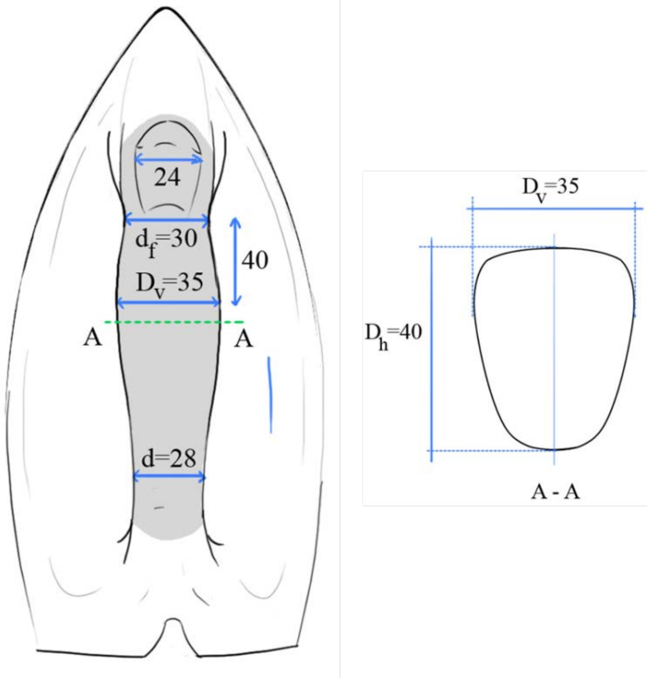


Figure 13-12: Top view with cross section A-A

13.3 Rapid prototyping

Rapid prototyping (RP) is a generic term for several methods of rapidly creating prototypes based on 3D computer-aided design (CAD) data. Slicer software slices the 3D-model into numerous 2D layers which are built up layer by layer by the 3D-printer, so-called additive layer manufacturing (Kamrani & Nasr, 2010). For this project Autodesk Inventor was used to create the 3D-models and convert the data to a .stl file. The slicer software Cura was used to prepare the model for printing and convert the .stl file into a .gcode file that the Ultimaker 2 printer can read.

RP allows for fast learning cycles and is widely used to test parts and assemblies for function, fit, form, ergonomics, visual inspection and can also be used as a visual prototype to communicate an idea. Another advantage is that the production cost is normally relatively low, as well as the production time. RP also creates the possibility to print extremely complex shapes and even make a functioning chain or whistle all in one piece. The materials used with RP already include several different plastics, papers and metals, but the technology is pushing rapidly towards new and innovative materials.

RP models can also be used as patterns for casting processes or a spray metal operation, often referred to as rapid tooling (RT). Rapid manufacturing (RM) refers to when the RP model is included in the final product, on the condition that the model meets the required materials specifications (Kamrani & Nasr, 2010). A typical RP flow chart is presented in Figure 13-13.

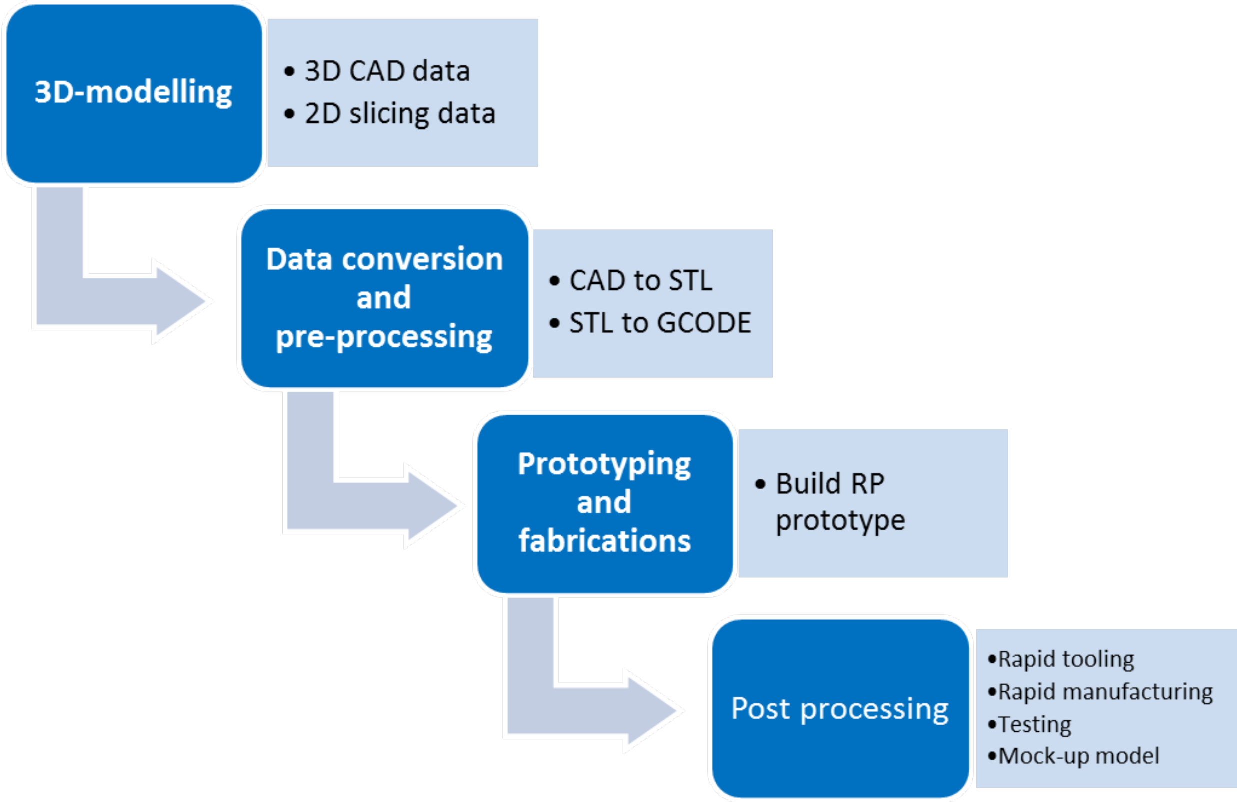


Figure 13-13: Rapid prototyping work flow chart (adapted from Kamrani & Nasr, 2010)

13.4 3D-modeling and printing

Once the main dimensions and design for the handle were drafted, a 3D-model was created in Autodesk Inventor, see Figure 13-14, and Figure 13-15 for dimensions.

Figure 13-14: First 3D-model design

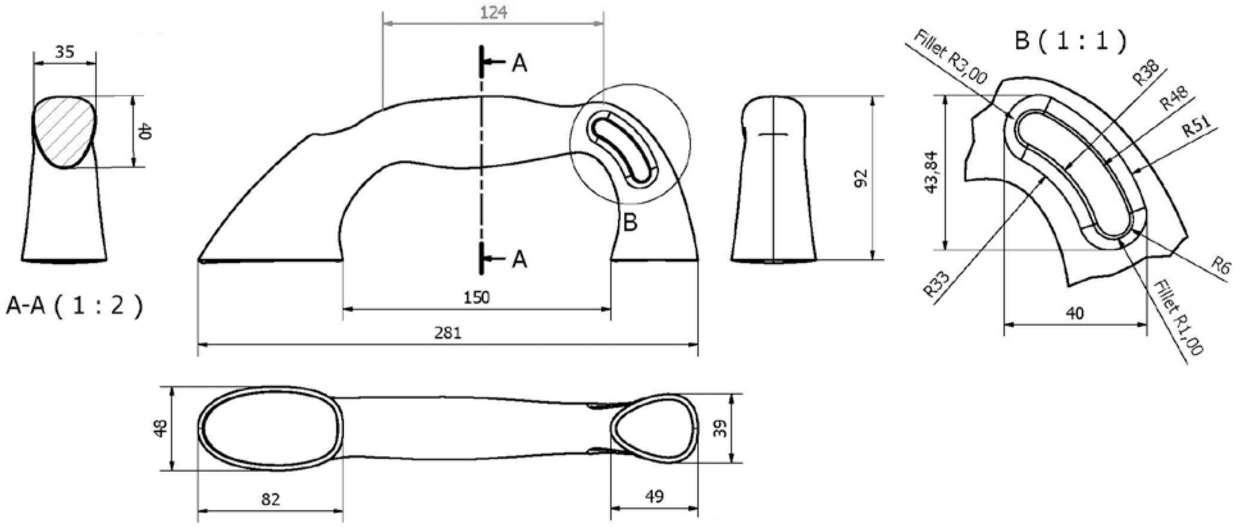


Figure 13-15: First 3D-model with main dimensions

The next step was to print the model in the Ultimaker 2 printer, and the software Cura was used to convert the 3D-model into printable 2D layers. Figure 13-16 shows the layer view of how the 3D-model is printed in the Ultimaker 2. The red is the outer shell, the yellow is the inner fill and the dark turquoise is the support material. The blue lines show the movement pattern for the printer nozzle. The turquoise brim on the builplate is printed to prevent corners on the model to lift because of warping, and must be cut off after printing. The turquoise "tower" in front of the part to the left, is support material needed for any sections of the model that have an overhang of more than 60 degrees (Cura, 2016). Figure 13-19 shows the finished 3D-print glued together.

Figure 13-16: Layer view of 3D-model in Cura and in the Ultimaker printer

13.5 Testing and evaluation

Once the print was glued together it was obvious that it was way too big (see Figure 13-19). Several of my fellow master students tested it and the feedback was that the mid-section was very comfortable to grip, but it was too long in the front and back and the opening for the hand was unnecessarily large. Considering this was only the handle and not the whole housing of the tool, it was clear that it had to be downsized and no further testing was considered relevant. After the test some minor changes were done to the 3D-model. The mid-section of the handle was made rounder to increase contact with the middle and distal phalanx of the fingers and the section before the thumb cavity was narrowed to give a better grip.

13.6 Result

The improved 3D-model is shown in Figure 13-17, the main dimensions in Figure 13-18 and the finished 3D-print in Figure 13-19 together with the first design for comparison.

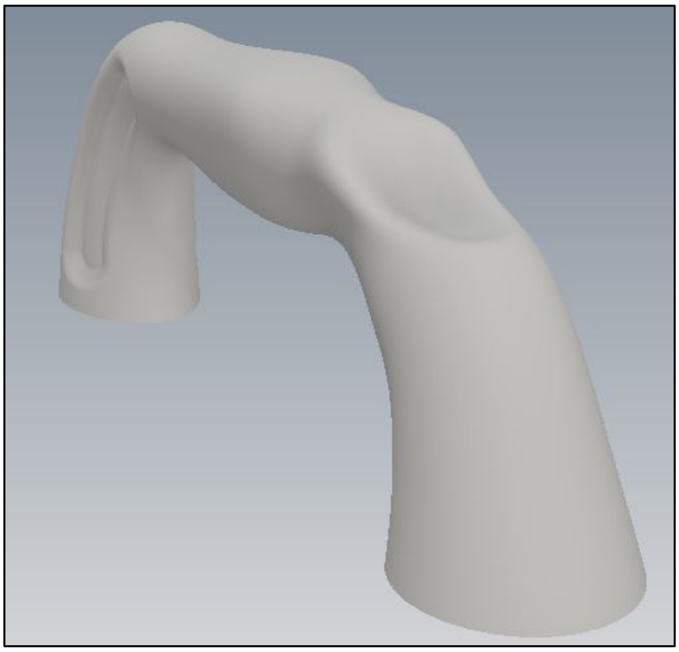


Figure 13-17: Improved 3D-model of handle

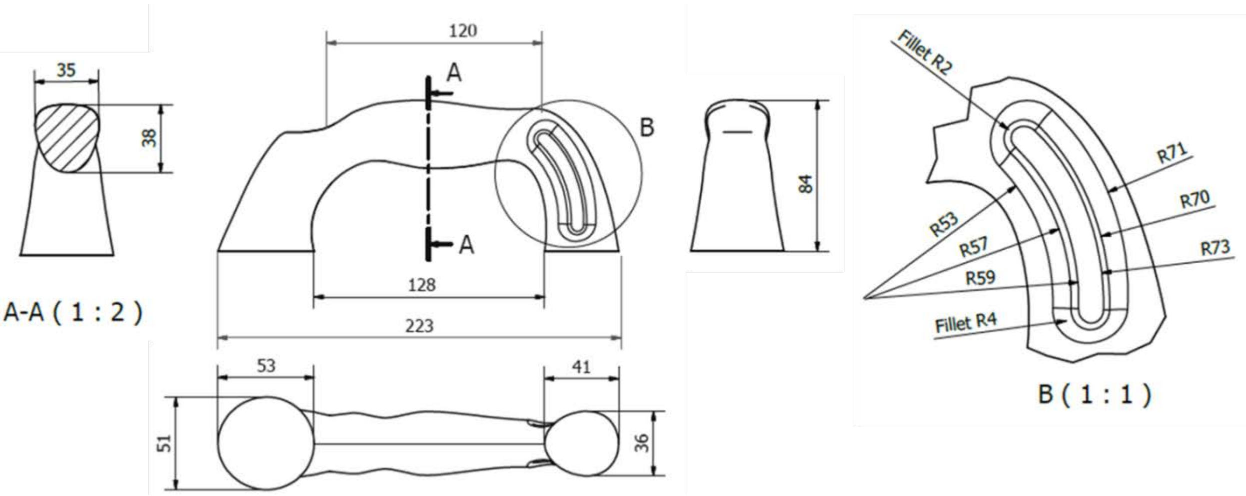


Figure 13-18: Improved 3D-model with main dimensions

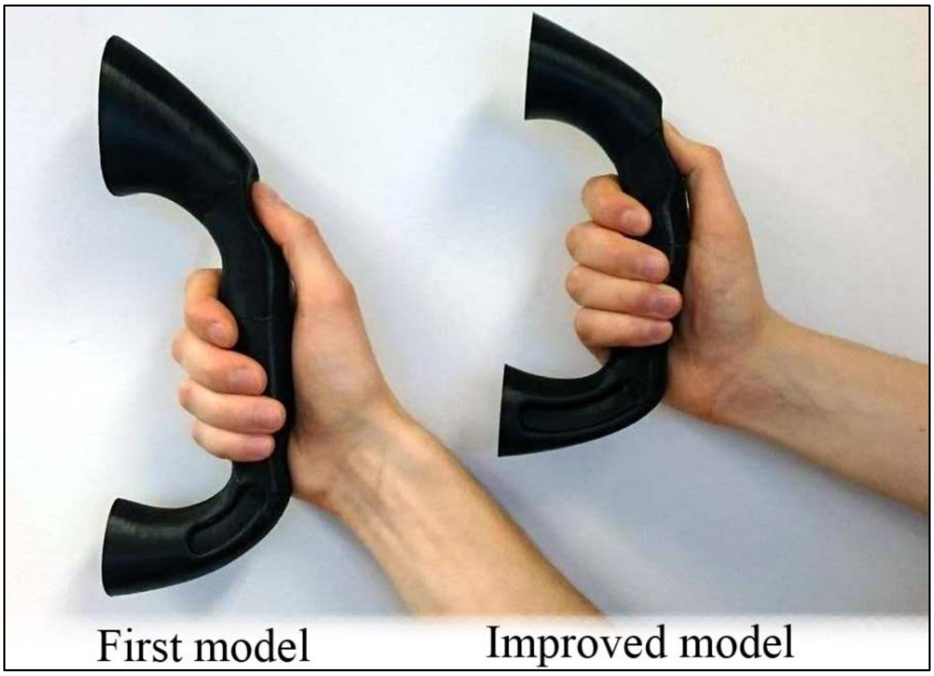


Figure 13-19: Finished 3D-print of the first and the improved model

Once the design of the handle was satisfactory the rest of the body/function housing was designed, see Figure 13-20. Several iterations were later done to the design to fit all the components of the brush mechanism, as described in section *14 Function.*

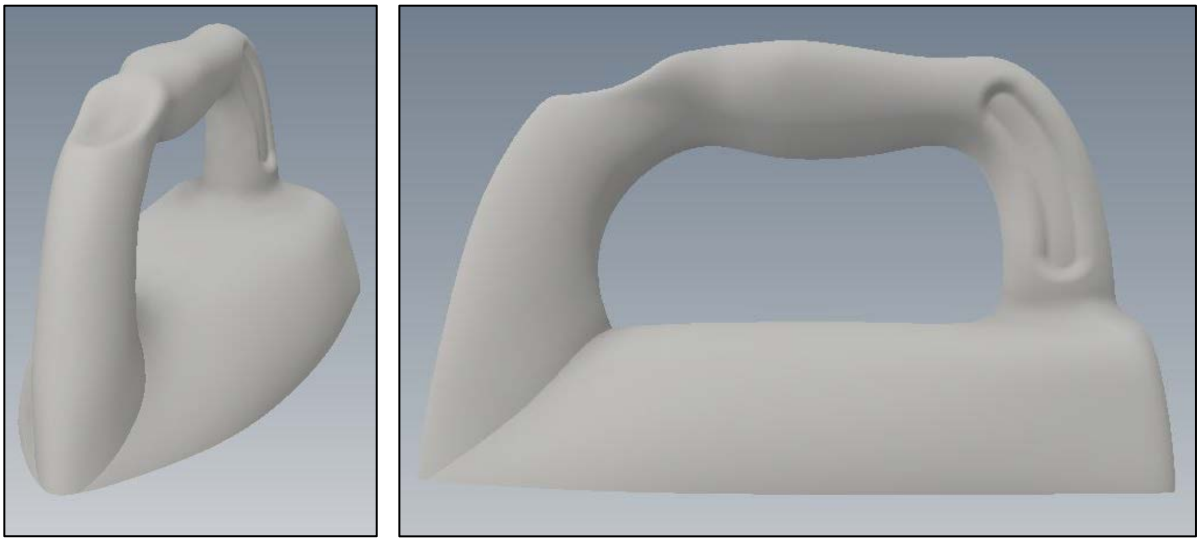


Figure 13-20: Complete 3D-model of tool

13.7 Rendering of the 3D-model

Photorealistic 3D-renderings have become an evident part of modern product development and design process. It is a low cost tool used to visualize a final product and is not far from replacing a physical mock-up prototype. A digital rendering has the same usages as a mock-up prototype; to visualize and communicate an idea, and test the design, size and appearance. Photorealistic renderings are also valuable when working with a second party or an external client, as they ensure a common understanding of the product, and they can be used as a tool of persuasion (O'Connor, 2010).

For this project Autodesk 3ds Max was used to render the 3D-model of the prototype as shown in Figure 13-21. Since both Inventor and 3ds Max are Autodesk software, they are compatible and the assembly part (.iam format) was imported directly from Inventor to 3ds Max. First the model was converted into an editable poly to be able to assign materials and colors to the different sections. Then a ground plane was created and the background (environment) was added. A free camera view was used to get the correct perspective, before a daylight system was created to give light and shadow to the rendering. To make the rendering even more realistic, reflection and refraction was added to the ground, in addition to several other control settings for lights, shadow, material and color.

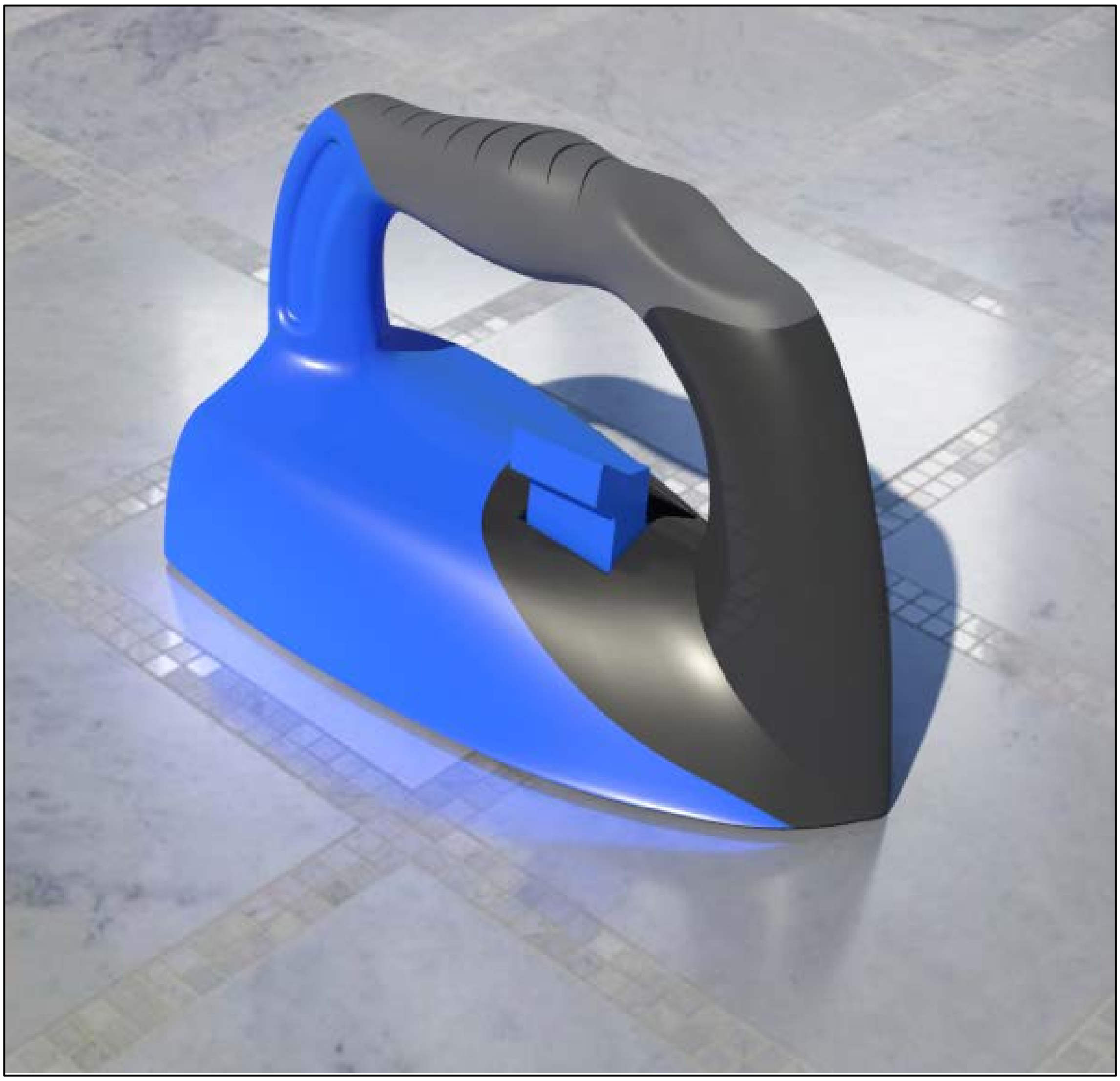


Figure 13-21: Rendering illustration of the final product

14 Function

The main feature that separates this tool from existing products is that the grout brush can be lowered and pulled up into the tool housing using a switch, depending on whether it is being used to clean the grout or the tiles. Some different options for this function were prototyped, Figure 14-1 shows one solution. The brush rotates around one fixed point (middle screw) so that the right side of the brush is lifted. The weakness is that the left side of the brush if not lifted and there is a need for a triangular space with a height of 70mm inside the tool.

Figure 14-1: Brush function prototype A

Figure 14-2 shows a different approach. Here the entire brush is lifted, but it takes a lot of space and the tool needs to be at least 40mm longer than the brush, which is undesirable considering both size and design. A third option was to look further into how the brush function of a vacuum cleaner head works and see if it was applicable.

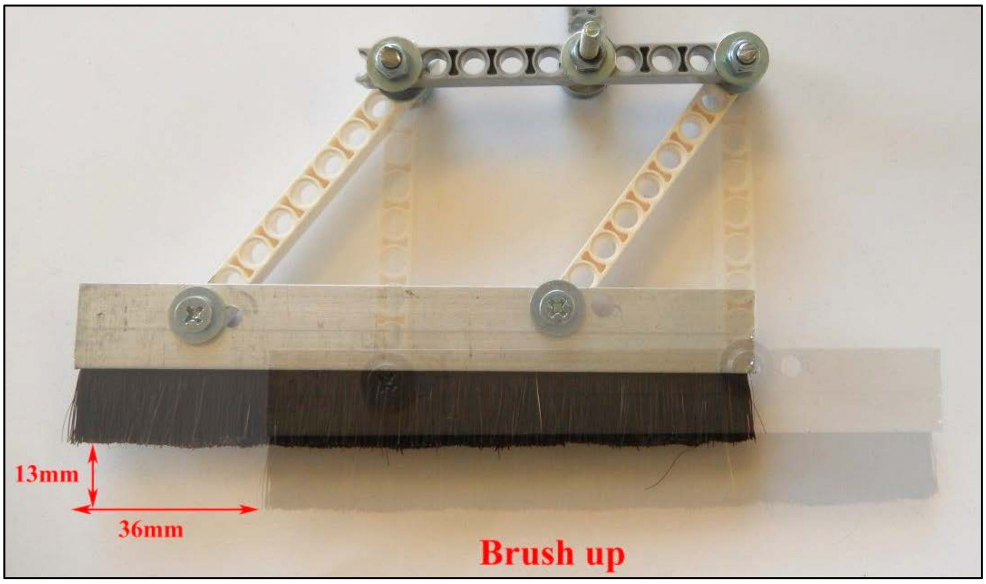


Figure 14-2: Brush function prototype B

After some testing it seemed that modifying a vacuum cleaner head would be the easiest and best space-saving option. The function to lower and lift the brush when vacuuming different surfaces was exactly what was needed for the prototype. A spare vacuum cleaner head (article 800226 from the hardware store *Jula*, similar model as the assembly in Figure 14-3*)* was used as inspiration for the mechanism and later modified to fit the model of the tool.

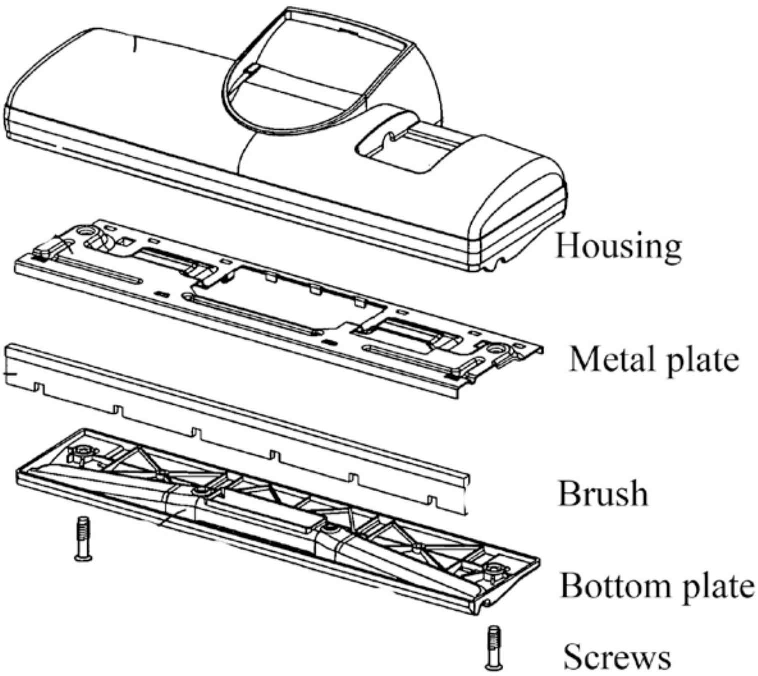


Figure 14-3: Vacuum cleaner brush head (for illustration only, different model was used in the prototype) (Adapted from Luo & Cho, 2011)

The main challenge was to compress the mechanism to fit inside the much smaller prototype model. The function housing of the model had to be enlarged several times and the length of the vacuum brush head mechanism had to be shortened drastically. To achieve this, the functions of the two switches (up and down of the brush) had to be comprised into one switch (Figure 14-4) and the metal plate holding the brush (equivalent to the *metal plate* in Figure 14-3) had to be shortened by cutting out a part of the mid-section. The brush was originally a part of a longer strip brush, which was cut to the desired length. Then the brush was attached to the modified metal plate as shown in Figure 14-5.

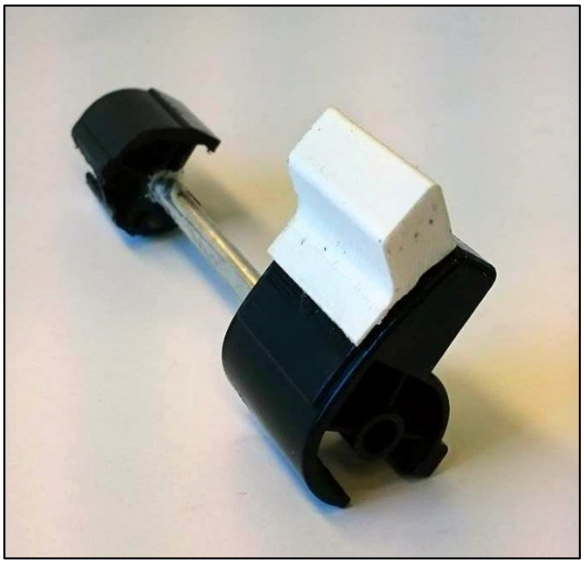


Figure 14-4: Shaft with brush switch

Since there were originally two different switches for up and down, the combined switch needed an extra piece to flip the switch back up (the white piece in Figure 14-5). The add-on part was 3D-printed together with the rest of the prototype (as described in section *15 Assembly of the prototype*).

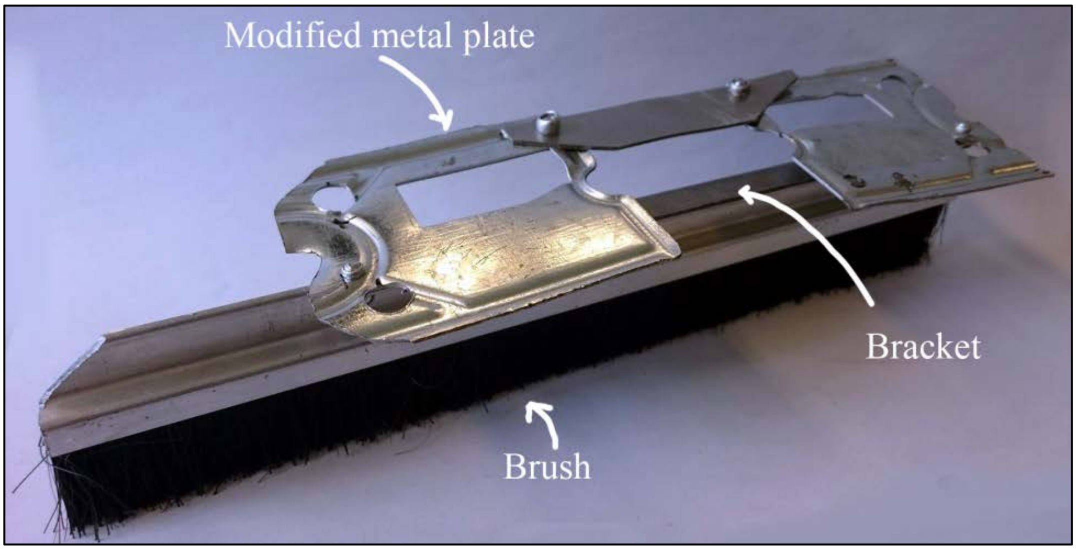


Figure 14-5: Metal plate with the attached grout brush

During this process, the 3D-model was used actively to develop the prototype. Several cyclic interactions where dimension restrictions were determined from the 3D-model, then the physical changes, were done before the 3D-model was updated again to match the prototype. This way there was a minimal risk of error when building the prototype, while also following the lean product development method of adapting the 3D-model to the prototype to reduce waste (e.g. time, materials) (Ward, Liker, Cristiano, & Sobek II, 1995).

Once the mechanism and the model were both updated to match each other, the next step was to create the inner structure to fit the parts and support the function and its moving parts. Figure 14-6 shows the finished model in an extruded view with all the components. *Appendix H: 3D-Model* contains more pictures of the 3D-models and part drawings with dimensions of all the different components. The 3D-model ended up being larger than what was envisioned for the design to fit the parts from the vacuum cleaner head. A smaller vacuum cleaner head could have been sought for, but at the point where it was clear that the result would be too big it would have been a complex and time-consuming job to modify a new mechanism and fit it to the 3D-model. The function of the prototype was determined to be more important than the design, so the first prototype will be a "proof of function with a compromise in design"-prototype.

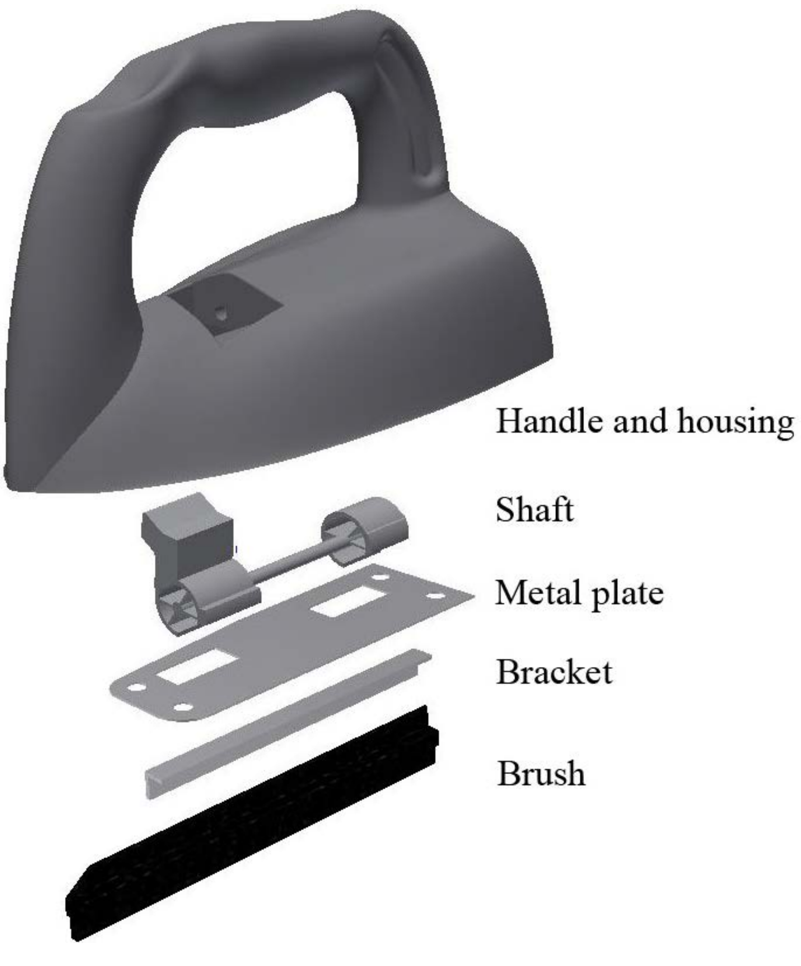


Figure 14-6: Extruded 3D-model with components

Figure 14-7 and Figure 14-8 show how the brush movement is created through a rotating shaft using a switch that pushes the metal plate (and the brush) down when it is flipped down. When the switch is flipped back up, four springs located underneath the metal plate push the metal plate (and the brush) back up. The vertical movement is 10mm (see Figure 14-8), which is the distance needed to pull the brush in when the tool is being used to clean tiles.

Figure 14-7: Half section view of model with brush in up position (left model) and down position (right model)

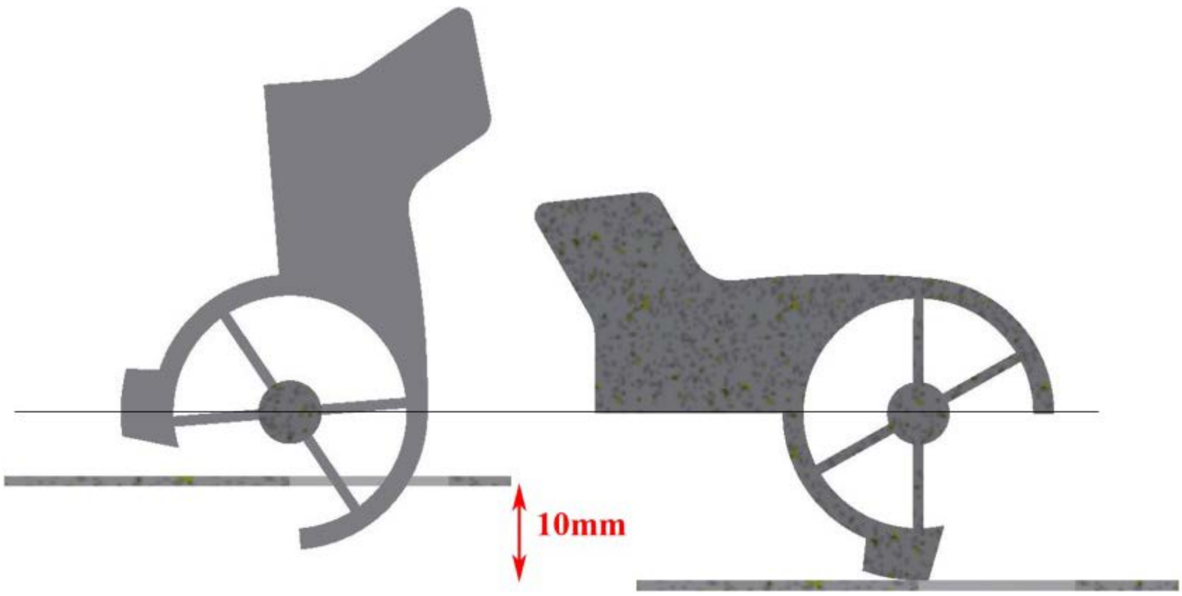


Figure 14-8: Detail view of shaft and metal plate in up and down position accordingly

The model had to be divided into four printed pieces to be able to insert the mechanism. Both the metal plate and the shaft are supported by rigid housing structure, so they have to be inserted before the prototype is glued together. Using screws as an alternative to assemble the model was discussed, an option that would have created the possibility of opening the tool. However, the extra production cost did not seem to make up for this need considering the tool is considered a low cost product.

15 Assembly of the prototype

The model was printed in a Stratasys Fortus 3D-printer using acrylonitrile butadiene styrene (ABS) plastic. The finished 3D-prints are shown in Figure 15-1.

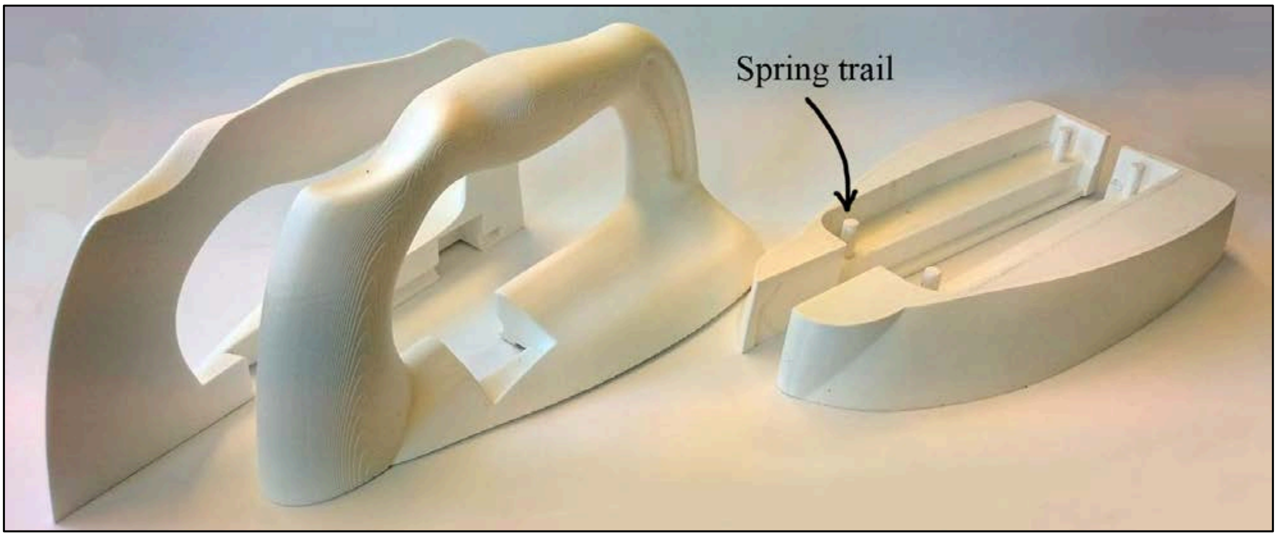


Figure 15-1: 3D-print of finished prototype

Unfortunately, but not unexpectedly, all the different parts did not fit together perfectly, so some modification had to be done. Firstly the holes in the metal plate did not match the four spring trails in the print so they had to be filed until they matched as shown in Figure 15-2.

Figure 15-2: 3D-model and metal plate with fitted holes

The next challenge was the springs and making the mechanism work. There are supposed to be four springs below the metal plate threaded onto the four spring trails. There were only two springs with the vacuum cleaner, and since the new design had four, two similar springs were found in the workshop and tested. It turned out that adding two more springs gave too much resistance force and the brush mechanism did not work. Four smaller springs with a lower compression spring rate were tested, but since the holes now were much larger than the initial 8mm, the springs went through and got jammed. The solution was to make some handmade plastic liners out of a plastic folder that would orient the spring and block it from going through the metal plate as illustrated in Figure 15-3.

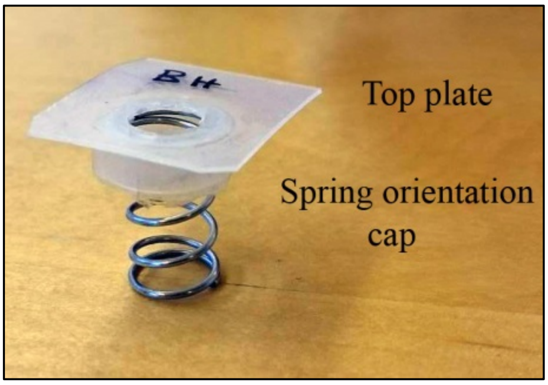


Figure 15-3: Plastic liner for the springs

The thorough preparatory work with the 3D-model paid off as there were no other complications and the finished prototype worked exactly as intended. Figure 15-4 shows the complete assembly of the prototype (the assembly lines between the different sections were removed in Photoshop).

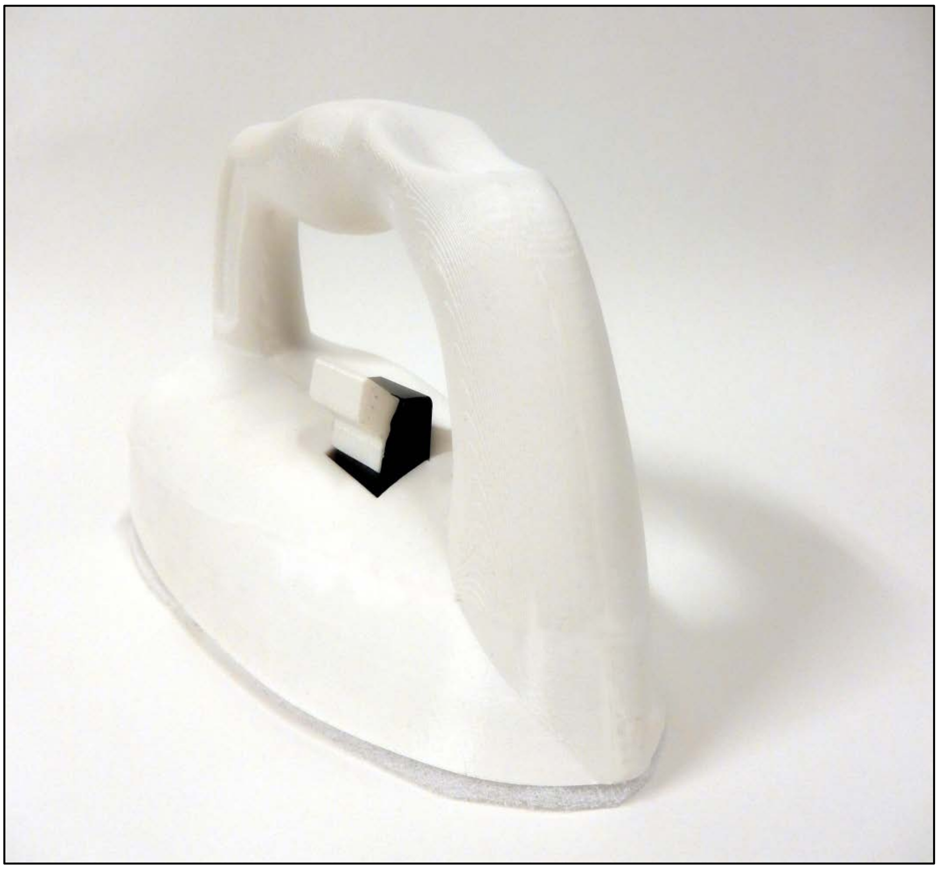


Figure 15-4: Complete assembly of the prototype

Figure 15-5 shows a three quarter section view of the prototype and Figure 15-6 illustrates the up and down position of the brush. The total weight was 736g, which is about ⅔ of the 1,1kg limit for handhold tools as described in section *13 Ergonomics*, but it still felt too heavy to be a cleaning tool. This was expected since the 3D-model had to be enlarged several times during the modeling phase to fit the mechanism. The high density of print, due to the 3D-printing process, and the fact that the print was designed with thick walls to enable modifications (e.g. machining) to fit the brush mechanism, also added weight to the prototype.

Figure 15-5: Three quarter section view

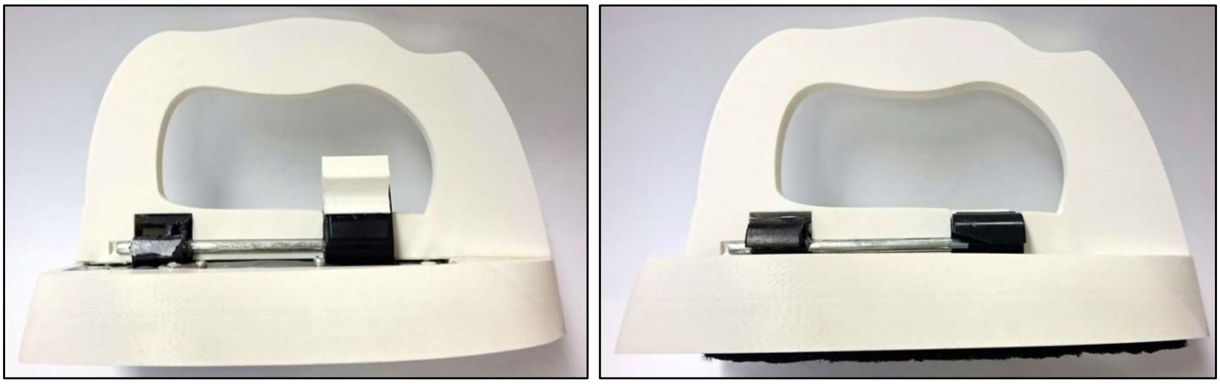


Figure 15-6: Prototype with brush in up and down position

The last part of the assembly was to attach the tile-cleaning sponge underneath. Jif bath scrub refill pads were cut to fit the prototype and fastened with Velcro hook strips (fastened underneath the prototype as shown in Figure 15-7).

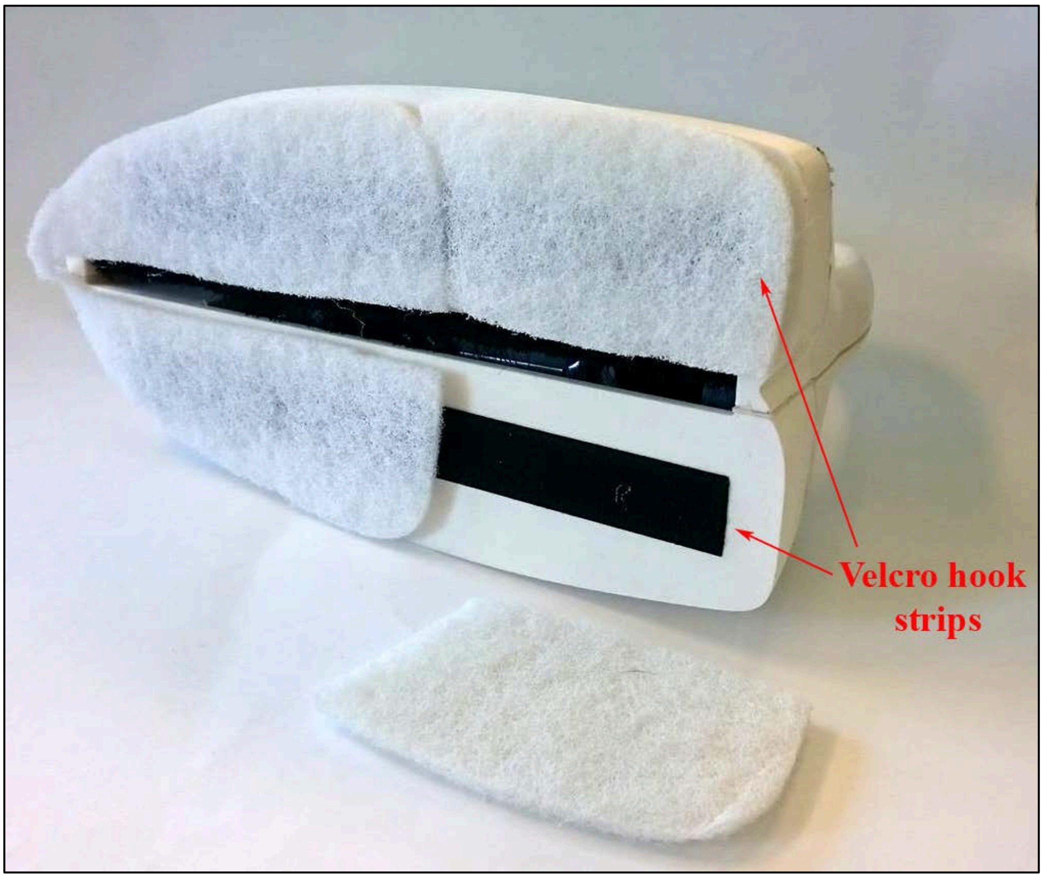


Figure 15-7: Prototype with tile-cleaning sponges

16 Testing and evaluation

16.1 Handle ergonomics

Both a subjective user experience test and an objective test were completed to evaluate the ergonomics of the tool. The first round of testing was conducted with only one test participant. In the subjective part the test participant were first asked a series of questions considering the ergonomic design and the user experience of the tool (the complete interview transcript can be found in *Appendix I: Prototype testing transcripts*, Norwegian only). Then they were asked to rate a pressure evaluation form illustrating various sections of the inner hand from "0 – no pressure" to "4 – very high pressure". The approach and the form were adapted from the work of Kluth et al. (Strasser, 2007) and can be found in *Appendix J: Pressure evaluation form*. For the objective test, the handle was covered in white acrylic paint (non-toxic, but might cause skin irritation if in contact for extended time (ColArt International SA, 2013)). Next, the participant gripped the tool, creating a grip pattern. The result from one example user test is presented in Figure 16-1.

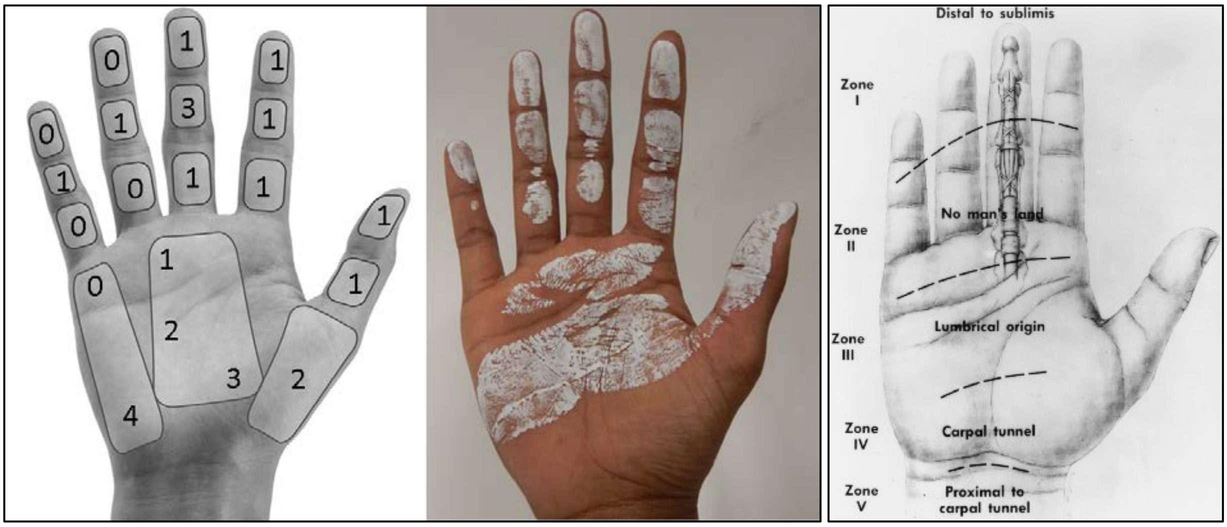


Figure 16-1: Pressure evaluation form (adapted from pngimg.com, n.d.), user test paint pattern and flexor tendon zones (Dr. Pal Singh, 2011)

Figure 16-1 shows a vague compliance between the subjective and objective test. The subjective test located the main pressure areas on the carpal tunnel, while the paint pattern clearly shows that it is located in the lumbrical origin. The paint pattern on the fingers shows that the pressure on the fingertips is higher than on the inner finger joint, and that there is barely any contact on the middle and inner joint of the little finger. The pressure rating 3 on the middle finger might have been a misconception of the combined pressure on the middle and the index finger, as the paint prints are very similar and the participant expressed difficulties separating them.

However, both of the tests imply that there are no severe pressure points and that the pressure is evenly divided over most of the inner hand with the highest values in the lumbrical origin. This substantiates that the ergonomics of the handle has achieved a direct force transfer from the user to the tool. "The way the handle was designed made it possible to transfer force from the whole arm to the palm of my hand, while the fingers were only used for support and directional guidance" (translated by Limseth, Gina, reproduced from: Participant A, 2016).

16.2 Hand and wrist postures

To evaluate the ergonomics of the hand and wrist postures of the prototype design a user test was done. Three cleaning tools were evaluated in the test; the prototype, from now on referred to as the Henkel prototype, a competing bath scrub tool from Jif (see Figure 16-3), available at most larger supermarkets in Norway, and a Colgate toothbrush. The user experience test was conducted at TrollLABS at NTNU using the tile wall prototype described in section 7.

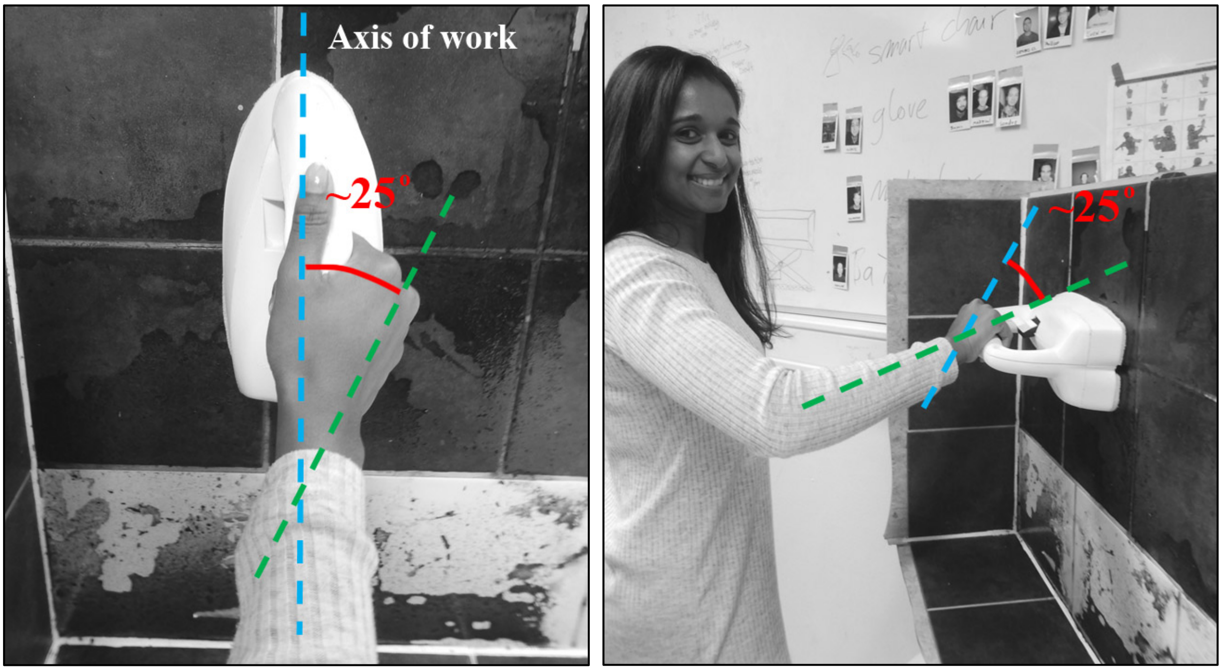


Figure 16-2: Wrist posture while using the Henkel prototype

The angle between the axis-of-work and the angle of the wrist is approximately 25 degrees when using the Henkel prototype, both in vertical and horizontal movements, which is a good result. Optimally the green and the blue lines should be aligned, but that would have required one left and one right handed version as described in section *13.2 Handle design*. The wrist extension is about 30-40 degrees which is well within the limits of 60 degrees and both the arm inflection and the wrist deviation were in neutral postures (see Figure 13-2 and Figure 13-4). The feedback from the test participant was that the tool was easy to maneuver in all directions and that it had a comfortable grip (Participant A, 2016).

Figure 16-3: Jif bath scrub (Lilleborg AS, n.d.) and wrist posture during use

The next tool was the Jif bath scrub. This type of power grip is called a friction coupling with indirect force transmission. It has a high involvement of the musculature in the palm and fingers to transmit the force onto the work surface (Strasser, 2007). During the test, the wrist extension was approximately 60-70 degrees and there was a clear ulnar deviation of almost 50 degrees. The angles are difficult to illustrate in Figure 16-3, but the picture clearly shows an uncomfortable wrist posture, in addition to the cumbersome grip with crooked fingers. "The Jif tool was clumsy and bulky and I had to put a lot of pressure on my index finger while using it, in addition to the high pinch force on the rest of my fingertips to keep it in place" (translated by Limseth, Gina, reproduced from: Participant A, 2016).

The toothbrush also has a friction coupling power grip. The small diameter of the toothbrush handle caused the fingertips/nails to dig into the palm and the soft bristles did not give enough resistance so the plastic tip of the toothbrush scratched against the wall. However, the toothbrush had a slightly better wrist posture than the Jif scrub with an extension of about 40 degrees and an ulnar deviation about 30 degrees.

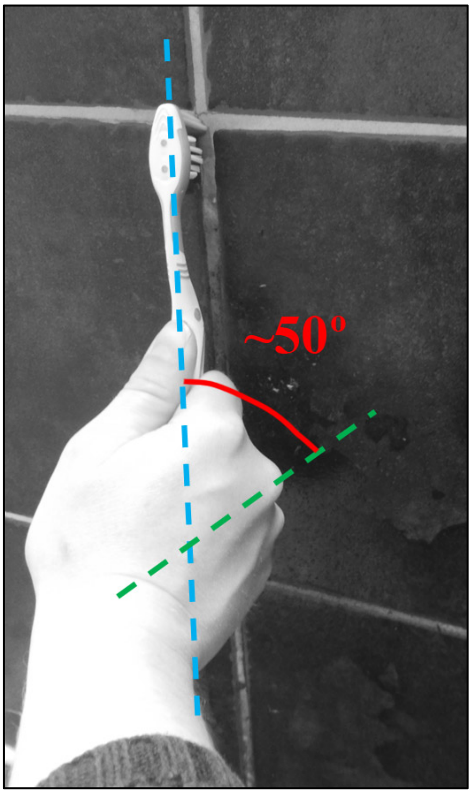


Figure 16-4: Wrist posture while testing the Colgate toothbrush

16.3 Force transmission

The objective with the force transmission test was to compare how much force the three cleaning tools (Henkel, Jif and Colgate) required during normal use, and the distribution of the forces. This test was also planned with one objective and one subjective approach. To get an objective measurement of the forces an Interlink Electronics Force Sensing Resistor (FSR) (model 402 Round) connected to an Arduino Uno as described in section *16.3.1 Arduino and the test set-up* was used. The test was conducted at TrollLABS at NTNU using the tile wall prototype described in section *7 Tile wall prototype.* Both the Henkel prototype and the Jif tool were tested with the Jif bath scrub sponge pads that contained soap. Jif bath scrub soap was added to the toothbrush to ensure equal conditions. Before the pressure test each of the tools were kept under running water until the pads were saturated and immediately tested on the wall. The Henkel prototype has a larger area covered with pads than the Jif scrub, and the toothbrush obviously absorbed much less water than the two others, but since this reflected a real user situation it was not considered a source of error. The pressure was recorded while each tool was moved up and down ten times against a specified area of the grout on the wall in a vertical movement. Photographs were taken during the test to evaluate the body posture and force transmission and after the test the test participant were interviewed to get a subjective evaluation of the tools.

16.3.1 Arduino and the test set-up

Arduino is an open source platform for electronics projects, it consists of a programmable circuit board (for this test we are using the Arduino Uno board) and a programming software that loads the coding to the card using an USB cable (B_E_N, n.d.).

The circuit set-up consisted of the Arduino Uno, the FSR sensor, a 3,3 kΩ resistor and connecting cables as shown in Figure 16-5

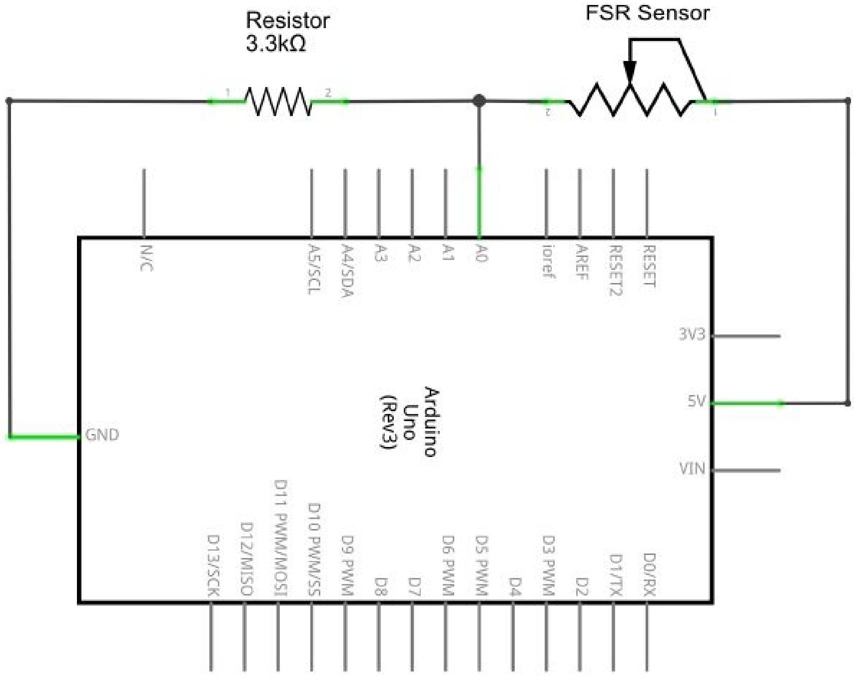


Figure 16-5: FSR sensor schematic (created with Fritzing, Friends-of-Fritzing foundation, 2015)

The script that was used to convert the measured resistance to gram force was found on codebender.cc, an online code editor for Arduino (Jim, 2016). The script uses the analog to digital converter (ADC) integer value that ranges from 0-1023 to calculate voltage, and then it takes the voltage and the static resistance (from the 3,3kΩ resistor) to calculate the resistance of the FSR sensor. The force is calculated as a guesstimate based on the resistance-force relationship log-log graph (Figure 16-6) generated by Interlink Electronics. As the graph shows there is a minimum actuation force with a threshold resistance value around 100kΩ. For any higher forces/lower resistance values the relationship follows an inverse power law (Interlink Electronics Inc., n.d.).

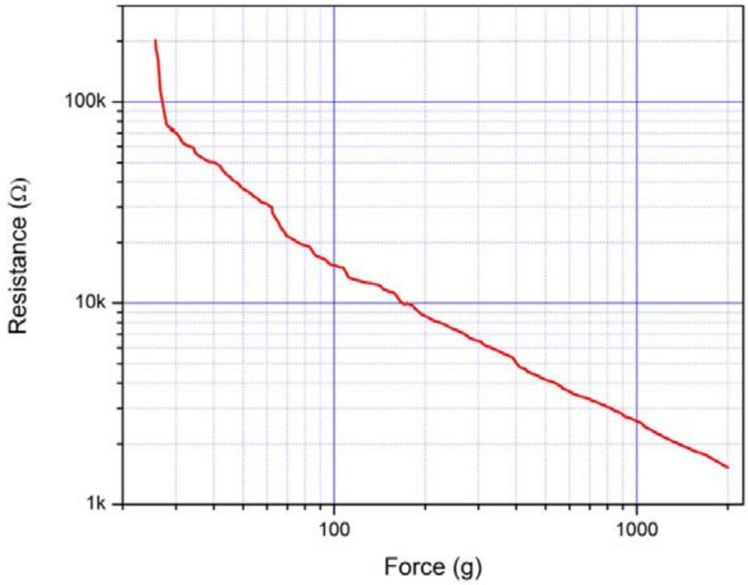


Figure 16-6: Resistance vs. force (Interlink Electronics Inc., n.d.)

For each tool the FSR sensor was attached at the point in the palm where the participant felt the most pressure while holding the tool. The set-up for testing the Henkel prototype is shown in Figure 16-7. For the Jif scrub the FSR sensor was located slightly more toward the center of the palm and to test the toothbrush the sensor was located on the inner joint of the index finger.

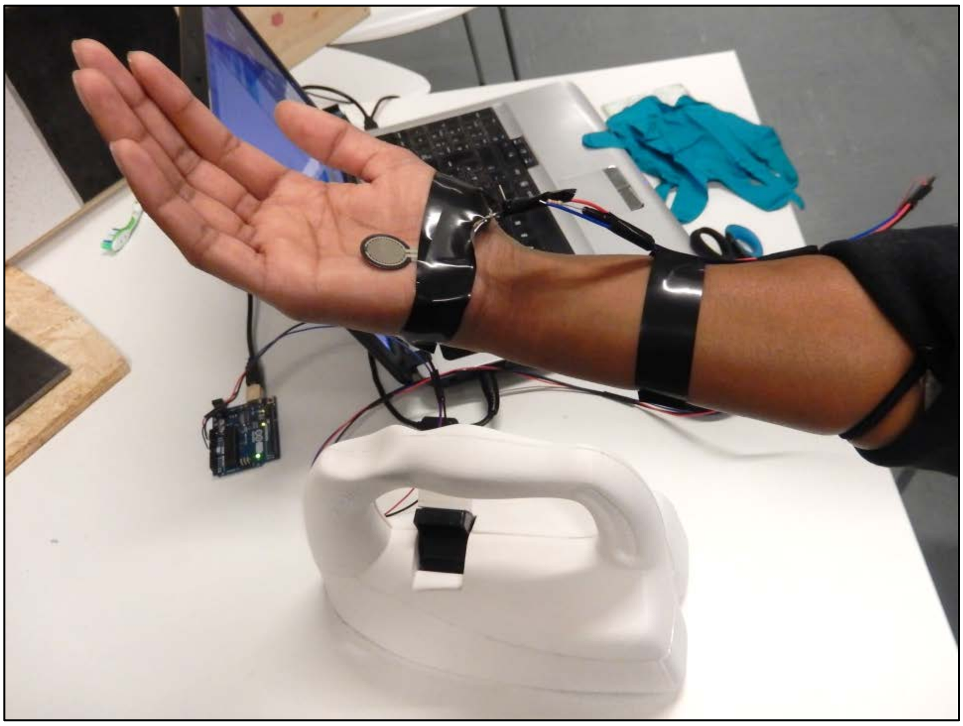


Figure 16-7: Henkel prototype pressure test set-up

However, while testing the participant expressed that she also put a lot of pressure on the fingertip of the index finger while using the Jif scrub so a second round with measurements was done for this tool.

16.3.2 Results

The tools were tested one by one and the results can be found in Figure 16-8. The up and down cleaning movements can easily be read from the zigzagged pattern on the graphs. It also shows the length of the cleaning strokes; Henkel prototype has clearly a longer up/down movement than the Jif scrub.

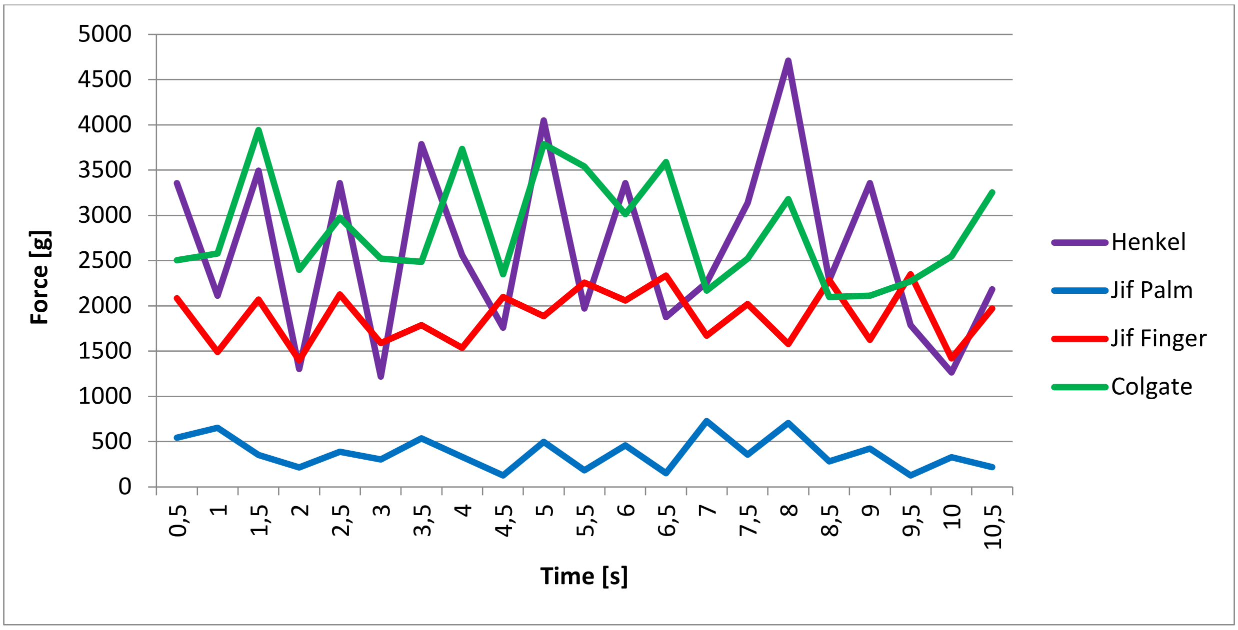


Figure 16-8: Force applied on the different cleaning tools during the test

The average force applied to the tools were 2837g for the Henkel prototype, 2627g for the Colgate toothbrush, 376g on the palm and 1887g on the fingertip using the Jif scrub. The active area of the sensor is 1,69 cm^2 (Interlink Electronics Inc., n.d.), which means that all the forces are far below the pressure limit of $10kg/cm^2$ as stated in section *13.1 Design analysis*.

Figure 16-9 shows the test participant holding the Henkel prototype in a positive coupling grip as described in section *13.1 Design analysis*. Throughout the vertical movement the angle between the neutral position of the wrist (green line) and the axis of grip (blue line) varied between 100-120 degrees.

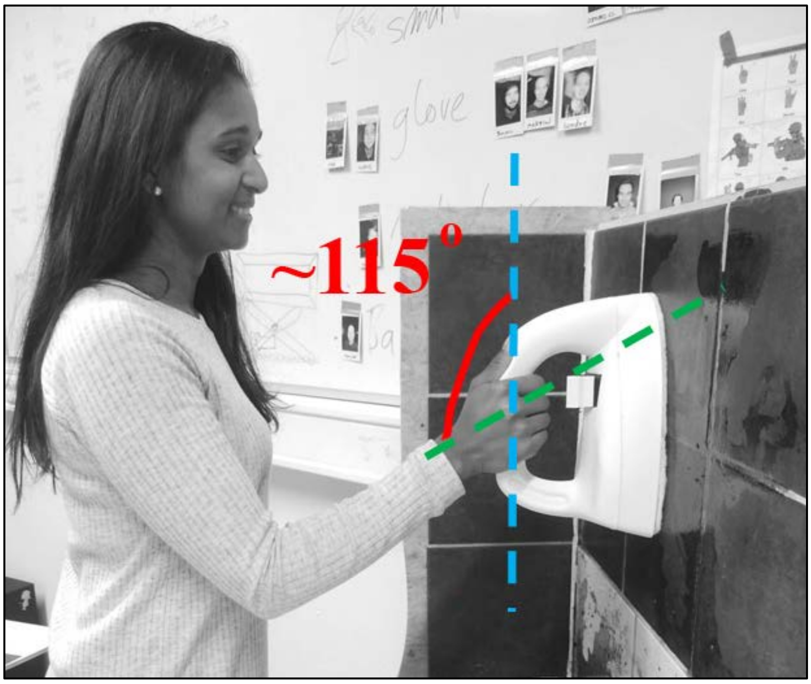


Figure 16-9: The Henkel prototype positive coupling grip with an approximate neutral wrist posture

16.4 User cleaning evaluation and visual feedback

The aim with this test was to see how well the different tools were able to remove a beetroot stain from the tile wall prototype. The beetroot had been on the wall for about two months, so it had fastened properly to the grouts and tiles, see Figure 16-10.

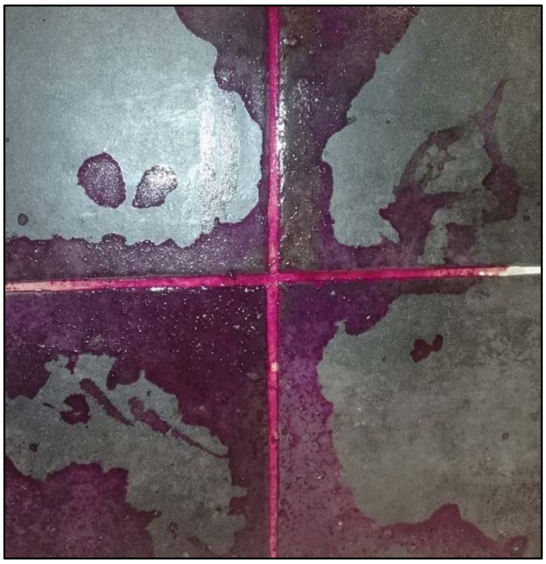


Figure 16-10: Beetroot stain before the cleaning test

All of the tools were wetted again and new soap was applied to the toothbrush, as described in section *16.3 Force transmission*. This time each tool was used to clean a separate area of the grout for one minute. The movement was purely vertical up and down and the wall prototype was standing vertically. The results are shown in Figure 16-11 (the wall was laid down to take the photograph)

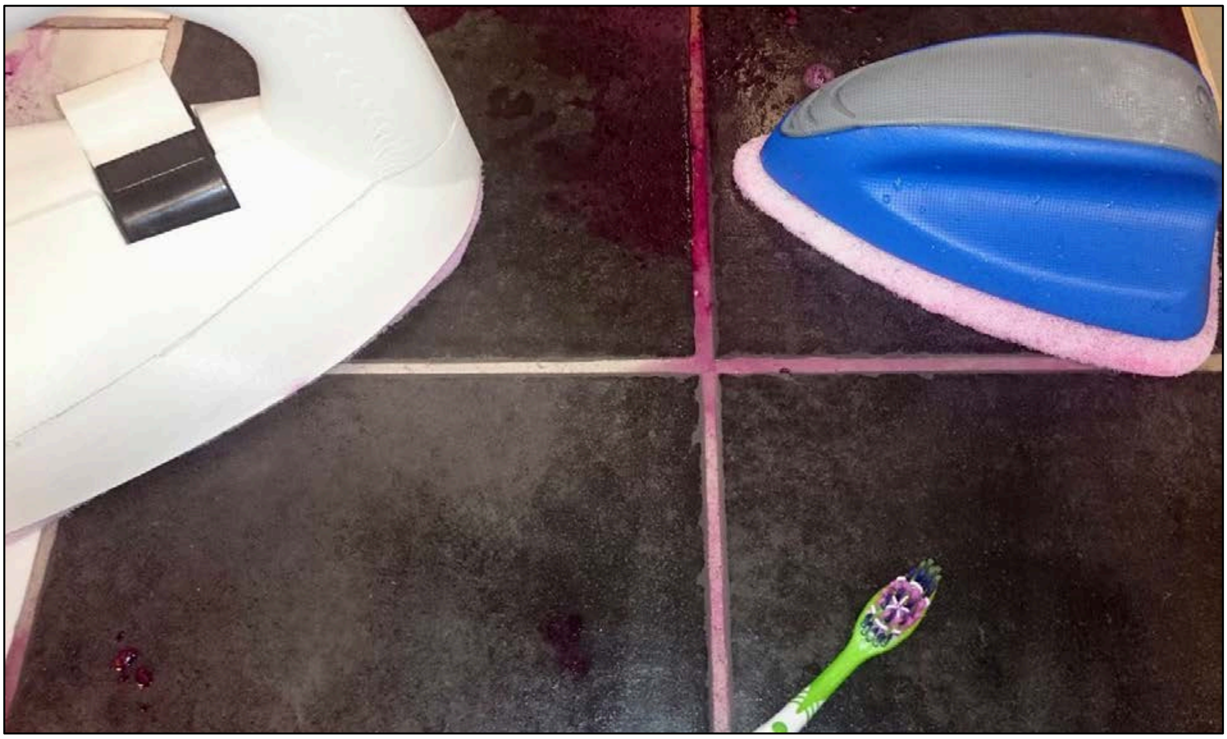


Figure 16-11: Cleaning test results

It is easy to see that the Henkel prototype was the only tool that managed to remove all of the stain and recreate the white/grey color of the grout. The toothbrush did remove most of the color, but because of the small cleaning area of the brush the one-minute time limit was not enough to get a good result. The Jif scrub was only used parallel with the cleaning surface and the sponge did not touch the concave grout surface. It is possible to flip the Jif scrub and use the sides or the front tip, but doing this resulted in an even worse arm-wrist posture that could not be considered recommendable, so we excluded it from the test. In addition, the sponge was attached with Velcro straps in the center of the tool so whenever the sides were used for cleaning the sponge would slip to the side, resulting in the plastic scratching the grouts.

The design of the back of the handle of the Henkel prototype with the grip rails facilitated stabilization, grip and force when cleaning in high areas as illustrated in Figure 16-12.

Figure 16-12: Cleaning with the Henkel prototype in high areas

During the user test the participant put down the Henkel prototype in such a way that it balanced on the back of the housing and the handle (see Figure 16-13). This was a new learning, but it was clearly an advantage as the tool can be put down without sullying other surfaces during cleaning and when it is put away between use the sponge will dry avoiding bad smell or growth of mold.

Figure 16-13: Henkel prototype position when not in use

16.5 Discussion

The results from the pressure test were credible. The FSR sensor had a range from 0-10kg, and when pinching the sensor as hard as possible we got values around 7500g which corresponded to an ADC value around 1000. It is possible that the forces applied were slightly higher than guesstimated by the script but they were still far below the limit and the different results are comparable to each other. The three tools had similar force values (when compared with the Jif fingertip result) and this strengthens the value and credibility of the subjective evaluations.

The Henkel prototype had the highest average applied force, but the pressure was evenly distributed over the lumbrical origin of the inner palm. The aim to achieve an angle between 100-110 degrees between the tool handle and arm-wrist system that would ensure a direct force transmission from the user to the work surface was closely reached. As Figure 16-9 illustrates, when the test participant was standing in a neutral position the angle was slightly higher, but she also expressed that the ergonomic handle gave her a stable and good grip, which made her able to use force from the whole arm (Participant A, 2016). Based on findings in section *16.2 Hand and wrist postures* the wrist posture was clearly best holding the Henkel prototype.

The Colgate toothbrush had a pressure result almost as high as the Henkel prototype, but all the pressure is located in one pressure point on the inner joint of the index finger. Based on these results, the discomfort with the fingernails digging into the palm (discussed in section *16.2 Hand and wrist postures*), the poor subjective user evaluation and the bad cleaning result the toothbrush is not considered a satisfying cleaning tool.

It was more difficult to test the Jif bath scrub. As mentioned in section *16.3.1 Arduino and the test set-up* two pressure tests had to be done. During the first one the FSR sensor was located in the middle of the palm, but the results were very low with an average force of 376g. When the FSR sensor was moved to the fingertip the results changed to an average force of 1887g. This meant that the direct transferred force from the arm was only one fifth of the force applied by the index finger, which is far from an ergonomic grip. The weight of the Jif scrub (102g) is almost a seventh of the weight of the Henkel prototype, but the participant still expressed that the Jif scrub was heavier to use over time because of the badly fitted grip (Participant A, 2016). Considering the Jif scrub is designed for cleaning tiles and grouts, the visual result in Figure 16-11 was disappointing and combined with the poorly executed ergonomics and the poor user evaluation the overall impression was bad.

These tests and user evaluations showed that the Henkel prototype has potential. The work done on the ergonomics really paid off and subjectively it is already slightly better than its competitor, the Jif bath scrub. Considering that the tests were conducted with the first prototype, the results were positive and satisfying. Some feedback, like the high weight and the large size of the prototype were already known, and it will be an area of focus for the next prototype.

16.6 Uncertainties and sources of error

First of all, the testing and user evaluation done throughout the process of this master's thesis are not scientific experiments in the fullest sense. They were rapid prototyping testing/evaluation cycles with a higher degree of freedom when it comes to external conditions, number of test participants and set-up. This was discussed with the supervisor and Henkel representatives, where the conclusion was that user satisfaction was the essential objective with the tool, and therefore subjective user evaluation and testing was satisfactory.

Considering the testing in section *16 Testing and evaluation* there was only one test participant. This obviously was not optimal, but due to time restriction and the difficulty of getting test participants this close to the deadline of the master's theses it was an acceptable solution. The handle ergonomics testing was the test where the accuracy of the results had improved the most with a higher number of participants. Kluth et al. (Strasser, 2007) used 12 participants for their study which gave them an average value for each hand segment. It would also have been interesting to see prints from a large male hand as well to compare the design for the other extreme user (the participant had a rather small female hand). The hand and wrist posture evaluation was partly subjective since the participant was asked to hold the tools in a "neutral position", however the results were good and it was clear that the goals for the handle ergonomics were achieved. Including several user test participants for the subjective description parts would have given a broader understanding, and maybe some pain points would have been amplified, but the quality of the feedback from the test participant was high and it gave us a lot of useful information.

The aim with pressure/force test with the Arduino and FSR sensor was to compare the three cleaning tools, so having one set of results from one participant was preferable (avoid variables such as height, muscular strength etc.). However, the test would have been more conclusive if the participant would wear a glove with multiple FSR sensors so that each hand segment could be compared against each other. As discussed in section *16.5 Discussion* the values from the script are guesstimated, so the absolute values of the readings are uncertain, but the relative values are comparable. As always, when working with electrical components errors with the components and the scripts could have affected the result, but in this case the script and the circuit was quite simple and easy to control.

17 Improvements – the beta prototype

The main issue with the Henkel prototype was the weight and the size. The handle was too high above the rest of the housing which made it less stable than what it optimally could be. The size of the housing was also too big, but this was set by the length of the shaft of the vacuum cleaner mechanism. A solution to this could be to look for a suitable smaller vacuum cleaner head as mentioned in section *14 Function* or design, 3D-print and machine the entire mechanism. The last option would be necessary before a production anyways. The tests concerning the ergonomic design of the handle gave excellent results so the challenge for the beta prototype would be to combine the current dimensions of the handle with a scaled down size of the bottom part of the housing.

The downscaling of the prototype would decrease its weight, but the 3D-printing process is the main reason for why the prototype is so heavy. As can be seen in Figure 13-16 the inner structure of a 3D-print is a fine diamond pattern that is created to be able to build the model. The final product would most likely be injection molded which does not require the same type of support structure. There would still have to be some support structure for the brush mechanism, but most of the housing could be hollow. This obviously requires a new 3D-model with the new inner walls.

A second prototype was 3D-printed with a Blueprint 3D-printer. Unfortunately there was no time to include the dimensional changes into a new print so this print is only a downscaling of the 3D-model of the first Henkel prototype, but it still gives a much better impression of the wanted design considering size. The weight is still too high (523g) due to the compact model as a result of the selective heat sintering (SHS) 3D-printing process. The two prototypes are shown in Figure 17-1, and a comparison with the main dimensions can be found in Figure 17-2.

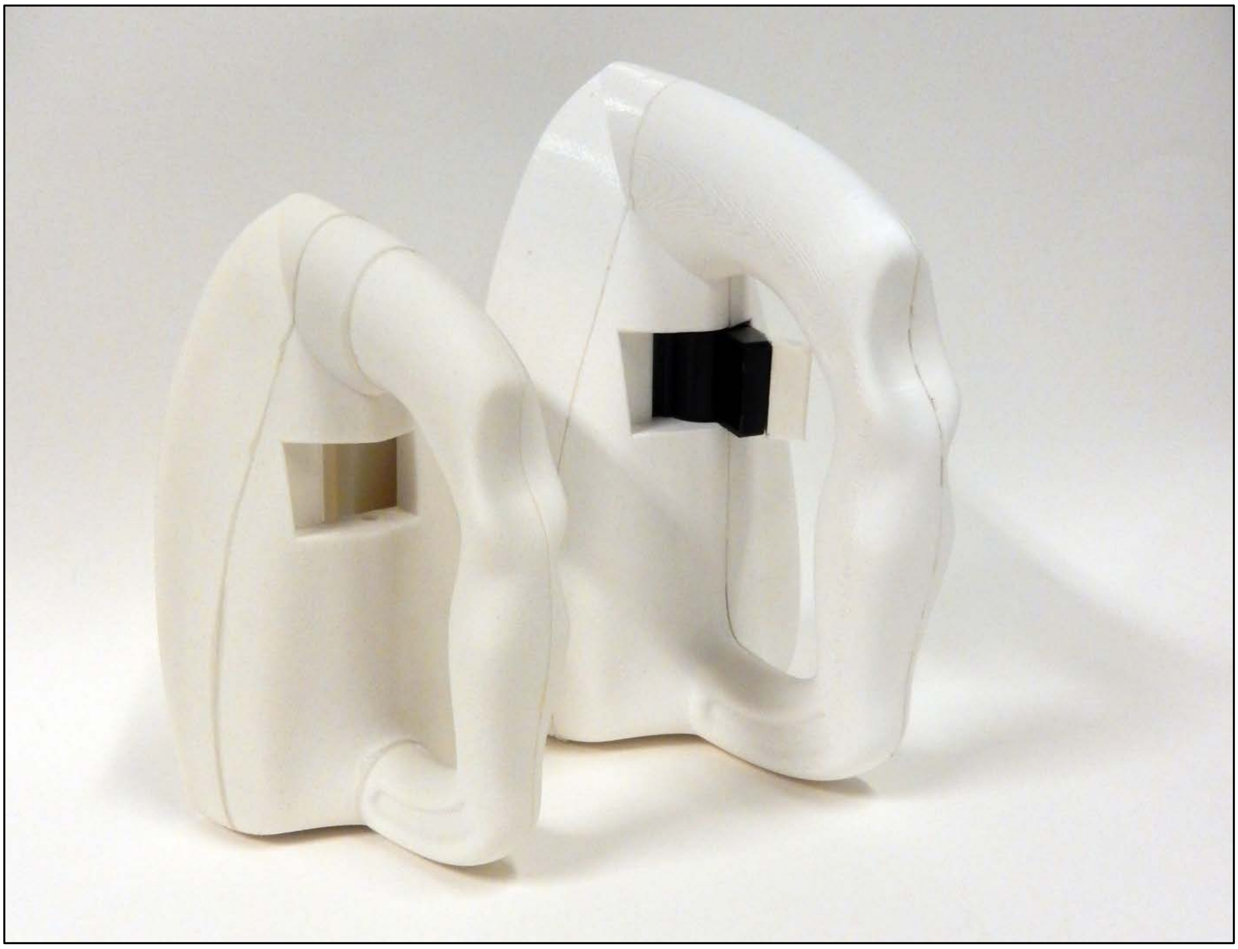


Figure 17-1: The visual (left) and functional (right) prototype

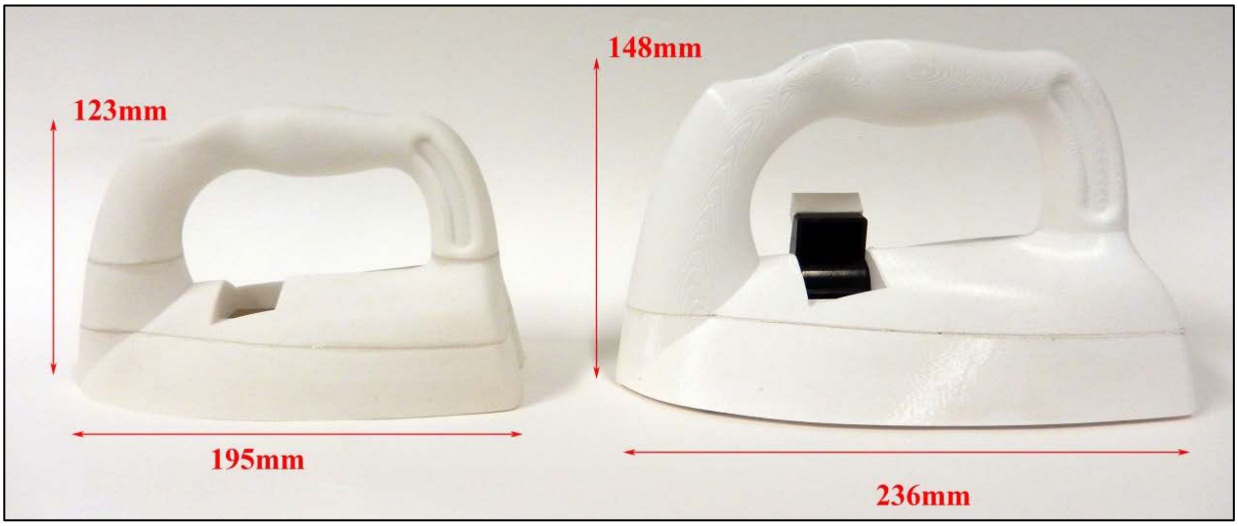


Figure 17-2: The two prototypes with main dimensions

Another area of improvement would be the brush. The advantage of the strip brush was that the length could be cut to fit the model. However, the brush used for the prototype was a bit too soft. The bristles were cut down to about half length to increase the stiffness, but then they were almost too short when the tile cleaning pads were attached. The brush should also reach further in the front of the housing so that the tip can be used to reach into corners and such. A small bend in the front of the brush (similar to the bend of the "slim brush" in Figure 7-6 in section *7.1 Tile wall experiment*) and an adapted housing could be one solution, but this should be explored and tested further. A different solution for the attachment of the tile-cleaning sponge should also be explored. The Velcro solution did work, but it was not optimal. It was ok when the sponges were dry, but as soon as there were in contact with water and soap they often fell off.

To make sure that the downsizing and the new mechanism with the improved brush are compatible a third rapid 3D-printed prototype should be made without considering the inner walls. During this process new challenges and insight might appear during the way creating the need of more prototypes, but the idea is that the next and improved prototype should be a pre-production prototype with a much more completed look including; surface treatment, color, a better fitted tile sponge and attachment system, the overmolding layer and inner wall structure.

17.1 Further work

To take the product to a next level it would be interesting to develop a motorized version as mentioned in section *11.2 Chosen concept – Manual cleaning "iron"*. Further testing should be arranged to compare the cleaning experience and results between the manual and motorized version. Then the selected version, if not both, should be refined and taken to the pre-production phase. During this process possible material suppliers should be contacted to retrieve price offers. Detailed production drawings, assembly drawings and part lists must be made in addition to required documentation and safety data sheet. Drawings, specifications and 3D-models must be up to date and sent to fabrication to create the molding die and prepare the production.

Before the product can be launched packaging must be developed and there is also a marketing job to be done. Upselling products such as refill sponges, a particular tile and grout soap to be sold with the tool or storage systems should be considered as well. Additional refill soap cartridges that are inserted into the tool somehow could also be an interesting idea to test.

18 Conclusion

The process started with the quest to develop "something for a bathroom, but not completely restricted to the bathroom" for the Colombian market, which would add value to Henkel AG & Company, KGaA. Both the problem and solution space were entirely undefined and there was no definite way to reach a final product. This is the textbook example of a case that has a great potential benefit of applying design thinking methodology, and where traditional product development based on requirements would have been practically useless. The preliminary need finding work for this master's thesis was conducted during the fall of 2015 and documented in the pre-master's project. Together with representatives from Henkel it was decided that the need of a tool to clean tiles and grouts was an exciting product idea to explore. At this point the process shifted from need finding into the wayfaring phase. The essence of wayfaring is to imagine, design, build, test and evaluate in rapid learning cycles. This is clearly reflected in this master thesis by the many different ideas, tests and experiments, workshops and prototypes that have continuously influenced and directed the development process. Especially the ideation and concept workshop at NTNU gave a boost to the divergent phase where more than 10 different concepts were rapidly probed. During the convergent phase, where also Henkel was consulted, the "manual cleaning iron" concept was chosen for further development.

The main functions and competitive features, such as the ergonomic handle design and the brush function were developed and tested first, in accordance with the wayfaring methodology. The repetitive and force-required movement during tile and grout-cleaning makes a high demand to the tool to ensure an ergonomic body posture. A lot of time and research was invested into the handle design, which according to the user evaluation and the force transmission test paid off. The result was a comfortable grip with an effective force transmission that was highly preferred over the competing Jif bath scrub.

During the 3D-modeling, 3D-printing and the prototype assembly phase a lot of new insight was gained. The possibility to test a physical prototype of such a high quality only a short week after the 3D-model was finished was definitely a motivation. The only negative factor was that there was not enough time left of the semester to develop a better fitted brush mechanism, so the prototype ended up being much bigger than envisioned. However, we succeeded in creating a "proof of function" prototype to conduct the testing, which was our first priority. Later, a second "proof of design" prototype was printed to get a more realistic impression of the size, so the two prototypes together gave a more comprehensive understanding of the concept.

The final goal in any product development process is to get the idea into production and sale. Time restriction was the main challenge for this project, but all the work and tests that were done clearly shows that the prototype has great potential. What makes this concept stand out compared to existing products is the two-in-one solution for tile and grout cleaning, combined with the ergonomically designed handle. Two common characteristics for most of the existing products on the market is that they either have a friction coupling power grip (holding a toothbrush), as the Jif scrub, Sonic Scrubber, Grout Gator and the Shower Shimmy, or the grip requires the use of protective gloves to avoid skin contact with the cleaning detergent, which is the case with the Jif scrub and the Scotch-Brite Grout Scrubber. The force transmission test results showed that the Henkel prototype had the highest average force applied, however, according to the user test evaluation it was still the favored cleaning tool. The expectation is that the next prototype will be lighter and smaller, hence the average force reduced, but that the user satisfaction and cleaning result will be the same or better.

For Henkel, this is a completely new addition to their product portfolio. In addition to the income from sale, it could be integrated as a branding tool. During the cooperation with Henkel it became clear there is a constant need to invent new products, introduce new smells or develop a new variation of a product to keep the interest of the consumers because of the large number of competitors. If the tool would be included in a cleaning detergent line, the unique look of the tool combined with an eye-catching packaging could be something that could boost the attention to the brand.

There is still a lot of work, further development and testing needed before the prototype can be launched to the market, but this master's thesis confirms that there is a need for such a tool and that the development of the design and function is on the right path.

18.1 Learnings and reflection

The greatest learning I am left with from this master's thesis is that I find this type of product development and design, using design thinking methodology, to be extremely rewarding and a lot of fun. The freedom of the assignment description allowed me to influence the development path direction in accordance with my interests, and the result ended up to be the perfect mixture between technical and creative challenges.

I was extremely lucky to have access to TrollLABS during the entire year, where I among other things arranged the workshop, built and tested prototypes and got a lot of inspiration and advice from my fellow "Troll" developers. I was also lucky to have a project founding that covered my trip to Colombia, Karen Cuesta's visit to Trondheim and all the testing and prototyping material.

Looking back at the process as a whole, I wish I had urged an earlier meeting with Henkel for the concept presentation. In the weeks before the meeting the path had directed slightly towards a development of the motorized concept, but during the meeting it became clear that a manual tool was more in accordance with Henkel's product policy and guidelines. If the meeting had been held in the end of March, and not the end of April, these weeks could have given more leeway to the prototyping and testing, or the freed up time could have been used to develop the beta prototype. However, this is how product development works in real life, especially when several parties from different countries are involved, and it shows how important it is to plan well ahead.

The 3D-modelling took much more time than I expected. I had experience with Inventor, but mostly with assemblies and production drawings, not creating new parts. Due to the complex shape of the tool a free-form 3D-modelling software such as Rhino would probably have been a better suited option. However, by the time I was made aware about this program the model was almost finished so I decided to continue with Inventor.

References

AleCastillo92. (2009, November 4). Javier Gomez Lopez. Retrieved from http://www.missosology.info/forum/viewtopic.php?t=24716

Alibaba. (n.d). Caulk (Silicone). Retrieved February 23, 2016, from http://www.alibaba.com/product-detail/3TREES-Neutral-All-Purpose-Silicone-Sealant_60268544587.html

B_E_N. (n.d.). What is an Arduino? - learn.sparkfun.com. Retrieved from https://learn.sparkfun.com/tutorials/what-is-an-arduino

blackmold.awarespace.com. (n.d.). What is Mold & Toxic Mold? Information, Spores, Colonies. Retrieved from http://blackmold.awardspace.com/

Bustamante, J. (2013). *Índice de Pobreza Multidimensional (IPM) Colombia*. DANE.

Carleton, T., Cockayne, W., & Tahvanainen, A.-J. (2013). Playbook for strategic foresight and innovation.

Carranza Tresoldi, J. (2013, January 23). Indicators - ¿How are urban and rural areas determined in census cartography in Latin America? Retrieved from http://www.popclimate.net/indicators/view/31-%C2%BFhow-are-urban-and-rural-areas-determined-in-census-cartography-in-latin-america

Central Intelligence Agency. (2016). *The World Factbook 2016-17*. Washington, DC. Retrieved from https://www.cia.gov/library/publications/the-world-factbook/geos/co.html

Cobabe, A. D., Meyers, D. O., Goff, D. E., Thiess, W. K., & Jackson Zhao, Q.-C. (2013, September 17). Cleaning apparatus with reciprocating brush head. Retrieved from https://patents.google.com/patent/US8533886B2/en

ColArt International SA. (2013). *Safety Data Sheet* (No. SDS no. 12591).

Colombia University. (2009). Urban extents. Retrieved May 18, 2016, from http://sedac.ciesin.columbia.edu/data/collection/grump-v1/maps/gallery/search?facets=region:south%20america

Cura. (2016). Cura (Version 15.04.5) [Windows].

Dávila, J. D. (2002). *Urban Poverty Reduction Experiences in Cali, Colombia: Lessons from the Work of Non-profit Organisations*. International Institute for Environment and Development. Retrieved from http://discovery.ucl.ac.uk/42/1/IIED_Davila_Cali_Colombia.pdf

Dembner, S. A. (2013). *Armonizar el medio ambiente con el desarrollo sostenible.* Organizacion de las Naciones Unidas para la Agricultura y la Alimentacion, Roma (Italia). Retrieved from http://www.sidalc.net/cgi-bin/wxis.exe/?IsisScript=CENIDA.xis&method=post&formato=2&cantidad=1&expresion=mfn=050063

Departamento Administrativo Nacional de Estadística (DANE). (2015a). *Pobreza monetaria por departamentos 2013*.

Departamento Administrativo Nacional de Estadística (DANE). (2015b). *Pobreza Monetaria y Multidimensional 2013*.

Dr. Pal Singh, A. (2011, October 10). Flexor Tendon Zones of Hand. Retrieved from http://boneandspine.com/flexor-tendon-zones-of-hand/

Eagle Brand Tiles. (2015, January 30). Glazed. Retrieved from http://www.eaglebrandtiles.com/blog/2015/01/30/shine-on-matte-finish-tiles/

Edwards, L. (2016, May 24). Future batteries, coming soon: charge in seconds, last months and power over the air. *Pocket-Lint*. Retrieved from http://www.pocket-lint.com/news/130380-future-batteries-coming-soon-charge-in-seconds-last-months-and-power-over-the-air

EHS Today. (2005, December 20). Ergonomic Guidelines for Selecting Hand and Power Tools. Retrieved March 25, 2016, from http://ehstoday.com/health/ergonomics/ehs_imp_37964

Entorno inteligente. (2015, October 4). VENEZUELA: Colombia y Venezuela estarán sin fronteras con el Proyecto Mapa. Retrieved May 18, 2016, from http://www.entornointeligente.com/articulo/7086694/'/articulo/7086694/VENEZUELA-Colombia-y-Venezuela-estaran-sin-fronteras-con-el-Proyecto-Mapa-04102015'

Expert Verdict. (n.d.). Sonic Scrubber picture. Retrieved March 14, 2016, from http://www.expertverdict.com/ev/sonic-scrubber-electronic-cleaning-brush

Floorvinyl. (2014, May 8). Cement. Retrieved from http://floorvinyl.freluxe.com/grouting-vinyl-tile-floors/

Flora. (2015, October 7). Corners. Retrieved from http://www.victory-eu.org/oregon-tile-and-marble-great-tile-selection-with-endless-choices/marble-subway-tile-with-corner-shelf-and-hexagon-tile-flooring-by-oregon-tile-and-marble-ideas/

Friends-of-Fritzing foundation. (2015). Fritzing (Version 0.9.2b). Retrieved from http://fritzing.org/

German Cosmetic, Toiletry, Perfumery and Detergent Association. (2015). IKW Recommendation for the Quality Assessment of the Product Performance of All-Purpose Cleaners 2014. *SOFW Jurnal*, (141), 47–56.

Gerstenberg, A., Sjöman, H., Reime, T., Abrahamsson, P., & Steinert, M. (2015). A Simultaneous, Multidisciplinary Development and Design Journey – Reflections on Prototyping. In *Entertainment Computing - ICEC 2015* (Vol. 9353, pp. 409–416). Cham: Springer International Publishing. Retrieved from http://link.springer.com/10.1007/978-3-319-24589-8_33

Goepel, K. D. (2013). BPMSG AHP Excel template with multiple inputs. Version. Retrieved from http://bpmsg.com/wordpress/wp-content/uploads/2014/01/AHPcalc-v2013-12-24a.pdf

Goepel, K. D. (2015a, June 7). AHP excel template with multiple inputs.

Goepel, K. D. (2015b, June 7). New AHP Excel template with multiple inputs | BPMSG. Retrieved March 16, 2016, from http://bpmsg.com/new-ahp-excel-template-with-multiple-inputs/

Good industry practices. (n.d.). Grouting for stones and tiles. Retrieved from https://www.bca.gov.sg/Publications/EnhancementSeries/others/design2Ch6.pdf

Google maps. (2015, November 2). Google Maps. Retrieved May 18, 2016, from https://www.google.com/maps/@63.4096486,10.3643505,10z?hl=no

Grabowski, B. (2011, October). Tool for cleaning tile and grout. Retrieved from https://www.google.com/patents/US8028366

Grout Gator. (n.d.). Grout Gator. Retrieved March 14, 2016, from http://www.groutgator.com/

Hefner, E. L. (1995, May). Tile grout scrubber. Retrieved from https://www.google.com/patents/US5412829

Henkel AG & Co. KGaA. (n.d.). Henkel AG & Co. KGaA. Retrieved May 14, 2016, from http://www.henkel.com/

Hisanaga, K., Yamada, K., Tsutsui, T., & Tanizawa, Y. (2008). Dirt and Grime in Bathrooms: Their Chemical Composition and the Origin of the Triacylglycerols Contained Therein. *Journal of Surfactants and Detergents*, *11*(4), 315–322. http://doi.org/10.1007/s11743-008-1085-3

Homedepot. (n.d). Glazed/Un-glazed. Retrieved February 24, 2016, from http://www.homedepot.com/p/Rust-Oleum-Transformations-1-qt-Pure-White-Cabinet-Small-Kit-263232/203921577

Hudson, R. A., & Bushnell, D. (2010). Colombia - a country study. In *Colombia: a country study* (5th ed, pp. 101–103). Washington, D.C: Federal Research Division, Library of Congress : For sale by the Supt. of Docs., U.S. G.P.O.

Interlink Electronics Inc. (n.d.). Interlink Electronics FSR Force Sensing Resistors Integrating Guide. Retrieved from http://seat.massey.ac.nz/143485/documents/2010reports/Sanjay%20David.pdf

Jafarmadar, H. H. (2000, May). Apparatus for cleaning tile grout joints. Retrieved from https://www.google.com/patents/US6059475

Jaka. (2015, May 27). Mold. Retrieved February 24, 2016, from http://orangemold.net/cleaning-mold-and-mildew-in-bathroom/

Jaramillo Otoya, A. (2013, September 4). Colombia elegido el país más amable del mundo. *Las2orillas*. Retrieved from http://www.las2orillas.co/colombia-es-considerado-el-pais-mas-amable-del-mundo/

Jim, L. (2016, April 28). Force sensitive resistior example. Retrieved from https://codebender.cc/sketch:295135

John tiling. (n.d). Porcelain. Retrieved February 24, 2016, from http://www.johntiling.com/Porcelain.html

Kamrani, A. K., & Nasr, E. A. (2010). *Engineering Design and Rapid Prototyping*. Boston, MA: Springer US. Retrieved from http://link.springer.com/10.1007/978-0-387-95863-7

Knoji. (2013, January 29). Limescale. Retrieved February 24, 2016, from https://tiles-tiling.knoji.com/how-to-clean-stained-tiles-with-stubborn-dirt-on-them/

Kordick, E. (2008, March). Grout cleaning apparatus. Retrieved from https://www.google.com/patents/US20080229530

Leifer, L. J., & Steinert, M. (2014). Dancing with Ambiguity: Causality Behavior, Design Thinking, and Triple-Loop-Learning. In O. Gassmann & F. Schweitzer (Eds.), *Management of the Fuzzy Front End of Innovation* (pp. 141–158). Cham: Springer International Publishing. Retrieved from http://link.springer.com/10.1007/978-3-319-01056-4_11

Leikanger, K. K., Balters, S., & Steinert, M. (2016). Introducing the wayfaring approach for the development of human experiments in interaction design and engineering design science. Presented at the International design conference - design 2016, Dubrovnic - Croatia.

Lewis Call, K. (n.d.). Shower Shimmy. Retrieved March 14, 2016, from https://www.kickstarter.com/projects/showershimmy/shower-shimmy

Lilleborg AS. (n.d.). Jif Baderomsskrubb - Jifrent. Retrieved May 25, 2016, from http://www.jifrent.no/Produkter/Jif-Baderom-og-Toalett/Jif-Baderomsskrubb

Limseth, G. (2015). *Needfinding in Colombia* (Pre-master project) (p. 97). NTNU.

Llenado, R. A., & Neubecker, T. A. (2002). Surfactants. *Analytical Chemistry*, *55*(5), 93R–102R.

Luo, M., & Cho, W. (2011, November 22). Vacuum cleaner and cyclone module therefor. Retrieved from http://www.google.com/patents/US8062398

Margret. (2015, July 16). Ceramic. Retrieved February 24, 2016, from http://www.silenciobarnes.com/sweet-ceramic-tile-saw-home-depot/

Moss, L. (2015, May 11). Colombia's Unemployment Rate Falls to Lowest Ever 8.9%. *Finance Colombia*. Retrieved from http://www.financecolombia.com/colombias-unemployment-rate-falls-to-lowest-ever-8-9/

National Center for Environmental Health. (2014, May 22). CDC - Mold - General Information - Basic Facts. Retrieved April 1, 2016, from http://www.cdc.gov/mold/faqs.htm

Nikolae. (n.d). Manual. Retrieved February 24, 2016, from http://www.123rf.com/photo_17755442_hand-symbol.html

Oral B. (n.d). Oral-B. Retrieved March 1, 2016, from http://www.oralbnordic.com/en-SE/productdetail/oral-b-pro-5000-electric-toothbrush

Participant A. (2016, May 24). User test.

Petersik, S. (2008, March 21). Different materials. Retrieved February 24, 2016, from http://www.younghouselove.com/2008/03/bathroom-breakthrough/

Pheasant, S. (2014). *Bodyspace* (Second). CRC Press. Retrieved from http://site.ebrary.com/lib/ntnu/reader.action?docID=10057184&ppg=6

Philips. (2016, February 25). Philips. Retrieved March 1, 2016, from http://download.p4c.philips.com/files/h/hx9332_05/hx9332_05_pss_.pdf

Pixbam. (n.d). Motor. Retrieved February 24, 2016, from http://www.pixbam.com/motors/brushless-motor-instruct/4134

Plattner, H. (2009). Bootcamp Bootleg Design Thinking. Institute of Design at Stanford University.

pngimg.com. (n.d.). Hand. Retrieved May 22, 2016, from http://pngimg.com/download/905

Porex Corporation. (n.d.). Technology: PE Plastics & Porous Polyethylene Materials. Retrieved May 13, 2016, from http://www.porex.com/technologies/materials/porous-plastics/pe/

Quickie. (n.d.). Tub n' Tile Power Scrub. Retrieved March 14, 2016, from http://www.quickie.com/product/tub-n-tile-power-scrubber/082?contextCategory=hpower

Ritchey, T. (1998). General morphological analysis. In *16th EURO Conference on Operational Analysis*. Retrieved from http://www.swemorph.com/pdf/gma.pdf

Román, C. (2011, December 13). Colombia: "Las mujeres Awá somos la raíz del árbol de la vida." Retrieved May 19, 2016, from http://www.acnur.org/t3/noticias/noticia/colombia-las-mujeres-awa-somos-la-raiz-del-arbol-de-la-vida/

Scotch-Brite. (n.d.). Scotch-Brite™ Grout Scrubber. Retrieved March 14, 2016, from http://www.scotch-brite.ca/wps/portal/3M/en_CA/CAScotch-Brite/Scotch-Brite-CA/Products/Product-Catalogue/~/Scotch-Brite-Grout-Scrubber?N=4337+3294227397+3294529206&rt=d

Sonic Scrubbers. (2013, January 14). Sonic Scrubbers. Retrieved March 14, 2016, from http://www.sonicscrubber.co.uk/

Stefan Karsten. (2016, February 17). Surface dirt in bathrooms [Phone].

Steinert, M., & Leifer, L. J. (2012). "Finding One"s Way': Re-Discovering a Hunter-Gatherer Model based on Wayfaring. *International Journal of Engineering Education*, *28*(2), 251.

Strasser, H. (2007). *Assessment of the Ergonomic Quality of Hand-Held Tools and Computer Input Devices*. IOS Press. Retrieved from http://site.ebrary.com/lib/ntnu/reader.action?docID=10196610&ppg=13

Swegle, R. (2016, February 15). Hot Water Extraction vs Steam Cleaning. Retrieved March 4, 2016, from http://jeffersoncity.steamprocarpet.com/hot-water-extraction-vs-steam-cleaning/

Sys teco. (n.d). Stain. Retrieved February 24, 2016, from http://www.sys-teco.com/tile-cleaning/rust-removal-from-tile.html

University of Washington. (u.d). Fatty Acids and Triacylglycerols [https://courses.washington.edu]. Retrieved February 16, 2016, from https://courses.washington.edu/conj/membrane/fattyacids.htm

UPCA. (n.d). Hard to reach. Retrieved from http://cleaningalliance.com/store/product/swiffer-sweeper-dry-sweeping-cloths-mop-and-broom-floor-cleaner-refills-febreze-lavender-vanilla-comfort-scent-48-count/

Vadodara, F. (2015, February 27). Epoxy. Retrieved from http://fairscreedtgglow.blogspot.no/

Wallender, L. (2016, March 2). Porcelain vs. Ceramic Tile: Bet You Don't Know The Difference. Retrieved May 7, 2016, from http://homerenovations.about.com/od/tiling/a/Porcelain-Tile-Vs-Ceramic-Tile.htm

Ward, A., Liker, J. K., Cristiano, J. J., & Sobek II, D. K. (1995). The Second Toyota Paradox - How Delaying Decisions Can Make Better Cars Faster-liker-sobek.pdf. *Sloan Management Review*, (Spring), 43–61.

Wulvik, A., Balters, S., Steinert, M., & others. (2015). PHOTOGRAPHY-A NEW TOOL IN NEEDFINDING. In *DS 80-9 Proceedings of the 20th International Conference on Engineering Design (ICED 15) Vol 9: User-Centred Design, Design of Socio-Technical systems, Milan, Italy, 27-30.07. 15*. Retrieved from https://www.researchgate.net/profile/Martin_Steinert/publication/281104174_Photography-_The_Answer_to_Combining_Needfinding_and_Visual_Thinking/links/5622862108aed8dd19440156.pdf

Xrcise Expert. (2014, April 26). Plane of motion. Retrieved from http://www.xrcisexpert.nl/berichten-plane-of-motion/

Appendix A: Risk assessment

NTNU HSE	Risk assessment of Master thesis	Made by: Gina Limseth Approved by: Martin Steinert	Date: 02.02.2016

Location: Department of Engineering Design and Materials

Participants (w/ function):

Martin Steinert (advisor), Gina Limseth (Student), Karen Cuesta (Student) and participants in Tech. Push Workshop

Short description of main activity/process: Master thesis – Gina Limseth. Applying the wayfaring model in product development: case study "tile/grout cleaner"

Is the project purely theoretical? No

Signatures: *Advisor:* *Student:*

ID nr	Activity/process	Possible danger	Probability (1-5)	Consequence: Human (A-E)	Consequence: Environment (A-E)	Consequence: Economic /materialistic (A-E)	Consequence: Reputation (A-E)	Risk evaluation (human)	Comments/status Suggested actions
1	Prototyping in Realization lab. General workshop activities	Damage from use of heavy machinery/tools if used incorrectly.	3	C	A	B	B	C3	Participants have workshop and HSE certification from NTNU. Guidelines for each machine must be followed, appropriate safety gear must be used, and when in doubt; ask qualified personnel.
2	Prototyping in TrollLabs General workshop activities	Damage from lighter machines, but some are expensive.	2	B	A	B	B	B2	Participants have workshop and HSE certification from NTNU. Guidelines for each machine must be followed, appropriate safety gear must be used, and when in doubt; ask qualified personnel.
3	Workshop in TrollLabs Early stage prototyping workshop in groups	Damage from lighter machines, but some are expensive.	2	B	A	B	B	B2	All participants have workshop and HSE certification from NTNU. Most of the students are familiar in the TrollLab.

Probability is evaluated by the following criteria:

Very low 1	Low 2	Intermediate 3	High 4	Very high 5
1 time per 50 years or rarer	1 time per 10 years or rarer	1 time per year or rarer	1 time per month or rarer	Happens weekly

Consequence is evaluated by the following criteria:

Grading	Human	Environment (water, ground and air)	Economic/ materialistic	Reputation
E Very serious	Death	Very prolonged and non-reversible damage	Outage and activity stop >1 year	Credibility and respect significantly and lastingly damaged.
D Serious	Serious injury, possible disability	Prolonged damage and long recovery time.	Outage > ½ year Activity stop up to 1 year	Credibility and respect significantly damaged.
C Moderate	Serious injury	Smaller damage, but long recovery time.	Outage and activity stop < 1 year	Credibility and respect damaged.
B Low	Injury that requires medical care	Smaller damage and short recovery time.	Outage and activity stop < 1 week	Negative influence on credibility and respect.
A Very low	Injury that requires first aid care	Insignificant damage and short recovery time.	Outage and activity stop < 1 day	Small influence on credibility and respect.

Risk evaluation = Probability x Consequence (human)

The risk evaluation for human is calculated and evaluated from the risk matrix.

Color		Description
Red		Unacceptable high risk. Measures must be taken to reduce risk.
Yellow		Intermediate risk. Measures should be considered
Green		Acceptable risk. Measures can be considered

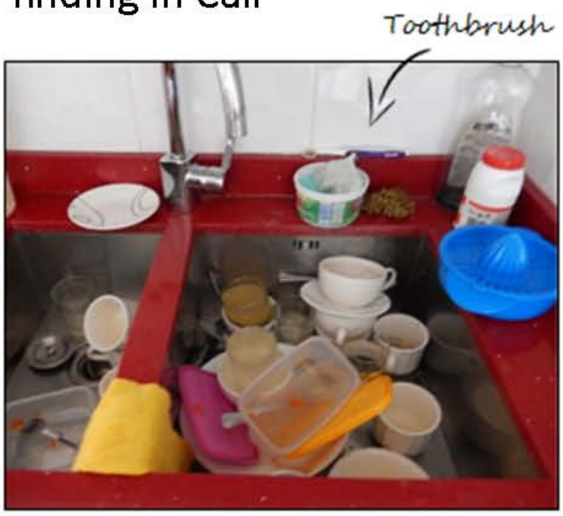
Risk evaluation for environment, economic/materialistic and reputation should also be done where a grade C or higher is found.

Consequence	Very Serious	E1	E2	E3	E4	E5
	Serious	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Low	B1	B2	B3	B4	B5
	Very Low	A1	A2	A3	A4	A5
		Very Low	Low	Intermediate	High	Very High
	Probability					

Appendix B: Photos from Colombia

Need finding in Cali

Karen's bathroom



Karen's kitchen

Karen's washing room

Need finding in Chocó

Gold mining shack polluting the Atrato river

Washing clothes in the muddy river

Drying clothes on the rooftop

Drying clothes on the rocks

Rainwater reservoir

Toilet

Riverboat transportation in Quibdó

Appendix C: Bathroom cleaning survey

Bathroom cleaning questionnaire

Female ☐ Male ☐

1. Who cleans the bathroom in your household?____________________

2. How often do you clean the bathroom?____________________

3. Roughly, how long do you take to clean the bathroom?____________________

4. What's the worst thing of cleaning the bathroom? Rank them from 1 to 4, where 4 is the worst.

   a. Shower ☐
   b. Sink ☐
   c. Bathroom floor ☐
   d. Toilet ☐

Why?

____

____

5. Which part is most difficult?____________________

6. What takes the most time?____________________

7. If you had friends coming to your house, and the entire bathroom is dirty and you can just clean one of the following, which one will you clean?

a. Shower
b. Sink
c. Bathroom floor
d. Toilet

Why?

____

____

8. How do you clean each one of these? Which products and tools you use?

a. Shower____________________

____

b. Sink____________________

____

c. Bathroom floor____________________

____

d. Toilet____________________

____

Appendix D: Bathroom cleaning survey results

Girls, n=13 (number of votes in parenthesis)

1	Who cleans the bathroom in your household?	Me (1) Me, husband (1) Me, flat mates (11)
2	How often do you clean the bathroom?	Every week (11) Every 1-2 weeks (1)
3	Roughly, how long do you take to clean the bathroom?	5-10 min (1) 10min (1) 15-30min (2) 20min (3) 30min (5) 1 hour (1)
4	What's the worst thing to clean in the bathroom? Highest score is the most difficult one.	
	Shower:	1+4+3+4+2+3+3+4+4+4+3 +2+4=**41**
	Sink:	3+2+2+1+1+1+2+2+1+2+1+4+1=**23**
	Bathroom floor:	2+1+1+3+3+2+1+1+2+1+2+1+3=**23**
	Toilet:	4+3+4+2+4+4+4+3+3+3+4+3+2=**43**
	Why?	**Shower in total 7** **Shower:** takes a long time, difficult to get away all soap stains (1), takes a long time, glass doors (1), lots of hair and takes a long time (1), takes a long time (1), drain is the worst (3) **Toilet:** Most dirty (2), most dirty, must bend down to clean floor and shower cabinet takes time (1), is disgusting (1) **floor:** most dirty (1) **Sink:** water lock always gets messy + limescale (1)
5	Which is the most difficult?	**Shower in total 8** Toilet (1), Glass doors in shower(1), Shower cabinet (1), None (1), Shower + floor (1)
6	What takes the most time?	**Shower in total 7** Toilet (3), Floor (1), Sink + shower (1), Shower + floor (1)
7	If you had friends coming over to your house, and the entire bathroom is dirty and you can just clean one of the following, which one will you clean?	
	Shower:	
	Sink:	1+1+1+1+1=**5**
	Bathroom floor:	
	Toilet:	1+1+1+1+1+1+1+1=**8**
	Why?	**Toilet:** Most likely to be used by others (2), guest must touch it (1), guests must touch it and they usually do

		not use the shower (1) **Sink:** easy to see that it is dirty (4), the most disgusting if dirty (1) **Toilet**: is most visible (2), disgusting if not clean (2), keep toilet seat down
8	How do you clean each one of these?	
	Shower	Water (1) Water, spray detergent. Cleans the drain (1) Squeegee (1) Soap and window cleaner, cloth, squeegee (2) Detergent spray, chloride for drain and shower head (1) Sponge, cloth, detergent (1) Water, detergent, cloth (1) Cloth, spray detergent, window detergent, squeegee (1) Rinse drain, spray detergent (1) Brush (1) Sponge, detergent (2)
	Sink	Water, detergent, brush (1) Water, spray detergent (2) Cloth (3) Cloth, detergent (5) Chloride and detergent (1) Sponge, cloth, detergent (1)
	Bathroom floor	Water, brush (1) Water, detergent (1) Floor cloth (1) Floor cloth, squeegee, detergent (2) Mop, detergent (4) Vacuum cleaner, floor cloth, chloride (1) Mop, detergent, cloth (1) Vacuum cleaner, detergent (1) Mop (1)
	Toilet	Detergent, brush (2) Spray detergent, paper, chloride, brush (1) Paper towels (1) Detergent, paper, toilet brush (1) Cloth, chloride, toilet brush (1) Toilet brush, cloth, chloride, toilet detergent (1) Cloth, detergent, toilet brush (2) Cloth, spray detergent, chloride, toilet brush (1) Toilet brush, cloth, detergent (1) Paper, chloride (1) Toilet brush, chloride (1)

	Guys, n=15 (number of votes in parenthesis)	
1	Who cleans the bathroom in your household?	Me and my parents (1) Me and my brother (2) Me, flat mates (10) Me (2)
2	How often do you clean the bathroom?	Every week (11) Every 1-2 weeks (4)
3	Roughly, how long do you take to clean the bathroom?	5min (1) 15min (2) 20min (1) 20-30min (5) 30min (3) 45min (1) 30-60min (1) 1 hour (1)
4	What's the worst thing to clean in the bathroom? Highest score is the most difficult one.	
	Shower:	4+4+4+4+3+4+4+2+3+3+4+3+3+4+3=**52**
	Sink:	1+1+2+2+2+1+1+1+1+2+1+2+1+1+1=**20**
	Bathroom floor:	2+2+1+1+1+2+2+3+2+1+3+1+4+3+2=**30**
	Toilet:	3+3+3+3+4+3+3+4+4+4+2+4+2+2+4=**48**
	Why?	**Shower in total 11** Shower: must scrub (1), most dirty (1), has to kneel (1), difficult to get away all soap stains (3), drain is nasty (4), takes a long time (1) **Toilet:** disgusting, difficult geometry (2), most disgusting (1) **Floor:** vacuum cleaning doesn't work on wet floor, mop boring (1)
5	Which is the most difficult?	**Shower in total 11** Shower drain (1), Toilet (3)
6	What takes the most time?	**Shower in total 8** Toilet (1), Shower drain (1), Floor (1)
7	If you had friends coming over to your house, and all the bathroom is dirty and you can just clean one of the following, which one will you clean?	
	Shower:	
	Sink:	1+1+1+1+1+1=**6**
	Bathroom floor:	
	Toilet:	1+1+1+1+1+1+1+1+1=**9**
	Why?	**Toilet in total 8** **Sink:** most likely to be used by others (2), most visible (1), the most disgusting if dirty (1), fastest to clean so it looks clean (1) Toilet: most likely to be used by others (5), most dirty

		(3)
8	How do you clean each one of these?	
	Shower	Brush (1) Detergent (7) Detergent, squeegee, cloth (2) Cloth (2) Cloth, scrub, detergent (1) Cloth, detergent (1) Sponge, detergent (chloride) (1)
	Sink	Water, spray detergent (7) Cloth (3) Cloth, detergent (2) Cloth, detergent (chloride) (1) Cloth, scrub, detergent (1) Cloth, detergent, paper (1)
	Bathroom floor	Water, detergent (6) Floor cloth (1) Mop (1) Water (1) Vacuum cleaner (1) Mop, cloth, detergent (1) Cloth, scrub, detergent (1) Cloth, detergent (2) Vacuum cleaner, mop, detergent (1)
	Toilet	Brush (2) Detergent (4) Cloth (1) Paper towels (1) Cloth, detergent (2) Cloth, scrub, detergent (1) Toilet brush, detergent (1) Disposable cloth, toilet brush, detergent (1) Cloth, detergent, chloride (1)

Appendix E: Product requirements AHP calculation results

AHP Analytic Hierarchy Process (EVM multiple inputs)

K. D. Goepel Version 07.06.2015 Free web based AHP software on: http://bpmsg.com

Only input data in the light green fields and worksheets!

n=	6	Number of criteria (2 to 10)	Scale:	1	Linear
N=	1	Number of Participants (1 to 20)	α:	0,1	Consensus: n/a
p=	1	selected Participant (0=consol.)	13	7	Gina Limseth

Objective: Calculate weights for different product requirements

Author: Gina Limseth

Date: 16-Mar-16 Thresh: 1E-07 Iterations: 6 EVM check: 2,0E-08

Table

	Criterion	Comment	Weights	Rk
1	Design	Ergonomics, color, shape	8,3%	4
2	Performance	Efficiency, reliability, usability, speed	40,3%	1
3	Price	Tool price, refill/maintainance	9,8%	3
4	Set-up time	Charging	2,8%	6
5	Adaptability	Flexibility, portability, reusability, fits all materials	33,9%	2
6	Weight		4,9%	5
7			0,0%	
8			0,0%	
9		for 9&10 unprotect the input sheets and expand the	0,0%	
10		question section ("+" in row 66)	0,0%	

Result

Eigenvalue			lambda:	6,578
Consistency Ratio	0,37	GCI: 0,34	CR:	9,2%

Matrix

		1 Design	2 Performance	3 Price	4 Set-up time	5 Adaptability	6 Weight	7 0	8 0	9 0	10 0	normalized principal Eigenvector
Design	1	1	1/7	1/2	6	1/8	3	-	-	-	-	8,31 %
Performance	2	7	1	5	9	2	5	-	-	-	-	40,27 %
Price	3	2	1/5	1	3	1/5	3	-	-	-	-	9,78 %
Set-up time	4	1/6	1/9	1/3	1	1/7	1/3	-	-	-	-	2,80 %
Adaptability	5	8	1/2	5	7	1	7	-	-	-	-	33,95 %
Weight	6	1/3	1/5	1/3	3	1/7	1	-	-	-	-	4,90 %
0	7	-	-	-	-	-	-	1	-	-	-	0,00 %
0	8	-	-	-	-	-	-	-	1	-	-	0,00 %
0	9	-	-	-	-	-	-	-	-	1	-	0,00 %
0	10	-	-	-	-	-	-	-	-	-	1	0,00 %

AHP Analytic Hierarchy Process

n= 6 Input 1

Objective: Calculate weights for different product requirements

Only input data in the light green fields!

Please compare the importance of the elements in relation to the objective and fill in the table: Which element of each pair is more important, **A or B**, and **how much** more on a scale 1-9 as given below.

Once completed, you might adjust highlighted comparisons 1 to 3 to improve consistency.

n	Criteria	Comment	RGMM
1	Design	Ergonomics, color, shape	8 %
2	Performance	Efficiency, reliability, usability, speed	41 %
3	Price	Tool price, refill/maintainance	10 %
4	Set-up time	Charging	3 %
5	Adaptability	Flexibility, portability, reusability, fits all materials	34 %
6	Weight		5 %
7			
8			
9		for 9&10 unprotect the input sheets and expand the	
10		question section ("+" in row 66)	

Gina Limseth 1

Name Weight Date

α: 0,1 CR: 8 % Consistency Ratio

1 Scale

A

B

i	j	Criteria A	Criteria B	more important ? A or B	Scale (1-9)
1	2	Design	Performance	B	7
1	3		Price	B	2
1	4		Set-up time	A	6
1	5		Adaptability	B	8
1	6		Weight	A	3
1	7				
1	8				
2	3	Performance	Price	A	5
2	4		Set-up time	A	9
2	5		Adaptability	A	2
2	6		Weight	A	5
2	7				
2	8				
3	4	Price	Set-up time	A	3
3	5		Adaptability	B	5
3	6		Weight	A	3
3	7				
3	8				
4	5	Set-up time	Adaptability	B	7
4	6		Weight	B	3
4	7				
4	8				
5	6	Adaptability	Weight	A	7
5	7				
5	8				

Appendix F: Ideation and concept workshop plan

Workshop

(~2 hours + lunch)

Introduction: 10min

- Who we are
- Who is Henkel
- Today's program
- Introduction to 1st interaction

Priming

- Video.
- Tell them about the pain points: Grouts and edges in tiles, type of dirt , show them the tiles and some brushes and sponges that already exist.
- Colombia introduction

1. Interaction: 20min

- Problem statement- Make them think in what problems they normally have when cleaning the tiles.
- Ideation phase (music)

Presentation: 10min

- Group presentation
- Feedback

2. Interaction: 20min

- Prototype building – Showing them the scenarios (the same as described in section *4 Product requirements*, subsection *4.3 Functionality*)
- (music)

Presentation: 10min

- Group presentation
- Feedback

3. Interaction: 20 min

- Prototype improvement. (music)

Final presentation: no time limit

- Group presentation
- Feedback

Pizza + drinks

Materials:

Paper (white+colored), glue, markers (different colors), thread/rope, scissors, pens, foam padding, cardboard, paperclips/nails etc., plastic materials, utility knife, sponges, cloths and other materials available at TrollLABS.

Appendix G: Concept AHP calculation results

AHP Analytic Hierarchy Process (EVM multiple inputs)

K. D. Goepel Version 07.06.2015 Free web based AHP software on: http://bpmsg.com

Only input data in the light green fields and worksheets!

n=	10	Number of criteria (2 to 10)	Scale:	1	Linear
N=	1	Number of Participants (1 to 20)	α:	0,1	Consensus: n/a
p=	1	selected Participant (0=consol.)	13	7	Gina Limseth

Objective Calculate weights for different product requirements

Author Gina Limseth

Date 17-Mar-16 Thresh: 1E-07 Iterations: 7 EVM check: 3,9E-09

Table

	Criterion	Comment	Weights	Rk
1	Manual iron	Manual cleaning "iron"	29,1%	1
2	Electric rotary brus	Electrical rotary brush/angle grider inspired	15,1%	4
3	Hot steam	Hot water extraction cleaner	4,3%	6
4	Tape	Grout cleaning tape	1,3%	10
5	Electric vibration ir	Electric vibration cleaning "iron"	19,5%	2
6	Vacuum add-on	Vacuum cleaner add-on	3,0%	7
7	Floor robot	Floor cleaning robot/super robot	5,0%	5
8	Rip-off gel	Rip-off gel	1,7%	9
9	Electric toothbrush	Electric toothbrush	19,2%	3
10	Grout machine	Grout cleqaning machine	1,8%	8

Result

Eigenvalue			lambda:	11,203
Consistency Ratio	0,37	GCI: 0,32	CR:	9,0%

Matrix

		Manual iron 1	Electric rotary brush 2	Hot steam 3	Tape 4	Electric vibration iron 5	Vacuum add-on 6	Floor robot 7	Rip-off gel 8	Electric toothbrush 9	Grout machine 10	normalized principal Eigenvector
Manual iron	1	1	3	5	9	3	7	6	9	4	9	29,08 %
Electric rotary brush	2	1/3	1	5	9	1	5	5	9	1	9	15,05 %
Hot steam	3	1/5	1/5	1	9	1/9	2	1/2	3	1/9	3	4,31 %
Tape	4	1/9	1/9	1/9	1	1/9	1/5	1/3	1/2	1/9	1/3	1,31 %
Electric vibration iron	5	1/3	1	9	9	1	9	9	9	1	9	19,46 %
Vacuum add-on	6	1/7	1/5	1/2	5	1/9	1	1/3	3	1/9	2	3,00 %
Floor robot	7	1/6	1/5	2	3	1/9	3	1	5	1/9	5	5,03 %
Rip-off gel	8	1/9	1/9	1/3	2	1/9	1/3	1/5	1	1/9	1	1,68 %
Electric toothbrush	9	1/4	1	9	9	1	9	9	9	1	9	19,24 %
Grout machine	10	1/9	1/9	1/3	3	1/9	1/2	1/5	1	1/9	1	1,84 %

AHP Analytic Hierarchy Process

n= 10 Input 1

Objective: Calculate weights for different product requirements

Only input data in the light green fields!

Please compare the importance of the elements in relation to the objective and fill in the table: Which element of each pair is more important, A or B, and **how much** more on a scale 1-9 as given below.

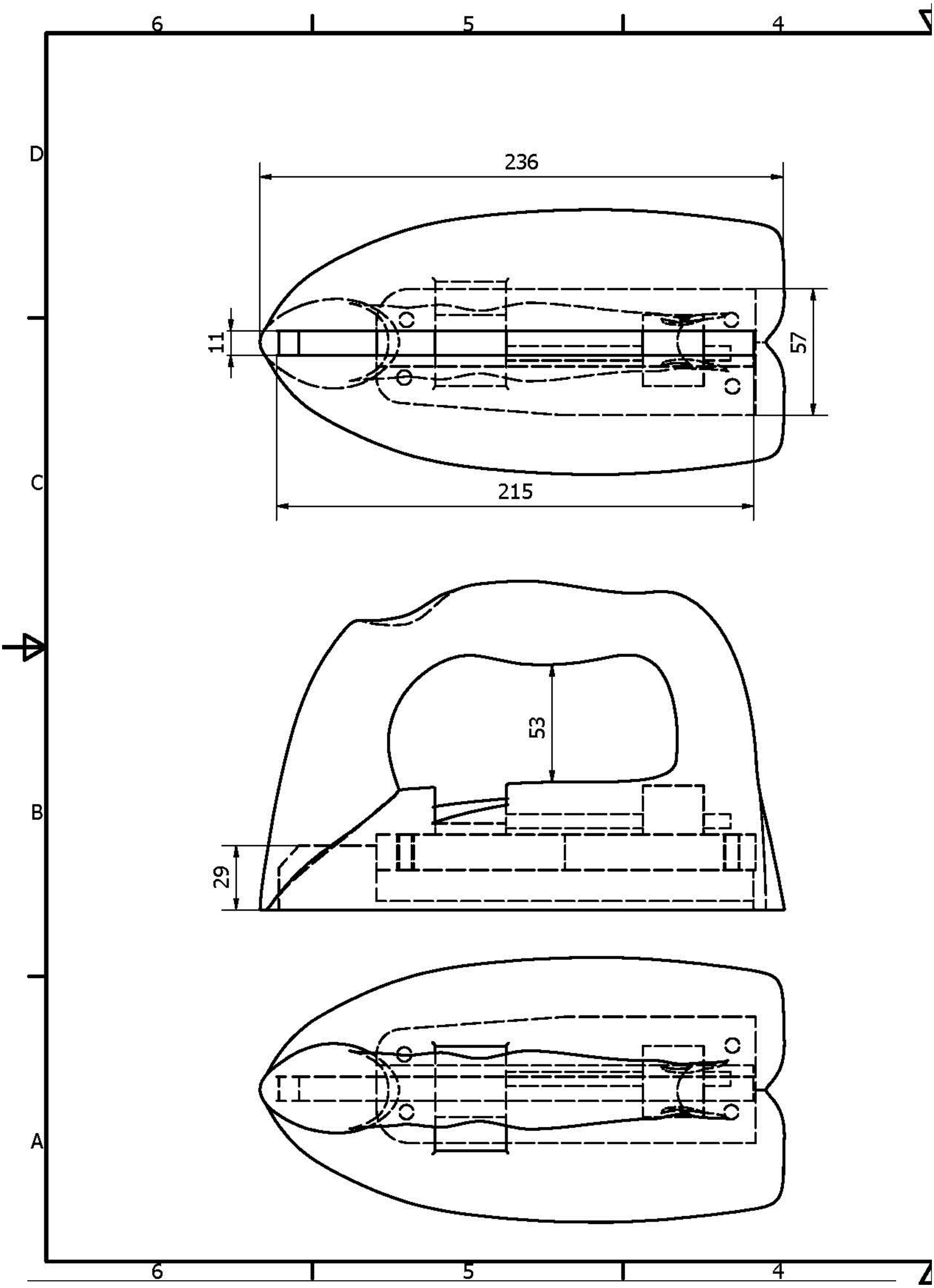
Once completed, you might adjust highlighted comparisons 1 to 3 to improve consistency.

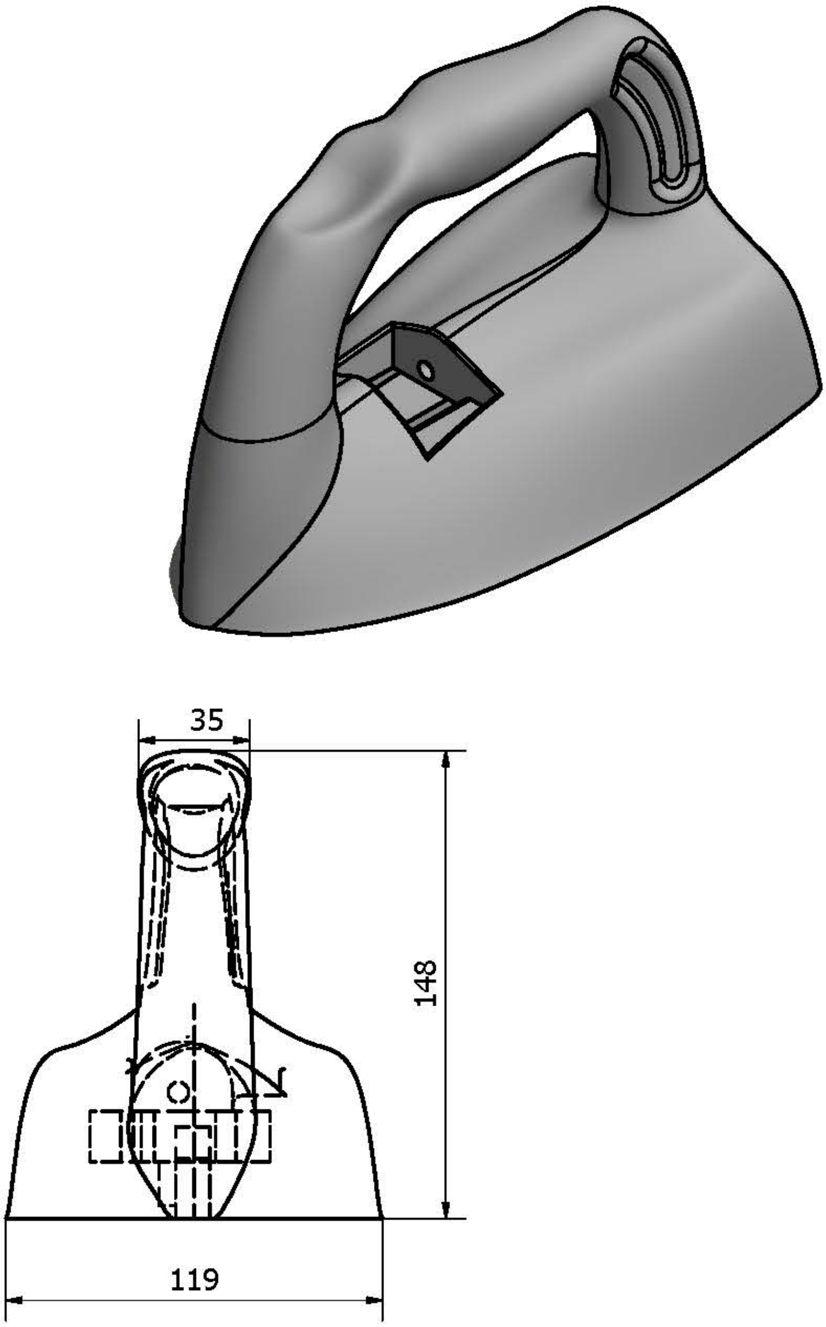
n	Criteria	Comment	RGMM
1	Manual iron	Manual cleaning "iron"	28 %
2	Electric rotary brush	Electrical rotary brush/angle grider inspired	16 %
3	Hot steam	Hot water extraction cleaner	4 %
4	Tape	Grout clearing tape	1 %
5	Electric vibration iron	Electric vibration cleaning "iron"	20 %
6	Vacuum add-on	Vacuum cleaner add-on	3 %
7	Floor robot	Floor cleaning robot/super robot	5 %
8	Rip-off gel	Rip-off gel	2 %
9	Electric toothbrush	Electric toothbrush	19 %
10	Grout machine	Grout cleqaning machine	2 %

Name	Weight	Date	α:	CR (Consistency Ratio)	Scale
Gina Limseth	1		0,1	10 %	1

i	j	Criteria A	Criteria B	more important ? A or B	Scale (1-9)
1	2	Manual iron	Electric rotary brush	A	3
1	3		Hot steam	A	5
1	4		Tape	A	9
1	5		Electric vibration iron	A	3
1	6		Vacuum add-on	A	7
1	7		Floor robot	A	6
1	8		Rip-off gel	A	9
2	3	Electric rotary brush	Hot steam	A	5
2	4		Tape	A	9
2	5		Electric vibration iron	A	1
2	6		Vacuum add-on	A	5
2	7		Floor robot	A	5
2	8		Rip-off gel	A	9
3	4	Hot steam	Tape	A	9
3	5		Electric vibration iron	B	9
3	6		Vacuum add-on	A	2
3	7		Floor robot	B	2
3	8		Rip-off gel	A	3
4	5	Tape	Electric vibration iron	B	9
4	6		Vacuum add-on	B	5
4	7		Floor robot	B	3
4	8		Rip-off gel	B	2
5	6	Electric vibration iron	Vacuum add-on	A	9
5	7		Floor robot	A	9
5	8		Rip-off gel	A	9
6	7	Vacuum add-on	Floor robot	B	3
6	8		Rip-off gel	A	3
7	8	Floor robot	Rip-off gel	A	5
1	9	Manual iron	Electric toothbrush	A	4
1	10		Grout machine	A	9
2	9	Electric rotary brush	Electric toothbrush	A	1
2	10		Grout machine	A	9
3	9	Hot steam	Electric toothbrush	B	9
3	10		Grout machine	A	3
4	9	Tape	Electric toothbrush	B	9
4	10		Grout machine	B	3
5	9	Electric vibration iron	Electric toothbrush	A	1
5	10		Grout machine	A	9
6	9	Vacuum add-on	Electric toothbrush	B	9
6	10		Grout machine	A	2
7	9	Floor robot	Electric toothbrush	B	9
7	10		Grout machine	A	5
8	9	Rip-off gel	Electric toothbrush	B	9
8	10		Grout machine	B	1
9	10	Electric toothbrush	Grout machine	A	9

Appendix H: 3D-Model





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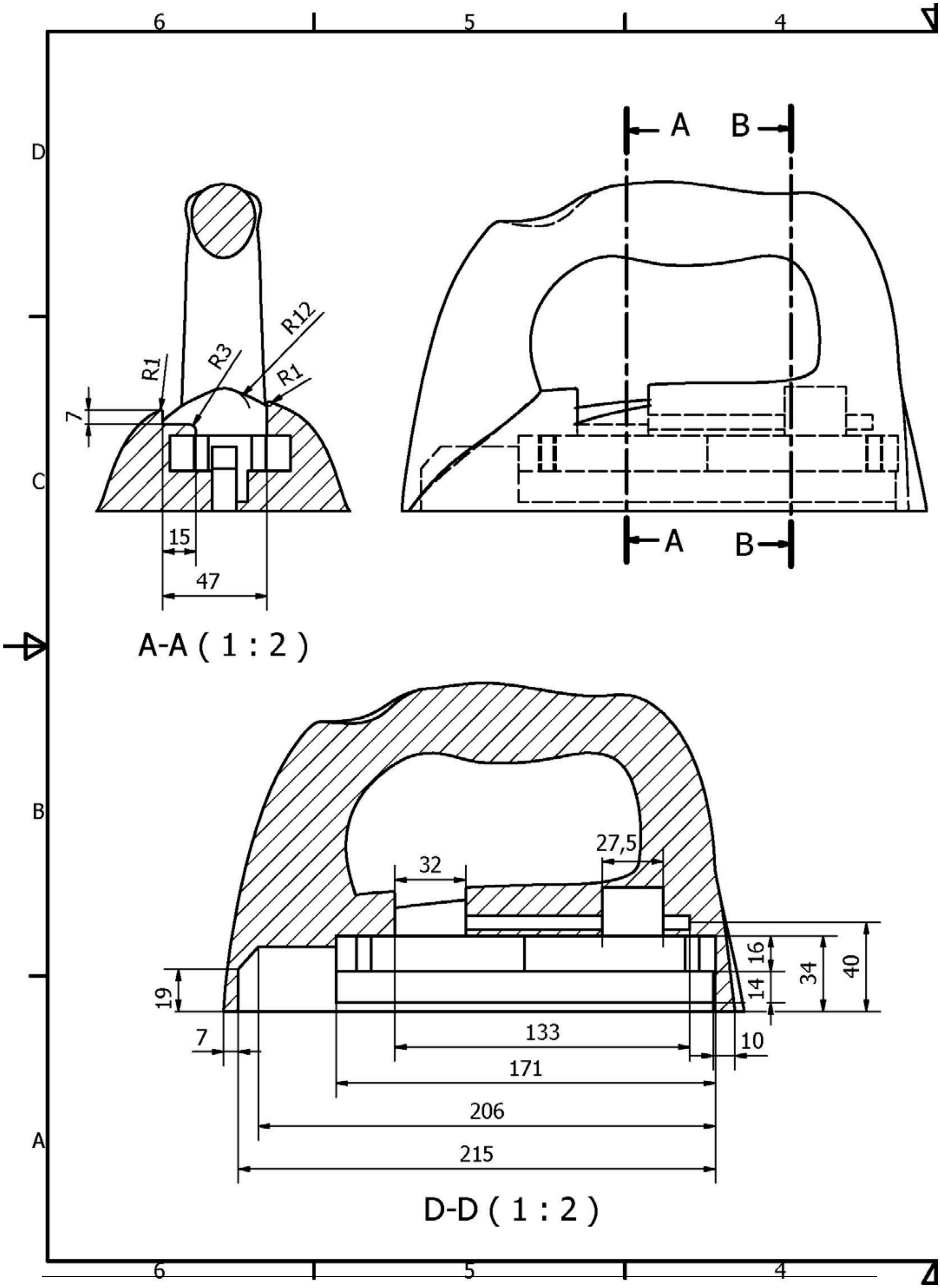
NTNU	Housing		
	1	Edition 0	Sheet 1 / 3


6
5
4
D
C
B
A
R1
R3
R12
R1
7
15
47
A-A (1 : 2)
A
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A
B
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27,5
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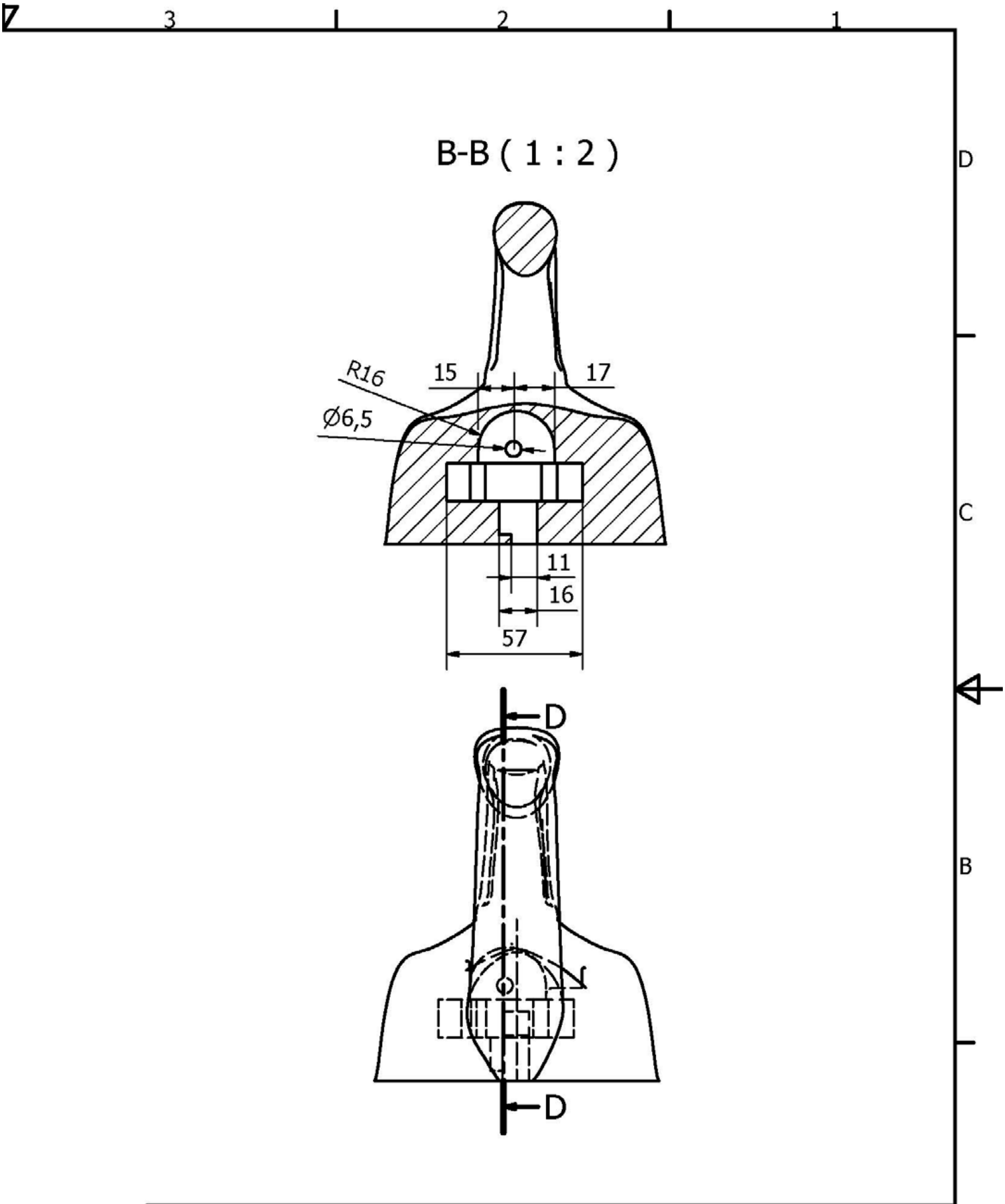
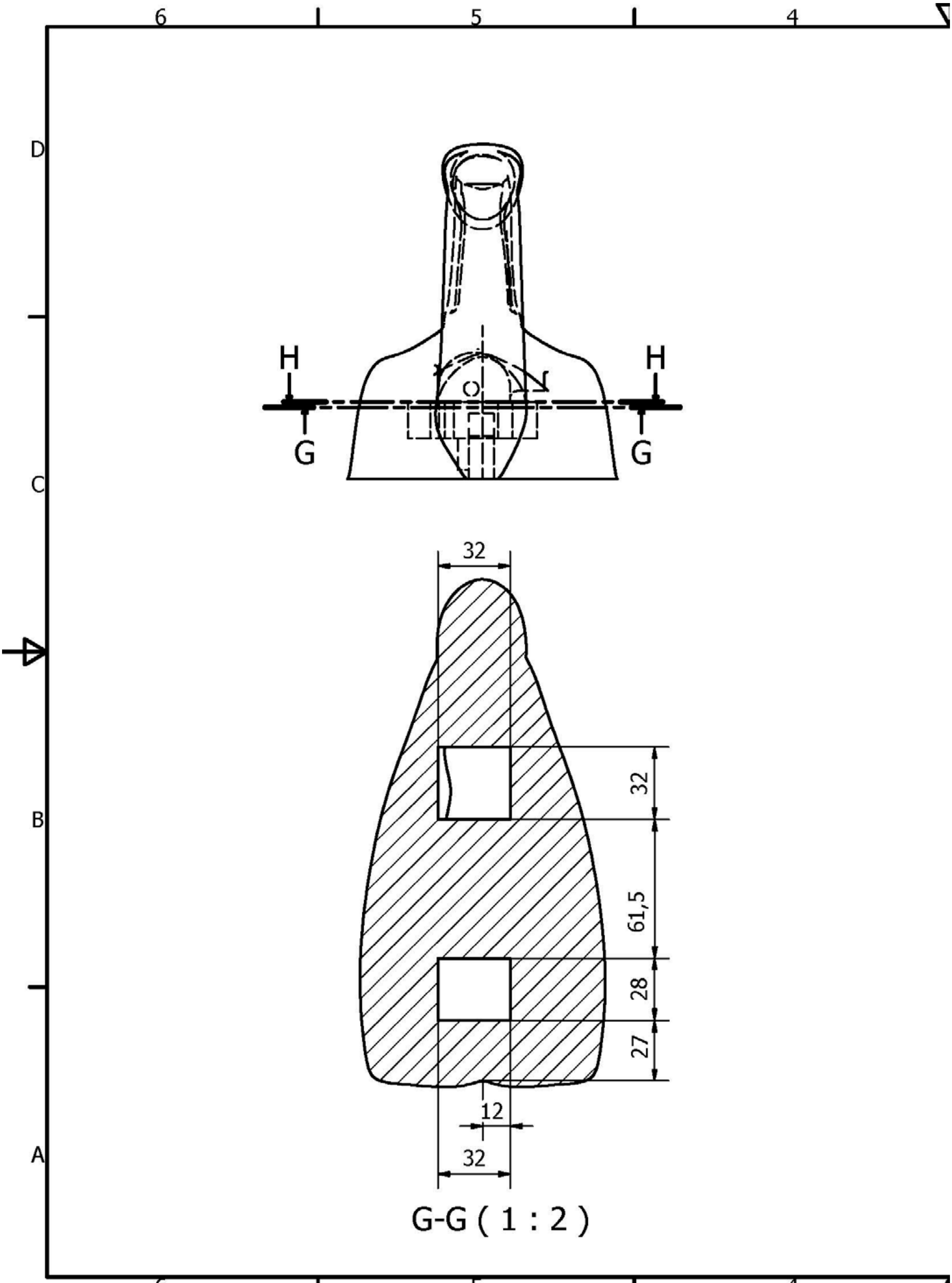
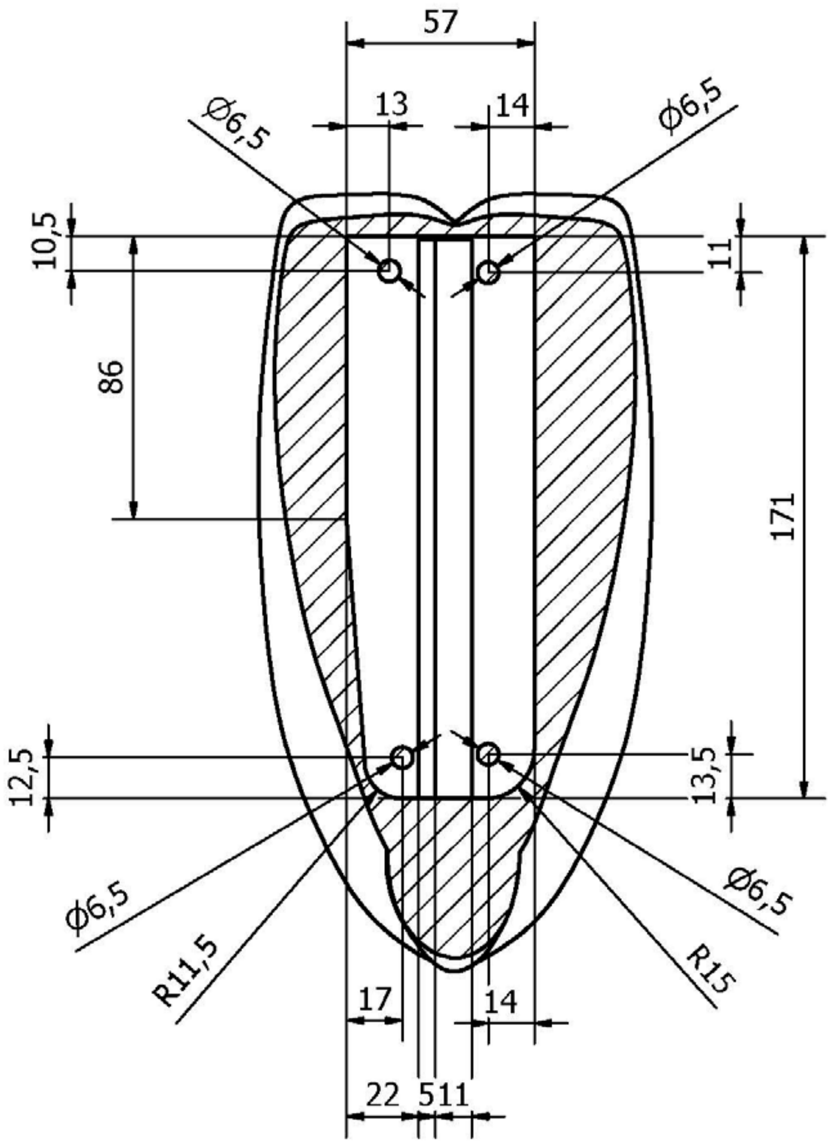
34
40
7
133
10
171
206
215
D-D (1 : 2)
6
5
4



	Designed by limseth	Date 31.05.2016
NTNU	Housing	
	1	Edition 0 / Sheet 2 / 3



G-G (1 : 2)



H-H (1 : 2)

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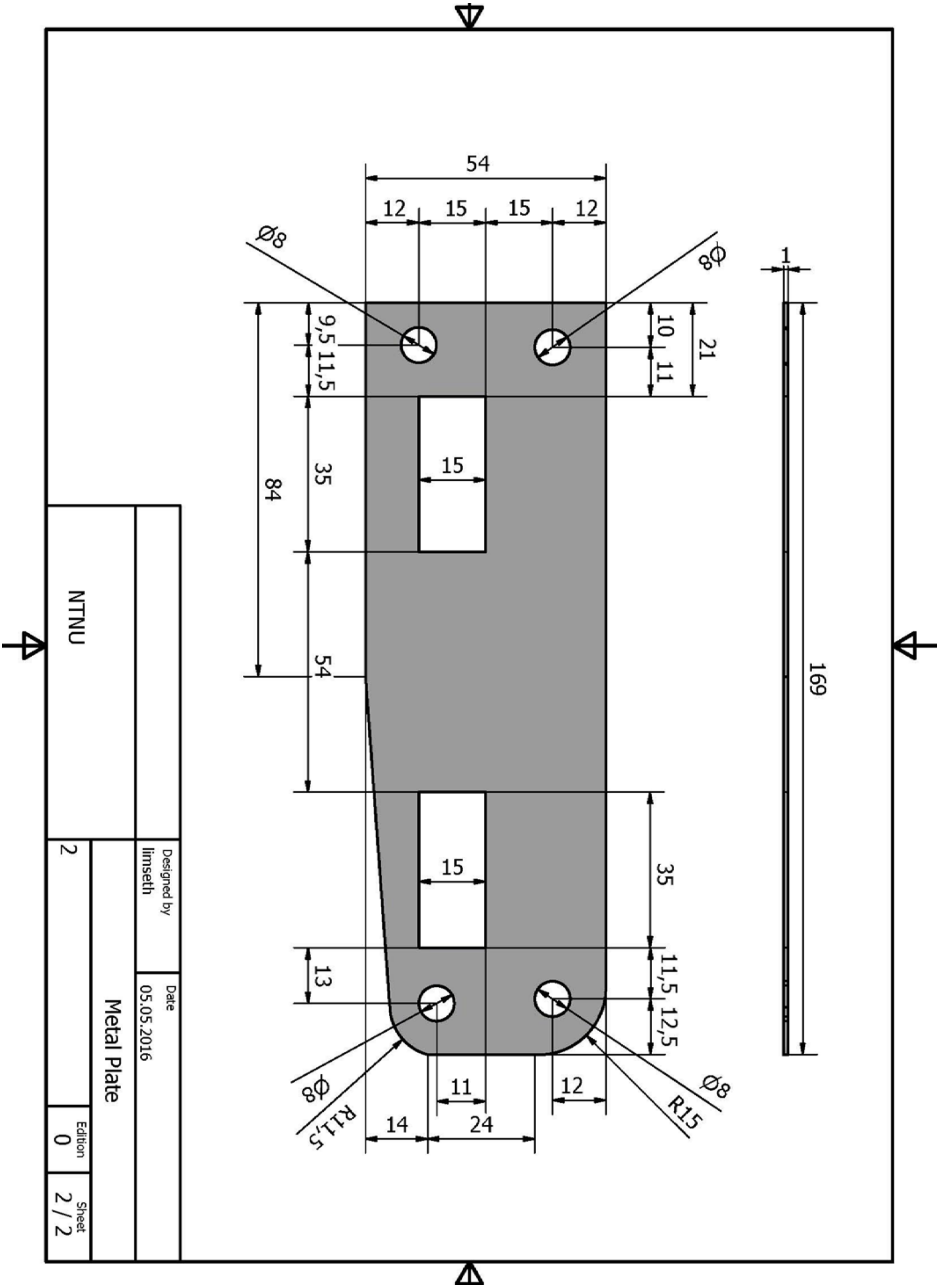
NTNU
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limseth
Date
05.05.2016
Metal Plate
2
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2 / 2
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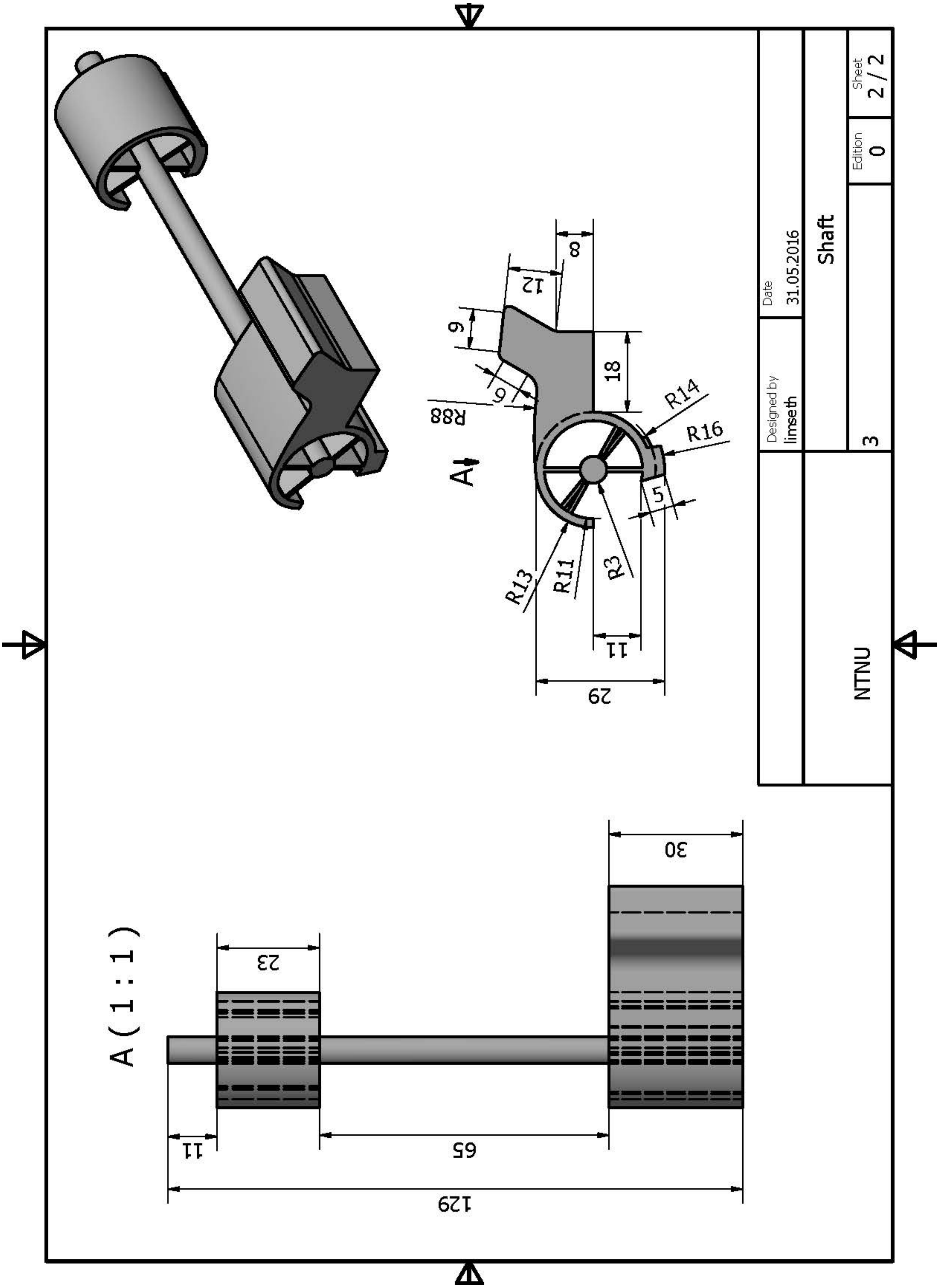
A (1 : 1)
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Appendix I: Prototype testing transcripts

Innspilling 1 – Beskrivelse av prototypen

- *Hvordan vil du beskrive modellen ved å se på den?*

Første inntrykk: ser ut som et strykejern, det er veldig massivt håndtak så man får ordentlig grep til å bruke det. Det er spisset så tuppen er mulig å bruke der det er vanskelig å komme til, mens bak er det rett til at det skal brukes på store overflater så man ikke bruker så lang tid. Jeg likte veldig god funksjonen med å velge «børste opp-ned»-funksjonen (2 funksjoner i ett). Kommer lettere til i fugen med midt børsten. Liker godt håndtaket. Ingenting som jeg kommer på som jeg ikke liker så godt med designet.

Det ser litt ut som en båt og, med tanke på hvordan den er formet, den virker lett å kjøre/bruke. Det er litt bevegelse i designet.

Assosiasjoner: sportsbil med blanding av kassebil – med kalesje.

- *Hvordan vil du beskrive den mens du løfter det opp?*

Første inntrykk: godt å holde i. det er formet så det er godt å holde for hånden, må være sånn for å unngå gnagsår eller å måtte bytte grep. Det er greit lett, litt tungt. Jeg føler meg stor, sterk når jeg holden den. Det er et verktøy jeg klarer å håndtere at det ikke er vanskelig. Lett å ta i bruk. Er ikke som når jeg skal løfte en stor at jeg tenker at det skal bli tungt, at det ikke er noe sted å holde. Her er det «hold – begynn». Jeg tror det ville tålt veldig mye, for det skal være mye vann og såpe så det ser slitesterkt ut. Viktig at det tåler mye såperester og at det ikke ligger igjen et belegg og at det er innbydende å bruke det neste gang uten å måtte vaske toolet etter å ha vasket med det.

- *Hvordan vil du beskrive toolet mens du holder det opp mot veggen?*

Det går veldig greit i alle retning , veldig greit å holde selv om jeg er skjør i håndleddene mine.

Innspilling 2 – Bruker test med Henkel prototype, Jif baderomskrubb og tannbørste

- *Hvordan var det å vaske med Henkel?*

Det var lettere å få kraft, for det var et bedre håndtak, fordi jeg brukte mere håndflaten for å trykke den inntil veggen. Fingrene var egentlig bare støttestruktur. Mens jif var litt mer klumpete så jeg brukte mere fingertuppene og de «putene» fremst på hånden. Jeg måtte konsentrere meg for å bruke nederst på håndflaten til å overføre kraft og jeg måtte bruke hele armen.

Med tanke på vekt var Henkel tyngst, men jif ble tyngre i lengden fordi jeg måtte bruke mer kraft. Jeg brukte mer slitsom kraft på jif, og mer funksjonell kraft på henkel

- *Hvordan syntes du tannbørsten var å bruke?*

Den var litt vanskelig fordi børsten var så myk så den ga ikke noe motstand så jeg måtte presse veldig mye og jeg kom inn på den harde plastdelen som ikke funket bra. Det som var bra var at den var smal så den kom letter til, men den var ikke veldig god å holde i. Det smale skaftet gjorde at fingrene presset inn i håndflaten.

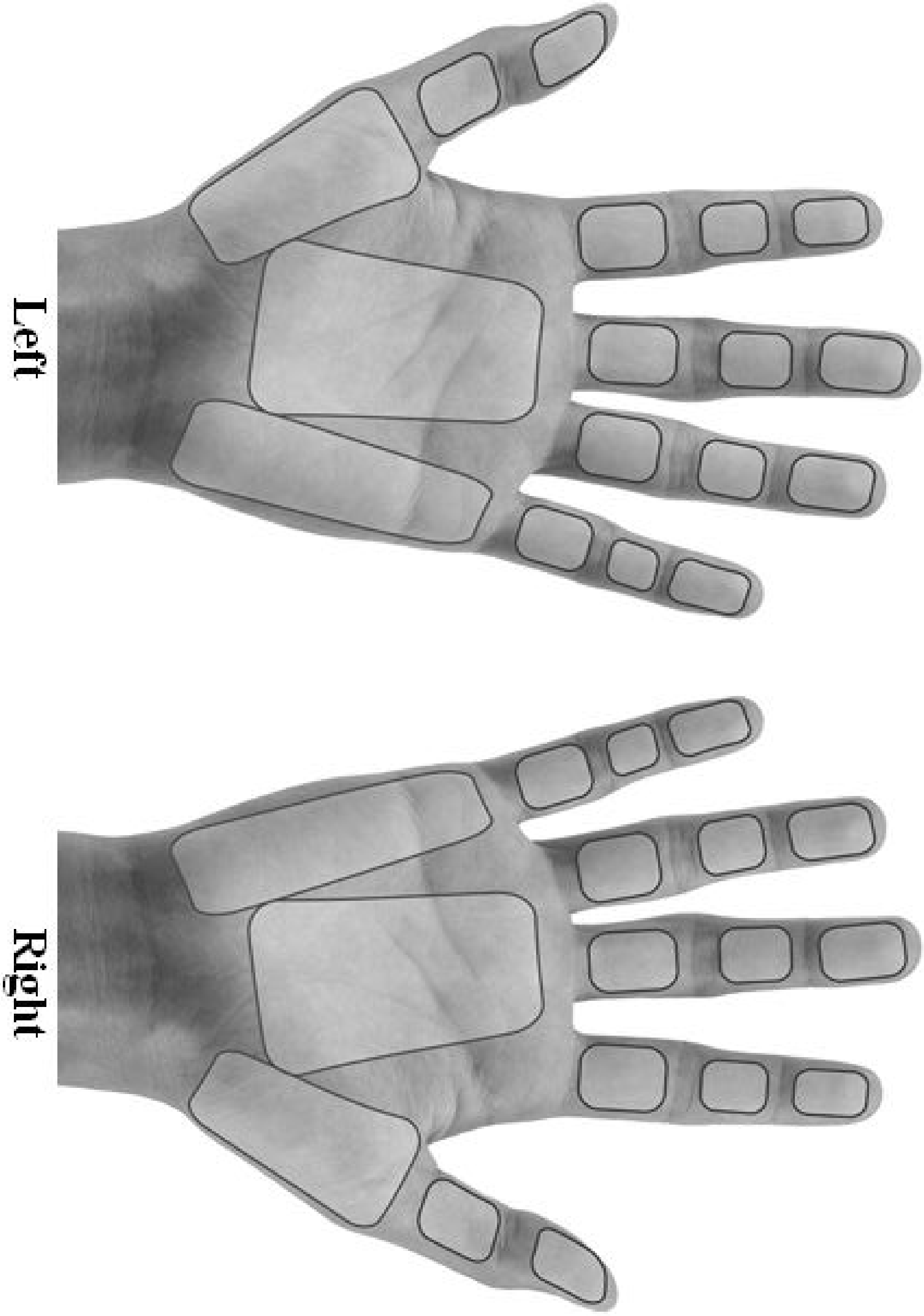
Når det gjelder jif så var den den klønete og klumpete at jeg måtte bruke fingrene mer enn håndflaten selv om man har mer kraft i håndflaten siden det kommer fra hele armen og fingrene har lite krefter sammenlignet. Den beste metoden var å ha pekefingeren langsmed toppen av «håndtaket» som gjorde at den egentlig som pushet hele greia ned, ikke håndflaten eller tommelen som bare var mer til støtte.

Henkel fikk jeg mer kraft i selve håndflaten fordi den lå bedre inne i hånden og fingeren hjalp bare til å holde den og for bedre grep. Den gjorde at jeg fikk kraft fra hele armen siden kraften stoppet inne i håndflaten og ikke gikk ut til fingrene.

Appendix J: Pressure evaluation form

Please rate the pressure on the various zones of the inner hand according to the scale:

0	1	2	3	4
No	Little	Medium	Heavy	Very heavy



Appendix K: Arduino script

```
const int FSR_PIN = A0; // Pin connected to FSR/resistor divider

// Measure the voltage at 5V and resistance of your 3.3k resistor, and enter
// their value's below:
const float VCC = 4.98; // Measured voltage of Ardunio 5V line
const float R_DIV = 3230.0; // Measured resistance of 3.3k resistor

void setup()
{
 Serial.begin(9600);
 pinMode(FSR_PIN, INPUT);
}

void loop()
{
 int fsrADC = analogRead(FSR_PIN);
 // If the FSR has no pressure, the resistance will be
 // near infinite. So the voltage should be near 0.
 if (fsrADC != 0) // If the analog reading is non-zero
 {
  // Use ADC reading to calculate voltage:
  float fsrV = fsrADC * VCC / 1023.0;
  // Use voltage and static resistor value to
  // calculate FSR resistance:
  float fsrR = R_DIV * (VCC / fsrV - 1.0);
  Serial.println("Resistance: " + String(fsrR) + " ohms");
  // Guesstimate force based on slopes in figure 3 of
  // FSR datasheet:
  float force;
  float fsrG = 1.0 / fsrR; // Calculate conductance
  // Break parabolic curve down into two linear slopes:
  if (fsrR <= 600)
   force = (fsrG - 0.00075) / 0.00000032639;
  else
   force =  fsrG / 0.000000642857;
```

```
    Serial.println("Force: " + String(force) + " g");
    Serial.println();

    delay(500);
  }
  else
  {
    // No pressure detected
  }
}
```