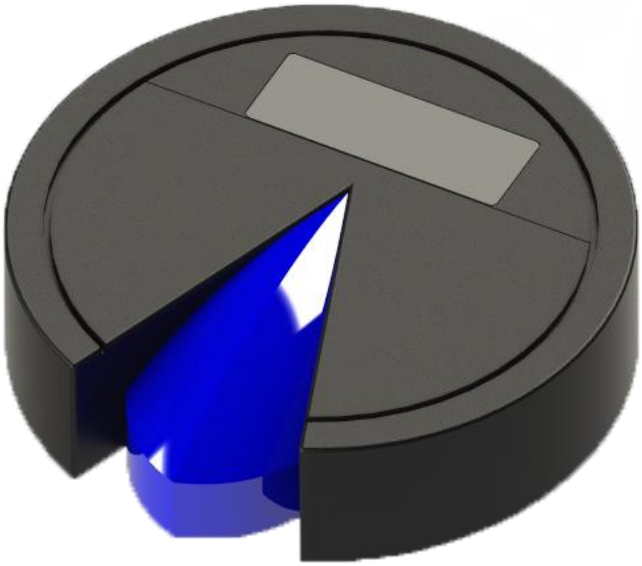
Designing a Robotic Vacuum Cleaner

Report - Project Group 16



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Designated to the staff from Philips and the instructors from the module ‘Consumentenproducten’.

Designing a Robotic Vacuum Cleaner

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This report is made in order to design, build and distribute the new robotic vacuum cleaner for Philips. In cooperation with consumers, staff and instructors, we designed a robotic vacuum cleaner, which is corresponding to the wishes and needs of todays market.

Summary

The concept behind the project 'Consumer products' is to design an improvement to the robotic vacuum cleaner from Philips. Philips wants to reach a broader audience with their robotic vacuum cleaner and after their first two robotic vacuum cleaners were not what the consumer expected; the new robotic vacuum that they launch should exceed the expectations of the consumer. Since this is not yet the case, they asked the University of Twente for help so that they get new ideas.

The focus of the robotic vacuum cleaner introduced in this paper is the cleaning performance. To realize a better cleaning performance, different problems were solved. The main problems encountered are that today's robotic vacuum cleaners have too small dust storages, not sufficient vacuum power and cannot clean the corners properly.

The target group which is focused on are people between 25 and 50 years which live in Western Europe and which have fulltime jobs, which is the reason why they are away from home most of the time. They therefore do not have enough time to vacuum their homes.

After brainstorming and designing a few concepts and ideas, a concept, suitable for the stated mission, the chosen target group and which is able to encounter these problems, was found. The Beetle Bot is the idea resulting from this paper. This robotic vacuum cleaner can detect corners and blow the dust out of the corners, to a place it can reach. The dust can also be dumped in a docking station which allows the robot to have a smaller dustbin inside, and therefore have more available space for a stronger battery and motor. With a larger, more sufficient motor, the vacuum power will improve. A larger battery will ensure the power for the larger motor.

Last is the marketing aspect of the new product. In the marketing decisions there is focused on two main aspects: blowing the dust out of the corners and the cleaning performance. To focus on these two aspects, people can be convinced that the product is different and better than products from competitors. The first year a push strategy will be used to convince the customers and stores to buy the product. After the first year, the people will be familiar with the product and the strategy will be switched to a pull strategy.

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1. Preface

In the second year of our Bachelor Program, a group of nine students got the task to build Philips new robotic vacuum cleaner. In our group we have 2 students from the Bachelor Program *Industrial Engineering and Management*, 3 students from *Industrial Design Engineering* and 4 from the Bachelor Program *Mechanical Engineering*. In this multi-functional team, we designed on behalf of Philips a new robotic vacuum cleaner, build a model of how it is supposed to look and designed a marketing campaign, with which the device can be distributed. In cooperation with Philips and the instructors of the University of Twente, we were able to build a device that we think is more satisfying for the consumer than the products that already exist.

2. Introduction

This paper describes the analysis, thoughts, ideas and final concept on the way of designing, building and distributing the new robotic vacuum cleaner for Philips.

The first part of the paper describes the analysis phase. In this phase research is done concerning the needs and wants from the market. Brands are compared especially regarding how they designed their robotic vacuum cleaner, but there is also taken a look at what people expect from a robotic vacuum cleaner. Finally the main problems were found, which had to be encounter with the new design. In this phase there is also a target group chosen and vision phrased.

The second part of the paper is the 'Design Brief'. This part focuses on the desired results and therefore the prospects and the criteria for these are specified.

In the next part, the concept phase is described. In this phase a few possible concepts are presented and finally the definite concept is chosen. The choices which are made in the selection phase are addressed and the final decision is explained.

In the following part, the chosen concept and the details of the new technologies which we came up with are explained precisely. A solidworks model of the device, as well as of the ducking station has been made.

The last part of this paper concerns the distribution and marketing phase. Focus points for the promotion and the look of the packaging are decided. This will be used for a specific promotion plan and strategy to sell as much products as possible.

3. Analysis

3.1 Market Analysis

There are many different companies that develop robotic vacuum cleaners. In the appendix under *'A. Market Analysis'* there is more detailed information about the main competitors. In the following the conclusion of the market analysis are presented.

Difference between 'traditional' vacuum cleaners and vacuum cleaning robots

A vacuum cleaning robot works a lot like a traditional, manual vacuum cleaner. The main difference is that a robotic vacuum cleaner is equipped with brushes, which move the dust to the nozzle. Some robotic vacuum cleaners have extra brushes which collect the dust on both sides of the robot and brush this dust right into the nozzle. This feature allows the robots to sweep along walls and clean thus more effective. The effectiveness of a robotic vacuum cleaner is also determined by the quality of the suction mechanism and the brushes. In comparison with manual vacuum cleaners, the cleaning process of robotic vacuum cleaners takes a longer time. It is slower and through its limited battery life it sometimes has to recharge within its cleaning round. Therefore completing the vacuuming of an entire room takes longer. This is something the consumer is well aware of and since the robot cleans mostly when the consumer is not at home, this should not be a problem.

Pros of robotic vacuum cleaner:

- The consumer saves time
- The consumer has to install the robot only once (after the purchase)
- The robotic vacuum cleaner will automatically vacuum on set times
- Most models do not require a dust bag

Cons of robotic vacuum cleaners:

- The suction power is weaker than in a traditional vacuum cleaner since it works on a battery
- It has a smaller dust storage
  The round-shape of the most robotic vacuum cleaners does
- not allow them to vacuum the corners properly
- The vacuum cleaning robot is not efficient around objects; the consumer has to tidy up and remove all small objects from the ground, like toys, shoes etc.[1]

Difference between brands

There are many differences between brands. These differences concern mostly the technology. Some robotic vacuum cleaners have many sensors, which makes the robot smarter. The device can determine where he already vacuumed through these sensors. The navigation method differs from zigzag method to spot method. Most of the robotic vacuum cleaners have a docking station which the robot can return to by itself.

Notable is, that the EasyStar from Philips is the dumbest[2] robot. It does not have a navigation route or docking station in contradiction to Philip's other robotic vacuum cleaner, the homerun. This one has

[1] http://www.robotstofzuigerinfo.nl/over-robotstofzuigers/

navigation, but failed at so many other aspects, that it has been removed from the stores. The Easystar also has a stairs detector to prevent it from falling down the stairs.

There are a lot of problems that occurred since the robotic vacuum cleaner is a relative new technologic device. Like mentioned above a robotic vacuum cleaner has to be charged quite often. The average time the robot cleans before it has to be recharged is short. Much brands have the same solution for this problem; a docking station. The robot can return to the docking station by itself.

Another problem is the small capacity of the dustbin. The robot is small which means it is easy to maneuver and can drive underneath furniture; concluding, there is little space for a dustbin. The Ecovacs vacuum robot has solved this problem by using the docking station as dust storage. This is a smart solution, because the robot has to return to the docking station when it is out of battery. This method has the advantage that it takes less time to empty the dustbin of the robotic vacuum cleaner.

A round shaped vacuum robot cannot vacuum the corners. A solution for this is a square shaped robot. But a square has its problems, too; it cannot find its way back from every place it has driven into. It also gets stuck easily when rotating around its own axis. The LG Hom-Bot Square has solved this problem by rounding the corners. The brushes are positioned on the sides through which still reach the corners.

Another advantage of LG robots is that the user can choose the method of vacuum cleaning (zigzag, cel by cell or spot). So each user is able to choose the method they prefer. In this way, many users will be pleased by the product because they can choose their favorite method.

Strengths per vacuum cleaning robot
iRobot Roomba: One does not have to clean the brushes manually any longer.
Ecovacs Robot: One of the main features of Ecovacs is the robot automatically empties its dust in a docking station.
Samsung SR8895: The robot knows where it has been, because of efficient room mapping.
LG Hom-Bot: This device has certain modes to clean the room. One of the modes is cell-by-cell cleaning, this is handy by large areas with many obstacles.
LG Hom-Bot Square: Is able to clean the corners with its brushes.
Philips Easystar: Is really small, so it can easily drive underneath the couch.
Traditional manual cleaner: He can reach under furniture and makes it very easy to vacuum stairs and vertical surfaces. Also the user can change different heads for different tasks.
Central vacuum system: These do not require a person to carry a heavy unit from room to room or up and down the stairs. There is furthermore no electrical cord which can tangle up.

3.2 Problem Analysis

Product Life Cycle
Understanding the Product Life Cycle is importance to a firm that is designing and launching a new

[2] We define a dumb robot as a robotic vacuum cleaner which does not have a clear path or method with which they clean the room. These robots have a random route.

product. The risk, associated with distributing a new product, can be estimated more effectively and the marketing campaign of the product can be planed more precisely. The Product Life Cycle has five stages:

1. Product development
2. Introduction
3. Growth
4. Maturity
5. Decline

The robotic vacuum cleaner is in the third phase of the cycle. The device is established and is now going to be distributed more and more. In order to do this, the robotic vacuum cleaner has to fulfill the wishes of the consumer. In this phase is the target group the center of attention since the growth can only be established through communicating with this group and observing their needs. If this research is down, a specific market plan, suitable for this audience, is worked out.

Results from the survey

Almost everyone has a vacuum cleaner nowadays. Most of these are controlled manually, but some are controlled by a robot. However, these robotic vacuum cleaners are not yet present in every household. That is why Philips is looking for a new design of a robotic vacuum cleaner, which will suit the needs of all those people, who are still using manual vacuum cleaners and do not know that robotic vacuum cleaners have significant advantages.

To find out, why people are not yet buying robotic vacuum cleaners and what they expect from these, we developed a survey[3]. This survey was filled out by 37 respondents. There average age was 44. Only one respondent does currently not own a vacuum cleaner; this person only uses a Swiffer to clean his floor. Each respondent, which owns a robotic vacuum cleaner, also still owns and uses a normal vacuum cleaner.

One owner of a robotic vacuum cleaner says it is useless and that furthermore many people would not buy one, if it does not replace a normal vacuum cleaner completely. The other respondent finds it useful but they think that the battery does not work sufficiently and this is the reason why they do not use it anymore.

To find out if the robotic vacuum cleaner has to switch rooms, the question ‘how many rooms do you vacuum?’ was included. The average amount of rooms which the respondents vacuum is four. The average size of these rooms is 15-30 m^2. This information is necessary to determine how big the dust storage has to be. Another aspect, which has to be brought to discussion when talking about creating a new robotic vacuum cleaner, is the problem of loose stuff lying on the floor. 41% of the respondents had lots of loose stuff lying on the floor. 53% are willing to remove this stuff, every time, before using a

[3] The survey and the survey analysis can be found in the appendix under *‘B. Survey’*.

robotic vacuum cleaner.

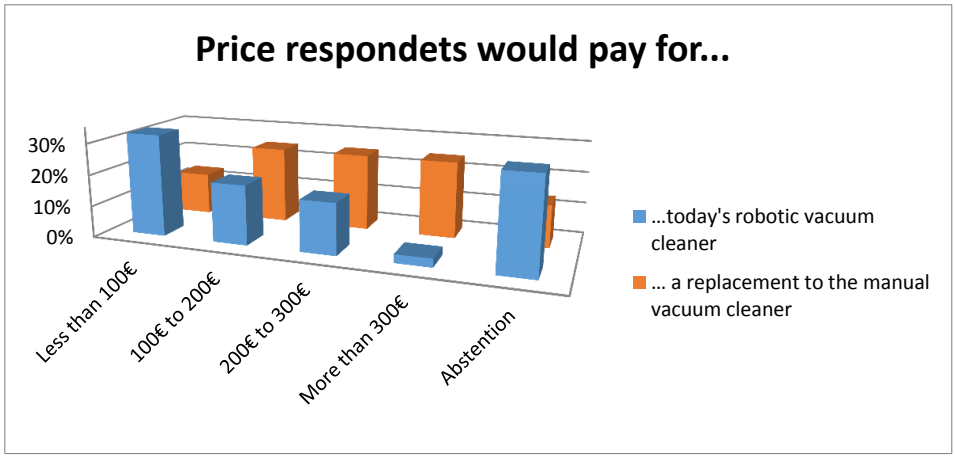


Figure 1 - Price analysis

'*Figure 1 - Price analysis'* represents the amount of money a household is willing to spend on today's robotic vacuum cleaner in contrast to a vacuum cleaner that replaces the manual vacuum cleaner. The average household is willing to spend 118€ on a robotic vacuum cleaner that is a complement on their normal vacuum cleaner. If the robotic vacuum cleaner is a replacement of their normal vacuum cleaner, people are willing to spend more money. The average amount these people are willing to spend is 252€.

On the question if people are willing to buy a robotic vacuum cleaner we received a lot of useful input why people would or would not buy a robotic vacuum cleaner.

The survey was useful, since the respondents gave a lot of useful input about their expectations. Many respondents said they are only willing to buy a robotic vacuum cleaner if it is able to replace there (current) manual vacuum cleaner completely. This implies for them, that it is as efficient as their vacuum cleaner. Another big concern of the respondents is the price of the device. Their wish is a reasonable price for the product they get offered. They are not willing to spend much more than what they would spend for a normal vacuum cleaner.

Through this survey, the main problems of robotic vacuum cleaners can be summed up. In '*Figure* 2 - *Problems & Causes - Robotic Vacuum Cleaner*' you can see the causes of the problems. The problems and their causes are explained in the following abstract.

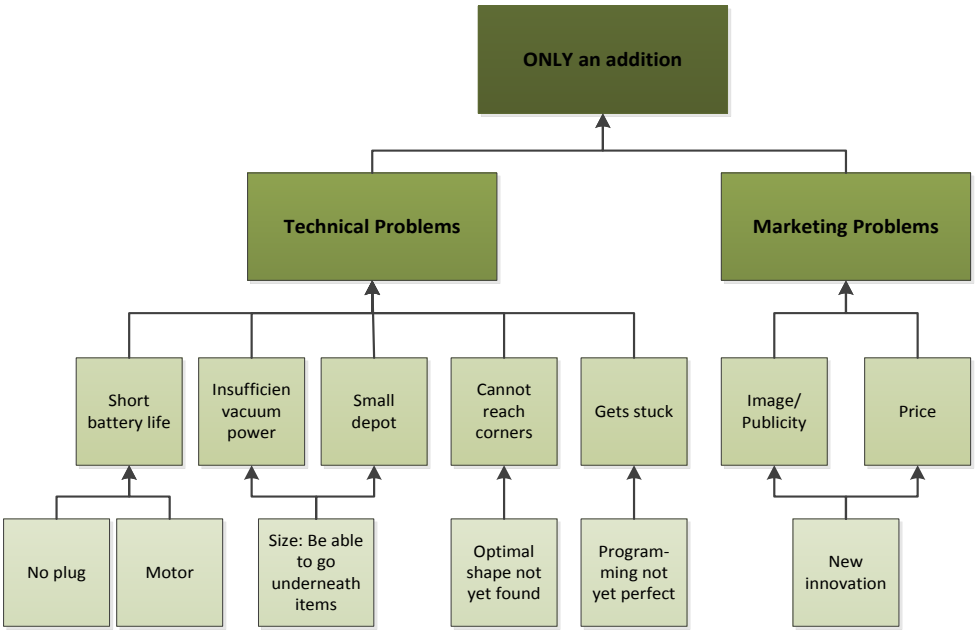


Figure 2 - Problems & Causes - Robotic Vacuum Cleaner

Most people, who already have a robotic vacuum cleaner, also have a manual vacuum cleaner. In today's household the robotic vacuum cleaner is just an addition to a manual vacuum cleaner. This might not seem as a problem since it could mean that consumers buys both products, but in reality it means that less households than expected are willing to spend money on a robotic vacuum cleaner. To successfully launch a robotic vacuum cleaner, this problem has to be solved. The solution might seem simple, but with today's technology it is not yet possible to design a replacement[4] for the manual vacuum cleaner. The main aspect of a new robotic vacuum cleaner should be upgrading the cleaning performance. Since current models do not succeed enough in solving this problem, it is difficult for companies to advertise and sell their products. They can only sell an addition, another item that you have to store in your home. Marketing would be much easier if they could sell a robotic vacuum cleaner with an upgraded cleaning performance. The technical specifications of the robotic vacuum cleaners are not yet fully developed.

Summarized it can be said that there are two major problems. The first one is the technical aspect; the way a robotic vacuum cleaner operates and its appearance. The other is the marketing aspect; selling it to a broad target audience. In the following the causes of these problems are analyzed.

[4] We define replacement as a robotic vacuum cleaner, which has all the features a manual vacuum cleaner and a hand vacuum cleaner have. It also has the vacuum power from a manual vacuum cleaner. This cannot be realized with the technology today, since there is no motor that can handle the vacuum power. This information is researched and provided from Philips.

Technical aspects

The robotic vacuum cleaners that exist are not made to vacuum like a manual vacuum cleaner. They are made to get rid of dust on an everyday basis, but cannot handle to vacuum small items, since the vacuum power is insufficient. The other problem of a robotic vacuum cleaner is the depot for the vacuumed items. Whereas a manual vacuum cleaner has a depot of about four liters, the robotic vacuum cleaner has only one eighth of this. This means that it has to be emptied more often; but people do not appreciate this additional work. The cause for these two problems is also one of the main characteristics of the robotic vacuum cleaners. Robotic vacuum cleaners are small. This feature makes it possible for them to drive underneath couches, tables and chairs, but is also the cause for the two problems mentioned above.

Another aspect which could turn into a problem is the battery life of a robotic vacuum cleaner. Since they do not have a plug and the motor is not as strong as the one of a manual vacuum cleaner, they often have to be charged. This again can lead to extra work and makes the product less desirable.

Another technical problem all companies try to manage is that the robotic vacuum cleaner has not the possibility to clean in corners like a manual vacuum cleaner. Companies tried longer brushes and special features but until now they have not found a shape or a feature, which can efficiently clean in the corners.

While coming into the corners is a big problem, coming out of the corners is a bigger problem. Robotic vacuum cleaners get stuck fairly often. Behind the user interface of a robotic vacuum cleaner sits a lot of programming. Since the robotic vacuum cleaner is a fairly new innovation, the programming is not yet quite what the customer desires. Coming home and finding your robotic vacuum cleaner under a chair and the room is not yet vacuumed all the way, is not what the customer expects from the device.

Marketing aspects

There are also problems not related to the technical aspects but related to the marketers. Since, like already mentioned, the robotic vacuum cleaner is a relative new innovation on our markets, they are not yet good established. A lot of people have not thought about buying a robotic vacuum cleaner and for others, they are simply too expensive. This is a major problem with new innovations. They are always highly priced because of the difficult technical aspects behind them, especially if you are looking for a product that really fulfills your wishes.

Conclusion

In conclusion we can say that the ‘‘new’’ robotic vacuum cleaner, that we are supposed to develop for Philips, does not have to replace the manual vacuum cleaner, but has to have an upgrades cleaning performance. To do that the robotic vacuum cleaner has to conquer the problems named above. For production purposes and to establish a relatively low price it has to be suitable for mass production of about 100.000 a year.

3.3 Future Scenarios

Robotic vacuum cleaners have been produced for a few years now, but the technology of these devices is still developing rapidly. Companies like Philips are trying to improve the sale of robotic vacuum cleaners and expect the sale ratings to rise in the future.

It is certain that things will change in the future. For a better application, changes have to be considered as well as made, too. If possible, a new design for a vacuum cleaner will be produced and released in about five years. In this section changes in the environment, technology and economy are predicted. Changes like these have to be respected while designing a new device. These scenarios are thus written for a possible future taking place five years from now.

Environment

The environment will get more important. There is already a growing focus on recyclable products and this will continue in the future. The government is promoting recycling and there will as well come more and more rules for companies to produce recyclable products. Not only is the use of recyclable materials and durable products better for the environment, but it will also become a good selling argument since the consumer is going to find this more important and will thus be willing to spend more money.

Technology

The technology is rapidly improving. If mobile phones are viewed as an example, a drastic increase of technology can be seen, evolving normal telephones into small mini computers within a few years' time. With this technology and the new technology that will be developed in the coming five years, very advanced programming will become much easier. In five years, users will be even more adapted to the technology, thus users are able to control and understand how such a technical device works. Users will want to have high-tech; selling this will thus get easier. With more technology available, it will become cheaper and easier to apply this technology inside of a robot.

Economy

The aftermath of the economic crisis will probably be less visible in five years. More people will be working again, which means that they want to spend less time on household chores and that they have more money to spend. With inflation, the actual costs for the vacuum cleaner can increase. Though robots are still high technology and people are probably willing to pay for that.

User scenario's

In the future, a lot of people will hopefully own a robotic vacuum cleaner. The devices will have a lot of advantages over normal vacuum cleaners. People go to work in the morning and arrive to a clean home after work; they have much more free time since vacuuming is not their task anymore. The robot will one day even be smart enough to clean around things lying on the floor. These advantages and others are demonstrated in comic strips which can be found in the appendix under *'C. User Scenario*'. These user scenarios demonstrate not only the consumers' wishes and expectations which have to be considered in the design, but they can also be used as marketing arguments.

Concluding:

- The vacuum cleaner should be durable and should consist of recyclable materials.
- Improved technology making programming easier and users are more attracted to robot vacuum cleaners.
- Economic circumstances stay equal due to higher prices of materials and increased income of the costumers.

3.4 Vision

Our vision is an automatic vacuum cleaner that has an upgraded cleaning performance. At this moment, a lot of people do not want to buy an automatic vacuum cleaner, because these are only additions to the normal vacuum cleaner and not replacements. We are not able to give the consumer the product they desires because of the current technology, but we desire to design a robotic vacuum cleaner that can compete with a normal vacuum cleaner in the aspect of the cleaning performance[5].

Furthermore we want to focus on two points. First we focus on the user interface. The robotic vacuum cleaner has to be self-explanatory. Everybody in our target group must understand how the robotic vacuum cleaner works and has to be able to work with it. Second, it has to be a smart robotic vacuum cleaner. There are robotic vacuum cleaners that clean the room randomly and have hopefully not mist a stop. We do not want such a robotic vacuum cleaner; we are willing to spend money in the development of a smart robot.

3.5 Target Group

Figure 3 - Target Group Collage

The target group for the robotic vacuum cleaner includes people who do not have much time to clean their houses. These people often have fulltime jobs, which is the reason that they are away from home most of the time, and have therefore not enough time to clean. It is estimated that the age of the target group is between 25 and 50 years and that they live in Western Europe. People who just started working are part of the target group, but also the people who have children. People that are above 50 years old are more likely to have enough free time to clean, since their children are grown up; therefore they are out of the range. There is a focus on people with an average salary, which means that they can afford an advanced robotic vacuum cleaner. They will nevertheless not be willing to spend money on a too expensive device; therefore it is necessary to be cautious with the cost of production. The targeted people are familiar with current technology and can easily adapt to the progress that technology makes. Furthermore the focus is on people with terraced houses and homes of job starters,

[5] We define cleaning performance as properly cleaning the corners of a room and more vacuum power than the competition.

for example apartments. These are all accommodations which do not have very big surfaces and are therefore a perfect environment for a robotic vacuum cleaner.

Summarized:

- Age between 25-50
- Modal income
- Fulltime job, approximately 38 hours
- Children
- Little time for household
- Small rooms, several floors
- Is familiar with current technologies

4. Design Brief

Below is the design brief. It contains the requirements of the robotic vacuum cleaner with appropriate specifications. The requirements are grouped in 'General', 'Functionality', 'Utility', 'Security' and 'Danger'. Some specifications need an explanation; these can be read in the last column.

Requirements	*Specification*	*Explanations*
General		
Purchase price	€500-600	To be competitive in the robot vacuum cleaning market the robot must be in the same price range
Life span	At least 700 hours of vacuuming. With a battery replacement each 2 years.	The vacuum cleaner has to work for about 5 years
Working area temperature	10-35 ^{O}C	The target market is Western-Europe.
Surface temperature	-5-50 ^{O}C	
Guarantee	2 years	
Noise	Max 80 dB	A traditional vacuum cleaner produces noise of 70 dB. It can be a little bit more noise because the robot will be drive the most of the time when nobody's home. Above 80 dB, the noise will be harmful for your hearing.
Functionality		

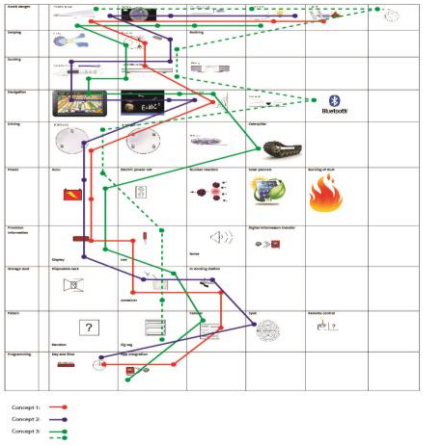
Vacuum	At least 90%	90% of the room should be vacuumed, aim for the highest possible vacuum performance
Store dust and hair	Minimal 3.5 L storage	Minimal 0.5L inside the robotic vacuum cleaner Minimal 3L inside a docking station. A traditional vacuum has this capacity too.
Water- and dustproof	Waterproof against splash water and dust (IP-53)	Waterproof against splash water
Vacuum in the corners		We will come up with a solution for this problem.
Drive independently		Programmed to find its own way through a room and back to the docking station (without getting stuck).
Height range	10 cm	There has to be cleaned underneath surfaces of 10 cm. So the robot can drive under the most furniture
Weight	10 kg	It should be easy to move the vacuum cleaner
Range per session	4m^2 per hour (in 8 hours 30 m^2). Preferred: 10 m^2 (30m^2 in 3 hours)	The vacuum cleaner has to be able to clean the house in the time the costumers is at work
Drive over barriers	2 cm	The vacuum cleaner has to be able to move over 2 cm barriers, thereby the robot can drive over thresholds and carpet
Vacuum power	>15 W	Philips' robot vacuum cleaner now has a vacuum power of 15 W. This should be increased.
Utility		
Simple manual – Action points before the first usage	15 actions	Open the box – Read the manual place the docking station – charging of the robot – Turning on the robot – Set day – Set time – Set the program
Simple manual – Action points before 'every-day' usage	3 actions	Emptying the dust storage; Open the robot, walk to the

		trash bin.
Different subsurface		Be able to identify different surfaces.
Self-explanatory		Interface, which makes usage easy
Simple maintenance by Philips		Philips should easily be able to replace simple parts of the vacuum. this saves money
Costumer replacement	Costumers should be able to replace the battery and if present the brushes.	
Security		
Maximum speed	5 km	Walking speed
Should not cause a **short-circuit**	Be able to move over wires without moving the too much	
Should not fall of elevations	Higher than 4 cm	The vacuum cleaner may not fall down the stairs or elevations
Danger		
Can fall of heights	An impulse of 100 Ns with a weight of 10 Kg	The vacuum cleaner has to survive a fall of a height of 1 meter
Someone can stand on the vacuum cleaner	Constant load of 800 N on a surface of 0.025 m^2 resulting in a pressure of 32 kPa	The vacuum cleaner has to survive when a person of 80 kg stands on top
Vacuum cleaner should not get stuck without interference	Move over barriers and cables.	

Table 1 - Design Brief

5. Concepts

5.1 Morphological overview



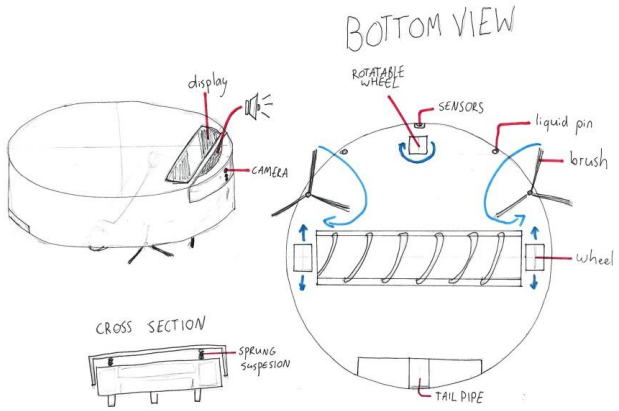
In the morphological overview our three concepts are presented. The figure can also be found in the appendix under '*D. Morphological Overview*'.
The concepts are described in detail in the next sections. The red line is for Concept 1. The blue line is for Concept 3. Concept 3 has two robots and therefore two green lines.

Figure 4 - Morphological overview

5.2 Concept 1 'Roundblowingbot'

Properties:

- Blows dust out of the corners
- Spring suspension to protect the motor
- Liquid pins to avoid spreading liquids
- Bigger battery
- Noises to notify the user that the robot is starting or is done with a program
- Standard cell by cell cleaning navigation program
- An application for mobile devices



Functions:

This concept is designed like the robots that are already on the market. A new addition is the tail pipe. With this pipe the robot can blow the dust out of the corners to a place that it can reach.
An other new addition is the spring suspession which makes sure that the vacuum cleaner will not break when someone (accidently) stands on it. The shell of the vacuum cleaner will lower to the ground and the wheels and the motor will therefore be protected.

Another addition are the liquid pins at the front of the vacuum cleaner to detect liquid when it is in the path of the vacuum cleaner. The robot will drive around liquids and therefore avoid spreading these when it detects them. Liquids are detected when both pins come in contact with it.

Further functions are:
This concept uses three kinds of sensors to navigate through the room. It uses Infrared, ultrasonic and a camera. These three sensors are placed on the front of the vacuum cleaner. Because the vacuum cleaner has a round shape, it will also be able to get a 2D image of the room. This allows the device to distinguish walls from objects, like chair legs. It is able to navigate around these objects and will not drive into any objects.

The vacuum cleaner uses a standard cell by cell program to move around the room(s). The vacuum cleaner will move from compartment to compartment, for example form kitchen to the hall to the living area, minimizing the time around you.
This concept has three wheels. Two wheels are in the middle, placed at the sides, and one in the front, placed in the middle. Both wheels in the middle can only move forwards and backwards, the one in the front can rotate.

The vacuum cleaner uses an electric motor powered by a battery. This battery is bigger than the one used on most vacuum cleaners available on today's market.

The interaction between the vacuum cleaner and the user is established through a display and sounds. The sounds are used to notify the user that the robot is starting a programed program or is done with the program. The display is to give more information, like error information and more program information.
Furthermore an application for mobile devices can be used to start the vacuum cleaner. When the user is not at home, he or she can start the device through this application.

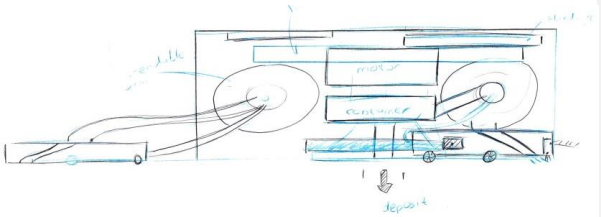
Target group:
This concept regards the wishes of our target group. It is good for busy people, because it will start everyday automatically at the same time. It will go around obstacles, so toys lying on the floor will not be a problem. Developing this vacuum cleaner will be complicated, which means that it will be expensive and therefore not feasible for the target group. In case children or animals feel the need to 'have a ride' on the small robotic cleaner, he won't break down since it has springs to support this extra weight.

Possible improvements that have to be made if concept is chosen:

- The robot can also have a docking station
- A better cleaning navigation program

5.2 Concept 2 'Octolifant'

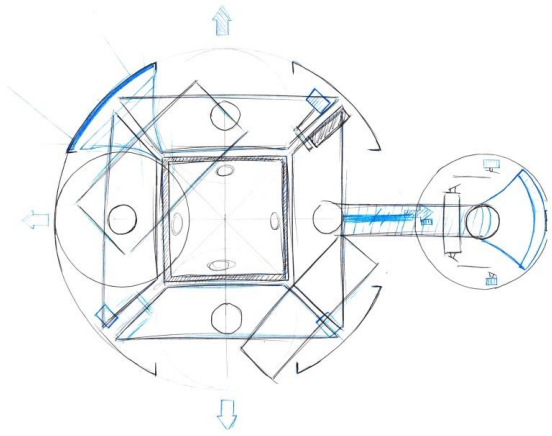
Properties:



- Four extendable arms with an own vacuuming mouth
- The main hub controls the extendable arms
- Vacuuming in 'spot' pattern
- Has its own docking station which can suck the dust out of the robot
- Arms can vacuum under furniture
- Programmable timer
- The robot can clean in 4 directions

Functions:

This concept is basically a multi-sucking device. It is a round robot, powered by a battery, which has four extendable arms. These extendable arms have a separate vacuuming mouth mounted underneath them and separate servo's to control the wheels.



All these arms are controlled by the main hub. When the robot is vacuuming, it drives for a short distance, then extends its arms, cleans and finally pulls them back in and drives off. If the robot comes near a wall, the camera and proximity sensor will register this and make the robot turn away from the wall. If the robot's camera registers a chair leg, it will maneuver around it in 'spot' pattern. The dust which the robot collects will be brought to the docking station. This docking station will also charge the robot and hold it during idle time.

The robot has a programmable timer which starts the robot at the given time. The robot will then automatically vacuum the room, and return to its docking station when it is done.

The advantage of this concept is the fact that it cleans in 4 directions. The arms move in and out and therefore go past a spot 2 times. This decreases the chance that dust is left on the floor. The extendable arms also have a smaller radius than the main robot, which reduces the unreachable area in corners. The arms are also more useful for vacuuming under couches.

Target group:

This concept is able to clean every type of dry floor and reach almost every spot of the room. The places it cannot reach can be reached with the hand vacuum cleaner, mounted on the docking station. The

complete package of the docking station and the robotic vacuum cleaner is very useful to people who just bought their first house. The timer function is very useful to people who do not have a lot of time when they are home, but want to come home to a clean house.

Possible improvements that have to be made if concept is chosen:

- An improved cleaning pattern
- The control of the expendable arms

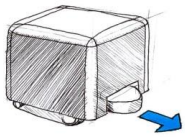
5.2 Concept 3 'Caterpillar Family'

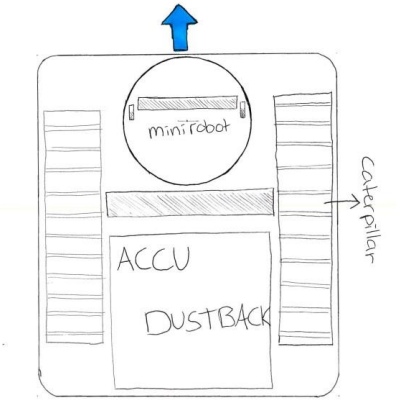
Properties:

- A tiny robot to: clean tiny passages, under low furniture, reach corners through its brushes
- Big motor and battery for more sucking power and battery life
- Bluetooth connection between the big robot and the small robot to exchange information
- Tiny robot can be used as hand vacuum cleaner
- The dust storage of the small robot can be emptied into the big robot
- Liquid pins to avoid spreading liquids

Functions:

This concept is a big robot with a tiny robot, which is inside of the big robot. The tiny robot is supposed to clean everywhere the big robot cannot reach.





The big robot is approximately 40 cm high and has a diameter of 40 cm. It has 2 caterpillar tracks. Each is driven by 2 wheels connected to a servo. Because of the rather big sizes, a good battery and a big storage can be provided. The tiny robot is approximately 5 cm high and has a diameter of 16 cm. The big robot can scan the area to find the most efficient way to vacuum the, to be cleaned, room. This information is transferred via Bluetooth to the tiny robot. The tiny robot returns after his task to the big robot. The tiny robot has a container for the dust, while the big one has a sack. The collected dust will be sucked out of the tiny robot, once back in the main robot. The main robot additionally has liquid pins to detect liquid and is through the stronger vacuum power, able to vacuum small and big items. After use, the robot will be charged through a magnetic feature. The vacuum cleaner will also have a display which will guarantee an easy usage. As an additional feature, the tiny robot can be used as hand vacuum cleaner for surfaces like staircases, tables and the seating area of couches and chairs.

There are several reasons for the particular design of this concept. It is a perfect replacement for the manual vacuum cleaner. The round shape and caterpillars are chosen because it makes sure the vacuum cleaner never gets stuck. The current vacuum cleaners cannot properly clean the edges, but through the use of the tiny robot this can be done. The small robot is also small enough to come underneath couches and cupboards. Bluetooth allows the two robots to communicate. Nevertheless, the tiny one needs a light to show something is wrong, in case the Bluetooth connection shuts down.

Target group:
This concept is a good fit for our target group. With the two robots, a clean house, even clean corners, are guaranteed. Although this model is bigger than the robotic vacuum cleaners, that have been developed, it guarantees a replacement of the normal vacuum cleaner with robotic features.

The price of this concept is going to be high, since two robotic vacuum cleaners have to be build. Although this concept turns out to be more expensive, through its durability and since it is a replacement of the vacuum cleaner, people are more likely to invest money.

Possible improvements that have to be made if concept is chosen:

- The caterpillars can be removed for wheels for more freedom of movement
- The cubic shape can also be a round shape (a round shape can rotate on its own axis)
- Can also have a docking station

5.5 Concept choice

To decide between the three concepts previously introduced, the most important requirements are selected from the design brief. The selected requirements are most relevant for the three concepts. The rest of the requirements is also important, but in a later stage of the design process since these say much about material choice, elaboration of the user interface, choice of motor and battery, and other elements which will be refined after the concept choice.

Comment [N1]:

The chosen requirements is given a weight, which determines the importance of the aspect. A weight between 1 and 5 can be appointed to each requirement, with 5 being the highest score and therefore most important and 1 being the lowest score and therefore less important. The reasoning for the requirements and the appointed weight are the following:

Requirement	Importance
Corners reachable	4
Cleaning speed	2
Dust storage	4
Replacement normal vacuum cleaner	5
Weight	1
Danger resistance	3
Feasibility	5
Durability	4
Vacuum power	4

Navigation	3
Price	2

Table 2- Requirements

- Corners reachable:
  In the problem analysis is discovered that the reachability of the corners reveals one of the main problems of current robotic vacuum cleaners. Since this is an aspect which has to be improved, we assigned an importance of 4.
- Cleaning speed:
  Since the target group includes primarily consumers that have to work all day, the cleaning speed is not from great importance. Nevertheless should the robot be done before the customers come home. An importance of 2 is assigned to cleaning speed.
- Dust storage:
  The dust storage is an controversial aspect by a robotic vacuum cleaner. On the one hand the device has to be small; on the other hand consumers expect is to meet the specifications a manual vacuum cleaner has. All together is to the dust storage inside the robot and the docking station an importance of 4 assigned.
- Replacement:
  Since today's market is not advanced enough to develop a replacement for the manual vacuum cleaner it is decided to give this only an importance of 3.
- Weight:
  Since the robotic vacuum cleaner is able to drive by itself the customer does not need to pick it up, therefore this requirement is of little importance and gets a weight of 1 assigned.
- Danger resistance:
  The robotic vacuum cleaner must be able to withstand some danger, but nevertheless it can break down in very rough situations. The consumer is responsible for the device and has to look out for dangers the device could encounter. It is assigned an importance of 3.
- Feasibility:
  This is the capability to accomplish the concepts. This requirement determines the costs of product and the possibility of producing the device. This should be one of the main focuses from making this decision and gets therefore an importance of 5.
- Durability:
  Durability is, beside the marketing effect, not really a focus point for the robotic vacuum cleaner. Therefore a weight of 2 is assigned to durability.
- Vacuum power:
  The main focus point of the vision is the vacuum power, it is defined as very important. So it is given a weight of 5.
- Navigation:
  It is required the robotic vacuum cleaner doesn't get stuck by the navigation program which is installed. It is not the main focus and gets therefore a weight of 3.

- Price:
  The results from the survey shows that the target group is willing to spend more on a vacuum cleaner with vacuum efficiency that comes close to the manual vacuum cleaner. Therefore it is not a big problem if the vacuum cleaner is a little more expensive. This is assigned a weight of 2.

In the next step of the concept choice, every concept gets a score between 1 and 5 for each selected requirement. The higher the score the more the concept fulfills the requirement as determined above. The importance of the requirement is multiplied with the concept score. All added together will give a total score for each concept, visible in the last row.

Requirement	Importance	Concept 1	Concept 2	Concept 3
Corners reachable	4	4.5	3	4.5
Cleaning speed	2	3	2	3
Dust storage	4	4	4.5	4.5
Replacement normal vacuum cleaner	3	3.5	2	4.5
Weight	1	5	2	1
Danger resistance	3	4	2	3
Feasibility	5	4	1	2
Durability	2	3	2	2.5
Vacuum power	5	3	3	4
Navigation	3	4	4	4
Price	2	3	1	1.5
Total		126.5	86.0	115.5

Table 3 - Concept choice

The most important scores given are these for 'feasibility' and 'vacuum power'. The highest score for feasibility reaches concept 1. In contrast to the other concepts, this concept has mostly features that are achievable. The other concepts are not realistic enough and are too advanced.

Vacuum power is the other important aspect of the device. Because of the vision to make a robotic cleaner that has an upgraded cleaning performance. Concept 3 scores here highest, since it is big and has a lot of space for a large motor. The other concepts are much smaller and the realization of the idea is here more difficult.

The chosen concept is Concept 1, not only because it has the highest score, but also because it fits the best in our profile of a new generation of vacuum cleaners. The unique selling points desired to accomplish are the following:

1. Clean the corners through blowing
2. Bigger dust storage in the docking stations
3. Docking station can be used as cleaner

4. Improved cleaning pattern, cell

5.6 Patent

Patents are an important part of the concept phase. If there already exists a patent, the idea for a product can be destroyed. This is why we looked up patents on robotic vacuum cleaners that can blow. The technique of blowing air is already used before, but not as specific as done with this robot vacuum cleaner. A few patents have been found that are comparable to the blowing mechanism of this robotic vacuum cleaner, listed in *'E. Patent',* but none of these are used blowing as a function to clean the corners.

6. Final Concept – 'The Beetle Bot'

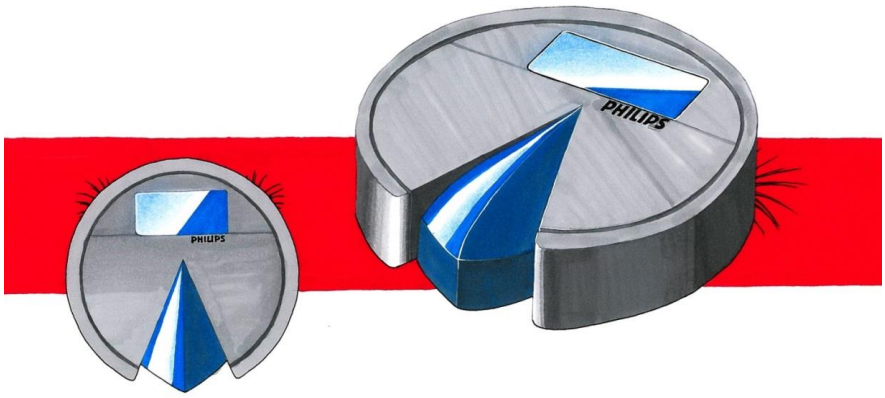


Figure 5 - Final Concept

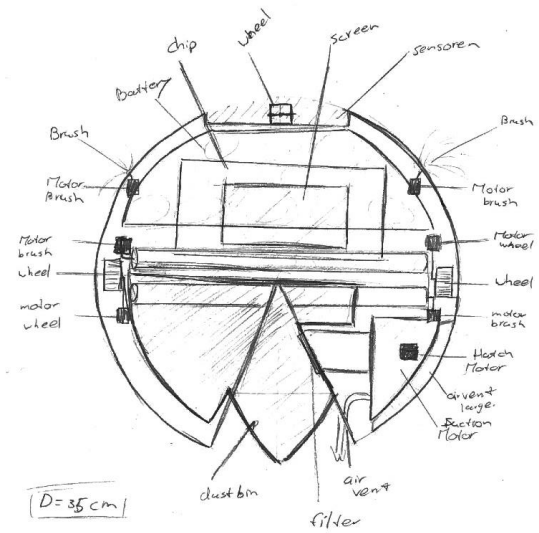


Figure 7 - Top view final concept

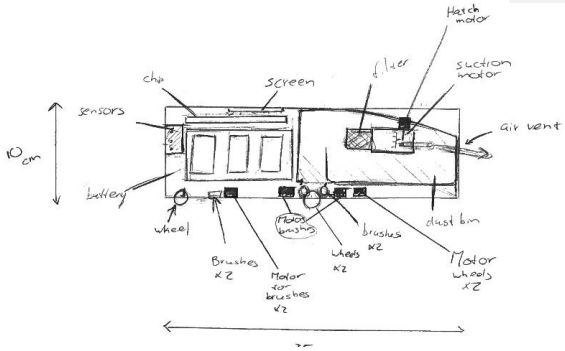


Figure 6 - Side view final concept

The final concept has some characteristics: a suction gap with two axial rotating brushes; a docking station that recharges the unit; a navigation system that works with cells; a display that communicates with the user to optimize its use. However the Beetle Bot has a few different functions which make it unique. It has the function to empty its own dust storage in the storage of the docking station. It also blows air to clean corners after which it will vacuum the blown away dust by following a certain pattern in the corner.

6.1 Corner cleaning through blowing

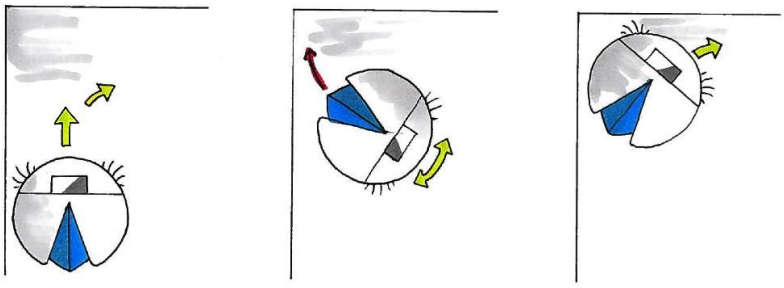
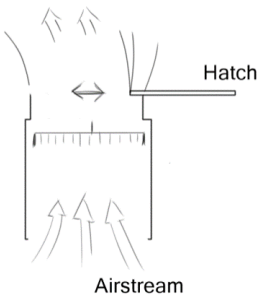


Figure 8 - Cleaning the corners



The unique selling point of blowing dust out of the corners can be realized in different ways. The best way to realize this idea is by using a hatch. The hatch is a simple concept where there are two paths for the air to travel through, one of which is closed. When it is needed to blow away dust the robot vacuum will close one hatch and open the other. This idea is chosen because of its simplicity and lack of complications. Further information can be found in attachment X. As well as the other ideas for cleaning the corners through blowing.

6.2 Vacuum system

At the suction gap there are two axial rotating brushes. These brushes:

- reduce the static electricity of the floor
- make it easier to vacuum dust
- make sure the carped is cleaned better because the carpet hairs are pulled apart and they concentrate the airflow resulting in a higher suction power.

Directly after these brushes there is an overflow with after that the dust storage, as shown in '*Figure 11 - Suction Gap*'. Because the airflow in the dust storage is a lot lower, larger parts will drop and only the small parts, mostly dust, will move with the airflow to the end of the dust storage. At the end of the dust storage there is an outlet to the motor, before the motor there is a HEPA (High-efficiency particulate absorption) dust filter. After the motor is the air outlet.

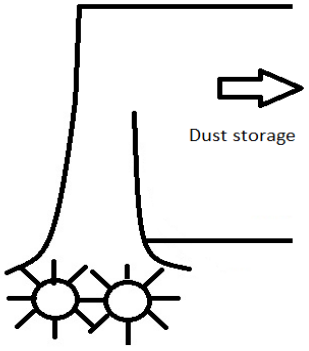


Figure 9 - Suction Gap

6.3 Emptying the robotic vacuum cleaner

Docking station

To improve the suction power and enhance user comfort, it was chosen to put in a bigger motor, which means a smaller dust storage in the robotic vacuum cleaner. To compensate this, there is a bigger dust storage in the docking station. To prevent that the customer has to empty the vacuum cleaner a lot, a self-emptying dust storage has been used. This means that only a small amount of dust is collected and then stored in the docking station. From the set of requirements can be read that a storage capacity of 3.5 liters is desired. Because of this small dust storage, it needs to be emptied frequently into the docking station. When the robotic vacuum cleaner is full, it will automatically return to the docking station to empty his dust storage.

Figure 10 - Docking station

Emptying-system

There are several options to transfer the dust of the robotic vacuum cleaner into the docking station. One option is opening a valve and hope that all the dust will fall out of the device into the storage of the docking station, whereby most likely not all the dust will get out and the filters will be constipated with dust. Another option is to place the vacuum motor of the robot in front of the storage so it is able to blow the dust out through another opening. This will most likely damage the rotors of the fan, when the robot is cleaning. The last and best option is that a motor is placed inside the docking station that can suck the dust out of the dust storage of the robotic vacuum cleaner. This solution is not ideal because it will increase the price of the end product. Nevertheless, this is the most realizable method. Therefore the chosen method is placing an extra vacuum motor in the docking station.

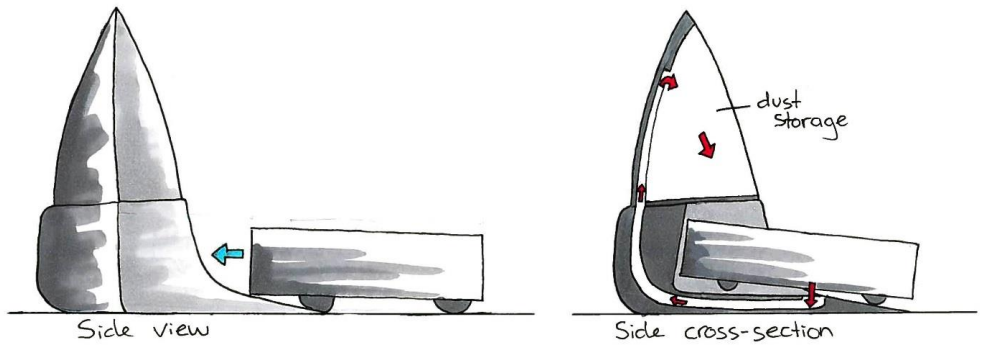


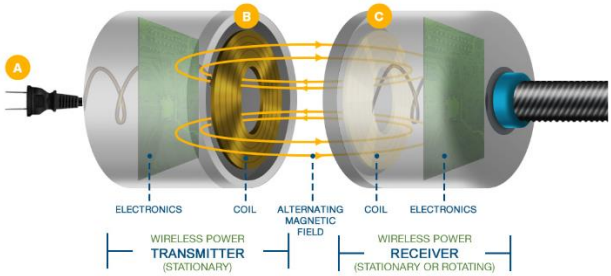
Figure 11 - Emptying robot in docking station

Functioning docking

The robotic vacuum cleaner notifies that the dust storage is getting full, when an increased amount of power is needed. It will automatically return to the docking station, where it will drive onto the docking station. This will activate the emptying mechanism. The vacuum motor of the docking station will start to empty the robotic vacuum cleaner. Dust is vacuumed from the robotic vacuum cleaner into the docking station through the same place where the dust is sucked in. The brushes of the robot vacuum cleaner will run at a low speed, so that these are cleaned as well and making sure that all dust particles are sucked into the docking station. The emptying mechanism will also be activated if the robot returns to the docking station if it needs to recharge. The docking station has to be emptied by the user when it is full.

6.4 Charging

Charging takes place as long as the robotic vacuum cleaner stands on the docking station. Inductive charging[6] is chosen and has advantages over a normal plug-in charger. First, it is less sensitive for misplacement; it does not matter if the robotic vacuum cleaner is a little misaligned in the docking station. Secondly, the system is less sensitive for wear and fluids. It is safe to use, because there are no pins that can be electrocuted. Momentarily "Powerbyproxi" is a manufacturer of these systems. They make chargers from 12 up to 240W. For a mobile phone (30W) the charging diameter is about 5cm. For the robotic vacuum cleaner the necessary amount of transferred W still needs to be calculated, but will be within



[6] http://powerbyproxi.com/wireless-charging/

the range. This system will thus also be applicable for robot vacuum cleaners. The inductive charging is momentarily a little less effective than normal chargers, but this system is probably much more optimized within five years.

6.5 Navigation system

It is important that the robot has a lot of sensors to detect several things. First it has to detect the corners and should be able to drive into these, turn and blow them clean. Second, if there are obstacles, the robotic vacuum cleaner has to be able to avoid them. Third, if there are couches or other obstacles above 10 cm, the robotic vacuum cleaner has to be able to go underneath them and clean.

To detect every object, five ultrasonic sensors has been used in the front. Two horizontal and two vertical ultrasonic sensors, so it can measure objects. One sensor is in the front on the downside of the robotic vacuum cleaner. When it detects a height difference that is too big, it will turn and go back. This will prevent the robot from falling down the stairs or other heights.

Further, the ultrasonic sensors have to detect the corners, so that the robotic vacuum cleaner can turn into the corner and blow all the dust out of it.

Further, infrared sensors have been used to detect if the robotic vacuum cleaner is able to go underneath objects. Infrared sensors are placed on the left, on top and one on the right on the top.

If the sensors detect an object, it means that there are objects which are lower than 10 cm and that means the robotic vacuum cleaner will not be able to go underneath it.

Also the robot has a camera on top. With the camera, the vacuum cleaner can see its surrounding. It takes pictures of the ceiling when the robot starts with cleaning and during its cleaning process. With the pictures, it can determine where it is in the room.

The robot has to find his docking station when his dust bin has to be emptied or the battery has to be charged. This is possible with radio signals which the docking station will send to the robotic vacuum cleaner, so it can find its way back.

With camera and sensors the robotic vacuum cleaner makes a map of the whole room. Then the robot knows how big the room is, where obstacles are and where it can drive underneath. This way, it can determine the best cell by cell route through the room and how much it has cleaned of the room; this can be seen on the display.

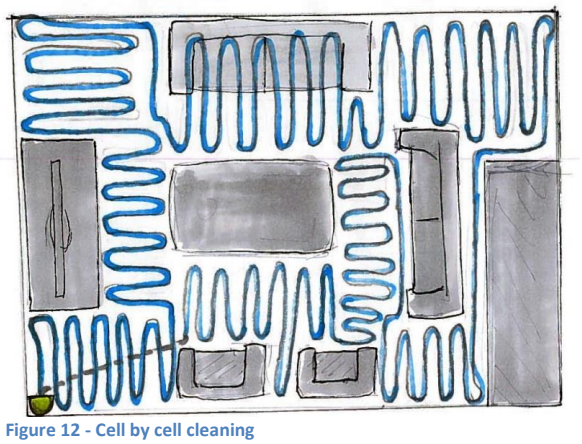


Figure 12 - Cell by cell cleaning

The robot will remember this map, but will also make new maps. When the user has removed furniture or changed the equipment the robot always designs a new map. This will not prevent that he rides against objects, therefore he also needs other features, but he can determine where in the room he is.

6.6 Equipment: Motor and Battery

The robot vacuum cleaner will be equipped with some standard parts. These are the batteries, and electrical engines. Deriving from the set of basic requirements, there are specific requirements. A short research has been done to determine the availability of these parts. Subsequently a calculation was done to determine the necessary sizes of the parts and characteristics. Batteries and motors are essential for the device, but they are available in many different sizes and can be selected to fit in a machine.

Requirements:
The new vacuum cleaner must be able to drive for at least 700 hours. The vacuum cleaner must have more sucking power and must have then still have power left for driving around, passing over doorsteps and carpet. The engines must also provide power for turning the brushes.

Based on these requirements, calculations have been done. These mathematical analysis and the arguments for the battery type are given in '*F. Equipment*'. For this design the dimensions for the battery and a motor are chosen to be:

Battery:
- Dimensions changeable
- Lithium ion battery
- 12 Volt
- 3.5 Ah
- Volume of about $5*10^{-4}m^3$

Motors:
- dimensions cylindrical but changeable

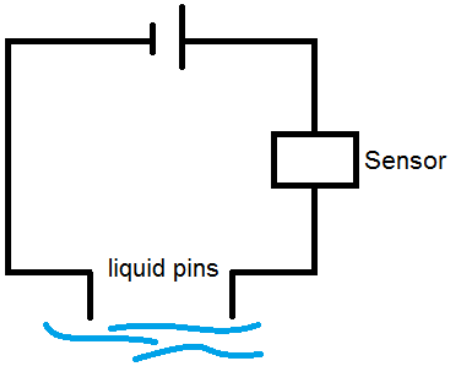
- Vacuum	= 30 W	= $3.4*10^{-4}m^3$	about 3cm diameter x 6cm long
- Brushes	= 3 W	= $0.34*10^{-4}m^3$	
- Locomotion	= 6 W	= $0.68*10^{-4}m^3$	
- Other	= 5 W	= $0.57*10^{-4}m^3$	

6.7 Liquid pins

Initially the concept of the robot had a danger prevention system for water. This would have been the liquid pins. Two pins on the bottom of the robot, which are connected to the battery of the robot in a way that, when water connects both pins, the sensors in the robot will register it.

These liquid pins are not included in the final product for several reasons. At first, the pins could scratch the ground, because they have to be so low to the ground to sense small portions of water.

Also the pins make an extra part on the robot, which reduces its durability.



If water hits the underside of the robot. It will stick to it due to adhesion, which will result in a continuous current through the pins. In this way the robot will keep sensing water and might somehow 'crash'.

Finally if the pins are added to the robot, it will become even more expensive and it is no guarantee that the pins will always work correctly. It is an extra addition, which will make the product only more complicated, without adding much value to the final product.

6.8 Communication with the user

It is important that the robot can communicate with the user and vice versa. The user must be able to set the robot.

The robot contains one display. This display is the communication tool between robot and user.

Things that are shown on the display:

Time – So the user can see the robot starts on the correct set time

Battery runtime – So the user can see why the robot is not cleaning the room on the set time

Error message – if there are any problems, for example the robot gets stuck or the brushes cannot run properly, the robot has to give a message so the user knows what he can change, so that the robot will continue. If the robot does not know where the error is, he gives a general error

The part of the room that has been cleaned – So the user knows the robot does his job properly.

When the brushes need to be cleaned – In this way, the user knows when it's time to clean the brushes. If they are not cleaned they will do their job, cleaning near the walls, not efficiently. The brushes will always give an equally good result, this ensures an equal cleaning performance, because the user is never too late to clean them.[7]

When the dust bin should be emptied – Gives a signal when it's almost full of dust. So the user can empty the dust bin in time.

[7] Except for procrastination by the user

If the robot is cleaning, charging or does nothing – When the robot is cleaning or charging in the docking station, the user can see this on the display. When the robot has no task, there will be no text on the display, only the time and when the robot will start cleaning.

The user should be able to operate the robot:

Turn on the robot – with a button

Turn off the robot – with the same button to turn on the robot

Set the day and time when the robot has to do its job – you have to press the on/off-button for 5 seconds. Then the set program appears on the display

Change the day and time the robot has to do its job - you have to press the on/off-button for 5 seconds. Then the set program appears on the display

6.9 Choice of appearance

Style

In this collage products from Philips, different types and styles, can be seen. They have for certain types of products, different styles.

As you can see:
Most of the products have rounded corners.
Most of the products are made of black or white plastics.
Sometimes a product has a color (accent) to give it another look.

Different looks appeal different target groups, like the Easystar vacuum robot which is also deliverable in pink and blue. [8]

Figure 13 - Style Collage

The hand blender is deliverable in different material types (plastics/metal), to make a difference in professional cooking and amateurish cooking.

The robot vacuum cleaner should be designed in the style of Philips. Philips has also a diverse style, but the rounded corners and the trim between two different kinds of plastics will be found in the product.

[8] The pink one is for women and the blue one is meant for men.

There are different reasons why the appearance is chosen like showed before. The first reason is that a round shape can rotate around its own axis without getting stuck. Other shapes may get stuck when they want to turn, for example between chair legs.

The appearance had to ensure that the function 'blowing' is clearly visible and understandable for consumers. Consumers will probably wonder why the robot blows dust instead of sucking it up. To make clear that it is normal that the robot blows, this is emphasized in the appearance of the robot. The back of the robot has been given a cutout, and a double-curved surface, looks like a tail, which tapers striker pointed is disposed. This indicates the direction of the air pipe.

Also, the product styles from Philips are taken into account. The product style is examined in the Philips collage. The rounded corners, simplistic shape, no hodge-podge and a color accent are reflected in this design.

Material choice

For the outside of the robot different types of plastics are chosen. De side of the robot has to be scratch and chock resistant.

Because the robot blows dust, dust will fall on the top of the robot. This does not look clean. By making use of a matt plastic, this will be less noticeable.

To emphasize the tail of the vacuum cleaner it shines. This can be realized with glossy plastic.

The wheels may not scratch the floor. These are made of plastic with an outer layer of a rubbery plastic. This outer layer is injection molded around the inner wheel. This way the part of the wheel that touches the floor will be soft and will not scratch it.

The robot also has inner parts which need to be constructed. These parts keep motors and other innards on their place. These parts are made of plastic.

6.10 Unique Selling Proposition

- **High cleaning performance**

In the development of the robotic vacuum cleaner was a focus on high cleaning performance. There are different components which ensure this. The dust bag of the vacuum cleaner is smaller in comparison with other robotic vacuum cleaners. Therefore there is more room for the battery and electric motor, which will result in more suction power. The small dust bag inside the robot will be compensated with a dust storage in the docking station and the performance of the robot will improve. Another element, which creates a high cleaning performance, is a unique way of cleaning the corners of the rooms by blowing. The robotic vacuum cleaner will be better than other models due to the combination of these components. This will keep the house clean and dust free.

- **Blowing in the corners.**

One of the main problems of the current robotic vacuum cleaners is cleaning the corners. Because of its round shape, it cannot reach the corners. There are some companies who tried to solve this problem,

but a real solution has not yet been found. The new development is a system that will blow the dust out of the corners. If the robotic vacuum cleaner detects a corner, it will turn, so that the blowing part is turned towards the corner. This feature will take care that every place in the room will be clean. If everything is clean, no one has to clean the room manually anymore after the robotic vacuum cleaner has finished. The only places that has to be cleaned manually will be places that are above the ground, like the couch or the stairs.

7. Conclusion and Recommendation

7.1 Summary/conclusion of the meeting with Philips

Philips emphasized that we should focus on a good cleaning performance. The corners and the floor itself should be our main target. It does not have to replace the original vacuum cleaner entirely. By using a large motor, a simple battery and a large dust storage in the docking station, we can achieve better suction-quality. The additional hand vacuum cleaner was too excessive. If people would need an additional hand vacuum cleaner they would buy it instead of wanting a complete set that would replace the vacuum cleaner they already own. Only focusing on the cleaning performance and the use of blowing the corner distinguishes enough itself from the other robot vacuum cleaners. It should show the buyer that it is better than every other model.

When cleaning the corner, the buyer might think de robot vacuum does not clean it. Because the robot blows the dust in the air the user could easily mistrust the machine. It is important to convince the customer that it really works and sometimes it is necessary to exaggerate a bit so the customer can see it works. This is why the robot vacuum should show by function, behavior and design that it cleans the corners and that is also the reason why the use of a small air pulse is not going to work. Although it would work it does not show the function and the buyer will not be convinced that the robotic vacuum cleaner really performs a good cleaning job. The solution for this can be: using the airstream of the vacuums motor and making the robot move a certain pattern in the corner. The design should also show that when he is in the corner he cleans it.

The usage of electrodes to recognize liquids is unnecessary because it does not add something to the cleaning performance. It makes the product more expensive and more complicated than needed. If we would make the robot vacuum waterproof from the inside it would be just as good and less expensive.

7.2 Conclusion

Blowing the corners

The robotic vacuum cleaner cleans corners by using the airstream. It blows the dust out of the corners. However it needs to be tested what exactly happens with the dust. The dust could fly up high in the air. Several problems should be considered. The dust could get so high that it is possible dangerous for the health of the user. Also it is possible that it will take a long time until the dust falls down. When the robotic vacuum cleaner already left the corner this dust will not be sucked into the device. The air, stream as intended, should blow the dust in a horizontal angle, so that the dust falls down onto the floor immediately. This way the dust can be removed without problems. As stated by

Philips, the robotic vacuum cleaner will also clean one more time around the corner, to show it really cleans everything and not only blow the dust in the air.

Cleaning carpet
There could come up problems with the brushes when the robot cleans a carpet. The brushes can get stuck or hold on to the carpet. A solution is pulling up the brushes if the robotic vacuum cleaner detects a carpet. The brushes could also be turned off. Both will prevent that the brushes break.

Replacement of the vacuum cleaner
The first idea of making a robotic vacuum cleaner that completely replaces a normal vacuum cleaner was not possible with the current technology. A recommendation for the future robot is to replace a vacuum cleaner. Elements to be reckoned with are: cleaning different floors, stairs and furniture. A solution for this problem is a hand vacuum cleaner, attached on the docking station. But it would be even better to develop a robotic vacuum cleaner that is able to do all tasks with one device.

Appendix

A. Market Analysis

iRobot
iRobot is the number 1 player globally. They own a lot of patented technologies and claim to provide superior cleaning performance. iRobot has a vacuum cleaning robot, but they have also robots for floor scrubbing and floor mopping.

Their newest vacuum robot is called the Roomba 800 series. The main improvement in the latest model is the addition of cylinders. With former models, hair used to tangle up around the brushes. The cylinders work like a conveyor belt, so one does not have to clean the brushes manually any more.

Roomba has five motors. One driving each wheel (2 total), one driving the vacuum, another one driving the spinning side brush and the last one driving the agitator assembly.

Roomba uses a system, the iRobot's AWARE(tm) Robotic Intelligence System, to make decisions itself. The AWARE system is made up of multiple sensors that pick up environmental data, send it to the robot's microprocessor and alter Roomba's actions accordingly.

There are special filters installed in the robot for better cleaning performance. The downside is that the robot still bumps into low objects, such as laptops, at full speed, which is probably due to the height of the sensor. Customers are rather happy with the Roomba cleaners.[9] The Roomba has better performance, less maintenance, good looks and

[9] http://www.expertreviews.co.uk/home-appliances/vacuum-cleaners/8366/irob

additionally not all animal hair is sucked up from the carpet.[10]

Ecovacs

Ecovacs is a Chinese company, very active in domestic robots, which have a huge range of applications. The company mainly focusses on intelligence.

One of the main features of Ecovacs is that the vacuum robot automatically empties its dust in a docking station. There are many extra features, like a remote control and an additive hand vacuum cleaner.[11] The reviews of this product are however a bit disappointing. The robot gets rather easily stuck and the programming does not work properly. Though there are a lot of features and the robot should be able to do all jobs any other random robot vacuum can do, too, the customers are not content with the performance.[12]

Samsung

Samsung is a rather new producer of vacuum cleaners. They combine intelligence and fancy design. Samsung is seen as N2 player in Europe and the key player in Asia.

The site of Samsung is not exactly up to date about their vacuum cleaners, but according to other sources, Samsung has developed three vacuum robots. Their newest model is the SR8895. The robot maps the rooms with 30 pictures per second. The cleaning trajectory is saved and it calculates where its docking base is. The robot follows a rectangular path for more optimal cleaning performance.[13] The suction power is rather disappointing and eight different modes are too many for the user. The robot knows where it has been and where not, because of efficient room mapping.[14]

LG

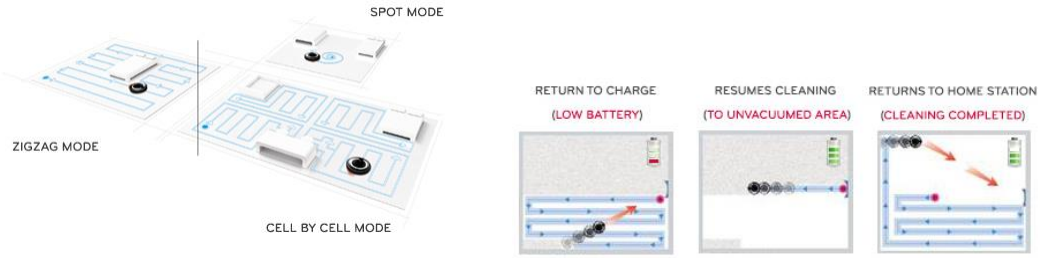
LG has two models, the Hom-Bot and the Hom-Bot Square. They are both 14 1/10" x 3 1/2" (DxH), but the shapes of these Hom-Bots are different. The Hom-Bot has a round shape. The Hom-Bot Square has, what the name implies, a square shape with very rounded corners. The brushes reach corners, wall edges and small areas more effectively than traditional round-shaped robot vacuum cleaners. The Hom-Bot has a dust bin capacity of 0,4L and the Hom-Bot Square a capacity of 0,6L. Traditional vacuum cleaners have a dust capacity of 4L.

Hom-Bot has three different cleaning programs. The consumer can pick the one that's best for the space to be cleaned. Hom-Bot will clean in "zigzag" mode to follow the most efficient cleaning path. For large

[10] http://spectrum.ieee.org/automaton/robotics/home-robots/irobot-roomba-800-series-combines-better-vacuuming-with-less-maintenance
[11] http://www.ecovacs.com/features/Deebot-D77.html
[12] http://www.amazon.com/DEEBOT-D77-Vacuuming-Ecovacs-Robotics/dp/B00F8
[13] http://www.robot-stofzuiger.nl/merken/samsung/sr8895/
[14] http://www.digitalversus.com/robot-vacuum-cleaner/samsung-navibot-silencio-

areas with many obstacles, Hom-Bot automatically splits the space "cell by cell" to help avoid missing a spot. The manual spiral mode is perfect for spot cleaning. The Hom-Bot has 5 ultrasonic sensors, 2 IR sensors, and a gyroscopic sensor. These help keep Hom-Bot on course and minimize collisions with household items.

Hom-Bot returns automatically to his docking station, when his battery is low and resumes cleaning, where it left off, after the battery is fully charged again.[15]



Philips EasyStar

Philips has developed the 'slimmest robot vacuum cleaner'. Philips EasyStar, is supposed to vacuum, where others cannot reach. They accomplished this through the slim design of the robot and a height of only 50mm. Additionally, it has extra-long side brushes, the robot can vacuum in the corners and closer to walls.

To create a user surface, that everyone understands, Philips developed the 1-button operation. The robot will start vacuuming, after it has been turned on. Special about this vacuum cleaner is also the 2-stage cleaning system, which can capture dirt and dust. To exhaust filter are built in to trap even fine dust.

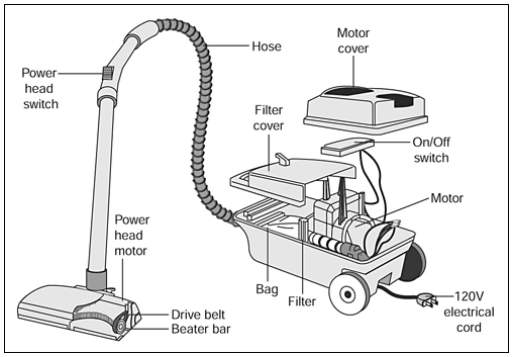
Philips has also another robot vacuum cleaner model, the HomeRun vacuum cleaning robot FC9910. With the integrated camera, sensors and software he maps the rooms so he knows where to clean and can dodge obstacles and stairs. He also has a docking station and when the battery must be charge, the robot will return to his station. It is not

[15] http://www.lg.com/us/vacuum-cleaners

possible to use the robot in a dark room. The robot has various cleaning methods; automatically, spot, climb and carpet. The robot vacuum cleaner needs sufficient light to be able to use its camera to create a map of the room.[16]

The 'traditional' canister vacuum cleaner

A vacuum cleaner doesn't really produce a vacuum, but a pressure differential (reduced air pressure in an enclosed chamber) that causes the suction. There are many models of vacuum cleaners. The model most common in Europe is the 'canister' vacuum cleaner , they dominate the European market.



The canister vacuum cleaner has an motor and dust collector (using a bag or bagless) in a separate unit. Usually mounted on wheels, which is connected to the vacuum head by a hose.

The main advantage of the vacuum cleaner is flexibility. The hose is flexible, hereby the head is very maneuverable. The head can reach under furniture and makes it very easy to vacuum stairs and vertical surfaces. Also the user can change different heads for different tasks. The most vacuum cleaners have also a button to control the suction power.[17]

Central vacuum system

The system sends dirt, dust, mold, pollen, and pet dander trough the network of hidden tubing in the walls to the dirt can located in a remote area of your home, for example the garage or the scullery. The best thing about central vacuum systems is that they don't require you to carry a heavy unit from room to room or up and down the stairs and you don't have an electrical cord which can tangle. Also the central vacuum system rids your home of the finest dust, unlike most portable vacuum cleaners, which leave much of the fine dust recirculating in the air. This type of vacuum cleaning is not common in European households. The most of the households have a 'traditional' vacuum cleaner. [18]

In comparison

	Roomba 800	Deebot D77	SR8895	Hom-Bot	Hom-Bot Square	Philips Easystar	Philips HomeRun	Princess Stofzuiger 332951
Price	700€	700€	550€	599.99$	799.99$	200€	599,99€	69,99€
Product	13" x 3 1/2"	13. 1" x	355 x 93	14 1/10" x 3	14 1/10" x 3	300*50	345 x 104	495x295x315

[16] http://www.philips.nl/c-p/FC9910_01/robotstofzuiger
[17] http://en.wikipedia.org/wiki/Vacuum_cleaner
[18] http://atomictoasters.com/wp-content/uploads/2012/09/central-vacuum-3.jpg

(DxH)		3.9"	mm	1/2"	1/2"	mm	mm	mm (lxbxh)
Weight	3.8 kg	3 kg	3.5 kg	3.18 kg	3 kg	1.3kg	4,1kg	6,5kg
Recharge time/ automatic	V	3 hours/V	90 min/V	3 hours/V	2 hours/V	4 hours	3 hours/V	
Cleaning time		100 min	120 min	90 min	100 min	50 min	100 min	infinity
Cleaning on schedule	V	V		V	V		V	
Cleaning speed			0.3 m/s				$40m^2/h$	
Full bin		0.7 L	0.6 L	0.4L	0.6L	0.2L	0.6L	4 L
Additional components		Remote control, detachable handheld vacuum		Remote control, voice alert	Remote control, voice alert		Remote control	Extension piece for cleaning crevices, baseboards and furniture
Floor type	Bare Floor, Laminate, Tile, Carpet			Bare Floor, Tile, Carpet	Bare Floor, Tile, Carpet	wood, laminate, tiles	Wood, laminate, tile and wall-to-wall carpet and loose rugs with a pile height up to 20 mm	Every type
Edge cleaning					V			V
sensors				Vision, Optical Flow, Ultrasonic, Infrared, Gyro, Accelerometer	Vision, Optical Flow, Ultrasonic, Infrared, Gyro, Accelerometer	stairs detector	Camera, gyroscoop, infrarood	Dust bin-full indicator

B. Survey

Enquête stofzuigergebruik

1. Wat is uw leeftijd?

2. Heeft u kinderen onder de 6 jaar?

3. Heeft u een stofzuiger in huis?
A. Ja B. Nee

4. Wat voor eens stofzuiger heeft u?
A. Een handmatige B. Een robotstofzuiger C. Kruimeldief D. Anders: ….

5. Hoe vaak stofzuigt u?
A. Dagelijks B. Meer dan een keer per week C. 1 per week D. 1-2 per maand
E. Minder dan 1-2 per maand

6. Hoeveel kamers stofzuigt u?
A. 1 B. 2 tot 5 C. 5 tot 10 D. Meer dan 10

7. Hoe groot is gemiddeld de oppervlakte per kamer, die u stofzuigt?
A. 0-15 m2 B 15-30 m2 C 30-50 m2 D>50 m2

8. Heeft u veel meubels in de kamers, die u stofzuigt, staan?

9. Liggen er veel losse spullen op de grond in de kamers, die u regelmatig stofzuigt?
Ja / Nee

10. Zo ja, bent u bereid deze spullen elke keer op te ruimen als u de robotstofzuiger gaat gebruiken.
Ja / Nee

11. Als u een robotstofzuiger heeft, hoe vaak zou u deze dan gebruiken?
A. Dagelijks B. Meer dan een keer per week C. Eens per week D. 1-2 per maand
E. Minder dan 1-2 per maand

12. Zou u een robotstofzuiger kopen als deze alleen ter aanvulling dient op uw normale stofzuiger?
Ja / Nee

13. Bent u bereid een robotstofzuiger te kopen?
Ja / Nee

14. Hoeveel bent u bereid te betalen voor een robotstofzuiger als deze alleen ter aanvulling dient op uw normale stofzuiger? En hoeveel als deze als vervanging dient?
1. …… 2. ……

15. In welke inkomensgroep valt u?
A. Rond modaal B. Boven modaal C. Onder modaal

Survey analysis

The survey was filled out by 37 respondents. From this group the average age was 44. What lies at the top of our target group. All but 1 of the respondents currently owns a vacuum cleaner, this person only uses a Swiffer to clean his floor. The rest of the respondents all uses a normal vacuum cleaner, also all the respondents who have a robotic vacuum cleaner own a normal vacuum cleaner and still use the normal vacuum cleaner.

One of the respondents who owns a robotic vacuum cleaner says it is useless and wouldn't buy one if it doesn't replace a normal vacuum cleaner completely. The other respondent does find it useful but the battery has become much less and there it is not used as much anymore.

The average amount of rooms the respondents vacuum is 4. The average size of this rooms 15-30 m^2. From the respondents 41% had lots of loose stuff lying on the floor, from this persons 53% was willing to remove this stuff, every time, before using a robotic vacuum cleaner.

The average people are willing to pay for a robotic vacuum cleaner that is a complement on their normal vacuum cleaner is €118,00. However 54% is willing to pay more than €50, with an average value of €182,00. If the robotic vacuum cleaner is a replacement of their normal vacuum cleaner people are willing to pay much more. The average is: €252. However 73% is willing to pay more than €100,00 with an average of €308,00. But only 24% is willing to pay more than €300 euro's.

On the question or people are willing to buy a robotic vacuum cleaner came a lot of useful input why people would or would not buy a robot vacuum cleaner. First of all a lot of people said they are only willing to buy a robot vacuum cleaner if it was able to completely replace there (current) normal vacuum cleaner and is as efficient as their normal vacuum cleaner. Also some people said there were not willing to buy a robot vacuum cleaner because they think it is not as efficient as a normal vacuum cleaner. Secondly a lot of people said something about the price, they are not willing to pay more than a normal vacuum cleaner or want a reasonable price. 27 % of the respondents answered positively without any conditions.

C. User Scenario

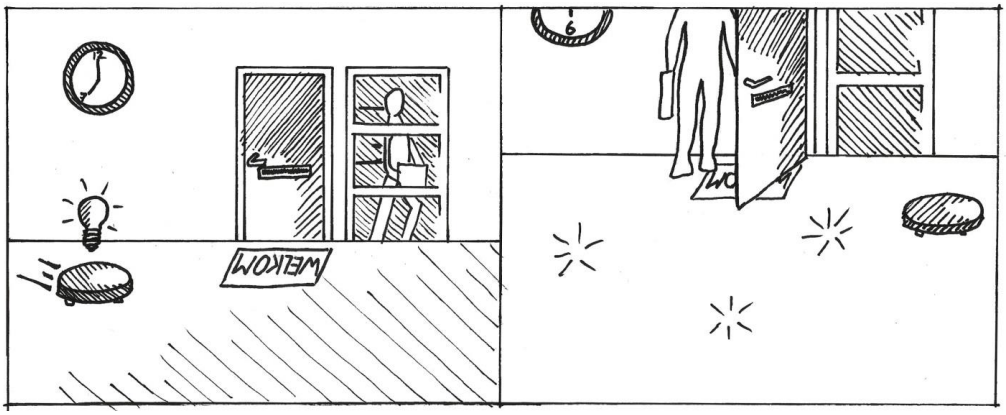


Figure 14 - Scanario: Working every day

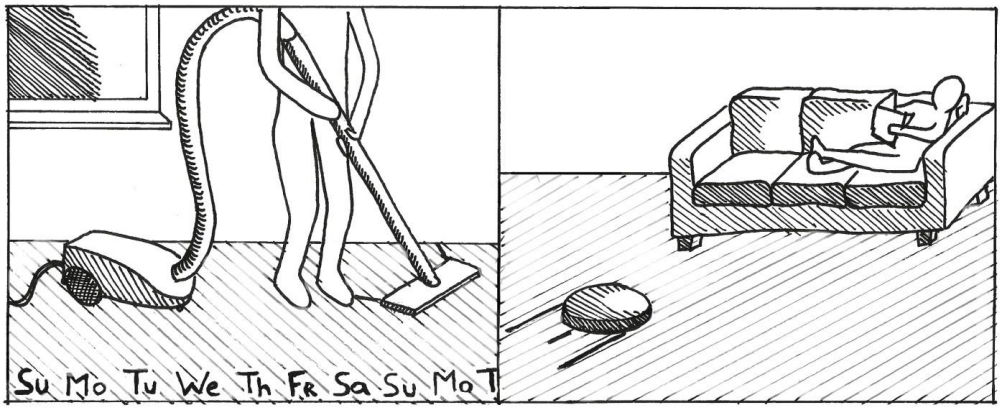


Figure 15 - Scenario: Allergy

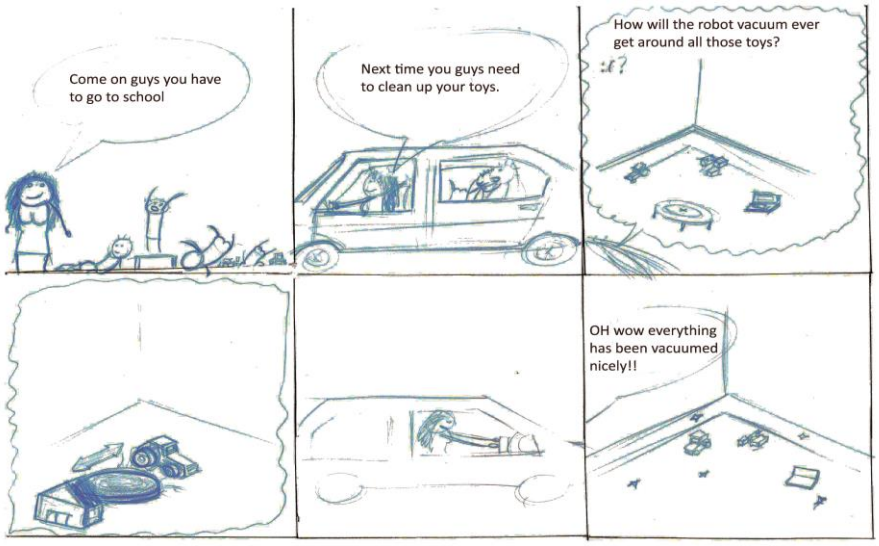


Figure 16 - Scenario: Children and a lot of mess

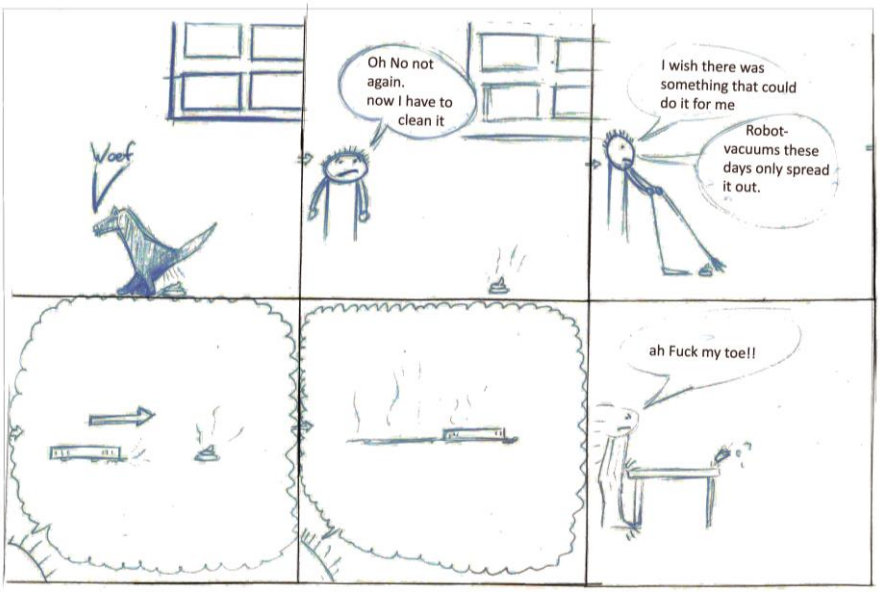
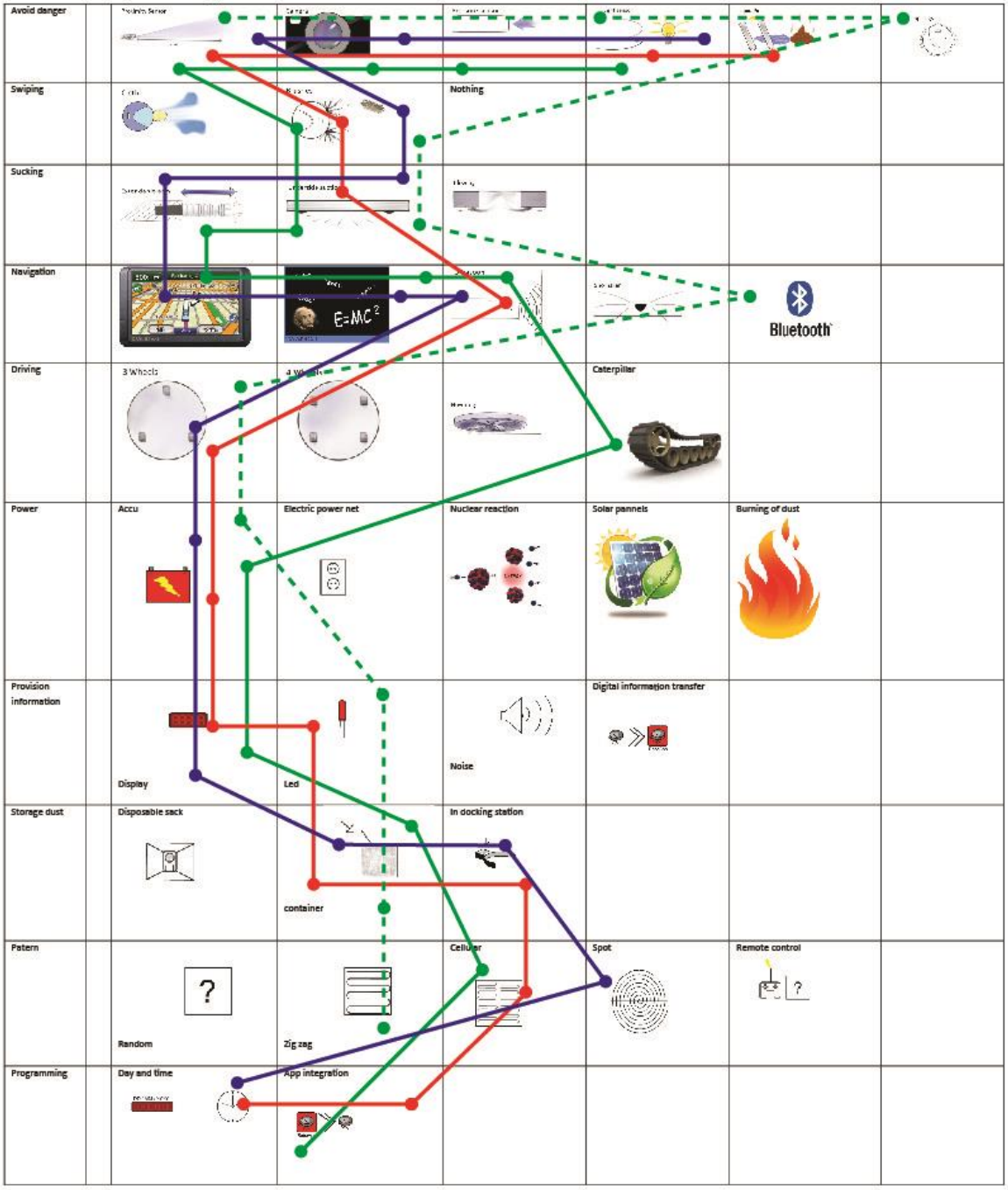


Figure 17 - Scenario: Animals in the house

D. Morphological Overview

Morphological overview



Concept 1:

Concept 2:

Concept 3:

E. Patent

Title: Blowrobot

Description: The robotic vacuum cleaner has a function with which it can blow air in the corners to get rid of the dust in there. Through this, the dust comes to places the robotic vacuum cleaner can reach. After it has blown air, it will collect the dust.

Key word/ CPC-searchcodes: Cleaner -> Platform for vacuum cleaner -> A74L: DOMESTIC WASHING OR CLEANING (brushes A46B; cleaning quantities of bottles or of other hollow articles of one kind B08B9/00; laundry D06F); SUCTION CLEANERS IN GENERAL (cleaning in general B08) -> A47L5/00: Structural features of suction cleaners -> A47L5/14: cleaning by blowing-off, also combined with suction cleaning

Comparable techniques:

Blower/vacuum device

Classification:

- international:	*A47L5/14; A47L5/24; A47L9/32; E01H1/08; E01H1/12*
- cooperative:	A01G1/125; A47L5/14

A hand held blower/vacuum device includes an impeller mounted in a scroll housing and a handle by which the device may be suspended and which is rotatably mounted to 5 turn between vacuum and blower positions. In both of the blower and vacuum positions a longitudinal axis of the grip generally lies in an upright plane that passes through a centre of gravity of the device, and the grip is disposed above the centre of gravity, such that the device 10 hangs below the grip in different balanced orientations in the blower and vacuum positions. 5369198_1 (GHMatters) P97029.AU

The reason we have chosen this publication is because it uses the same technique as our idea, it cleans by blowing. There are a few differences. First our product is automatically and this design is manually. Second, our design is primarily for the corners and in this design the main environment of the device is not specified. But despite of the little differences, the technique and the core purpose is the same, cleaning by blowing.

BLOWER VACUUM DEVICE AND ATTACHMENT THEREOF

Classification:

- international:	*A47L5/14; A47L5/24; A47L9/14*
- cooperative:	A01G1/125; A47L5/14; A47L9/1427

An attachment for a blower vacuum device comprising a collection bag; a coupler for removeably coupling the attachment to an air outlet of the blower vacuum device and for directing air from the air outlet into the collection bag; and a rotatable cuff fixed to the collection bag and rotatably mounted to the coupler such that the collection bag is rotatable with respect to the air outlet.

The idea in this publication is comparable with our idea of cleaning corners by blowing air. There are two main differences. Our design is not removable from the robotic vacuum cleaner whereas it is possible in the publication. Second, our devise is automatic and the vacuum cleaner in the publication is manually. Despite of the little difference, the two designs are comparable.

VACUUM CLEANER

Classification:

- international:	*A47L5/14; 47L9/16*
- cooperative:	

The present invention relates to a vacuum cleaner in which cylindrical dust chambers which are divided by a partition wall and can be connected with each other, and a suction chamber connected to the dust chamber are formed in a main body; a blower is formed in the suction chamber; a first connection port of which both ends are stretched down while being connected with the dust chamber and the outside of the main body to connect a solid discharging side of the cylindrical dust chamber and the outside of the main body is formed in the main body; a collecting bag is connected to the connection port; a rotary opening/closing unit which transfers the solid introduced to the dust chamber to the first connection port by force is formed in the dust chamber; and a filter for filtering the solid is interposed at the upper end of a second connection port which connects the dust chamber and the suction chamber, or the filter is interposed at the rotary opening/closing unit.

This design looks a lot like our design. There are two main differences. First, the design above is manually, while ours is a robot, which will do it automatically. Secondly, our design is designed for corners, when the robotic vacuum cleaner detects a corner, it will blow. The design above is not specified for any place or surface. The technique it uses, is the same as ours and therefore we added this one in the report.

PORTABLE MOTORISED BLOWER WITH ANTI-VIBRATION HANDLE SYSTEM AND REDUCED OPERATING WEIGHT

Classification:

- international:	*A47L5/14; A47L9/02; A47L9/32; B08B5/02; B25G1/10; F16F15/06; F16F7/116*
- cooperative:	A47L5/14; A47L9/02; A47L9/32; B25G1/10; F16F15/06; F16F7/116

A handle (16) is disclosed having an elongate portion (21) and a outrigger portion (26). The elongate portion has a longitudinal axis (24) which extends between two ends (22, 23) and is shaped to be grasped by an operator in use. The outrigger portion extends away from one end of the elongate portion and has a free end (27). The three ends (22, 23, 27) are each connected to the blower or other appliance by a corresponding anti-vibration coil spring (32, 33, 37) through which a corresponding bolt (42, 43, 47) passes. The outrigger portion prevents the elongate portion rotating about its longitudinal axis. In addition, the elongate portion can be grasped by a hand of an operator in either one of two positions. A first position substantially above the blower's centre of gravity provides a balanced grip whilst the blower is not operating. When the blower is operating, air is expelled from a tube having an exit generally coplanar with, or aligned with, the handle. In those circumstances, the handle is grasped at a second location spaced from the first location in a direction extending away from the tube. The blower operates in a stable equilibrium condition and can be weighed by a spring balance having a hook located at the second handle location. A weight reduction of approximately 1 kg reduces operator fatigue. The handle (16) at the second location (66) is tilted relative to the tube (14) and its outlet (15) so that when the blower is used on level ground the air exit tube points downwardly at approximately 45 DEG and the second location of the handle is substantially level. The blower has a two-part body one part (51) of which has a grille for an air intake, and the other (52) of which has the internal combustion engine mounted thereon. Fasteners (42, 43, 47) extend from the handle through the other part and into blind holes in the one part. Thus the fasteners are not visible when the blower is viewed from the air intake side.

The idea in this publication is comparable with our idea of cleaning corners by blowing air. There are a few differences. Our design does not have a handle to operate is manually, but is a robot which is programmed to work automatically. This design has multiple pipes where air comes out whereas our design only has one. The technique form the designs are comparable.

Aeroacoustic Duster
Classification:

- international:	*A47L9/02*
- cooperative:	A47L5/14; A47L9/02; A47L9/08; F15D1/00

The invention disclosed herein provides for high particle removal rate and/or heat transfer from surfaces. The device removes particulate matter from a surface using a bounded vortex generated over the surface, with suction in the vortex center and jets for blowing air along the periphery. The jets are

tilted in the tangential direction to induce vortex motion within the suction region. The vortex is said to be bounded because streamlines originating in the downward jets are entrained back into the central vortex.

This product also uses cleaning by blowing, like our design. The main difference is that in our design, it will blow automatically, while this product is manual. Further is our idea specified for the corners of a room, whereas the product of the publication does not specify, where it is supposed to be used for. But the core business of the product is the same as our design.

F. Equipment: Motor and Battery

Requirements:

The new vacuum cleaner must be able to drive for at least 700 hours. The vacuum cleaner must have more sucking power and must have then still have power left for driving around, passing over doorsteps and carpet. The engines must also provide power for turning the brushes.

Philips:

Philips uses different types of batteries. “The power of these batteries hardly decreases through time. When the battery becomes less powerful, these can be easily be replaced.“ There aren’t any specifications about the used engine on their site.

The two kinds of batteries which Philips has now in use, are the following:

FC8801/01 vacuum cleaner and CRP756/01 battery

NiMH battery operating time t = 5/6 hour

U = 14.4 Volt I = 0.8 Ah

P = U*(I/t) = 13.8 Watt

Total weight cleaner = 1.3 kg

FC9910/01 vacuum cleaner and CRP777/01 battery

Li-ion battery operating time t = 5/3 hour

U = 14.8 Volt I = 2.2 Ah

P = U*(I/t) = 19.5 Watt

Total weight cleaner 4.1 kg

These batteries are rather rectangular, but they can be formed in many different shapes. The volume limits the amount of energy that can be stored. If an approximation should be made: Battery CRP756/01 is about 3cm x 3cm x 8cm = $7.2*10^{-5}$ m^3, and battery CRP777/01 about 5cm x 8cm x 8cm = $3.2*10^{-4}$$m^3$. The robot cleaner has to have a higher vacuum power than the previous versions. This means the motor has to be at least an above 19.5 Watt electrical engine.

Battery type:

There are many different types:

Ni-Mh

This type is used by the current Philips vacuum cleaner. The maximum number of charging cycles is 500-2000. The energy density is half that of the other techniques, but they cost less than the other.

LiPo
This type has the highest energy density, but it has the lowest number charging cycles and has the highest price.

Li-Ion
This type scores on: energy density charging cycles and price between LiPo and NiMh

Supercapacitor
A capacitor doesn't stores its energy electrochemical, a advantage of this are the charging times in the range of minutes. The very low energy density makes it unpractical.

Battery type	MJ/kg	MJ/L	Cycles
Lithium polymer	0.36–0.95	0.90–2.23	300-500
Lithium-ion	0.36–0.875	0.9–2.63	400-1200
Nickel-metal hydride	0.288	0.504–1.08	500-2000
Supercondensator	0.018	-	-

Battery type	MJ/kg	MJ/L	Cylces	Price	Milieu
Lithium polymer	0.36	0.9	300		
Lithium-ion	0.36	0.9	400	2.5..	
Nickel-metal hydride	0.288	0.504	500	2.75..	
Supercondensator	0.018				

Sauce: http://en.wikipedia.org/wiki/Rechargeable_battery

The vacuum cleaner will be equipped with a Li-ion battery pack because it has a high energy density and a price between the other.

Lifetime and speed:
A lithium ion battery can be recharged for about 800 cycles. If the operating time should be at least 700 hours, it means 1 cycle should be good for at least:

$$t = \frac{operating\ time}{cycles} = \frac{700}{800} = 0.53 \frac{min}{cycle}$$

From the client survey it can be concluded that the target group has in average four rooms of 30m^2. If the vacuum cleaner should clean all rooms in one time, an area A_{floor} of 120m^2 should be vacuumed. The effective diameter of the vacuum cleaner will be about $D_{cleaner}$ 0.3m. This means that a distance has to be traveled of:

$$S = \frac{A_{floor}}{D_{cleaner}} = \frac{120}{0.3} = 400\text{m}$$

If one cycle is 53 min, then the robot has to travel with at least a speed of:

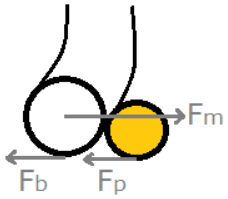
$$v = \frac{s}{t} = \frac{400}{53 * 60} = 0.12\ \text{m/sec}$$

Vacuum Motor:

The new vacuum cleaner has to have a higher vacuum power. Philips is not specialized in making motors, selecting a motor from another company seems to be the more likely scenario. If a motor of 30W is considered, the new vacuum cleaner will have an improved sucking power of 50%. There are many 30W electric engine suppliers. The electrical motors are usually cylindrical and have dimensions of 3cm in diameter and 6 cm long. These motors are commonly available for voltages of 6, 12 and 24V.

Brushes Motors:

The vacuum cleaner does not only contain a vacuum motor, but needs other motors as well. Imagine that the vacuum cleaner will get two small vertical brushes on each side and a cylindrical brush on the underside. These brushes need to be moved. With a rough estimation, taking a friction coefficient of 0.45[19] of POM against steel at dynamic dry conditions, the Fw can be calculated.
Imagine that the brushes are pushed to the floor with a normal force of 1N.
Then Fw of the brushes is:



$$F_{wbrush} = F_N * \mu = 1 * 0.45 = 0.45N$$

If a particle, that weighs about 0.01 kg, should be sucked up, the force of the brushes should be big enough to move this particle. If the friction coefficient of the particle is assumed to be the same as the brushes, the force of the brushes motors should be:

$$F_{mbrush} = F_{wbrush} + g * \text{mass particle} * \mu = 0.45 + 0.1 * 0.45 = 0.495\ \text{N}$$

The intended diameter r of the brushes is 0.1m. The torque due to nine hairs in the side brushes is:

$$T_{brush} = 9 * F_{mbrush} * r = 0.22\text{Nm}$$

The turning speed can be changed to find a good amount of power. The brushes should turn faster than the velocity of the robot itself. With an turning velocity of 1 m/sec, the needed power is:

[19] http://www.werktuigbouw.nl/abc/cof.htm

$$P_{brush} = T_{brush}\omega_{brush} = 0.22 * \frac{1}{r_{brush}} = 2.2W$$

The long cylindrical brush with hairs will give a lot of friction. From market research could be concluded that IRobot had found a very good way of dealing with this problem. A special type of plastic should be used and another design should be made, but then the same principle could be used. If a 0.03m diameter cylinder would be used with a velocity of 3 times the cleaning speed and a friction coefficient as before, the needed power is:

$$P_{cyl} = F_{wcyl} * 3v_{clean} = 0.45 * 3 * 0.12 = 0.16W$$

Locomotion Motor:

The vacuum cleaner will weigh about 10 kg. This means a gravity force of approximately Fz = 50 N per wheel. With a rolling friction coefficient of approximately a tire on a very sticky road (carpet) equal to 0.1[20], a radius of 0.03m and a cleaning speed of 0.12m/sec, the needed power due to normal riding is:

$$T_{wheel} = \mathrm{r} * \mathrm{F}_z * \mu_{rol} = 0.15\mathrm{Nm}$$

$$P_{wheel} = T_{wheel}\omega_{wheel} = \frac{T_{wheel}v_{clean}}{r_{wheel}} = 0.6W$$

From the set of requirements, the vacuum cleaner must be able to pass over doorsteps or obstacles of Dh = 0.02m. If the vacuum cleaner has to pass this obstacle, the torque T can be calculated. A simplified VLS is given in *'Figure 19 - Wheel and doorstep'*, in which the Fw is neglected, because this is very small in comparison to the Fz. The needed torque then is:

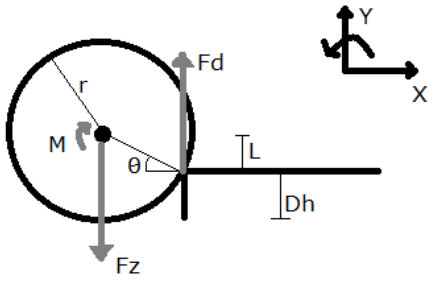


Figure 18 - Wheel and doorstep

$$\text{with } \theta = sin^{-1}\left(\frac{\mathrm{L}}{\mathrm{r}}\right)$$

$$P_{wheelobst} = \frac{\cos\theta * r * F_z * v_{clean}}{r_{wheel}} = 5.6\mathrm{W}$$

Other power:

The robot vacuum cleaner uses a program and has a display for information. There is also power needed for these functions. The needed amount of power is estimated at another 5W.

Battery requirement:

If is chosen for a 30W vacuum motor engine, approximately 9W for the other motors, another 5W for display or calculations and 4W as safety, with a voltage of 12 for each unit, there is a battery needed that provides an electric current I of:

$$I = \sum\frac{P}{U} = \frac{30}{12} + \frac{9}{12} + \frac{4}{12} = 4A.$$

[20] http://www.werktuigbouw.nl/abc/cof.htm

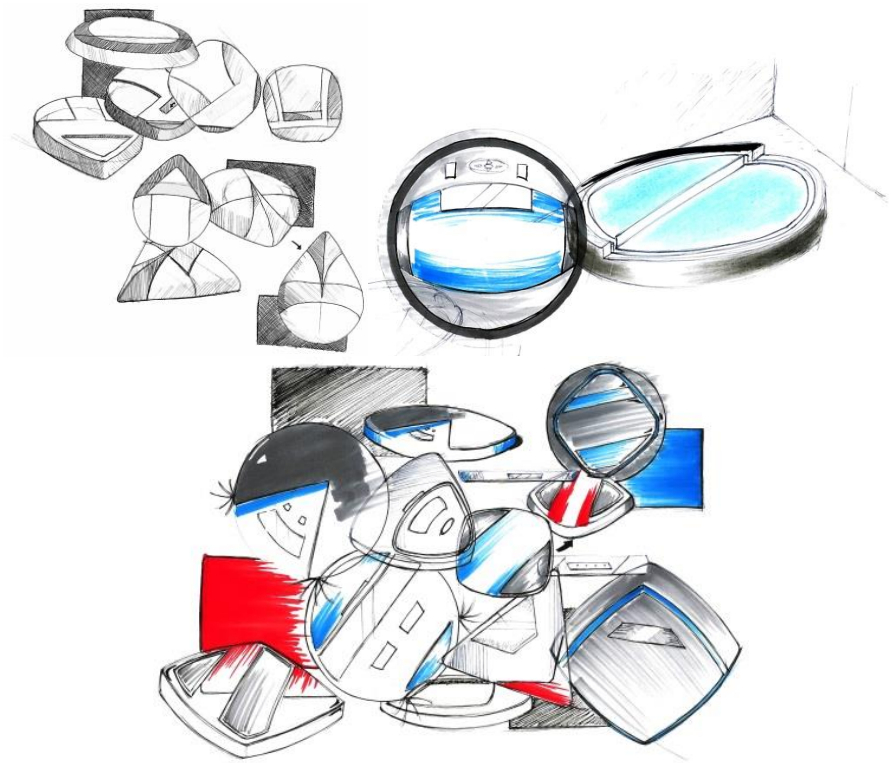
The battery should be able to provide an amount of ampere-hour of:

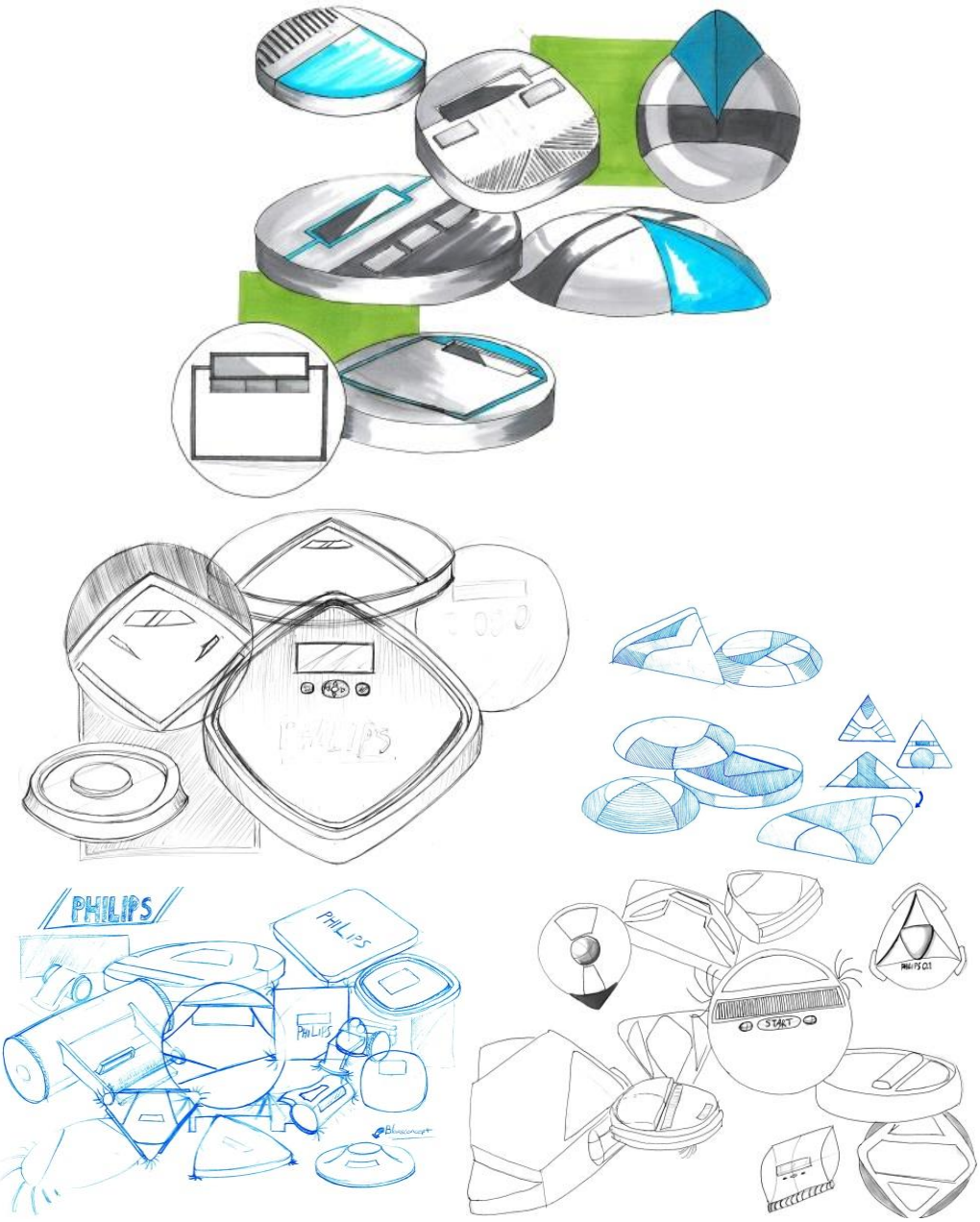
$$Ah = I * t = 4 * 0.875 = 3.5Ah$$

This is about equivalent to a volume of battery of $5*10^{-4}m^3$.

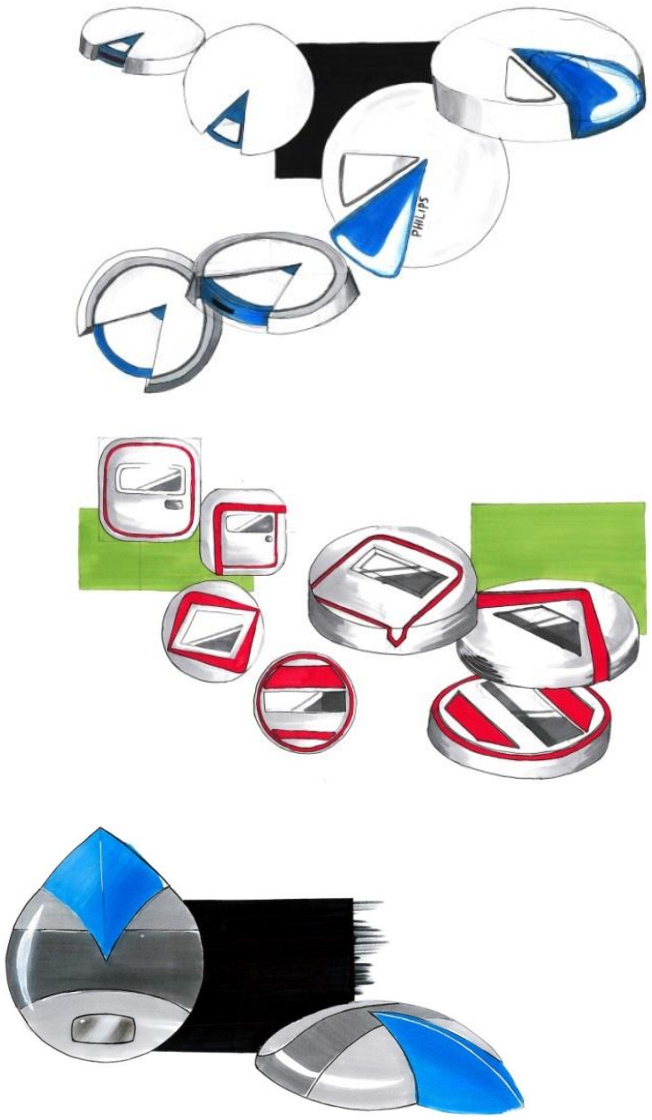
G. Sketches

Idea Sketches

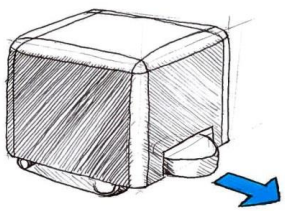


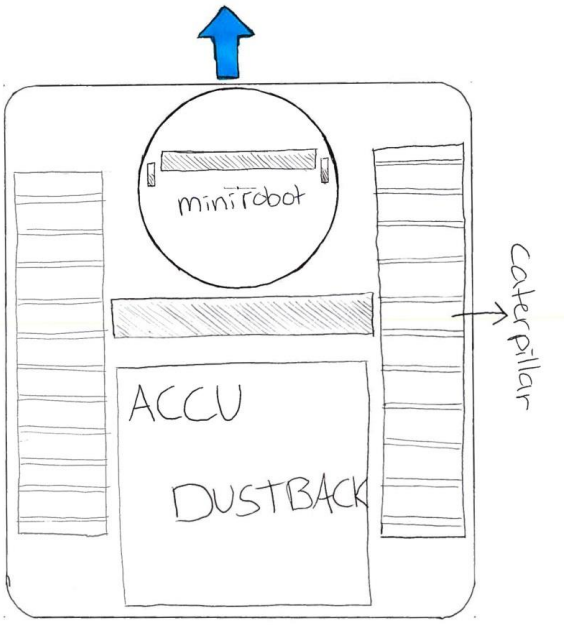


Concept Sketches

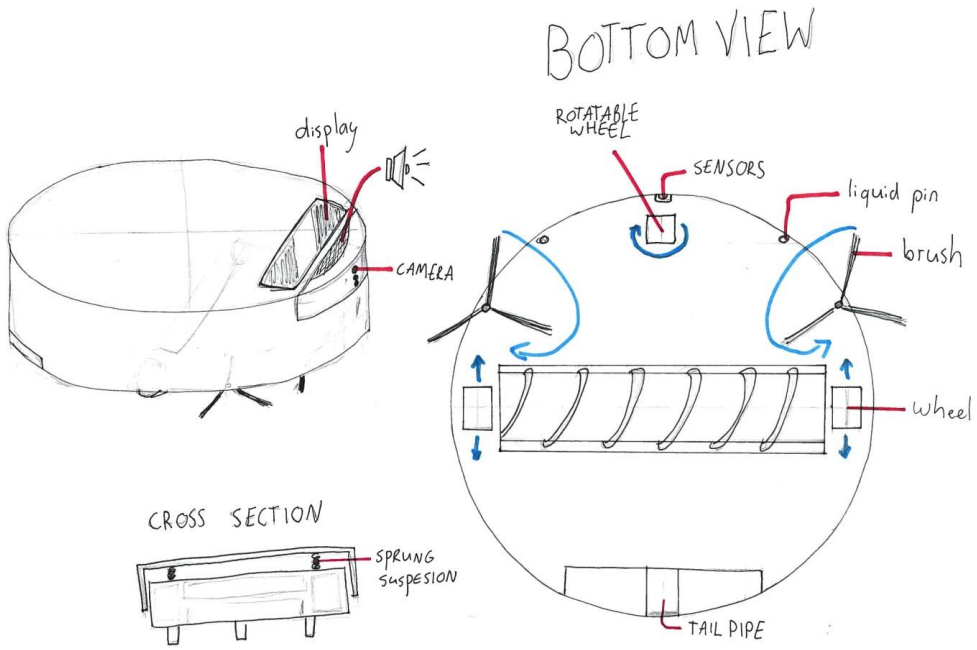


Concept 1

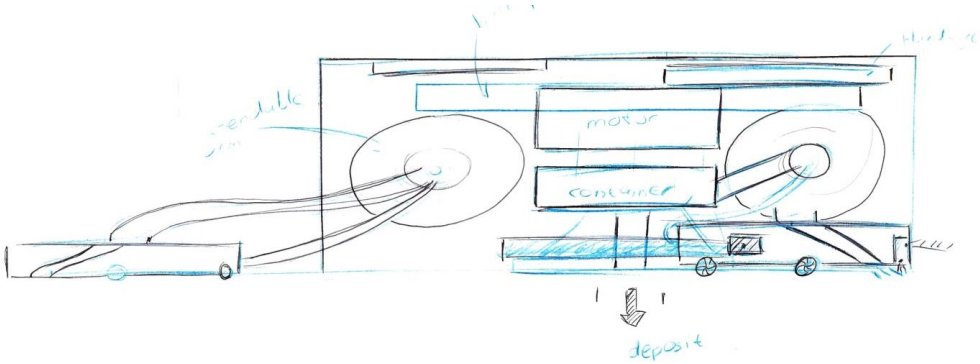


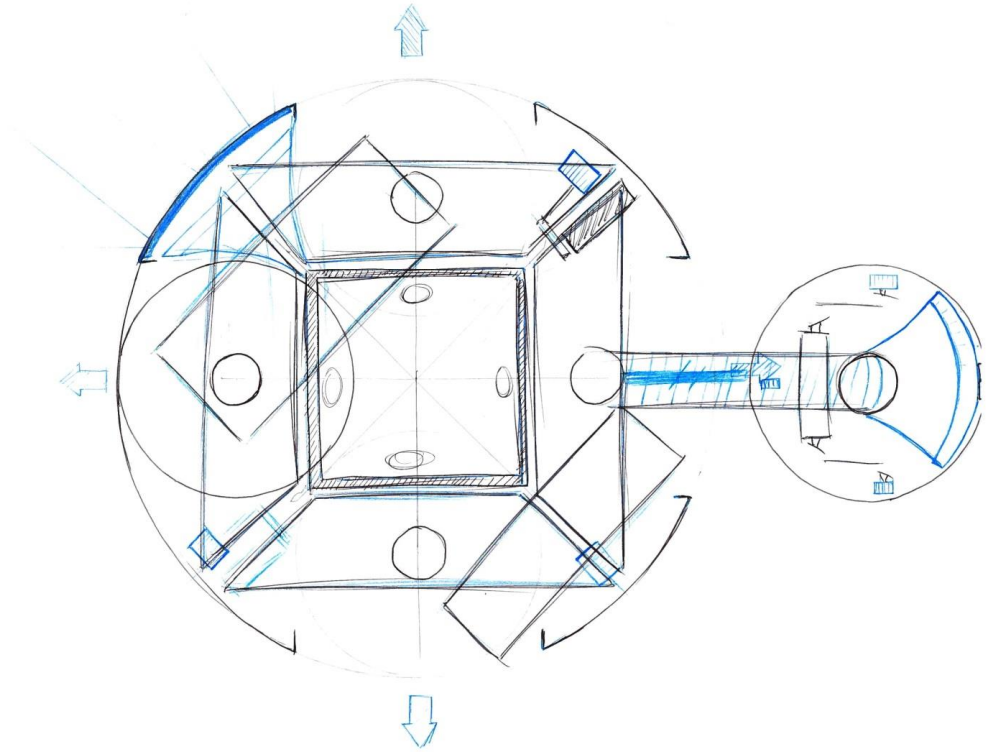

minirobot
caterpillar
ACCU
DUSTBACK

Concept 2

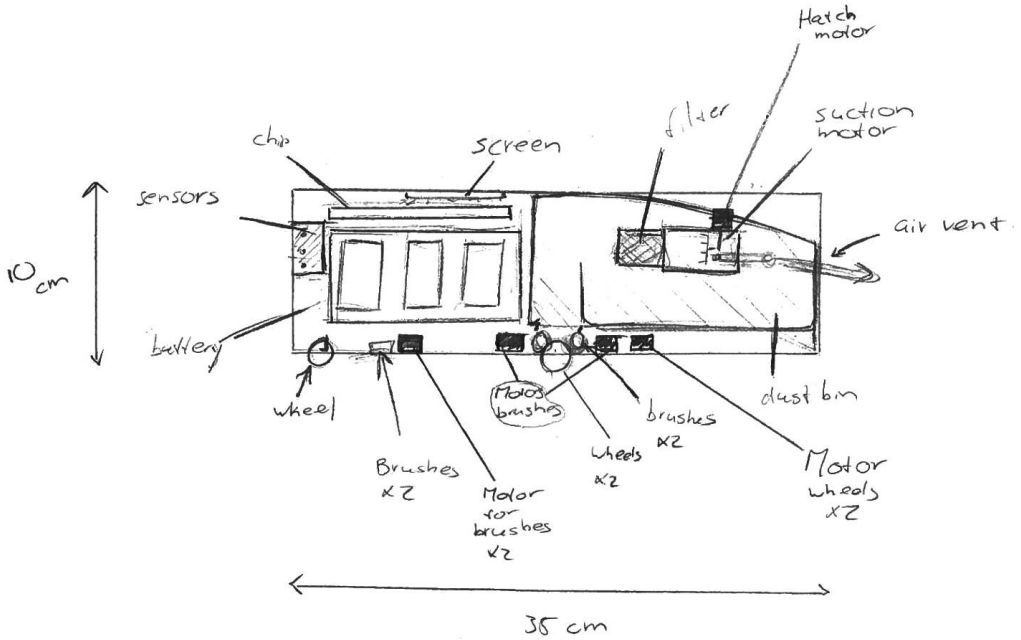


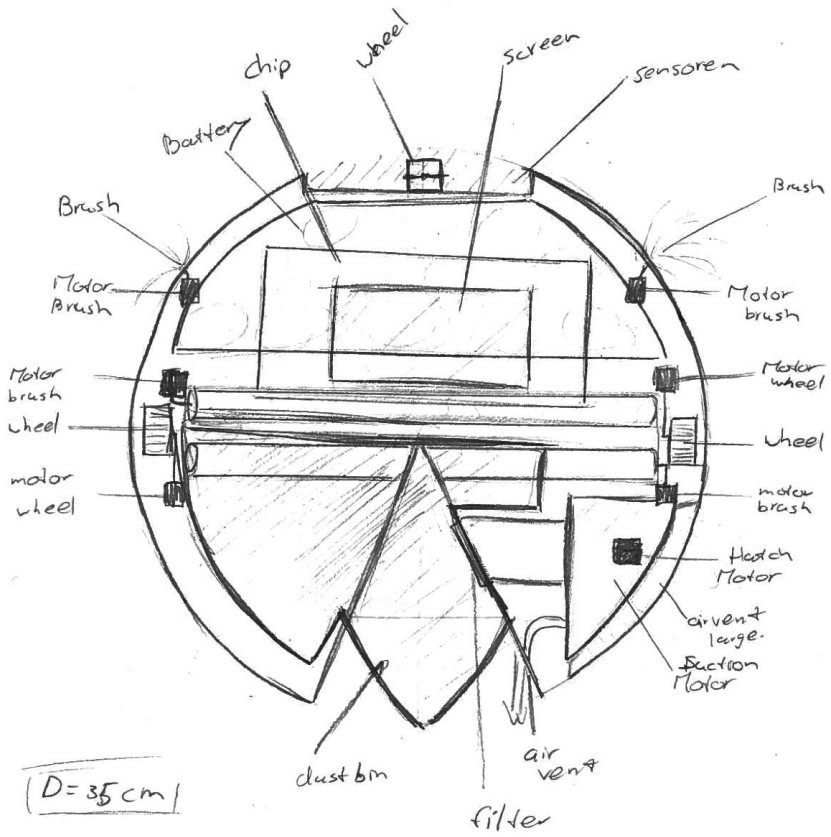
Concept 3



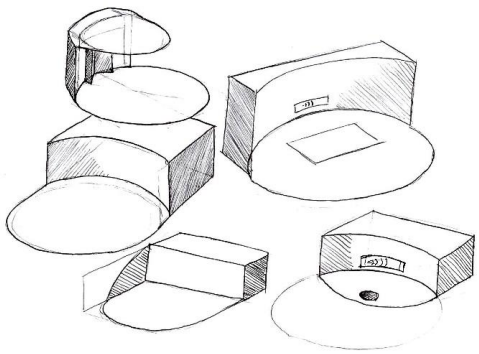


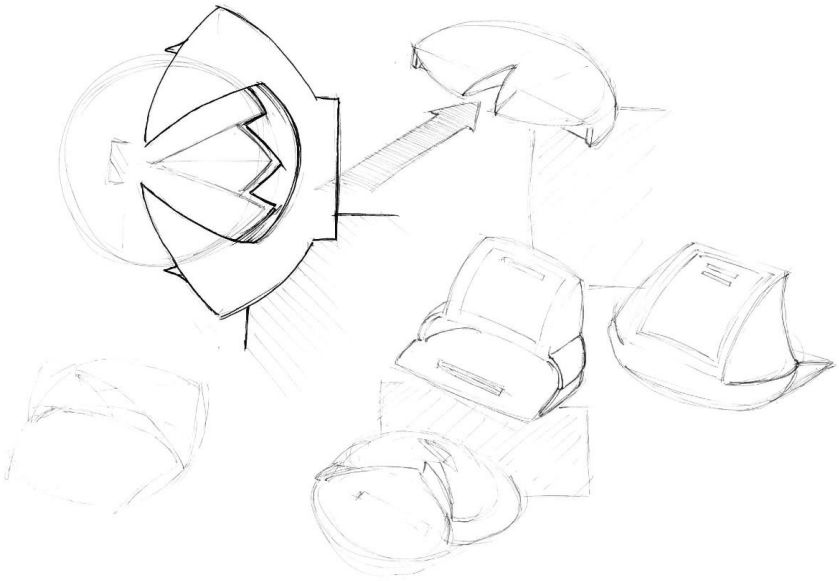
Final concept

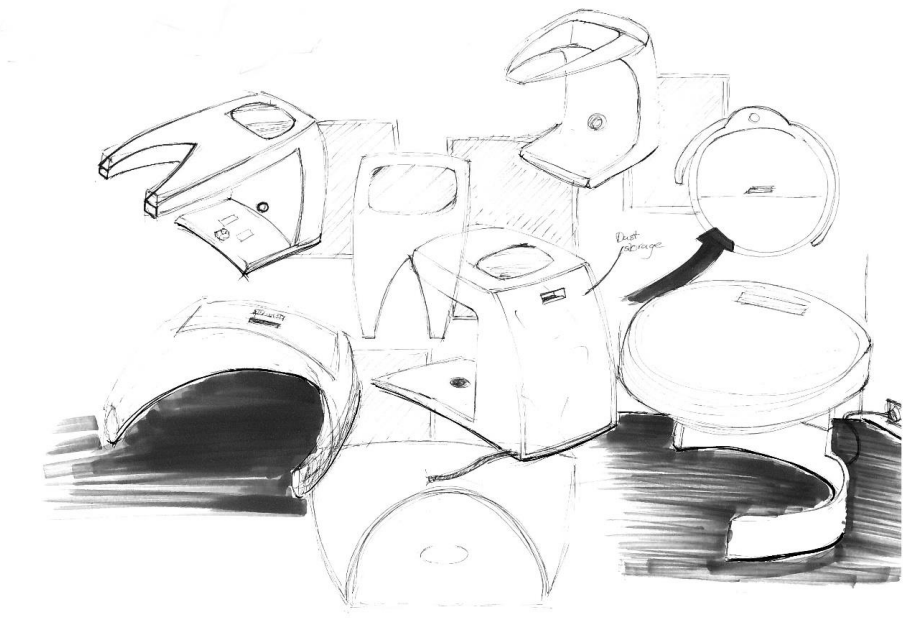


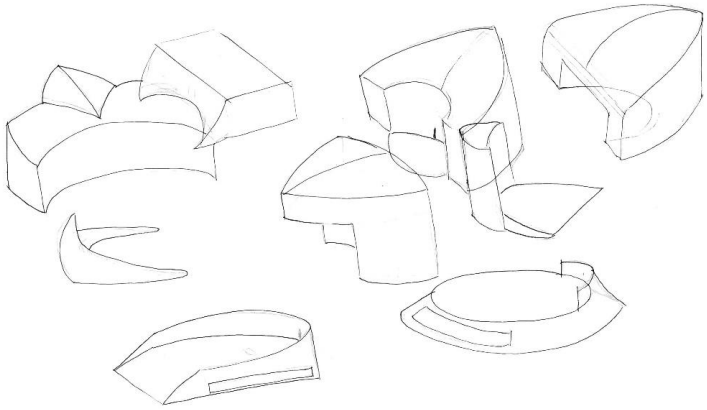


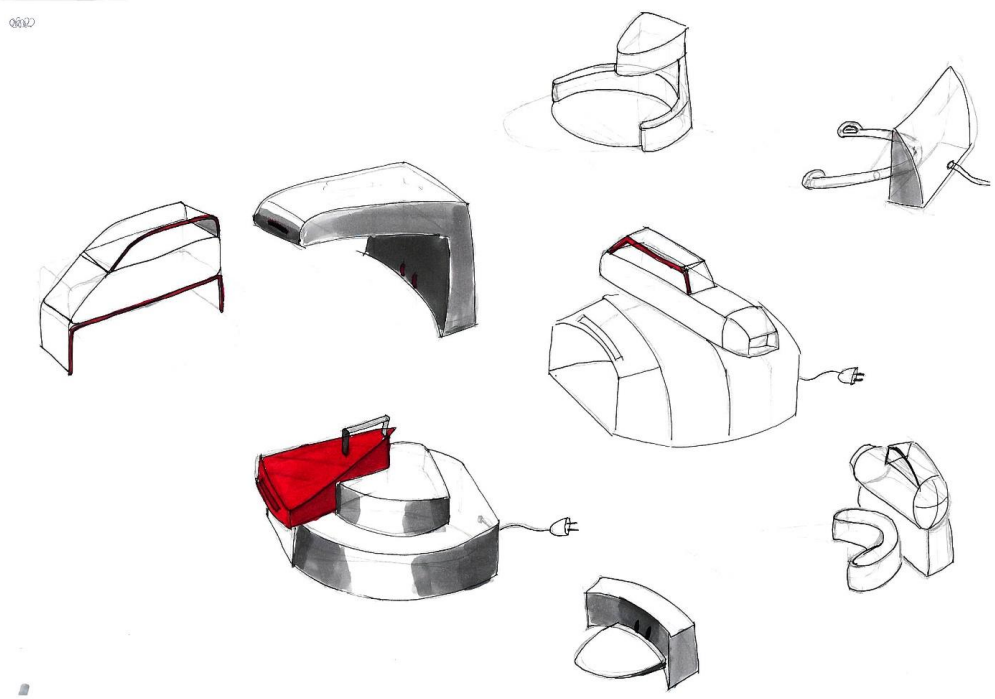
Docking station sketches

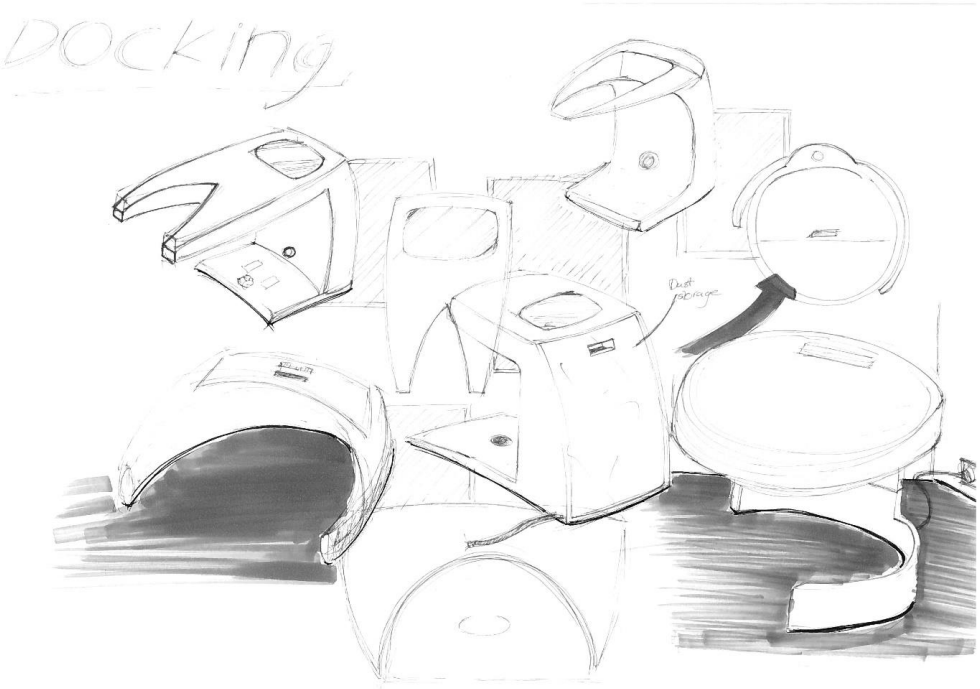











Docking

H. Final Concept

Corner cleaning through blowing

There were four concept ideas to blow dust from the corners:

- Continuous blowing airstream
- valves
- pulse
- Air-hatch

These ideas are explained below:

A continuous blowing airstream might ask more power from the motor but is easier, less expensive and its durability is better. When the vacuum moves through the room it should not blow dust away when following its path (it suffices complicated path-planning). Because the blowing air is at the backside of the robot it will continuously blow the ground that has already been cleaned. However, at parts the robot cannot reach, such as corners he can turn and let the airstream blow away the dust. This way it will not be a problem to use a continuous stream. Even if it might happen that the robot blows some dust over a previously cleaned part, this will not be noticeable and it will be cleaned the next day. Daily use of the machine will result in a floor which is free of most dust particles.

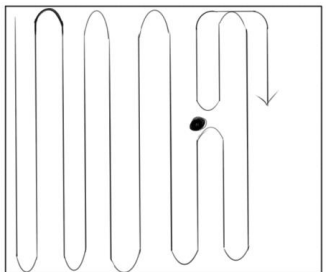
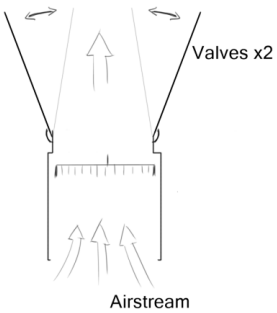


Figure 19 - Cleaning path

To create an optimal path for the machine we must consider that it blows. When taking certain corners it is possible that the machine blows dust on cleaned areas. To avoid these problems the robot should not go around objects. Instead it should resume its path. Later when he can move along the object it will clean the part he had missed. The idea is featured in '*Figure* 9 - *Cleaning path*'. In this setting a sweeping turn in the corner is more effective than standing still in the corner waiting for the dust to be removed.

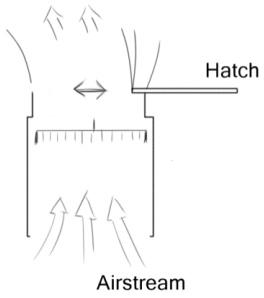
However this will end in a very difficult path to program. It would be easy to follow its path if there was one object to avoid. But a room will be full with objects. So its path will be very complex. To program such a troublesome pattern requires a lot of professional programming. This will lead to many errors and bugs in the system.

It is also possible to use valves which move towards each other, creating a smaller path for the air to travel through. However to use this technique a lot of space is needed. Not only for the valves itself but also for the motor to move the valves.



The pulse, a short powerful blast of air, shoots the dust out of the corner in an instant. It uses a compressor to release a bundle of air. However it is possible it gives the user the idea that the robot does not clean the corners but just blows dust away. This shifts the problem to a different area.

It would be easier and less expensive to insert an extra motor for an air-hatch. The air-hatch works as follows. Behind the motor there are two paths the air can go.
However at all times, one of the paths is closed by a hatch. The two paths consist of a large path and a small path. When the air travels through the large path the vacuum cleaner will not blow away any dust. When the air travels through the small path it will be bundled to create a flow of air which is strong enough to blow away dust in corners. The hatches open and close when the vacuum cleaner is in a corner. When in the corner it opens de small path and closes the large path and when leaving reversed.



It is to be concluded that the best idea for the robotic vacuum cleaner is the use of a hatch.