

Embodiment design of a grocery delivery robot

Master thesis by Romy Geitenbeek
July 2021

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From cool transport to user-friendly
hand-over

Delft University of Technology
Faculty of Industrial Design Engineering
MSc Integrated Product Design

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Acknowledgement

Dear reader,

Here it is, my graduation thesis for the master Integrated Product Design at the Delft University of Technology. After some lovely years of studying at the Industrial Design Engineering faculty, it is time for me, with a heavy heart, to say goodbye to my life as a student. This thesis might have been the challenging yet most inspiring project I have done throughout my education. I would like to take this opportunity to thank some people who have helped me throughout this journey.

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My last gratitude goes out to the AMS Institute for providing me the assignment of my thesis and the accessibility to the Husky robot platform. Without the robot platform, my prototype would not have looked this advanced.

Since now I have expressed my gratitude, please go ahead and read!
I hope you enjoy the topic as much as I do,

Romy Geitenbeek

Executive summary

Last mile delivery is often seen as bottleneck for delivery service growth: it is the most costly and highest polluting segment of the delivery supply chain. By integrating delivery robots in society, last mile delivery can be automatized to create a more cost and time efficient and sustainable delivery service. This also applies to the grocery delivery service. However, no grocery delivery robot, that can operate on the sidewalk, is designed yet. How should such a grocery delivery robot look like? And how do we want the delivery robot to interact with the user?

This thesis provides an embodiment design for a grocery delivery robot, with the focus on the human-robot interaction at the doorstep. A desired human-robot interaction can be achieved by creating functional, ergonomic, intuitive, functionally looking, trustworthy, aesthetically pleasing and environmentally friendly design that will empower the customer to feel in control of the delivery process. To realize a functioning delivery robot, a prototype and design has been created according to a form follows function approach. A prototype of the embodiment design has been integrated with the Husky platform at the AMS Institute in Amsterdam to test and validate the human-robot interaction.

The design enables, a cool, temperature-controlled delivery with user-friendly hand-over. The user-friendly hand-over is envisioned by an automatic vertical crate hand-over movement, which mimics the current almost effortless interaction of retrieving crates from a grocery delivery service. This hand-over will not only make the experience of retrieving groceries more joyful and ergonomic, but it will also enable a better future integration with entire delivery process. Last mile delivery will only be more efficient, sustainable, and able to offer customers more control of the delivery process, if the delivery robots are integrated within the entire delivery process.

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Project structure

1. Introduction: Highlighting the relevance of designing a grocery delivery robot and defining the goal of the project.

By designing an embodiment on top of the Husky robot platform, with a focus on the human-robot interaction at the customers doorstep, a grocery delivery robot can be created to enables a more efficient last mile delivery process.

2. Analysis: Finding answers to research questions to meet design goal.

By making use of literature studies, evaluation models and interviews, conclusions were drawn about how to design for the target audience, a desirable human-robot interaction at the doorstep and how to design for the future.

3. Design vision: Phrasing a vision based on conclusions of research questions defined in the analysis.

The design should create a new way of delivery that will empower the customer to feel in control of the delivery process and create an ergonomic, intuitive, functionally looking, trustworthy, aesthetically pleasing and environmentally friendly design. The design vision will function as a guide for designing the embodiment.

4. Design approach: Defining a sequence of the design process.

By making use of a “form follows function approach”, the design process will be more structured and efficient.

5. Embodiment design: Defining design choices for all aspects mentioned in the design vision.

Design decisions are made to create a functional, ergonomic, functionally looking, intuitive, aesthetically pleasing, trustworthy, and environmentally friendly embodiment design.

6. Prototyping: Evaluating embodiment design to create proof of concept.

Human-robot interaction as the mechanisms for crate hand-over is being tested and evaluated by a prototype.

7. Final design of embodiment

The final embodiment, human-robot interaction, potential integration scenario and unique selling points are presented. The embodiment enables cool transport with a user-friendly hand-over.

8. Reflection

The embodiment design is reflected based on feasibility, viability, and to what extent the design meets the design goal and vision. Spoiler alert, it does.

9. Recommendations

Points of improvement, topics for further research and my personal recommendation are described.

I. Introduction

The introduction highlights the relevance and the advantages of designing a grocery delivery robot. The assignment, scope, challenges and project goal can also be found in this chapter.

Context
Last mile solution
Assignment
The challenge
Project goal

1.1 Context

The development of delivery robots got a huge boost at the start of the Covid-19 pandemic. The pandemic not only caused a rapid e-commerce growth in 2020, but it also created a surge in public interest for a new way of contactless delivery (Bhatti et al. 2020). A delivery robot can provide a contactless delivery service and can therefore be a safe alternative for those stuck in quarantine. There are a few companies that are developing delivery robots. However, all of them are under development and being tested in trail areas for now.

1.2 Last mile solution

Besides, using delivery robots as a solution for people stuck in quarantine, it can also be used as a solution for last mile urban delivery. According to McCrea (2016), the current last mile delivery makes up 50% of the total logistics costs of any shipment. It is seen as the future bottleneck of delivery service growth (Wang, 2019). Delivery robots might be able to decrease the last mile delivery costs. The robots can for example offer a good solution of delivery during peak hours.

Relevance of designing a grocery delivery robot

It has become increasingly difficult for delivery vans to enter mega urban centers during these hours. Delivery by these vans will take a lot of time and therefore a lot of money, especially when the delivery robot can just deliver the goods by making use of the sidewalks without traffic jams. Delivery robots could reduce the amount of delivery vans on the road, which will reduce not only the traffic jams, but also the CO2 emission in the city center (assuming the delivery robots will be electric). Since there are no employees needed, the company would not only have to pay fewer employees, but they would also be able to offer more flexible delivery hours. The robots are able to deliver goods at any hour of the day.

Starship delivery robot¹
- hot meal delivery



1.3 The assignment

The Amsterdam Institute for Advanced Metropolitan solutions (AMS) would like to create a grocery delivery robot. They bought a robot called “Husky” from Clearpath (figure below), that can be used as platform for the rest of the design. The delivery robot should function as a last mile delivery solution for the city center of Amsterdam in the near future. To test the delivery robot, the AMS Institute suggested to create a design that could deliver lunch to firms positioned on the Marineterrein. By testing the robot, AMS would like to inspire other companies and make them aware of future possibilities like this.

The embodiment on top of the Husky platform should not only make the robot look like a delivery robot, but it should also enable a clear and desired human-robot interaction with the user. The steps made in this process of designing a grocery delivery robot can also be used as guidelines for future delivery robot designs.



1.4 The challenge

The delivery robot could be the first grocery delivery robot that will be able to operate on the sidewalks. However, the robot platform, bought by AMS, is not able to deliver goods to customers yet. The general problem is that the robot platform does not have an embodiment nor a system to communicate with the customer yet, resulting in an undesired human-robot interaction at the customer's doorstep.

The challenge would be to design an embodiment that enhance a desired human-robot interaction for the customer when retrieving goods at their doorstep. Delivering goods with a delivery robot is a whole process, see figure 1.1. The main focus in this project will be to design an embodiment with focus on the human-robot interaction at the doorstep for the near future.

“The goal of this project is to design and prototype an embodiment on top of the Husky, so the robot would be able to function as a **grocery delivery robot** in the near future, while establishing a **desired human-robot interaction** for the customer when **retrieving goods from the robot at their doorstep.**”

The entire grocery delivery process

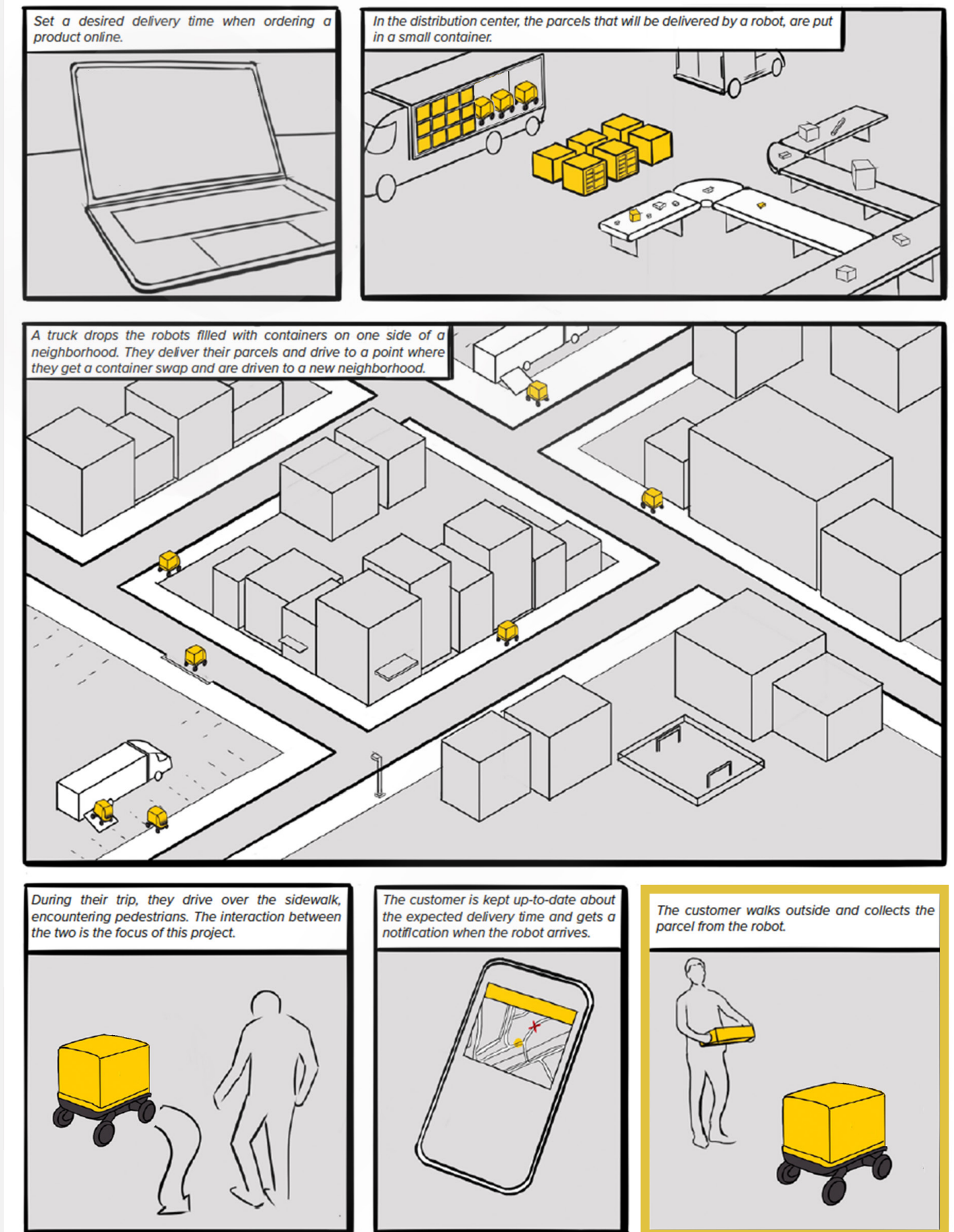


Figure 1.1 - Multiple phases of a grocery delivery process, by De Groot (2019)³

2. Analysis

This chapter presents a detailed analysis to tackle aspects of the design goal. More information can be found about the target audience, how to design for a desired human-robot interaction and how to design for the future. Take-aways of this chapter can be used to phrase a design vision in the next chapter.

Target audience
Design for positive
human-robot interaction
Design for the future

2.1 Target Audience

**Who is the customer?
And what are their needs?**

2.1.1 The target audience

The target audience are people in the Western world, who would like to have groceries delivered. For the test run, the AMS institute would like the robot to deliver lunch at firms positioned at the Marineterrein in Amsterdam. So, for this project the target group might as well be “employees working at the firms on the Marineterrein.” However, the delivery robot should eventually be able to operate in the city centre and be suitable for as many different people as possible. Therefore, the target audience remains, people in the Western world, who would like to have groceries delivered.

2.1.2 Needs of target audience

There are different kinds of situations and reasons, why users would like to make use of a (robot) delivery service. By dividing the target audience into different groups, a more complete overview of all different needs of the target audience can be determined. I conducted a small brainstorm to divide the target audience in the following groups: the occasion group, the practical group and the comfort group.

Group 1. Occasion group

This customer would like to have goods delivered for a certain occasion. This group could be a firm that would like to have lunch delivered at their company during lunchtime or a group of people that are having lunch in a park.

This user group also often acts from a group perspective. The occasion group would like to have a fun experience. This group would like to be reassured that the order arrives complete and on time for their event.

Group 2. Practical group

The customer would like to have goods delivered to their house (or store) for more practical reasons. They might not own a car to go to the supermarket or by ordering groceries online they are able to compare the products (price-, nutrition- and even environmentally friendly-wise).

This user group would like to be in control of the ordering and the delivery process of the delivery robot. They would like to know at what time and where they can expect the robot, so they can schedule their busy lives around it.

Group 3. Comfort group

The customer does not want to waste his or her time going to the grocery store. They just want to have food in their houses and spend the time they would go to the grocery store for something more useful. The comfort group does not want to have to think about this process too much. The groceries should just be there, when they would like them to be there.

The three user groups have different needs. However, they have one need that is important for all of them: they all like to have some sort of control over the delivery process (being reassured of arrival time, controlling the arrival time and delivery process). In the current situation, the supermarket is delivering groceries in time slots between two and three hours. This means that the customer cannot leave the house in between those hours, which will make them feel less in control of the delivery process as of their own schedule. The delivery robot has the opportunity to share its navigation and take the customer needs more into account, which eventually would make the user feel more in control of the process..

The target audience of a delivery robot are people in the Western world, who like to have groceries delivered.

2.1.3 Conclusion target audience

The delivery robot should be suitable for as many different people as possible in the future. To be more precise, the target audience of the delivery robot are people in the Western world, who like to have groceries delivered to a certain address. The delivery robot should make the customer feel in control of the delivery process and their own schedule. This is a need, which is not fulfilled by the current delivery service process. By splitting the target audience into three different groups, more specific needs for future scenarios were found, which are taking into account in the design of the final embodiment. The experience of retrieving goods should be fun and the delivery robot should look accountable in order for the target audience to rely on the service.

2.2 Design for a desired human-robot interaction

What is a desired human-robot interaction? And how to design for it?

Figure 2.2.1 – Seven facets of User Experience ⁵



The focus of this project is to design an embodiment that enables a desired human-robot interaction for the customer at the doorstep. Now that the needs of the customers are established, how to design for a desired human-robot interaction? And what is a desirable human-robot interaction?

In this case, a desirable human-robot interaction will follow from a positive user experience. However, a positive user experience is depending on many different factors. According to Zahidi et al (2014), the seven facets of Morville can be used to evaluate the quality of user experience and can therefore be used as a tool to design a positive user experience.

The seven facets' models (figure 2.2.1) shows that a user experience will be perceived as positive when a design brings value to the customer. The delivery robot will only be valuable to the customer, if the service is useful, usable, desirable, accessible, credible and findable. This paragraph provides key insights in how to create valuable design that enables a positive user experience and therefore a desirable human-robot interaction, while making use of the seven facets model.

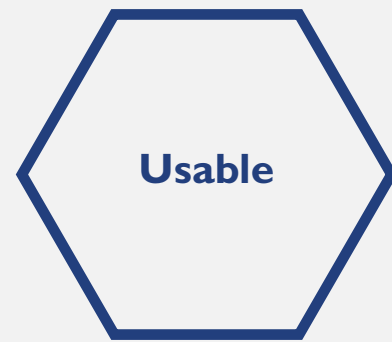
Create useful design by designing for a fast autonomous delivery robot adoption

2.2.1. Useful design

What makes a delivery robot useful? A delivery robot is only useful if people are willing to interact with it and if the robot does what it supposed to do; deliver goods. The robot should be accepted by the customer as a delivery service. If people are not willing to interact with a delivery robot and therefore not buying the goods that are delivered with a service like this, then the robot is not useful.

But how to make sure the delivery robot will be easily adopted? Looking at the Covid-19 pandemic, the situation did create an opening for autonomous delivery robot adoption. According to Pani et al. (2020). The pandemic has created a surge in the public interest and demand for autonomous delivery robots since it can provide contactless delivery, a highly sought-after service under the directives of social distancing.

Pani et al, conducted research to learn more about people's psychological barriers to autonomous delivery robot adoption. They found out that already more than half of their research group was willing to pay extra for a service like this. However, almost 40% of the research group were not willing to pay at all. The most predominant reason for not willing to pay was found to be depending on their satisfaction with existing delivery methods. Pani et al. (2020) therefore recommended that delivery fees to the consumers should initially be priced lower or at least the same as existing van-based deliveries in order for people to adopt the autonomous delivery vehicles.



Key factors useful design:
A useful design can be created by stimulating autonomous delivery robot adoption by creating a familiar and trustworthy design.

Familiar design can be created by making use of grocery or delivery association in shell design. Trustworthy design can amongst other things be created by publicizing the operational procedures, so people already trust the process without experiencing the service yet.

Besides the willingness to pay for the service, the lack of familiarity and trust are also found to be significant psychological barriers to autonomous delivery robot adoption. According to Laurel (1990), The operation of an interactive system is best achieved by means of a metaphor or analogy which indicates the importance of familiarity. Being familiar with a system means that we are ready to operate it in an appropriate way, based on our prior experiences (Herstad et al. 2012). For example, the robot could look a bit like a shopping cart, so it is easier for people to understand what the robot does and therefore adopt the service faster.

Thereby, to make the user more familiar with the usefulness of delivery robots, e-commerce companies and on-demand delivery platforms should focus on publicizing the operational procedures (e.g., interactive unlocking, theft prevention measures) and potential advantages (e.g., delivery speed, flexibility, contactless handling, and convenience) of autonomous delivery robots to the end-users. More research about trust and familiarity can be found in paragraph credibility.

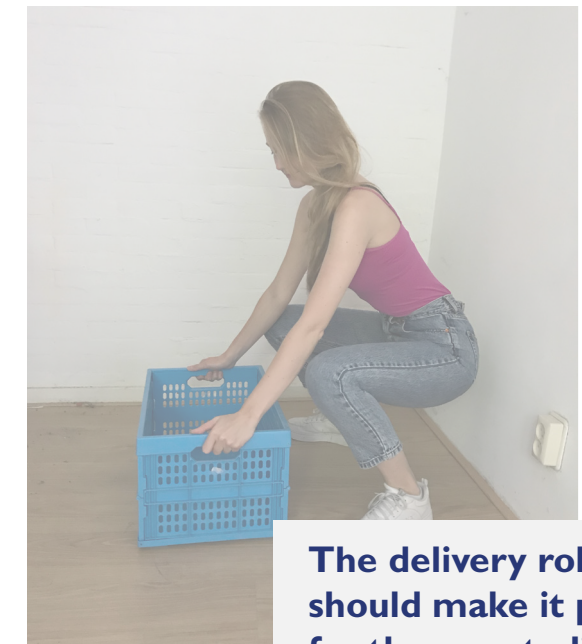
2.2.2 Usable

The delivery robot should be easy to use for as many people as possible. Usability can be measured in terms of the ergonomic attributes of a product (product-oriented view) and in terms of mental effort and attitude of the user (user-oriented view) (Bevan et al. 1991).

Ergonomics

At some point in the human-robot interaction the user should lift the crates with groceries from the robot. To make this lifting interaction as ergonomics as possible, lifting techniques and aspects such as lifting height and box size should be taken into account. To make the robot as suitable for as many companies as possible, the typical crate size of grocery companies will be used in the design. The crates cannot be easily fitted between your knees and are therefore even harder to lift in an ergonomic way. According to Kingma (2010), the best technique to lift a large box (the box does not fit easily between your knees) from the ground is the weightlifter's technique in combination with handles located at the upper part of the box (figure 2.2.2).

When lifting a weight, it is always more ergonomic to bend the knees instead of bending the back (stoop lifting), even if the load does not have to be lifted from the ground. In order to bend ergonomically, feet should be able to be positioned around the load and the load should be lifted holding it as close to the body as possible. Lifting a large box (of even 15kg or more) from the ground at the bottom should always be avoided, since it will lead to high back loads. In order to support this lifting technique in the design of the robot, make sure that there is enough room for the feet, knees and hands to lift ergonomically.



The delivery robot should make it possible for the user to lift crates ergonomically

Figure 2.2.2-
Ergonomic lifting

The maximum weight a man should lift is 25kg and a woman should not lift anything heavier than 16 kg (Translyft, 2019). However, the height/position of the box has an influence on how much weight a person should carry. The most weight can be lifted, when holding the weight as close to the body as possible and when the load will be retrieved at elbow height.

The elbow height differs per person. According to Dined (2004), the average elbow height of Dutch women (age 20-60) is 755 mm. The average elbow height of Dutch men (age 20-60) is 817 mm. This elbow height should be taken into account, when designing the height, where the crates will be retrieved from.

Mental effort

To make the human-robot interaction of retrieving goods from the robot so effortless as possible, an intuitively interaction design is necessary. Intuitive use of products involves utilizing knowledge gained through other experience(s) (Blackler et al. 2007). Intuitive interaction is fast and generally non-conscious, so people may be unable to explain how they made decisions during intuitive interaction (effortless).

The tool of Blacker et al. (2007) can be used to design an intuitive interaction for the grocery delivery robot. The idea of this tool is that you start to look at each possible interaction individually and try to keep it as primitive intuitive as possible by looking at different levels of intuition.

First, it is important to look at body reflectors: an interaction that you learned so early in life that it almost seems innate, like a door handle. If a body reflector is not suitable for the design, then population stereotypes should be considered. Population stereotypes are engrained from an early age and derive largely from experience of cultural conventions. An example of a population stereotype is turning a lock counter-clockwise to open it.

The last step is finding a metaphor to create intuitive interaction. As explained in the previous paragraph, metaphors can help you understand and adopt a completely new product. Because of that, the user might automatically assume that the interactions of the metaphor will be similar to the interactions of the new product.

The interactions of the delivery robot should be designed according to the tool of Blacker et al. to design an intuitive interaction. Since the delivery robot will be a new product, the metaphors will be important in the design process. The robot should not only mimic the hand-over of a current delivery process (figure 2.2.3), but it should also create an association with groceries shopping.

An advantage of a delivery robot is that the robot would be able to help the user if the interaction is not clear/intuitive enough. Of course, it is still important to make the interaction as intuitive as possible, so the user should not have to put in a lot of mental effort, but at least the robot can be used as a back-up to help the user.

Usable

Key factors usable design:
Usable design can be created by designing an ergonomic and intuitive interaction.

By supporting the weightlifter's technique in the design of the robot an ergonomic interaction can be created. Intuitive design can be created by making use of interactions and aesthetics from other experiences that are known by the user.

The current hand-over is intuitive



Figure 2.2.3- Intuitive hand-over⁶

2.2.3 Desirable

What makes a product desirable? A positive reception of a product can be based on the products' functional and innovative performance, its aesthetics, its meaning, its emotional response, its ergonomics and its price (Gotzsch, 2004). Since some aspects are already covered in the analysis, the main focus of this paragraph is how to design an aesthetically pleasing, meaningful design that provoke a positive emotional response by the user for the delivery robot.

Aesthetics

According to Roth (2014), the variety and unity of a product needs to in balance in order to have a good overall aesthetics. Aesthetic pleasure is not only important for creating a desirable product, but also for the perceived usability of a product. Users perceive aesthetically pleasing products as more usable ones (David et al., 2010).

Meaning

According to Gotzsch (2004), the meaning of a product is depending on the company's brand identity and the user's self-identity. Thereby, the meaning should match the appearance and function of a product (Ozcan, 2011).

Brand identity

In this project, the brand identity is not from that great importance, since the delivery robot is not assigned to a brand yet. The delivery robot might be a part of the future FoodLogica vehicles. FoodLogica pictures themselves as a flexible yet scalable solution working with food businesses to solve their last mile delivery challenges. They would like to picture themselves as sustainable (electric vehicles), flexible (long operating hours and time sensitive deliveries) and modular (different vehicles). Their logo is green with white and on their website, they are promoting a green-orientated lifestyle. But again, it is very likely that the delivery robot does not have to fit in the brand identity of FoodLogica.

User identity

Expressions in products can reflect its user's identity. An expression like this can make a product attractive because it can respond to the user's wish to be part of a group or on the contrary to be seen as different from a group of individuals. A product can facilitate this type of communication and inform others about individuality, status, ambitions, life-style and social class (Gotzsch, 2004). In some scenarios, the robot will deliver lunch to firms. Therefore, it might be nice if the robot will fit people's identity at work, which could be professional, part of a bigger team and responsible.

A product is desirable if the design is aesthetically pleasing, fits the brand and user identity and arouse a desired emotion.

However, not all customers will be at work. Some of them might also receive their groceries at home. In this scenario, it might still be nice for the robot to look professional and responsible. The robot is still delivering food, which comes with a certain expectation. The robot should be careful and make sure that the groceries arrive at the doorstep in the right condition. Determined might be a good meaning for a delivery robot to have.

Emotion

Emotional attachment

According to Schifferstein et al. (2008), consumers will act more careful with a product they are emotionally attached to. Consumer-product attachment can be described as the strength of the emotional bond a consumer experience with a durable product. However, the users of the delivery robot will not own the robot, they will only use it. It is very unlikely that the user will be interacting with the same delivery robot every time they use the service. Since the user is not owning the robot, it could be a bit harder to design a robot the user would feel emotionally connected to. However, people tend to attach with a product if they can relate with it. According to Nass et al (1994), people will apply social characteristics to a product even though they believe that the product does not possesses human-like emotions. For example, people still assign a name and gender to their Roomba vacuum cleaner, even though it is a very machine-like robot (Sung, 2009). The attribution of human features onto objects by the observer is called anthropomorphism. A delivery robot can be anthropomorphized by the customer based on its behavior and its aesthetics.

Robots tend to be anthropomorphized based on three characteristics: their movement, physical embodiment and their mimicking of human behavior, like sound, movement and social cues (Darling, 2015). Darlin has suggested that anthropomorphic framing, such as giving a machine a name, results into a higher level of empathy towards the device and makes it less likely that people perform a violent act on it.

Emotional attachment towards a robot, could also negatively influence the intended use of the robot (De Groot, 2019). For example, a high level of anthropomorphism gives the impression that the robot wants to have interaction with people. This can hinder the efficiency in delivering the goods, since the pedestrian on the sidewalks might want to interact with the robot even more. Another scenario could be that the user might feel disappointed if the user expected the robot to talk and the robot is not able to. People tend to anthropomorphize robots very quickly. Therefore, it might not be needed to mimic human non-verbal communication to reach a desired level of humanness.

According to De Groot, the robot should not look like a human at all, in order to avoid interaction with the pedestrian. However, Darlin (2015) said that a higher level of empathy towards the device makes it less likely that people perform a violent act on it (vandalism, theft). Therefore, a balance should be found in how human-like the robot should look.



Interviews emotional state target audience

The delivery robot will arouse an emotion in the user. The user, however, is already in a certain emotional stage. The delivery robot might be able to help the user experience a better emotional state by interacting with it (positive design). By finding out which aspects makes the user experience a good or a bad day, can help turning a user's negative emotional state into a positive one. Ten participants (Dutch, age 20-65) were asked to describe what aspects ensured them to have a pleasant and an unpleasant day. Summarizing the interviews, the participants experienced a fun day when they had some social interaction, were relaxed, had the feeling that their work/effort matters, that they were in charge of their own work/day or saw some personal growth. On the other hand, the participants experienced an unpleasant day when they had unplanned disruptions, self-doubt, some circumstances which they could not control, the feeling that their work was not relevant or just feeling bored. Concluding, the design of the delivery robot could make use of the positive day experiences of the target audience to turn a potential negative emotional user state into a positive one. The design should make the user feel in control, confident and entertained by making use of the robot delivery service.

Key factors desirable design:
Desirable design can be created by a design that is perceived as aesthetically pleasing, professional and reliable. A balance should be found in how human- or machine-like the embodiment should be in order to prevent pedestrians from interacting with it at the sidewalk (but still enable some sort of attachment with the user at the doorstep).

The delivery robot may inadvertently change the user's negative state into a positive one, by making the user feel in control, confident and entertained. This will subconsciously amount to a desirable product.

Desirable

2.1.4 Findable

The robot should be easy to find for the customer in front of their doorstep as the app of the service in the app store. Since the robot will be a physical object what moves towards a given address, I do not think it would be hard to find the robot. However, the website or app should not get lost in the millions of other (delivery) apps and websites. It is important to make sure the lay-out of the app fits the purpose and brand identity of the delivery robot. Since the delivery company is not related to a specific company yet, the lay-out could still be any color/shape as possible.

The colours orange, yellow, green, black and white could be suitable as brand colour. According to Cerrato (2012), orange is stimulating to the appetite and gives an impression of affordability. Yellow on the other hand is a warm and happy colour, which creates a sense of cheerfulness and playfulness. Physiologically, yellow stimulates the mind and mental activity and is often used at places where they want people to keep moving (most people cannot stay for long where there is a lot of yellow). For example, fast food restaurant combines yellow with red to encourage people to eat lots quickly and move on fast. Green is an ideal colour to promote environmentally friendly products and is

beneficial for anything to do with health and healing. White is the colour of new beginnings. Black on the other hand reflects authority, power and control, but it can also be a bit intimidating, unfriendly and unapproachable. However, it can also be seen as sophisticated, dignified and serious, but also as protection and comfort.

The Husky will be used as a platform for the delivery robot. Some parts of the Husky would be hard to cover up, since it has some big surfaces, including the dominant yellow side surfaces and the big black wheels. However as described above, yellow represents cheerfulness (fun experience) and it helps people realize that the object will not be staying in the same place for a long time. The back wheels might look a bit dominant and serious, but it also gives the impression that the customer can trust the robot with their goods. The colour white can be used as addition. The white colour can integrate calmness in the design and since white is the colour of new beginnings, it might not be associated with other products, but more with a completely new innovative product. So, the potential colours that could be used in the design of the robot, app and other marketing lay-outs for the robot could be yellow, black and white.

Findable

Key factors findable design:
A clear consistent lay-out should be chosen for the design of the app, and the embodiment. The colour yellow is often associated with food and delivery.

2.1.5 Accessible

The robot should be easy to access. This can mean two things; it should be easy for the customer to find the robot at the doorstep, and it should be easy for the user to get access to the goods.

Navigation

In order to make sure the robot makes it to the intended spot at the doorstep, navigation is needed. The Husky is currently making use of a Skylark navigation system. This system is making use of two navigation disks, two GNSS receivers, some connecting cables and a Wi-Fi antenna (Figure 2.2.4).

However, it might be better to use a different kind of navigation system. The navigation disks are quite big, need to be located at a certain position from each other and are getting easily interrupted by placing materials or objects on top of it. The robot must for example be able to function in a tunnel as well. The disks are thereby quite big and protruding and therefore also not vandal-proof. A better option would be to use an Inertial measurement unit (IMU) + GPS sensor.

An IMU allows a GPS receiver to work when GPS-signals are unavailable, such as in tunnels, inside buildings, or when electronic interferences are present. These components are currently also used in some other delivery robots. The IMU is necessary to navigate precisely. By only using as GPS sensor, for example like the same one as positioned in your phone, the navigation could be a few meters off. The IMU and GPS sensor should be connected with an ultrasonic sensor and multiple camera's (stereo camera, TOF camera), in order to drive autonomously. The most important takeaway for the embodiment is that room needs to be created in the embodiment for all those sensors and cameras. By integrating the camera in the embodiment, extra attention should be paid to the position of the camera within the robot. The camera should be put on a proper height and the embodiment should not block the view of the camera in order to function as desired. To contribute to a desirable human-robot interaction, the delivery robot should be able to share its location with the customer. This could be done by making use of a sim card connected to a microcontroller and battery.

Goods access

To make sure only the intended customer can access the robot, a certain access system needs to be designed. Current robots are using codes on a touchscreen and unlock buttons via an app. It is very important to keep the users' privacy in mind. People are getting more conscious about their data and what companies are using it for. It is important to make intentions with cameras and data clear.

2.2.6 Credible

The main challenges, when creating a credible delivery robot, are that people should believe the robot would be able to do its job, that it would be safe for them to retrieve the goods and that the goods are from a certain quality. Credibility relates to the ability of the user to trust the product. In order to be trustworthy, the product should do what it supposed to do, the product should last for a reasonable amount of time and provided information should be accurate and fit-for-purpose (Interaction Design Foundation, 2020).

2.2.6.1 Food quality

The delivery robot should be able to transport goods, while keeping them in a certain condition. According to the Government of the Netherlands (2020), businesses involved with food must meet national safety and hygiene requirements in order to safeguard consumer health. Companies are required by law to formulate a food safety plan in line with the Hazard Analysis Critical Control Point (HACCP) system (Safe Food Alliance, 2020).



Key factors accessible design:
It should be easy for the customer to find the robot at the doorstep, and it should be easy to access the goods. The delivery robot should have a GPS system and a lock system to provide the user its location and access.



Figure 2.2.4. Husky with current sensors ⁹

If the goods arrive at the customers' doorstep in a bad condition, it would not only be bad for the human-robot interaction at the doorstep, but it can also be hard to find out which company is liable. Therefore, the robot should meet some requirements.

Food condition requirements

- Perishable goods must be cooled between 4°C and 7°C (Nederlandse voedsel- en warenautoriteit, 2020).
- The non-perishable goods must be preserved in a dark, dry place at a temperature between the 12°C and 20°C (Voedselcentrum, 2020).
- Deep frozen goods must be cooled at a temperature of -18°C or cooler (Nederlandse voedsel- en warenautoriteit, 2020).
- The temperature of the goods should be able to be measured (FoodLogica interview appendix B).
- The goods of different customers must not be mixed (Jumbo interview, appendix C).
- The cooling container must not contain holes or cracks, so no vermin will be able to enter, when the opening is closed (TLN, 2020).

Interview FoodLogica – Food transport requirements

An interview with an employee of FoodLogica was conducted, in order to get more familiar with responsibilities of food transporting companies and employees that are loading those transportation vehicles. FoodLogica is a logistic company focusing on refrigerated last mile solutions for exceptional food brands. Key finding of this interview, which can be turned into requirements can be found below.

- After and before delivering the goods, the container/crates should be assessed by the employee to see if a clean-up/disinfection is needed and executed if it is.
- The employee is responsible for making sure the goods are transported at the right temperatures.
- The temperature of the goods and the container should be noted/tracked right before the robot will start its route.
- The employee should visually check the goods on deviations (damaged packaging, presence of pests, expired food) and replace the goods if necessary.

*If the employee cannot prove that the requirements for the transportation has been met, the company, where the employee is working for, can be held responsible.

2.2.6.2 Trustworthy appearance

As mentioned in the introduction of this paragraph, the robot should look trustworthy in order to be credible for the user. The importance of credibility and a trustworthy appearance is similar to the importance of first impressions (Interaction Design Foundation, 2019). If the user does not trust the product, no amount of persuasion can remove that feeling. Failure becomes seared into the user's memory and then giving the product a second chance seems unlikely, especially if a market has plenty of alternatives. The delivery robot should look like it is able to deliver the goods safely and on time. The robot should not only look like he will not get robbed or vandalized, but the design should also prevent this from happening.

But how to prevent or discourage vandalism or theft? According to Goldstein (1996), there are a few different types of vandalism.

1. Predatory vandalism.

The destruction is caused by burglary or theft and sometimes by the effort to cover up the act (destroying a park meter). In order to prevent this kind of vandalism, people should think that nothing valuable is being transferred in the robot and if they think it does, the possibility of getting caught with experiencing consequences should not make it worth to steal.

2. Vindictive vandalism.

Something is vandalized in order to express animosity or anger toward, and perhaps to intimate, a particular individual or group. Since there are no conflicts in the delivery service world, it is not very likely that the future robot will be vandalized in order to express anger. Maybe if the delivery robots take over a lot of jobs, without creating other jobs in return, people might express themselves with vandalizing the robots (graffiti or destroying the robot in some way that it will not be able to function anymore). The delivery robot should create new other jobs as well or

make the robot become part of the community as well.

3. Playful vandalism.

Who can break the most windows? This kind of vandalism can also happen by accident out of curiosity. The delivery robot will be a new object that is manoeuvring himself through the streets. Children might want to play with it, maybe even sit on it. According to Bosch (2020), people are less provoked to interact with the robot, when the robot is behaving more predictable. This will reduce people's curiosity. The robot should therefore drive smoothly and take control with its direction if a person starts to be curious and act playful. The robot should be designed in such a way, that children will not see the robot or its movement as a game.

4. Peer-group pressure.

Sometimes, teenage children vandalism objects out of boredom or peer pressure. It can be quite easy to hide an act of vandalism for a teen, since they probably will not bring a traffic sign back home as souvenir. The vandalizer usually does not see the consequences of their action. They often do not believe they are hurting someone. If they would know that vandalism costs taxpayers a lot of money (the property must be repaired and investigated) and that money can therefore not put in something they might be interested in, such as the local dance studio, they might act different the next time (MiddleEarth, 2012). Maybe the delivery robot could show the vandalized that it will affect other people in some way.

2.2.7 Valuable

What will make the delivery robot valuable to the customer? The delivery robot will be valuable for the user, since it can offer them more control of the delivery process. This service will be a new way of future delivery. People do not want to wait up and be stuck at home waiting for their package anymore. Products are invented to give people more time, so they can spend their life the way they want to. This robot could not only be valuable to the customer but also for the delivery service business. The company does not need to pay salary for the delivery service employees anymore. Thereby, the delivery robot is probably

more efficient than the delivery vans, since it can operate on the sidewalk (no traffic jams, no searching for a parking spot). The delivery robot service could also be an improvement environmentally wise. By making a zero-emission robot, the robot will have a better impact on the environment than the current delivery vehicles. If only delivering goods is not valuable enough, there could always be an opportunity to add an extra function to the robot, so the robot will be able to function as a street cleaner or as promotions by adding posters on the embodiment.

The delivery robot will be valuable for the user, since it can offer them more control of the delivery process.

Credible

Key factors credible design:

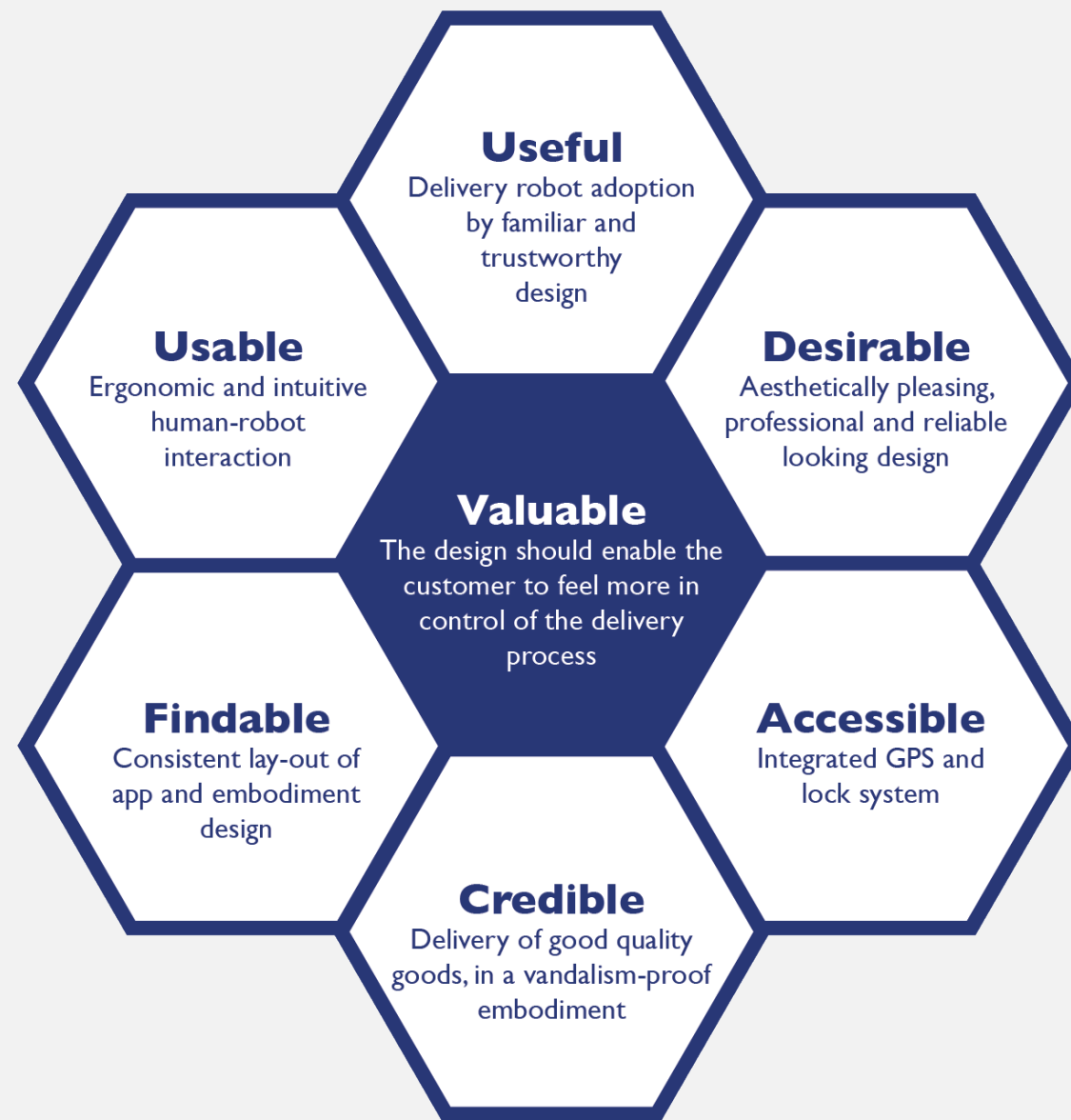
The goods must be delivered in good condition.

The food must be preserved at a right temperature and that should be assured by the transportation company. Thereby, the robot should look trustworthy, and the embodiment should discourage people from vandalising the robot.

2.2.8 Conclusion

A desirable human-robot interaction at door doorstep will arise from a positive user experience at the doorstep. Using the seven facets of Morville (figure 2.2.5), several key takeaways could be defined to design a positive user experience at the doorstep.

A product needs to be adopted by users, before it will be seen as a useful product. Users will eventually only interact with the delivery robot if they think that the robot is useful. A delivery robot tends to be easily adopted, when the design of the robot looks familiar and trustworthy. Another important part of product adoption is the publicity. The operational procedures and potential advantages of the delivery robot should therefore be properly publicized.



However, the robot should also look friendly to ensure a desirable human-robot interaction at the doorstep. A balance should be found in creating a human- or machine-like robot. A more machine-like robot might discourage people to interact with the robot on the sidewalk, but a more human-like robot might look more friendly and easier to empathize with. People are less likely to perform a violent act on a product when they empathize with it more.

To make the robot findable in the street view and the app of the service also not get lost in the millions of other (delivery) apps and websites, it is important for the colours and shape to stand out and fit the purpose and brand identity of the delivery robot. The colours, black, white and yellow could be used, so people will associate the design with a delivery service company, appetite, but also professionalism and hygienic.

Another important factor of the human-robot experience is the accessibility. The customers would like to know that they are the only ones that are able to get access to retrieve their goods. In order to have access, the robot should provide clear information in how to retrieve the goods. Thereby should it also be able to share its navigation and keep the customer up to date about the process.

Credible design must be created, so the users will believe that the robot is able to handle its job and capable of delivering goods in a certain quality. The robot should be able to prove that the goods were kept in a certain temperature. Thereby, the robot should contribute to a trustworthy look and make it hard for people to vandalize it.

Eventually the robot will be seen as valuable at the doorstep, when the design is useful, usable, desirable, findable, accessible and credible. The robot should do what it supposed to do: deliver goods. The delivery robot could be even more valuable if it helps the user feel more in control of the delivery process as of their own planning of the day; a need that the current delivery service is not fulfilling.

Figure 2.2.5. Conclusion seven facets of User Experience

After the adoption of the delivery robot, people should look at the robot as an easy-to-use product (usable). Therefore, the design should provide a physically and mentally comfortable interaction. The goods should be retrieved with an intuitive and ergonomic interaction.

To create a desirable delivery robot, it is important that the design enables a fun experience at the doorstep, looks aesthetically pleasing and that the meaning of the design fits the user identity. The design should arouse a positive emotion to enable a fun experience. A positive emotion towards the robot can be co-created by making sure that the robot arrives at the customers doorstep at the agreed time. A determined looking robot will probably be less likely to get held up by people along the way and is therefore more likely to arrive on time.

Conclusion design for a desired human-robot interaction

2.3 Design for the future

2.3 Design for the future

Designing a delivery robot can be challenging, since it can be hard to predict how people will interact with such a new product in the future, especially when they have not interacted with something similar before. Thereby, the way people are behaving, the technology they are used to, and people's point of view might also be different in the future. By analysing trends, a prediction can be made about certain aspects of the future.

Having a prediction about future delivery services will help to design a robot that is innovative and also suitable to be used in the world in a few years.

The Vision in Design Process model from Hekkert & van Dijk (2011) (figure 2.3.1), can be used as a tool to design a desired product and interaction for the future. By analysing the old product, interaction and context and by using trends to predict the future context, interaction and product, a vision for the design phase can be phrased. The complete trend analysis can be found in appendix D.

2.3.1 Past products and interaction

For the past almost twenty years, the most common way to make use of grocery home delivery (in the Western world) was by ordering groceries on an online platform, selecting a timeslot of approximately 2 or 3 hours and wait at home for the service to arrive. A downside of this service is that the customer cannot leave the house for a while, since they need to wait for the service to arrive. An advantage of this interaction is that the customer does not need to think too much about the interaction when retrieving the goods. The supermarket employee would just ring the doorbell or call the customer and handover the crates at the doorstep.

Before the supermarket delivery services existed, people had their groceries delivered by a milkman or a greengrocer. The milkman was also allowed to leave the milk right in front of the customers house or even in some cases leave the milk within their house. The customers always had the same milkman and therefore trusted him by entering their homes.

The ability for a design to look trustworthy and the almost effortless interaction of the current motion of handing over the crates from the employee to the customer, must be taken into account when designing the delivery robot. The delivery robot might also reduce the time the customer has to be stuck at home waiting for the groceries to arrive.

2.3.2 Past context

The process of retrieving goods has changed over the past few years; instead of seeing it as a physical task that took almost half a day back in the days, it changed into a more lay-back activity, whereby the delivery employee brings your groceries to your doorstep.

The services are more and more adjusting to the activities of their customers life. In the Western world, it is more common for both genders to have jobs now (Ely et al, 2020). Therefore, it is more common that all adults in a household have jobs and that less time is available for grocery shopping or waiting at home for the grocery delivery service to arrive. The delivery service needs to adjust to people's life now, instead of the other way around.

The delivery robot should hand over the groceries with the same effortless interaction as the current handing over interaction in the current delivery process

The delivery robot service should adjust to people's life, not the other way around.

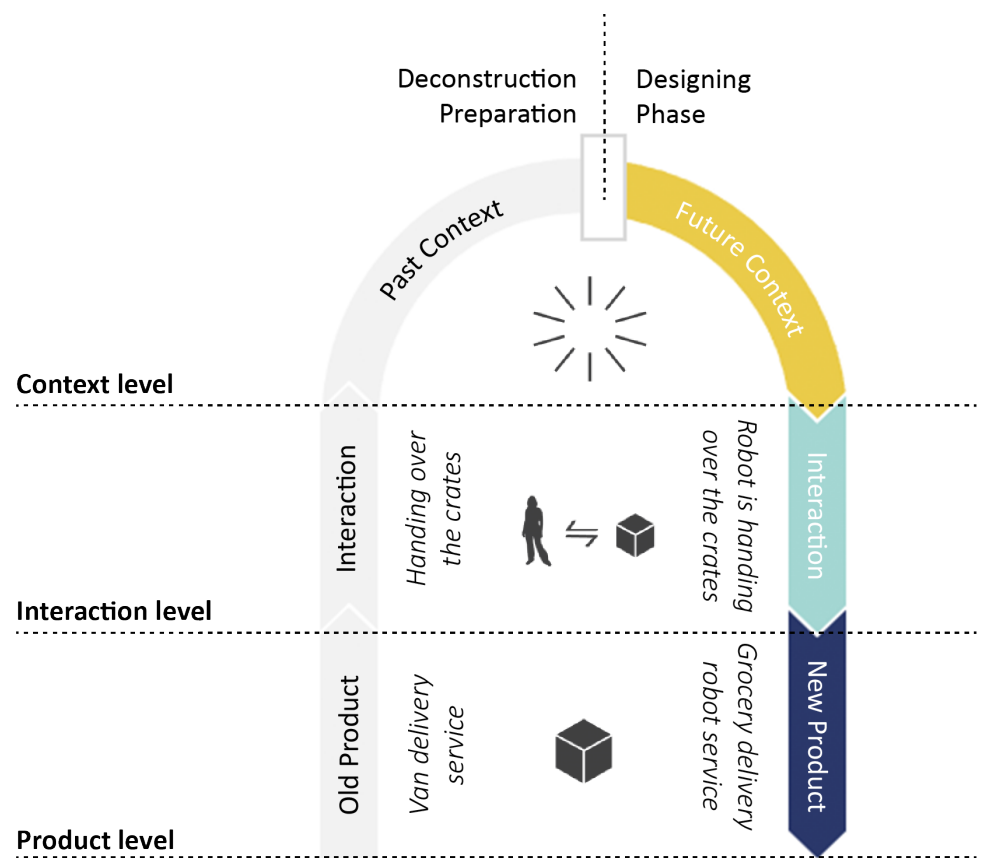


Figure 2.3.1. Future design vision model of the Vision in Design Process (VIP).⁸

2.3.3 Future context

Due to the rapid growth of the e-commerce business (partly caused by the Covid-19 pandemic) and the increasing competitive market, customers are getting more used to having a good customer service.

Future customers will expect to have good service or otherwise they will be dissatisfied.

The competition of customer service is also starting to express itself in the grocery delivery service businesses. Companies such as Flink and Gorillas are already promising to have groceries delivered within 10 minutes. If the delivery robot wants to join this competition it should be able to deliver the goods in the same amount of time or join the market with an even better alternative. If the robot is not able to achieve at least the same delivery time than these new companies, then the robot should find new areas in which it can stand out.

In the future context, people will be even more aware of the environmental problems (Winston, 2019). The world already witnessed the impact of climate change on some natural systems and these changes/hazards will only become more visible over time. People will be more thoughtful about their choices. Tools to analyze information will be more developed in the future and will make some decisions easier to make. For example, it will be easier to choose products with the lowest carbon footprints, highest wages for employees and fewest toxic ingredients (Oldham, 2020).

The delivery robot could offer the customers a sustainable solution. The robot could not only be a zero-emission vehicle, but it could also bring them sustainable choices (avoiding meat, transferring products produced in the same country). Even if the robot would not be able to deliver goods within 10 minutes, the robot could still be the most sustainable option for the customer and the most profitable solution for the delivery companies.

So, in the future, it will be important that customer service will meet as many wishes and needs of the customers as possible. **If the robot will not be able to compete with other delivery services in one customer need, then other unique selling points to compete with the delivery services should be found.**

The existence of delivery robots in the future

That delivery robots will be operating on the sidewalk in the future can be seen as a fact. A few delivery robots are already being tested in trial areas these days and even though, it is still illegal for autonomous vehicles to participate in road traffic, the laws might be changing soon. Germany, for example, already adopted a draft law on autonomous driving in February 2021 (Simmons, 2021). The laws about autonomous vehicles operating on the sidewalks are less clear. This law might change even sooner than you think, since a robot driving with 4 kilometres per hour on the sidewalk provokes less danger than a vehicle going 100 kilometres per hour on the highway surrounded by traffic. Thereby, less ethical questions are involved when designing an autonomous delivery robot, than when designing an autonomous delivery car. The question is therefore not when delivery robot will operate on the sidewalks, but how will such a future interaction and product look like?

2.3.4 Future interaction

I believe that the future human-robot interaction should be easy, intuitively and effortless. As described in future context, the quality of the customer service will become even more important in the future. People are getting used to fast delivery and companies who are working really hard to meet their customer's needs. If the customers' needs are not met, then it is likely that the customer will not choose to use the delivery robot service again.

Since it is a challenge to design an interaction for the future, it can be useful to take a look at the human-robot interacting of robots that are currently operating in trial runs. Some of the most developed robots are displayed in figure 2.3.2. Not all of these robots are delivering groceries, but since all of them provoke a human-robot interaction when handing over goods, they can all still be used as an inspiration source. Only the Robomart and Nuro, are designed to deliver groceries (while making use of the main road, not the sidewalks). The other robots are delivering meals or packages.

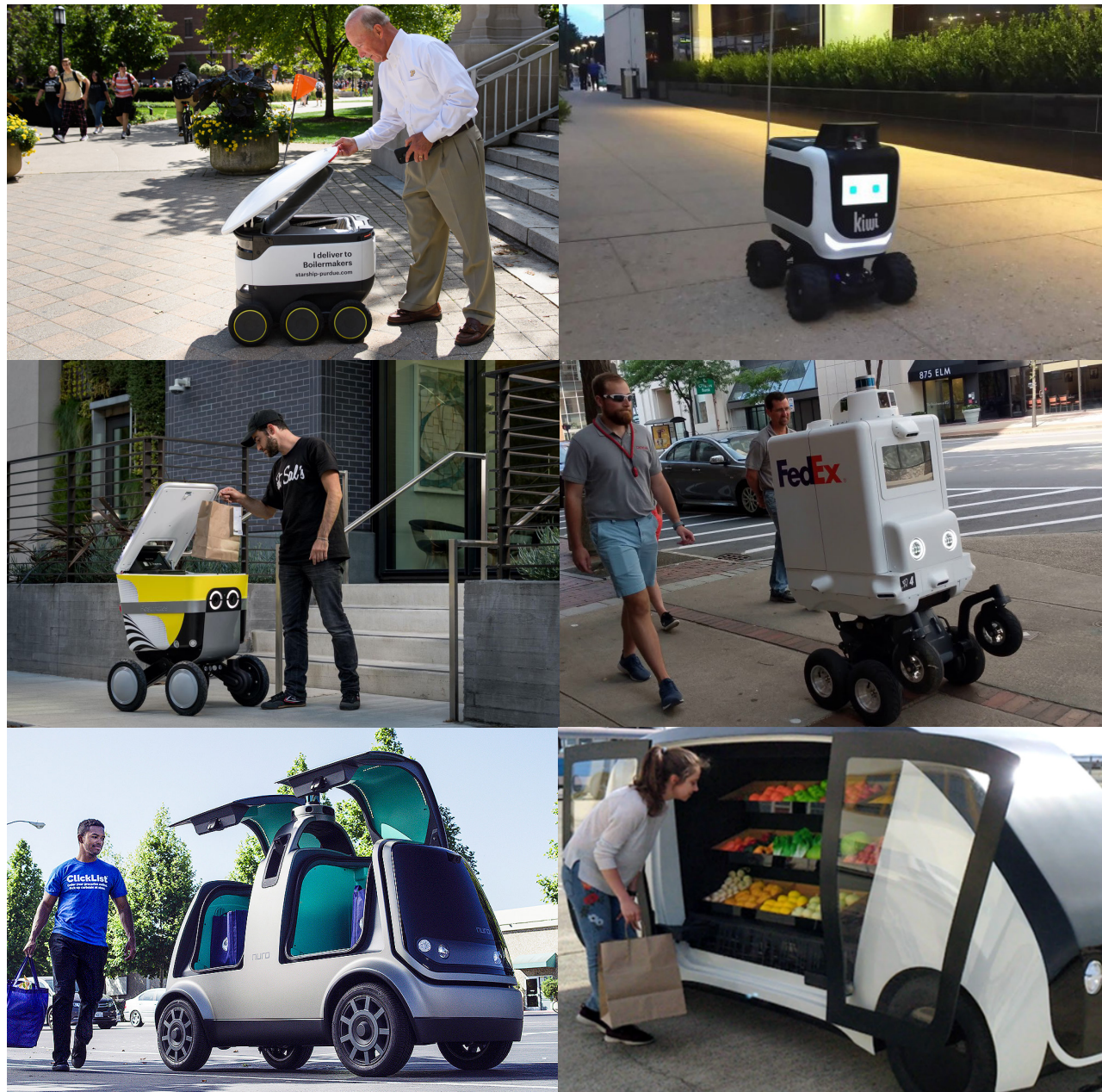


Figure 2.3.2 Delivery robots: 1. Starship, 2. Kiwi, 3. Postmates, 4. FedEx, 5. Nuro, 6. Robomart.⁹

Takeaway's inspiration existing human-robot interaction **The human-robot interaction is, to a great extent, effected by how functionally looking, intuitive and ergonomic the design is.**

- Functionally looking
De Groot (2019), concluded in one of his experiments, that a delivery robot should be functionally looking in order or the user to understand what the

robot is transporting and how it will hand the package over. In the experiment participants evaluated different existing delivery robots and concluded that they associated rectangular shapes more with delivery robots than sphered shapes. **To create a functionally looking design, it is important to be aware of what kind of associations users are having with the design.**

The associations the user will have by seeing the embodiment of the delivery robot should match the function of the robot and the way it will interact with the user. If the association does not match, it is more likely for the user to experience a negative human-robot interaction. People tend to associate the appearance of robots with products they already know. The characteristics of the product that the robot is associated with, are reflected onto the robot.

The Kiwi (figure below) for example looks a bit like a remote-controlled toy and therefore looks unpredictable. The Postmates might looks like a minion and therefore might be perceived as childish. The two designs can provoke an undesired interaction, since these metaphors might give a wrong impression about the capabilities of the product and interaction. The Starship on the other hand, was not associated with any other design at all in the experiment of De Groot. Therefore, it could be a bit hard to interact with it, but it also creates an opportunity to create a new association of its own.

- Intuitive
In order to stimulate intuitive interaction, use cues are from great importance. The users must be clearly cued, what they must do in order to retrieve their goods. An example of a clear use cue in an existing delivery robot is the red and green light underneath the handle of the lid on the Starship robot. These lights clearly indicate when the user is able to open up the lid. The robot should also make the user aware of his automatic actions in order to prevent confusion.

- Ergonomics
Looking at the existing delivery robots, ergonomics is an aspect where is still much to be gained. Almost all of the existing robots are quite small. The customer needs to bend a lot in order to retrieve the goods. This interaction is not very ergonomic. A student, who is currently living in Madison, a trial area for the Starship robot, mentioned that the robot looked small and that he could imagine people being afraid to trip over it. He also mentioned, that because of the size of the robot and the somewhat childish flag, it would probably be easy to break or rob the robot.

Aspects to create functionally looking, intuitive and ergonomic design should be taken into account in the final design.



Kiwi delivery robot¹⁰
- hot meal delivery

2.3.5 Future product

According to Holland (2018), the economy is shifting towards a more “experience economy”. This means that people these days, but even more people in the future, will prefer experiential purchases over material purchases. **A delivery robot can respond to the need of the customer to have a fun experience.**

In the future Western world, food will be perceived even more as fun, than how it is perceived today (appendix D: food trends). It will not just be seen as a fuel, but more as a fun experience. The delivery robot has the opportunity to be a part of such a fun food experience. The robot delivery service might also be experienced as a more fun, if the users feel like they are contributing to the greater good. By creating a sustainable delivery service, the users might not only feel like they are making a sustainable choice, but they might also have the opportunity to show other people that they care about the environment by making use of a service like this. This might contribute to a fun experience. So, the delivery robot should not only be sustainable,

but people should also be able to see that the robot is sustainable. The robot should be easy to repair, reuse, re-manufactured and easy to be recycled. The robot should be electric (zero-emission), deliver less meat and use reusable packages, such as crates, without using plastic bags.

An even faster robot delivery service can be created by designing a robot that can easily be integrated with other (automated) delivery processes.

The less time consuming the service will be for the customers, the more time they will have to create other fun experiences. Some processes within the delivery business are actually innovating as well. For example, Ocado's warehouse in the United Kingdom started automating order picking for grocery delivery by making use of robots (Vincent, 2018). They are using hive-grid-machines to lift, move and sort groceries in order to compose an order (see figure 2.2.3). To make the grocery delivery process even more efficient, it might be possible to integrate the delivery robot within this process.

2.3.6 Conclusion

Designing a grocery delivery robot can be challenging, since it can be hard to predict how people will interact with a new product, like the delivery robot, in the future. By analysing trends, a prediction was made of how the future context, interaction and product will look like.

In the future context, the robot delivery service should find a way to adjust to the customers life instead of the other way around. It is more common for both adults in a household to have a job nowadays. People have less time available to go to the grocery store or wait at home for the grocery service to arrive. In the future context, the robot delivery service should consume less time of the customer than the current grocery delivery.

In the future, customer service will be key to a thriving business. Due to the increasing competition in online services, people are expecting good customer service. Otherwise, it is very likely that the customer will not use the service again. In the grocery delivery sector, companies are starting to compete with delivery times. If in the future context, the delivery robot is not able to compete with the same delivery time as those other companies, then the robot should find new areas in which it can stand out. One of the options could be to compete in the field of sustainability. People are getting more aware of environmental changes and are more likely to choose for an option that seems right for the environment.

The future human-robot interaction of handing over the goods must require at least the same effortless interaction as the current handing over interaction between the customer and the delivery employee. The delivery robot will be seen as an innovation and should therefore also be experienced as similar or as an improvement, compared with the current handing over process.

To create a positive future human-robot interaction, it is also important to pay attention to design a functional looking, ergonomic design that stimulates an intuitive interaction. A functional looking design is especially needed so the user understands what the robot is transporting and how to interact with it. Association of the user group need to be taken into account when designing a functionally looking design.

The future delivery robot should respond to the fact that in the future people are more focused on purchasing experiences instead of products. To make the robot delivery service a fun experience, the robot must have a sustainable design. The robot should not only be sustainable, but it should also look or be promoted as sustainable. Choosing a sustainable service and showing other people that you used one, might contribute to a fun experience. To create a fast service, the robot should be designed in such a way, that the robot can be easily integrated with the other (automated) delivery processes.



Figure 2.3.3. Robots at Ocado's warehouse ¹¹

3. Design Vision

In this chapter, key finding of the previous analysis have been used to phrase a design vision

From research to design: Design Vision

To create a new way of delivery that will empower the customer to feel in control of the delivery process and their own schedule by letting them decide when and where they want to retrieve their groceries.

To make the user feel in control of the delivery process and experience as little mental and physical effort as possible at the doorstep, the design should enable intuitive human-robot interaction and an ergonomic design. Thereby, an aesthetically pleasing and functional (looking) design is needed to create a desired product and communicate the intended use of the robot. The customer should experience the robot as trustworthy, so they would feel ensured/in control with letting the service transfer their goods. The delivery service has the possibility to be an environmentally friendly decision for the customer.

The design vision is divided into subcategories, to have a better understanding of how to start designing based on this vision. The subcategories are intuitive human-robot interaction, ergonomic, trustworthy, aesthetically, functionally looking and environmentally friendly design.

Intuitive human-robot interaction

The delivery robot is a new product. Since it is quite likely that the user has not interacted with a robot like this before, it is necessary to make the interaction intuitive. By making use of metaphors, the design and interaction will look more familiar to the user. The interaction will be perceived more effortless and easier to use when the interactions are intuitive.

Ergonomic design

The current existing delivery robots are not taking ergonomic aspects into account yet. This robot has the possibility to stand out based on an ergonomic design. The goods should be easy to retrieve without the user having to adopt an uncomfortable position with their body. Thereby, it should be comfortable for the employees to place the goods into the robot as well.

Trustworthy design

The user needs to believe that the delivery robot is able to handle its jobs. The robot should be able to deliver the goods on time, in complete order (no theft) and in a certain condition. The robot should not look like a human at all, to avoid interaction with the pedestrian. The robot should not get interrupted in order to deliver the goods on time. Interaction with the pedestrian might causes this interruption. On the other hand, by creating a more human-like robot, people are more likely to feel empathy towards the robot and will therefore not perform a violent act on it (vandalism, theft). A nice balance of how human-like the robot must look like should be found in order to create a trustworthy design.

Aesthetically pleasing

People will perceive a product as usable if they think the product looks aesthetically pleasing. A product is perceived as aesthetically pleasing if the variety and unity of a design are in balance. By integrating the user's identity (or the identity the user would like to have) in the design, the robot might also be perceived as desirable. Creating a design, what make the user feels in control, confident and possibly also entertained, also contributes to the desirability of the robot.

Functional (looking) design

The function of the delivery robot is to deliver goods. It is more likely for the delivery robot to get accepted, when the functions are visible in the appearance of the robot. People tend to associate the appearance of robots with products they already know. By using metaphors or features of already existing products, the functions can become clear by just the way they appear.

Environmentally friendly

People are becoming more aware that climate change is a problem and that we need to start doing something about it. The delivery robot should have an environmentally friendly design and business strategy. The robot should be easy to repair, reuse, re-manufactured and easy to be recycled. The robot should not only be a sustainable choice, but the customers should also feel like they are making a sustainable decision by choosing for this service (marketing).

4. Design Approach

This chapter provides a design approach for the embodiment design.

4. Design approach

The design vision is used to come up with a design plan for the embodiment. All directions described in the design vision will have a great impact on the human-robot interaction at the doorstep. However, some aspects have less design freedom, since those aspects need to meet more strict requirements, than others. The design process remains an iterative process, but by starting to design the parts that have to meet the strictest requirements, the faster this iterative process will be.

The most important requirement is that the delivery robot is able to function as intended; it should be able to deliver groceries to the customers doorstep in a desired condition and at an agreed time. The design can be aesthetically pleasing and enable an intuitive human-robot interaction, but if the delivery robot is not able to deliver goods to customers doorsteps, then the customers will not experience a positive user experience. Therefore, the “form follows function”- design approach has been chosen for this project.

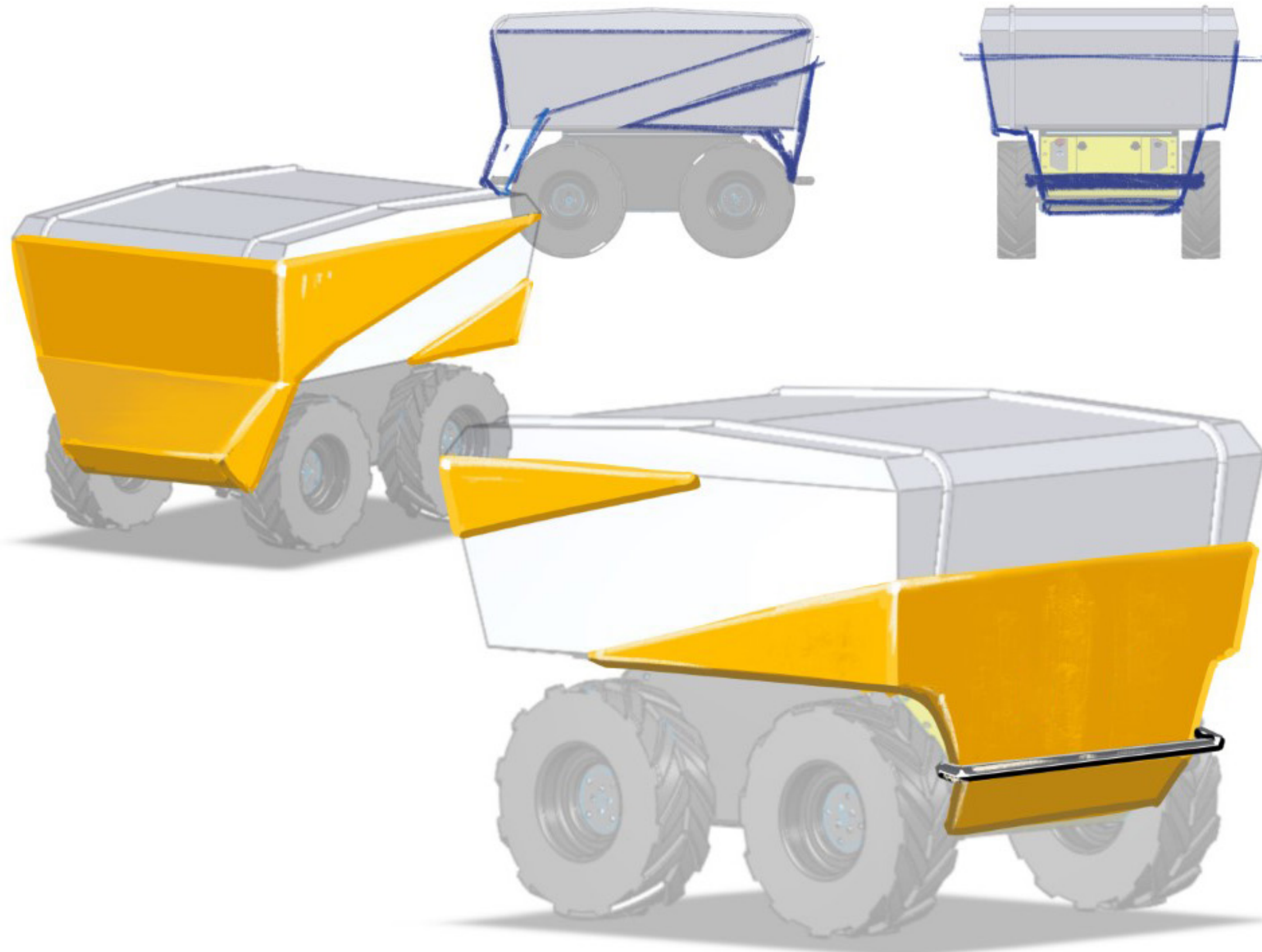
Form follows function - design approach

5. Embodiment Design

This chapter shows detailed design decisions to create an embodiment design in line with the design vision. By the end of the chapter, you must have a clear imagine about functional, ergonomic, intuitive, functionally looking, trustworthy, aesthetically pleasing and environmentally friendly design decisions for the delivery robot. The aim of the embodiment design is to enable cool transport and a user-friendly handover.

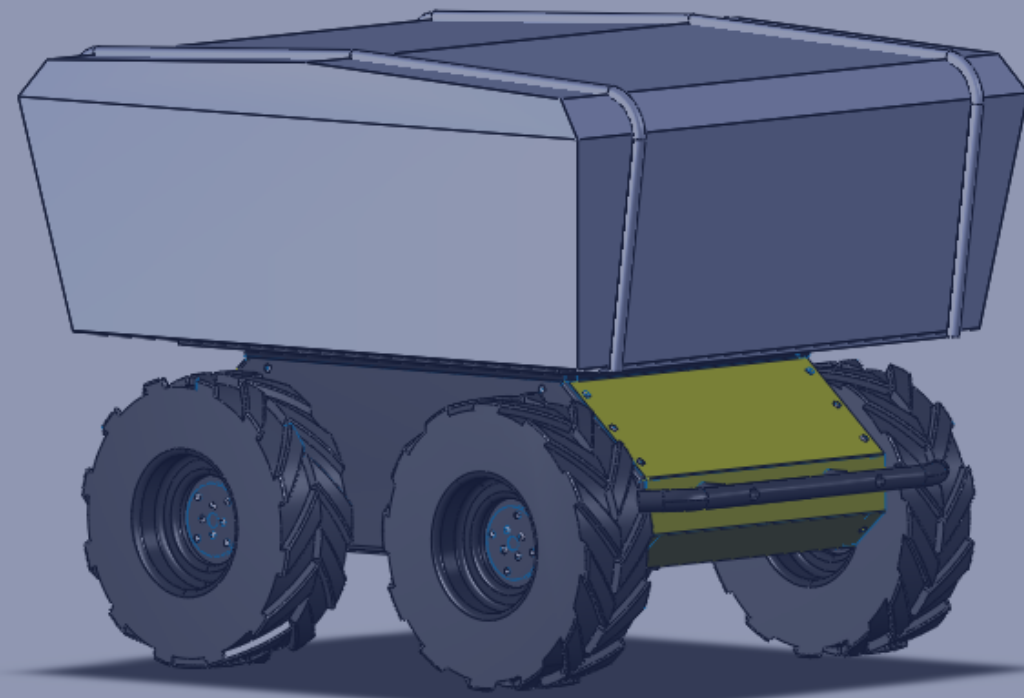
Functional design
Ergonomic design
Intuitive human-robot interaction
Functionally looking design
Trustworthy design
Aesthetically pleasing design
Environmentally friendly design

Ideation of shell and embodiment design



Embodiment design
of the first grocery
delivery robot, that
is able to operate
on the sidewalks





5.1 Functional design

Interview employee Jumbo grocery delivery service

I conducted an interview with an employee of the Jumbo grocery delivery service in order to find out what service the current grocery delivery service is providing. The delivery robot should be able to replace the current service. Key findings from this interview are used as requirements for the design of the cooling system and cool box. The entire interview took around 30 minutes and can be found in appendix C.

According to the grocery delivery employee, an average customer at the Jumbo delivery service orders about two or three crates per order. This is however with a minimum order amount of 50 euro. Grocery delivery services are currently using three different kinds of crates: a regular one, a cool box crate and a freezer box crate. The user can borrow the regular crate for 5 euros. The other two crates (cool box and freeze box) need to be empties at the doorstep, so they can be returned immediately. In the cool and freeze box, the goods are packed in plastic bags, which makes the unloading easier and faster. The customers can return the plastic bags after emptying them at home or just pay 5 cents for every plastic bag. The goods of one customer cannot be mixed with food of other customers. The current system is making use of time slots. The delivery employee will call the customer if he will not be able to deliver the goods in time. The employee will reschedule the delivery moment to later that day or will move it to the next day if the customer agrees.

The results from the interview are used as requirements for the design of the cool box. The delivery robot must be able to carry at least the same number of crates as the current grocery delivery service and the goods should be preserved according to the law of food storages. If the delivery robot cannot replace the current grocery delivery robot, then the robot might not be the best fit for this sector.

In this paragraph, components needed to create a functional design are defined. These components include the cool box, lights, cameras, and navigation sensors. Without these components the delivery robot cannot function as intended.

The main function of the delivery robot is to make sure that groceries arrive in good condition and on time at the customers doorstep.

But how to make sure that groceries arrive in good condition and on time?

5.1.1 Cool box design

A design of a cool box is needed to keep the goods protected and at a certain temperature. The dimensions of the cool box and the type of cooling system within the cool box are depending on the amount and what kind of goods the delivery company would like to transport.

The delivery robot should be able to replace the current grocery delivery service and therefore be able to provide the customer with at least the same service. But what does this service entail?

5.1.1.1 Dimensions of the cool box

The dimensions of the cool box are largely depending on the amount of goods the company would like to transport. According to an employee of Jumbo grocery delivery service, the average customer is ordering two or three crates per order. The delivery robot will also make use of these universal crates to create an efficient transmission of goods between warehouse and the robot delivery service. However, is it possible for the robot to also carry at least two or three crates of groceries?

The delivery robot can only carry two crates of groceries, since the Husky robot platform is only able to carry 75 kg. A crate with groceries can weigh up to 16 kg. Besides the mass of the crates, the robot also needs to carry a cool box, cooling system, batteries for this cooling system, cool elements and an overall shell for the embodiment.

The components of the embodiment should be designed as light weighted as possible since the Husky is only able to carry 75 kg.

The dimensions of the cool box are largely determinative of the final shape of the embodiment. **To create a light cool box, which will not frighten people at the sidewalk or doorstep, the dimensions of the cool box will only be slightly bigger than the size of two crates.**

The positions of the crates within the cool box still have some design freedom (figure 5.1.1). The crates will be positioned horizontally next to each other to create universal design. More arguments for this design decision can be found in the following paragraph 5.2 Ergonomics.

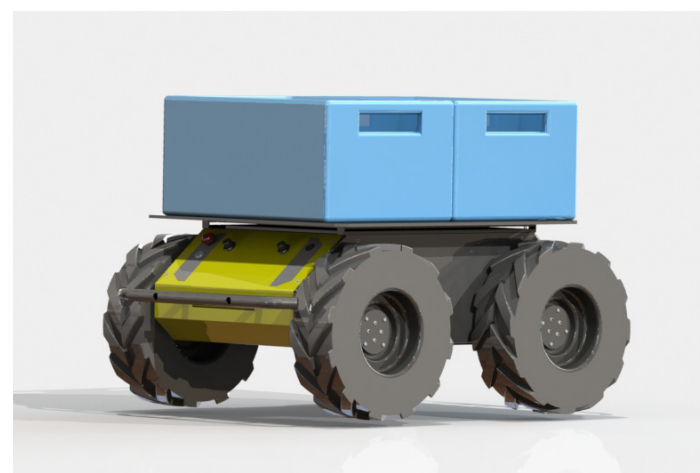


Figure 5.1.1 Crate position on top of the Husky

5.1.1.2 Cooling system of cool box

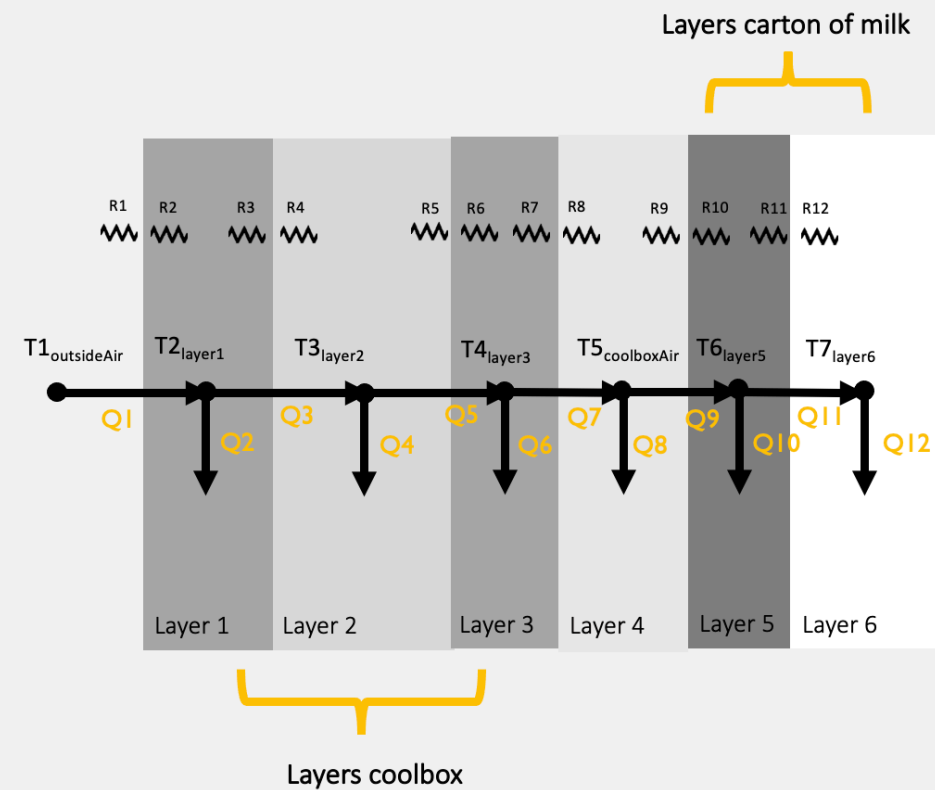
For a grocery delivery service it is important to be able to prove that groceries are always kept at a certain temperature in order to not be held accountable if groceries arrive in a bad condition. Current grocery delivery companies are making use of active cooling systems to keep groceries at intended temperatures. There are different kinds of active cooling systems available: one heavier than the other. However, all of them need a relatively heavy battery to operate.

One of the biggest challenges of this project is to create a lightweight embodiment. Making use of a lighter (and less expensive) passive cooling system might therefore be more convenient. A passive cooling system is focused on maintaining optimal operating temperatures with low or no energy consumption at all. **However, is a passive cooling able to keep the goods at the right temperature for at least 6 hours?**

Arguments for 6-hour operating time
The Husky is only able to drive for 3 hours (straight), if it is fully charged. Let's say that the Husky should deliver two crates at two different customers, located with the biggest distance as possible, so the robot will actually need those three hours to deliver all the goods. The robot might pause for 30 minutes at each customer each. The goods should then be able to stay cold for at least 4 hours. The robot might be hold up somewhere along the road and it would be too bad if all the food will go to waste. So just to be sure, the robot should be able to cool the product for at least 6 hours straight.

An analysis of active and passive cooling systems can be found in appendix E. An experiment was conducted to find out if a passive cooling system would also be able to keep groceries at the intended temperature for at least 6 hours.

Figure 5.1.2 - Model for passive cooling experiment



Experiment passive cooling system

I conducted this experiment to find out if groceries can stay within a certain temperature range in a passive cooling system for six hours straight (assuming a worst-case scenario with an outside temperature of 40°C). In the delivery robot, perishable goods need to be kept at a temperature of 4°C - 7°C and the frozen goods below -18°C. The model in figure 5.1.2 is used to determine the amount of time the goods needed to reach a certain temperature. Each layer within the passive cool box offers some resistance (R) in the heat transfer (Q) between the outside temperature and the temperature within the cool box. The layers absorb some of the heat. How much heat each layers absorbs is depending on a few variables, such as surface area, thickness of layer, thermal conductivity, mass, and specific heat capacity of the material.

For the experiment, variables from an average cool box and an average carton of milk have been used. An average cool box is made from PE (outer and inner shell) and has a foam, expanded polystyrene (EPS) as insulation material. The experiment was executed multiple times and every time different variables were changed, such as the begin temperature of the goods, the materials or thickness of the layers within the cool box or the volume of the goods itself. At some point in the experiment a cool element was added as well.

The results are promising. One carton of milk with a begin temperature of 4°C will reach a temperature of 7°C after 5,4 hours. This number of hours will only increase, when the volume of the cold product is bigger. Nine cartons of milk (begin temperature of

4°C) will for example reach a temperature of 7°C after 11,4 hours. By placing a cool element (320x265x30 mm) in the cool box, milk will heat up even more slowly. It will take one carton of milk (begin temperature of 4°C) 16,4 hours to reach a temperature of 7°C. Promising results also occurred when calculating with frozen goods. For example, it took a frozen carton of milk (begin temperature of -21°C) 3,6 hours to reach a temperature of -18°C. But by adding a frozen cool element to the cool box, the frozen carton of milk would reach a temperature of -18°C after 13,9 hours. **Analysing these results, it would actually be possible for the groceries to stay below a certain temperature for 6 hours.**

Takeaways experiment passive cooling system

- By making use of a cool element and a cool box, with outer and inner layer made from PE (minimum thickness of 0.001 m) and a middle layer made from EPS (minimum thickness of 0.01 m), it would be possible for groceries to maintain in the intended temperature range for at least 6 hours.
- The thinner the layers of the cool box materials, the faster the groceries were heating up, but the lighter the cool box turned out.

Changeable variables of the materials within the cool box

- By designing a cool box with a material with a greater specific heat capacity [C] or mass [kg] (thereby also volume [V] and density), the longer it takes for the products to heat up within the cool box.

- The greater the thermal conductivity [k] of a cool box material and the greater the contact area [A] of the cool box and the products, the faster the cool box and goods will heat up.
- The thickness [L] of the materials within the cool box are from great importance. The thicker the layers, the more time it will take for the products to heat up.

More takeaways

- **The air within the cool box will heat up faster than the products itself.** For example, the air (begin temperature of 4°C) will already reach a temperature of 7°C after 18 minutes as a box of milk in the same circumstances without a cool element after 5,4 hours.
- Opening the cool box will influence the temperature of the cool box and the goods. The effect on the goods is still visible, but small. For example, the lid has to stay open for almost 3,9 hours will one carton of milk with a begin temperature of 4°C, reach a temperature of 7°C. When closing the lid again, the temperature of the air inside the box will drop and the cool box will continue to cool the goods. The cool box itself will lose its cold temperature faster than the carton of milk. However, the cool element will eventually compensate this loss and the effect will not be visible long term.

So, it is possible, by making use of a passive cool box with an integrated cool element, to keep goods within the intended temperature range for 6 hours straight. However, the temperature within the cool box heats up faster than the actual goods. **Since it will not be feasible to have a mechanism that is measuring the temperature of all products, an active cooling system must be integrated to cool and measure the temperature of the air within the cool box to prove that the goods are preserved at the intended temperatures.**

The delivery robot would also be able to continuously measure the temperature and send a signal if something is wrong. In the current process, the temperature is only measured when the goods are still in the fridge at the warehouse and in the van right before transportation.

Concluding the experiment, a passive cooling system would be able to cool the products for 6 hours straight. However, an active cooling system is needed to measure the temperature of the air within the cool box to prove that the goods are preserved according to the law. **However, a less advanced active cooling system is needed since the system only needs to cool the air.** The complete experiment can be found in appendix F

But what active cooling systems are existing? And which one will be the best fit for the grocery delivery robot? There are three different active cooling systems; thermoelectric, absorption and compression cooling system. All three of them have advantages and disadvantages to be integrated in the delivery robot. For example, the absorption cooling system can be powered by gas as by electricity. This might come in handy just in case the delivery robot will run out of battery. The goods can then still be cooled by making use of a boiler, so no food needs to be wasted. The compression cooling system on the other hand, can cool down faster and to an even lower temperature than the other two cooling systems. The compression cooling system is the most energy efficient, but also the most expensive one. The thermoelectric cooling system is the system with the best lifespan expectation. The only part of the cooling system that can wear out is the fan that circulates outside air across the plate. Since the thermoelectric system only contains a few moving parts and does not contain any fluid, the cool box can easily be dropped or kicked without having a risk of damage.

All three active cooling systems would be able to function within the delivery robot. However, the thermoelectric cool system (figure 5.1.3) might be the best fit, since this system is not only the cheapest but also the least heavy. As described before, the weight of the cooling system is the most important criterion since the robot is only able to carry 75kg. Even though the thermoelectric cooling system is not very energy efficient, the system still uses the least amount of power compared to the other two.



Figure 5.1.3 - thermoelectric cool system¹²

The less power it uses, the smaller (and less heavy) the battery can be. By making use of temperature control, an even smaller battery can be used. The cooling system would be able to turn itself on and off by measuring the temperature of the air inside the cool box.

More details thermoelectric cooling system: The thermoelectric cooling system is making use of the Peltier effect as a cooling method. A Peltier cooler is mounted in the lid of the cool box, along with a fan system to disperse the heat to outside the box. The heat sink device transfers heat from the inside to the outside, with consumption of electrical energy. The Peltier components should be able to make the inside of the cool box 40 degrees colder than the outside temperature. The thermoelectric cooling system is also the only system that can warm the cool box. This might be useful with low outside temperatures.

Concluding, the thermoelectric cooling system shall be integrated in the cool box of the delivery robot. The system is not only the least heavy, but also the cheapest and the most shatter-proof of all three cooling systems. PE (outer and inner layer with a thickness of 0,001 m) and EPS (middle layer with a thickness of 0.01 m) will be used to keep the groceries cool and to save energy. The more isolated the cool box, the less often the cooling system needs to be turned on. The cool box will be slightly larger than two crates, so the embodiment will not frighten pedestrians at the sidewalk.

5.1.2 Navigation components

To make sure that the delivery robot can arrive on time, lights, cameras, and navigation sensors need to be integrated in the embodiment design.

Navigation sensors are necessary for the robot to know where he is and where to go. By making use of an Inertial Measurement Unit (IMU) in combination with a GPS-sensor, the robot will have very accurate navigation. With these sensors, the robot would also be able to drive through tunnels or underneath bridges without losing track of the road.

Camera sensors are needed for the robot to participate in (sidewalk) traffic. The delivery robot will use of the same types of cameras that the current existing delivery robots are making use of. This includes stereo and TOF cameras.

Besides the camera and navigation sensors, the robot also needs to have lights to participate in traffic. The robot should make itself visible and its intentions clear. Flashlights are designed to clarify the direction intentions of the robot.

5.1.3 Implementation functional design

Cool box design

The cool box is positioned directly on top of the Husky platform. The dimensions of the cool box are big enough to fit two crates, a thermoelectric cooling system and two cool elements. The cooling system is integrated in the wall of the cool box. The cooling elements are also integrated in the wall, but easily retrievable by opening a lid on the side of the cool box (figure 5.1.4).

Navigation sensors

The components needed to navigate (IMU and GPS sensor) are positioned in the middle part of the Husky.

Camera sensors

The cameras are positioned in the front of the embodiment. By adding a layer to the cool box, the camera will be able to have a 180-degree view.

Light

The lights are positioned on the front and back of the robot. Both flashlights as lighting to make the robot visible at night are integrated in the design.

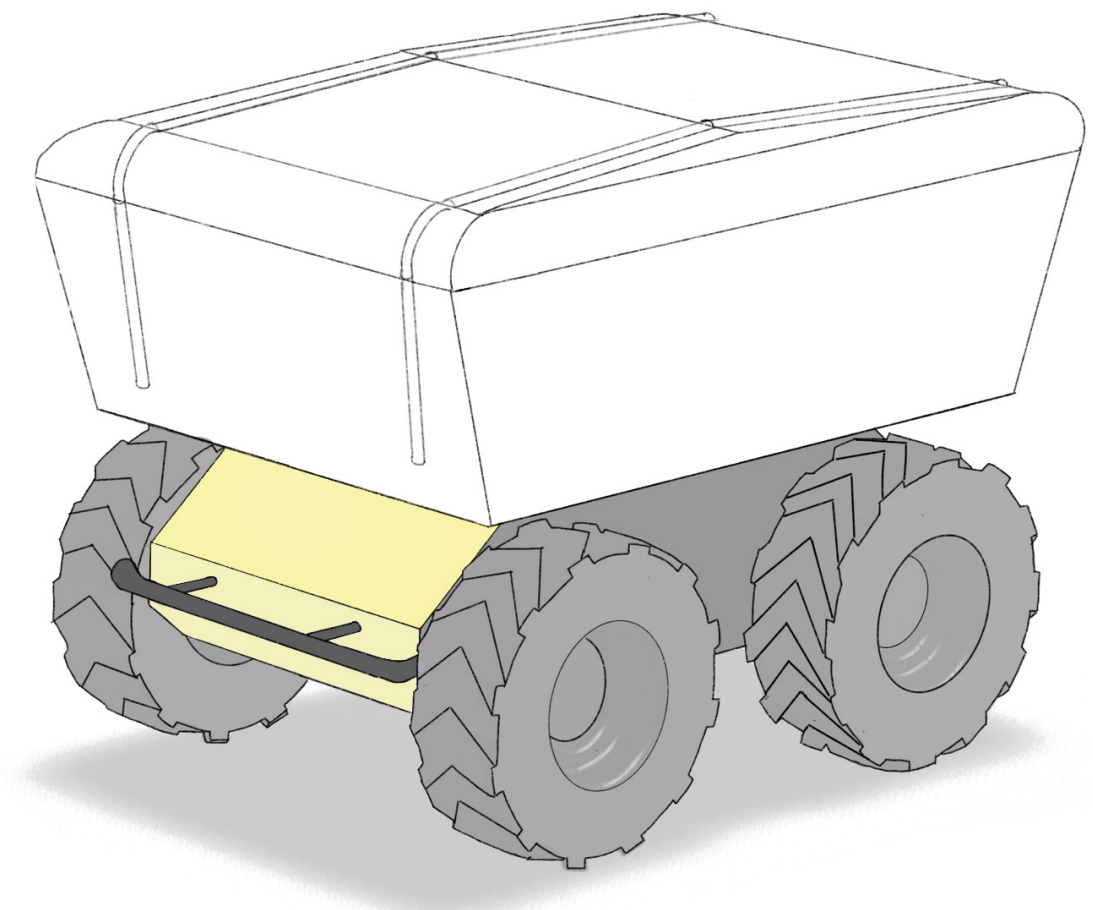


Figure 5.1.4 - Cool box design



5.2 Ergonomic design

In this paragraph, design decisions are defined and validated by a user test on how to retrieve and return crates in a universal ergonomic way.

5.2.1 Universal ergonomic design

The delivery robot will hand over crates with groceries, which can weigh up to 16 kg. Since no employee is around to help the customer retrieve it, the robot should enable an ergonomic retrieving interaction for as many people as possible of the user group. But what is ergonomic design? And how to create an embodiment that can provide an ergonomic interaction?

According to Acevedo (2018), ergonomics is the science of refining the design of products to optimize them for human use. Through understanding of the human form, muscle systems and human limitations, ergonomic principles can be applied to products to increase ease of use and reduce injuries.

The challenge, when designing an ergonomic delivery robot, is to create a design that enables an ergonomic interaction for the entire user group. The user group of the grocery delivery robot are people in the Western world, who would like to have groceries delivered. Every human is unique and since the user group is such a big group, people within this group will differ from each other on many different areas. They can differ in height, strength, knowledge, physical and mental capabilities and even in the language they speak. To make the interaction suitable for the entire user group, universal design should be created. Universal design is a design that is able to be used by as many people as possible.

Universal design should be created to enable an ergonomic human-robot interaction for the entire user group.

User test: Universal design for ergonomics

By conducting a user test, I gained more insights in how to create ergonomic design that enables an ergonomic interaction of retrieving the crates for as many people as possible. The most important factors to retrieve crates from the robot in an ergonomic way are the height and the weight of the crate and the position it is being retrieved in.

In this user test, seven participants were asked to lift a crate or a bag with an unknown weight from a certain height. The experiment was executed several times in random order, with different heights and different weights (each time with only one changed variable).

Key findings experiment

- Lifting a crate, while standing at the long side of the crate is perceived as comfortable. Lifting the crate, while standing at the short side of the crate, is perceived as uncomfortable (figure 5.2.1.B). While standing on the short side of the crate, it can be hard for the user to put the same amount of force on each arm while lifting. Extra strength is also needed to turn the crate while lifting it. The turning movement is experienced as uncomfortable.
- Lifting the crate from the highest position, as from the lowest position (figure 5.2.1.A.) was both perceived as comfortable by the test group. However, retrieving the crates from the higher position was experienced as a bit more comfortable than retrieving it from the lower position.

Since all participants were tall (taller than the average Dutch male or female), it will make more sense to let the user lift the crate from the lowest position. In this way, it will be comfortable for tall as for short people to retrieve the crates in an ergonomic way.

- It is less comfortable to lift a bag from a crate, especially if the crate was located at the highest position. The vertical lift movement of lifting the bag out of the crates was experienced as uncomfortable.
- The crate should not weight more than 16kg. Lifting more weight than 16kg, is perceived as uncomfortable (figure 5.2.1.C).
- The weight of the crate must be estimable. This helps giving the user an estimation how much force they need to apply to lift the crate. If the weight estimation does not match with the actual weight, the lifting can be experienced as uncomfortable.

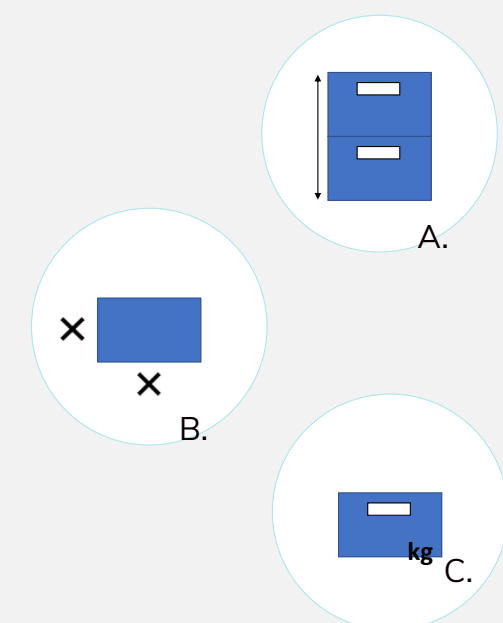


Figure 5.2.1 - Experiment variables

It will not be possible to create an ergonomic universal design, by using average body measurements from the user group. However, average body measurements did help me setting up the experiment. In this experience, I found out that even though the average elbow height of the user groups said otherwise, the best height to retrieve crates by as many people as possible is a bit lower than the average elbow height. According to this experiment, a universal ergonomic retrieving interaction can be created, when the crates will be retrieved from the lowest position (crate right from the Husky platform), while standing at the long side of the crate. The crate should contain two handles and not weigh more than 16kg. The lift movement should also have some freedom of movement, since lifting a crate in a strict vertical direction is perceived as uncomfortable.

5.2.2 Implementation ergonomic design

Crate position

The crates will be positioned on top of the robot platform as low as possible. In this way, it will not only be comfortable for tall people to retrieve the crates, but also for short people. Both crates will be positioned next to each other, so the interaction of retrieving the crate is the same. The only downside about positioning the crates like this, is that the customer needs to walk to the opposite side of the robot in order to retrieve the second crate (if he ordered a second one). This interaction might be experienced as uncomfortable. However, the robot is not big enough to turn the crates with 90 degrees

Users position

The user will already be provoked to stand at the long side of the crate, since the wheels of the robot are positioned at the short side.

Handles

The crates are positioned in the cool box. It is important for a comfortable interaction that in the handles are free to grab. The cool box will push the crate out of the cool box, so the handles are free to grab (figure 5.2.2). More information about this mechanism can be found in chapter 6.

Lifting

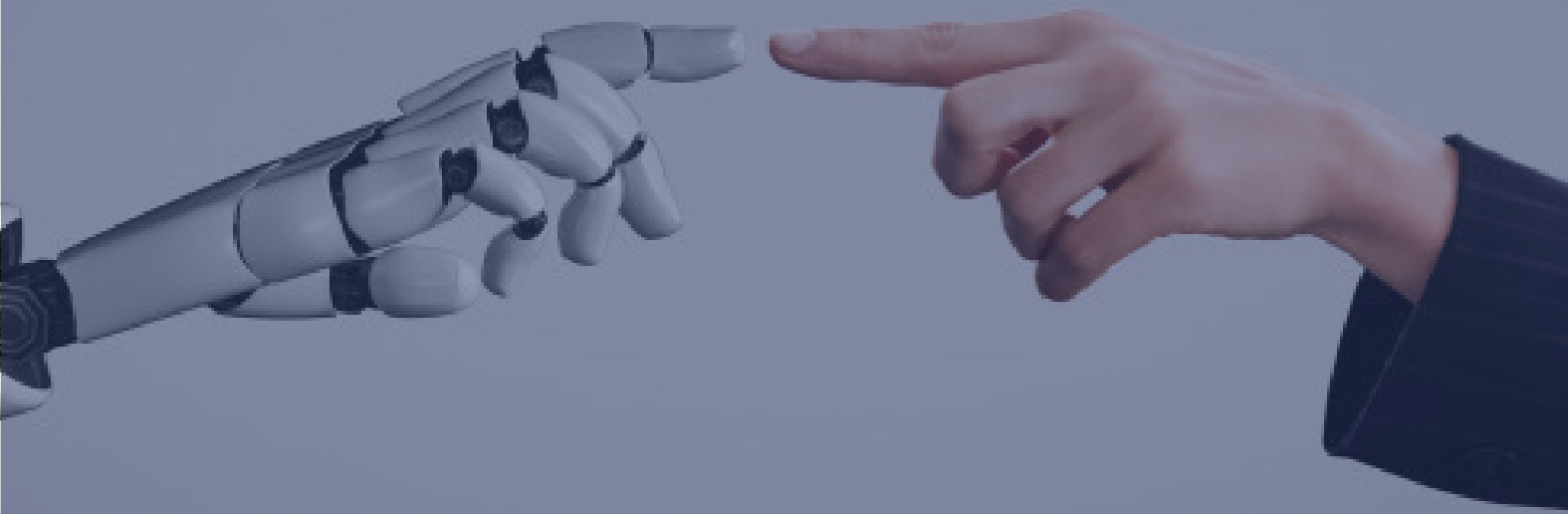
The user should be able to lift the crate, while keeping it near to their body. Not much embodiment is designed between the user and the place where the crate is positioned. The small space of embodiment that is existing, can be used as fulcrum (figure 5.2.3). The user can position his feet underneath the embodiment, which will also contribute to an ergonomic interaction.



Figure 5.2.2 - Exposed handles



Figure 5.2.3 - Ergonomic lifting by fulcrum.



5.3 Intuitive human-robot interaction

In this paragraph, design decisions to create intuitive interaction, within the ordering process as within the physical process of retrieving the groceries from the robot, are defined. There are different kind of customer-robot interactions during the delivery process. Some of them requires physical contact with the embodiment of the delivery robot. The other interactions are taking place from a distance by making use of an app. The overall experiences will be perceived as more effortless if the interaction is intuitive. But how to make an interaction intuitive?

5.3.1 Intuitive app interaction

To make the interaction between the customer and the app as intuitive as possible, similar patterns, icons, color-codes, placement of buttons and consistencies is used as in other apps. Making use of an app is already so integrated in our society, that people do not have to think about how to use an app anymore (if the app is designed in a familiar way). The app will also already give away some cues how to physically interact with the robot. The “app is in progress” animation could for example be a small animation of the robot that is releasing the crates. In this way, the customer will already be familiar with how the robot will release its crates, so they will not be surprised by it at the doorstep.

5.3.2 Intuitive interaction of retrieving goods

The interaction of the current grocery delivery service is already intuitive. The employee will ring the doorbell and will hand the crates over. This interaction does not cost the customer much effort. The process of the robot handing over the crates must go automatic to enable an interaction with at least the same amount of effort needed from the customer. But how to design a human-robot interaction to make the physical interaction of retrieving crates feel intuitive?

Experiment intuitive human-robot interaction

I conducted an experiment to evaluate some ideas for intuitive interaction of retrieving crates. In this experiment, three concepts were designed to mimic the effortless hand-over interaction of the current delivery service. In all concepts, the crates will be pushed out of the cool box, so the handles will be exposed. This will not only make it easier and more ergonomic for the user to lift the crate, but it also ensures that the cool box can function as intended, since most part of the cool box remains sealed. In this experiment, seven participants were asked to give their opinion.

Evaluation concept 1

All participants choose the first concept (figure 5.3.1) as the most intuitive and as the most fun one. They experienced the vertical movement as friendly. One of the participants even described the robot as happy. The movement implies an impression of handing over. This is exactly the interaction that the final design should have.



Figure 5.3.1 Intuitive design concept 1

Concept 2.

Some participants liked the second concept (figure 5.3.2) but were not super excited about it. They understood how to retrieve the crates but mentioned that they did not think that the lid was aesthetically pleasing. Some even mentioned that it looked a bit fragile. It also would not be possible to retrieve both crates at the same time with this concept. One crate needs to be retrieved first, then the robot should close the lid, open the other one and then the second crate would be able to be retrieved.



Figure 5.3.2. Intuitive design concept 2

Concept 3.

The third concept (figure 5.3.3) was perceived as the least favourite. Some participants mentioned that they were not sure where to stand in order to retrieve the crates and how to retrieve it. The third concept might also be dangerous for the surrounding. The robot should be aware of certain objects or people around it. The robot would only be able to push the crates out if the space around the cool box is completely free. If not, then the robot needs to wait for the object to move or the robot needs to move itself. This interaction might confuse the user.

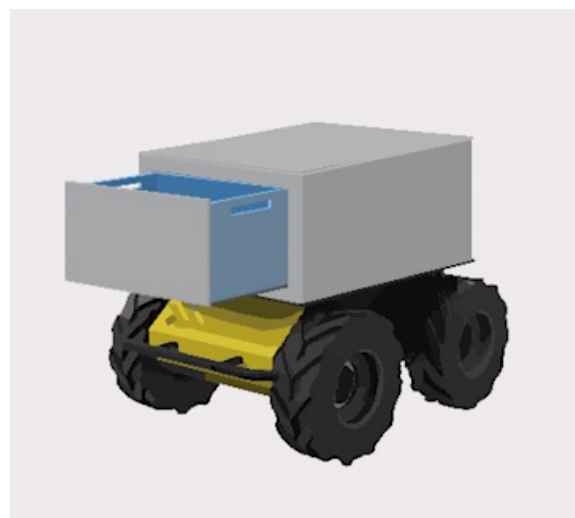


Figure 5.3.3. Intuitive design concept 3

The interaction of the first concept will be used in the embodiment of the delivery robot. The interaction is not only intuitive, but it also mimics the handing over interaction of the current delivery service. Thereby, with the first concept, it seems that the robot is excited to hand over the crates. This can create that fun experiences what the user group is aiming for. Speed of this mechanism is very important for experiencing this interaction. More details about the working principle of the vertical movement can be found in chapter 6 Prototype.



Figure 5.3.4 Intuitive design sliding mechanism

5.3.3 Implementation intuitive human-robot interaction

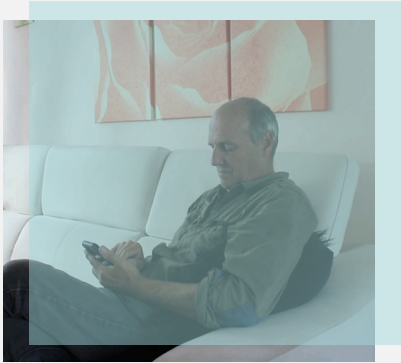
Revealing crate design

As described in the conclusion of the intuitive human-robot interaction experiment, the crates will be pushed out of the delivery robot in a vertical way. The lid must move in some way that the user does not experience any discomfort when lifting the crate. In concept 1, the user must lift the crate over a part of the lid. This creates an unnecessary heavy lift movement. In the final design, the lid will slide off the embodiment (figure 5.3.4). The slide bars on the embodiment will already give the user an impression on how it will move. The robot will latterly open up, let his guards down, to hand over the crates. This will also contribute towards a friendly human-robot interaction at the doorstep. The mechanism behind this principle can also be found in chapter 6 prototype.

The pictures on the page below, displays the future intuitive interaction of ordering and retrieving groceries.

Intuitive human-robot interaction delivery process

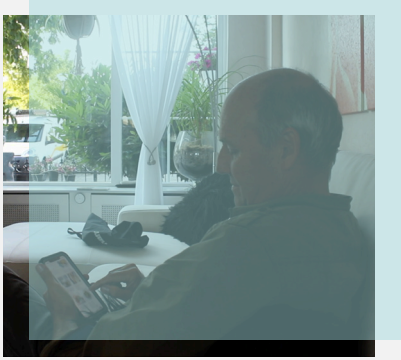
The user can order his groceries by using an intuitive app



The robot will keep the customer posted by the app, so the customers knows exactly when to head home.



The robot will send you a messages , once it arrived



The yellow embodiment of the robot will make the robot easy to find.



The user can, again use his app, to unlock the robot.



The app shows an animation of how the crates will be released by the robot, so the user will be more prepared.



The user is able to stand close to the robot in order to retrieve the crates.



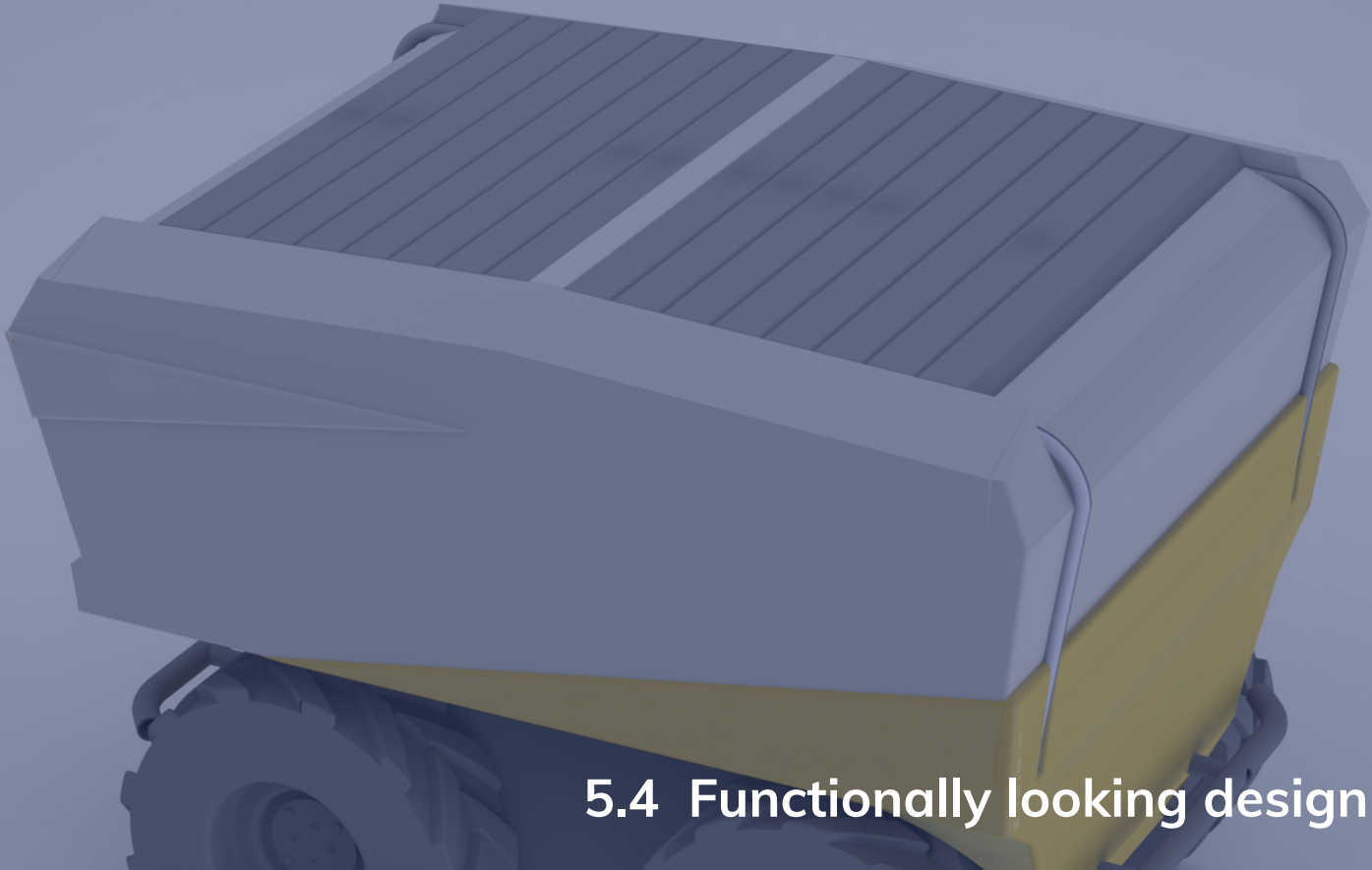
The robot will hand over the crates autonomously, so the user does not have to figure out how to open the cool box. The user can grab the crates once they are exposed.



The user can use the fulcrum to enable a more ergonomic lifting posture.



The user will say goodbye through the app, and start moving towards the dock station, after the user said goodbye in the app too.



5.4 Functionally looking design

In this paragraph, design decisions to create a functionally looking design are determined.

5.4.1 Design for service adoption

To stimulate autonomous delivery robot adoption and to make clear for the customers as for the pedestrians, what the function of the robot is, a functionally looking design should be created. But what are the features that make a grocery delivery robot look like a robot that is delivering groceries?

User test: Functionally looking design

I conducted a user test to find out what kind of features make people aware of the function of the robot. In the user test, eight different delivery robots were shown. The participants were asked to

describe what they thought the robots were transporting and why. After discussing all robots, the participants were asked to rank the delivery robots, based on how functionally looking they thought the existing robots were. The entire user test can be found in appendix G.

Key findings functionally looking user test

- Dimensions and perceived stability of a robot will give people the first impression of what the robot is transporting. People expect larger and heavier goods to be transported by a larger and a more stable looking robot.
- Especially the wheel design is important for the perceived stability of the robot. The bigger the wheels and the further apart the wheels are positioned from each other, the more stable the robot is perceived.

- Brand familiarity plays an important role in function perception of delivery robots.
- Even if the user does not know the brand, people expect the logo to reveal something about the function of the logo. For example, some participants thought that the delivery robot from the brand Kiwi was transporting fruit, even though it was transporting warm meals.
- The design of the doors is also perceived as a clue on what the delivery robot must be transporting. The size of the line would give away the size of the goods and how to retrieve it.
- When no clues can be found about the function of the robot, then people tend to find an association with the shape. The participants found it especially hard to associate a function with the existing futuristic looking delivery robots, such as the starship robot.
- The colour yellow is often associated with delivery.

The dimensions, wheel design, brand familiarity, door design as logo and shape association are important, when designing a functionally looking robot.

5.4.2 Implementation functionally looking design

Dimensions

The embodiment of the robot will be tight-fitting. The Husky is a compact robot platform, and everything needs to fit on top of it without looking too bulky or freighting. The top embodiment will therefore not be much bigger than the two crates. The customer would be able to guess that the robot is delivering crates, due to the size of the embodiment.

Stable design

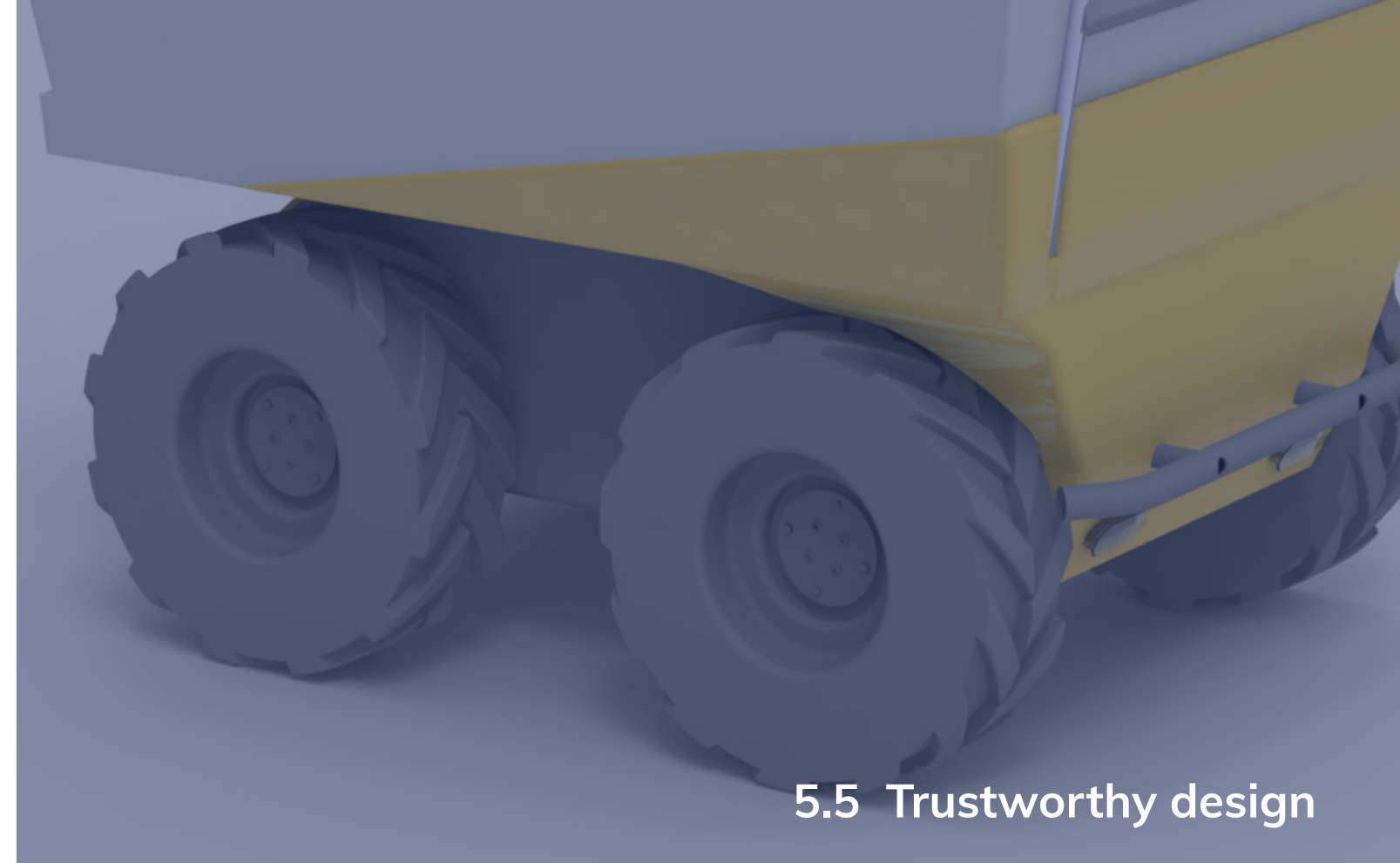
The crate will have a maximum weight of 16kg, so the robot should look like it is stable enough to transport at least 32kg. The design of the wheels is already determined, but the embodiment is designed symmetrical and kept as close to the ground as possible for a more stable look.

Lid cues

The details of the lids already give away the size of the goods. The lid is designed slightly bigger than the top area of a crate. The slide bars on the side of the embodiment let the customer know how the robot will open, and where the user can expect the goods to appear.

Brand

The delivery robot has not been assigned to a brand yet, but by mentioning Albert Heijn on the embodiment people will directly understand that the robot is transporting groceries.



5.5 Trustworthy design

In this paragraph, features to create a trustworthy looking design and a design that will discourage people to vandalise or interact with it, are determined.

5.5.1 Trustworthy appearance

The customer should trust that the robot will deliver the groceries on time and in a good condition. Thereby, should the customer believe that the robot will not get vandalized or stolen from, to trust the service with their order. But how to make a design look trustworthy?

User test: Trustworthy design

I conducted a user test to find out what makes a delivery robot look trustworthy.

A similar user test has been executed as described in the previous paragraph: functionally looking. In this user test, participants were asked to rank existing delivery robot based on level of trustworthiness. The participants were asked to explain their thought. The entire user test can be found in appendix G.

Key findings trustworthy user test

- The bigger the delivery robot, the more trustworthy the robot was perceived. For example, small delivery robots such as Kiwi and Starship were perceived as too small to look trustworthy. A small robot could be easily flipped over. The robot could get stuck somewhere and it would not probably have enough power to help itself.

- The more stable a robot appears, the more trustworthy the robot will be perceived. A robot will appear stable when the wheels are big and positioned further away from each other. Symmetry was also experienced as an important factor of how stable the robot was perceived. A more symmetric design is perceived as more stable.
- People tend to trust a robot more if the design of that robot looks more thought-through. A design looks more thought-through if the materials are from high-quality and if the design has an interesting shape with some round-offs.
- Brand familiarity also plays an important role in the perceived trustworthiness of a robot. For example, if the participants were familiar with the brand of the robot and they were positive about it, they automatically trusted the robot a bit more.
- One participant also mentioned that he trusted the robot more, since he noticed a camera on a design, “so the robot must be aware of its surroundings”.

The dimensions of a robot, the perceived stability, brand familiarity and how thought-through a design is experienced are important features in creating a trustworthy design. A design is also experienced as trustworthy if the design arrives at the customer's doorstep in good condition and on time. To make sure that the robot arrives in good condition and on time, the robot should be designed to discourage people from vandalizing the robot and from interacting with it on the sidewalks.

5.5.2 Vandalism prevention

Since, vandalism can be caused by a various number of reasons, it is important for the delivery robot to try to tackle this problem with multiple features within the embodiment. So, will an alarm go off if somebody will try to lift or tilt the robot. As soon as the robot moves in an extreme angle, the alarm will keep going off until the robot reach a normal angle again. By making use of machine learning, the robot will prevent taking routes through neighbourhoods that the robot (or its colleagues' robots) has experienced vandalism. People feel more empathy towards more human-like products. By integrating lights in the front of the embodiment, people will tend to associate it with a face, especially in combination with the bumper (mouth) of the robot.

5.5.3 Prevention of interaction with pedestrians.

The embodiment of the robot should not only keep the robot from getting vandalised, but also from being held up at the sidewalk by pedestrians. The robot should discourage people to interact with it. By giving the robot a bit of a vehicle-look, the user might does not get provoked to “play with it”. Of course, people will be curious about such a new autonomous robot, and they are definitely going to test the limits of the robot for the first few months. After a while, the adults will be more familiar with the robot and will already be less provoked to have a long, for the robot unnecessary, human-robot interaction at the sidewalk. Children are probably the only age group that will never get used to such a product and they will always be triggered to interact with it. By creating this somehow vehicle-look, children might be a bit too scared to interact with it.

The big coarse wheels also help to discourage this playful interaction with children.

Enumerating, the delivery robot will be experienced as trustworthy as the robot are on time and in good condition at the doorstep. This can be envisioned, by creating stable, thought-through looking design that discourage people to interact with it at the sidewalk and to perform a violent act on it.

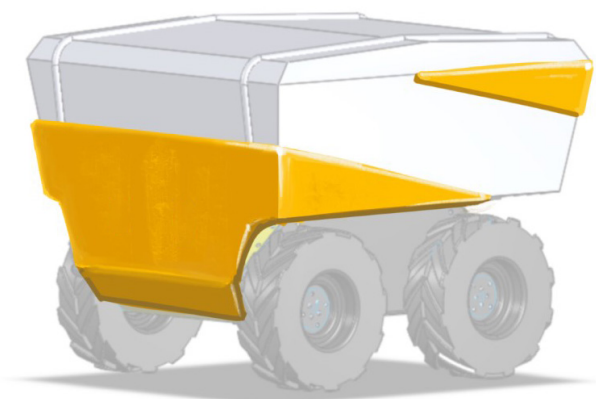
5.5.4 Implementation trustworthy embodiment

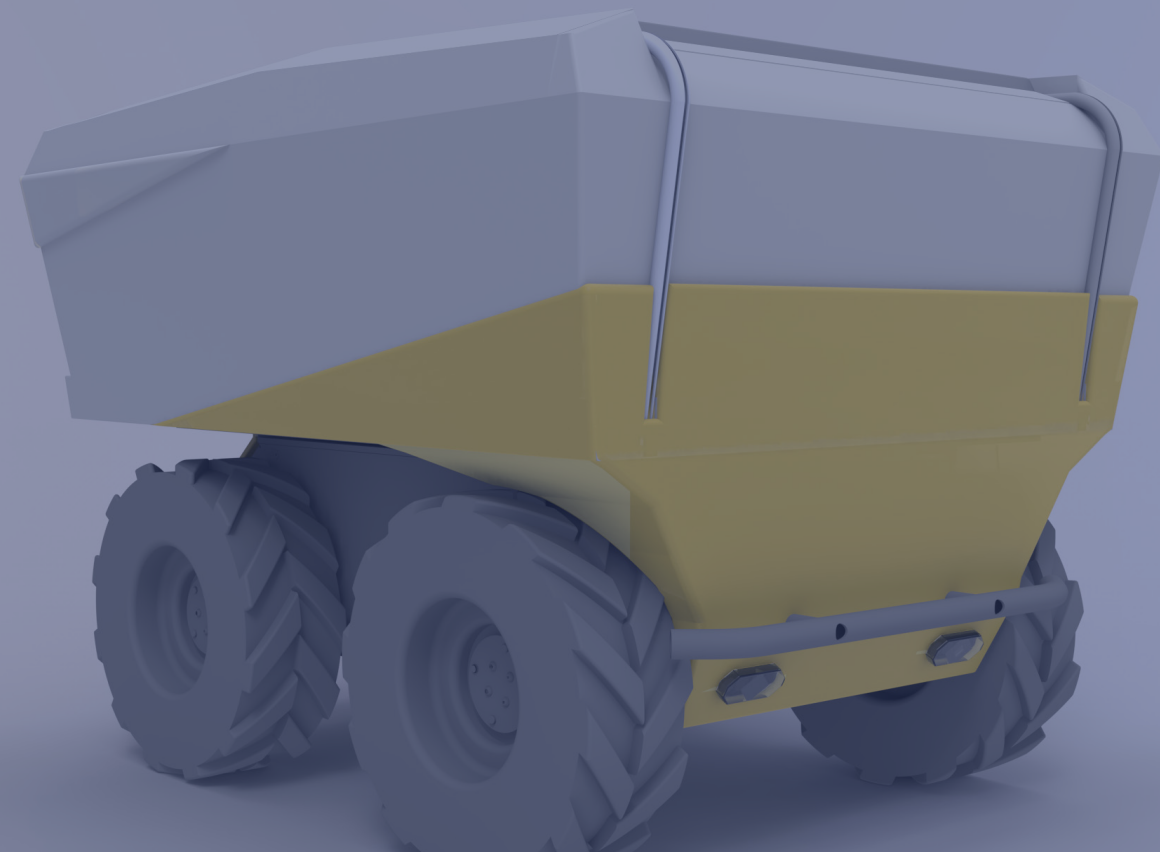
Human-like features

The lights and the bumper of the embodiment can be associated with a face. People tend to emphasize more with products that are easy to anthropomorphize and are therefore less likely to perform a violent act on it.

Analogy: Robot on duty

The shell of the embodiment is designed in such a way that it almost looks like that the robot is holding the cool box. The robot looks a bit friendly and the “arms” on the side are initiating that the robot is carrying (heavy) goods and that the robot is on its way to the customer. This association might discourage people to have a long interaction with the robot at the sidewalk





5.6 Aesthetically pleasing design

In this paragraph, design directions to create an aesthetically pleasing embodiment are defined.

Several factors influence whether a design will be experienced as aesthetically pleasing. So is an aesthetically pleasing design sensitive to trends and the environment it is located in. Thereby should a design match the meaning associated with the product and the emotion it evokes to be perceived as aesthetically pleasing. In this paragraph, a user test, a trend analysis, an analysis to create a design that fits the environment, and a model called the nine moments of experience, are used to define those aesthetically pleasing design directions.

5.6.1 Aesthetically pleasing features of current delivery robots

How aesthetically pleasing a product is being perceived is based on subjective opinions, which differs per person. I conducted a user test to find out if I could find some common opinions about aesthetically pleasing features of currently existing delivery robots. Those features can be used in the grocery delivery embodiment.

User test: Aesthetically pleasing design

A similar user test has been executed as described in chapter 5.4 and 5.5 functionally looking and trustworthy design to find out what aspects of current delivery robots are perceived as aesthetically pleasing.

Participants were asked to rank existing delivery robots based on how aesthetically pleasing the participants thought the designs were. The participants were asked to explain their answers. The whole user test can be found in appendix G.

Key findings user test aesthetically pleasing design

- An embodiment of a delivery robot is often experienced as aesthetically pleasing if people feel like the design is thought-through. A design is perceived as thought-through if it does not look just functional. The design should show some details, for examples some lines to indicate door openings or some round-offs.
- The opinions of the participants differed significantly. However, they agreed on a few things; the robot design should not have any protruding objects, it should look user-friendly (comfortable height), stable and maybe even a bit minimalistic.

5.6.2 Automotive trends analysis

Trends play an important role in the decision process of how aesthetically pleasing a product is encountered. Since the delivery robot can be seen as a small vehicle operating on the sidewalks, automotive trends can be used to design an aesthetically pleasing shell for the delivery robot. But what are the current automotive design trends? And how vehicle-like should the delivery robot be designed?

Looking at some brand-new automotive designs (figure 5.6.1), you can see that all vehicles are making use of clear lines and angles. Some designs are more futuristic than others, but all of them are a bit rectangular: a shape that you start seeing more often in the current automotive industry.

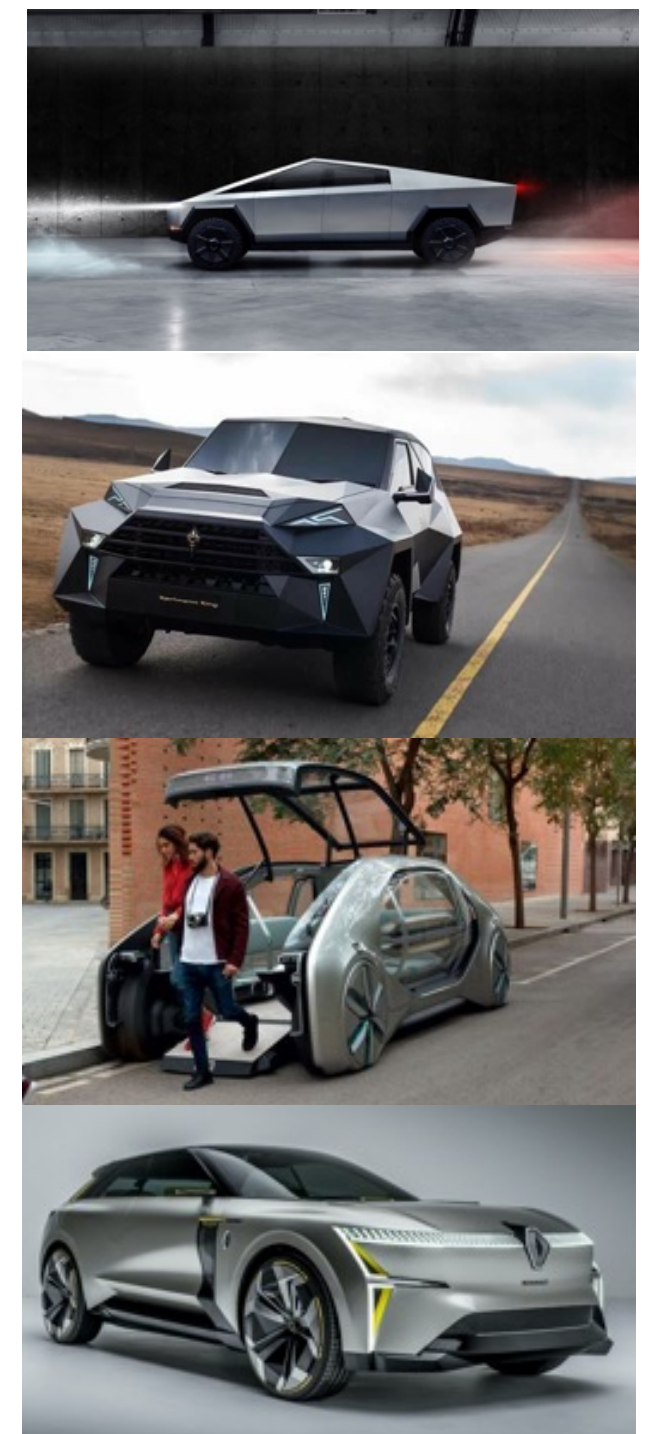


Figure 5.6.1. Automotive design trends ¹²

The upper left picture is the Cybertruck from Elon Musk (Tesla). The truck is already out for sale in the United States. As all Tesla's vehicle designs, this design will probably have an influence on the future designs in the automotive industry. I do not expect all future cars to look that rectangular, but I do think that future automotive designs will have more sharp lines and angles (like the Renault at the bottom in figure 5.6.1 on the left bottom). Looking at this trend, the delivery robot should have some integrated rectangular shapes, strong lines, and visible angles to be experienced as aesthetically pleasing in the near future. This design language of the robot will also respond to the users' need to have a professional, powerful, and trustworthy looking design.

But how vehicle-like should the robot look like? A vehicle-like design might trigger pedestrians to have less interaction with the delivery robot at the sidewalk. People already encounter other vehicles in their daily lives, and they unconsciously know how to interact with it. Seeing a robot that looks a bit like a vehicle, that they are already familiar with, might provoke a similar kind of (often evasive) interaction. However, the delivery robot should not completely discourage people to interact with it, since the robot as the human will be sharing a sidewalk together. This will be a completely new situation in which the pedestrian needs guidance from the robot to know how to interact with it. The delivery robot should therefore not 100% look like a vehicle. Details in the embodiment can be positioned in such a way that the robot is easier to anthropomorphize, so the design will be perceived as less vehicle-like.



Figure 5.6.2. New ¹⁵ Dutch neighbourhood

5.6.3 Design to fit the environment

For a design to be perceived as aesthetically pleasing and to stimulate delivery robot adoption, it is important to design an embodiment that matches its surroundings. But how to create a design that fits its environment?

To find a good fit, I got inspired by a commonly used design methodology of landscape architects. In this methodology, the environment is analysed by five key elements (line, form, texture, colour, and scale) to integrate an object within its surrounding by implementing features from those key elements in the design.

The delivery robot is designed to be operating in the Western world, including the Netherlands. If you look at for example a Dutch neighbourhood, you will see a lot of grey roads, sidewalks, bicycle lanes, street lanterns, houses, and rectangular gardens. Especially the key elements "line" and "texture" can be interesting, when creating a delivery robot embodiment design that should fit its environment. Horizontal and vertical lines are a recurring element in the Dutch street scene (figure 5.6.2). Another recurring element are the little pieces of green, in form of grass, trees or some plants in between the

houses to create a more friendly-looking neighbourhood. A certain texture, inspired by nature, could be used in combination with clear lines to integrate the embodiment of the delivery robot with the environment.

The challenge is not only to create a delivery robot that will be experienced as aesthetically pleasing in its surrounding, but also to give people the feeling that the delivery robot (the embodiment design) always has been there. This can be achieved by designing an embodiment that fits its environment.

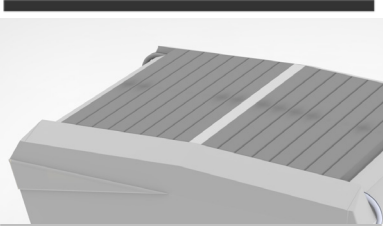
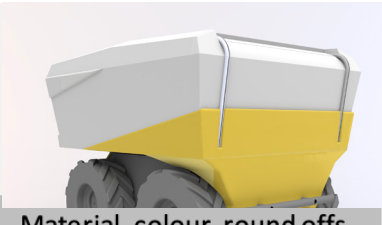
	MICRO	MACRO	META
AESTHETICS	 Strips on lid Variety	 Merging overall shape Unity	 Clear line design Fit in street-environment
MEANING	 Stable, symmetric design Trustworthy	 Vehicle vs human-like Determined and friendly	 Material, colour, round offs Professional, reliable
EMOTIONS	 Lid design Curious	 Interaction movement Joy	 System is working Satisfaction

Figure 5.6.3. Nine moments of experience

Aesthetics

Micro. A design will be experienced as aesthetically pleasing on micro level if it shows some variety. The variety is reflected in the design by creating some details in lid design and in the design of the lights.

Macro. The overall shape of the embodiment must be designed as a unity to be perceived as aesthetically pleasing on a macro level. A unity is created by merging the cool box with the Husky with an extra piece of embodiment design.

Meta. The design of the delivery robot should match its surroundings to be perceived as aesthetically pleasing. By making use of horizontal lines and a bit of a vehicle-like look the design will blend in within its environment.

Meaning

Micro. Looking at the design on micro level, the robot should look trustworthy. By creating a stable looking design, the robot will be perceived as trustworthy. The embodiment is design symmetrical and designed as compact as possible to enable a stable looking design.

Macro. The delivery robot be perceived as determined while operating on the sidewalk and friendly, when interacting with the customer at the doorstep. By making use of different types of movements, those different meanings can be achieved. Unloading the crate in a fast vertical movement can be perceived as happy or friendly. By making creating a balance in human/vehicle-like features the robot is able to provoke both meanings.

Meta. Looking at the robot from a greater perspective, the robot must look professional and liable. By making use of dark colours, shiny materials and round-offs, the robot will look professional and liable.

Emotions

Micro. The design details of the lid should make the user curious about how it will work.

Macro. The interaction at the doorstep of handing over the crates must bring joy to the customer. The movement implies something happy or friendly.

Meta. People should be satisfied when they are thinking about the whole delivery process. It is working as intended as should offer the user more time.

By incorporating these features into the embodiment design, the robot will not only be experienced as aesthetically pleasing, but also as a pleasant user experience.

5.6.5 Nine moments of experience

Whether a design is experienced as aesthetically pleasing is depending on more factors than just the physical design of the embodiment. The meaning and the emotion people associate and feel towards a product or service also contributes towards how aesthetically pleasing a product or service is experienced. If the aesthetics does not match its meaning or the emotion, then

there is a greater chance that people do not experience the embodiment as aesthetically pleasing. The nine moments of experience model (figure 5.6.3), is used to get a better idea of how the users should experience the embodiment and how to implement those features in the actual design. For each level (micro, macro and meta), design decisions about aesthetics, meaning and emotions are gathered and translated into specific embodiment features.

5.6.5 Implementation aesthetically pleasing design decisions

So, the embodiment of the delivery robot will be experienced as aesthetically pleasing if the design looks thought-through, stable, user-friendly and has no protruding objects. Thereby, it is important for the design to keep up with the automotive design trends to be perceived as aesthetically pleasing in the near future as well. To stimulate delivery robot adoption, it is important to create an embodiment that fits its environment. A design of a product that matches within its environment it is more likely to be experienced as aesthetically pleasing. Finally, the variety and unity of the embodiment should be in balance as it should look trustworthy, professional, reliable, and friendly at the doorstep to be perceived as aesthetically pleasing.

Though-through design

The design looks though-through by making use of round-offs, yellow, black, and grey colour combinations as by the integrated details in the design to show the user how the doors will slide open.

Lines and sharp angles

Clear horizontal and vertical lines are used in the design to make sure the robot match its environments as to keep up with the automotive trends.

Balance in unity and variety

A balance of unity and variety is found by creating a design that contains details but still look like one product. The yellow embodiment is designed to connect the Husky with the cool box.



5.7 Environmentally friendly design

As a designer, I feel like it is your duty to design sustainable products. Small design changes can already have a big impact on the environment. This chapter provides design decisions for a sustainable embodiment design and ideas on how the robot could promote sustainable life choices.

5.7.1 Sustainable embodiment design

As mentioned in the analysis, the robot should be easy to repair, reuse, re manufacture and easy to be recycled. The embodiment is designed in such a way that all parts are easy to repair. For example, three sides of the cool box can be unscrewed. By unscrewing a side, the mechanism for lifting the crates and sliding the lids are exposed. The motors, wires, and cool system could be replaced so the cool box would be able to function again. The delivery robot is assembled in four different components, the cool box,

the Husky, the shell, and the navigation part. If one of those parts are not functioning as intended, then that part could be replaced, and the robot will be able to function again (efficient). The broken part could be repaired or even be re-manufactured and reused in another delivery robot. By repairing and re-manufacturing the part, knowledge is gained about the parts of the working principles that are wearing out fast or are not designed properly. This information is useful for a possible redesign. By choosing the same material for multiple parts, it will be easier to recycle the embodiment. The robot itself will be electric (zero-emission), thereby the robot will only make use of reusable crates and reusable cool elements (no plastic bags). By making use of temperature control in the cool box, energy is saved.

5.7.2 Promote sustainable life choices.

In the future, it might be able to shop your groceries based on their ecological footprint. Supermarkets might provide more information about their products. The delivery robot could be a delivery service that stimulates this behaviour and delivers more sustainable goods.

5.7.3 Implementation sustainable design

Design for repair

The parts that are most likely to break are easily accessible by loosening screws integrated in the cool box. The mechanisms can be repaired, so the lifespan of the embodiment will be extended.

Design for re manufacture

The delivery robot can be divided into three different parts: the Husky, the cool box, and the connecting part of embodiment with the integrated lights. If one of those parts break down, then it can easily be replaced without having to throw away the other parts.

Reusable components

The crates and cool elements are reusable. The cool elements are easy to retrieve by opening a hatch in the cool box.

5.8 Conclusion embodiment design

By combining all design decisions, a good foundation has been laid for a grocery delivery robot. The design features a functional, ergonomic, intuitive, functionally looking, trustworthy, aesthetically pleasing and environmentally friendly design.

With this design, the delivery robot should be able to empower the customer to feel in control of the delivery process and let them experience as little mental and physical effort as possible at the doorstep.

But does the design function (and interact with people) just as well in real life as it does on paper? Let's find out in the next chapter!

Conclusion embodiment design

6. Prototype

This chapter provides proof of concept. I created a prototype to test and evaluate the interaction at the doorstep. The prototype includes a mechanism for vertical crate movement and a mechanism for sliding doors. The shell of the embodiment is prototyped as well.

Prototype of vertical movement mechanism
Prototype of sliding lid mechanism
Prototype of cool box and shell design
User test final prototype
Main takeaways prototype

A prototype is used to get proof of concept. The mechanisms, shell embodiment and the human-robot interaction at the moment of hand-over are being evaluated by this prototype. The prototype also gives a better impression of the dimensions of the embodiment in real life.

6.1 Prototype of vertical movement mechanism

A vertical movement mechanism is designed to “pop” the crates out of the cool box. The crates must make a vertical movement of around 15 cm to release the handles of the crates. Due to this movement, the handles will be free to grab, and the crate can be retrieved in an ergonomic way. Requirements for this mechanism are that the design needs to be compact, lightweight, and able to lift at least 16kg, without tilting the crate.

6.1.1 Working principle vertical movement mechanism

A mechanism that is familiar to an elevator mechanism has been used to enable vertical movement. The mechanism is positioned within the cool box and each crate has their own mechanism to function independently.

The mechanism (figure 6.1.1) contains of a bottom plate, pulley system, wires, an axle, and an electromotor. The axle is fixed to ribs of the cool box and can rotate by making use of a motor. Two wires, that are also connected with the pulley system, are attached to the axle, and will wind up by a rotating movement of the axle. By winding up the wire, the bottom plate will make a vertical movement. The vertical slots in the walls will help the bottom plate to make a straight vertical movement.

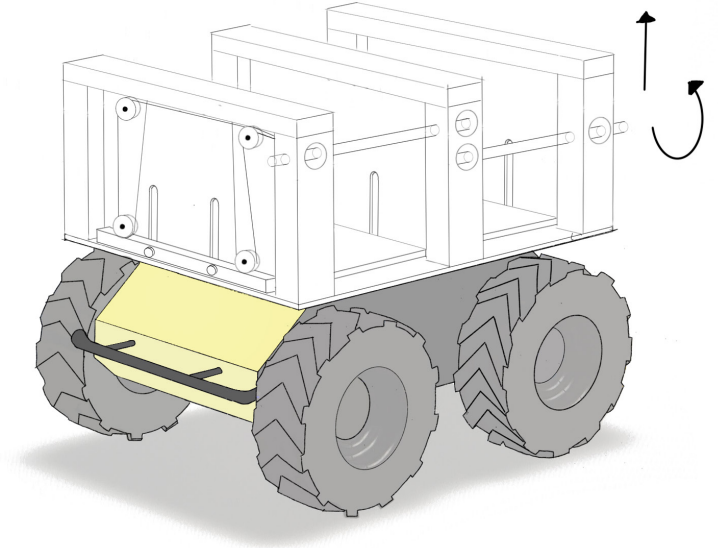


Figure 6.1.1 - Vertical movement mechanism

By integrating slots in the walls and by connecting both wires to one axle, the bottom plate and therefore the crate will not be able to tilt. When connecting the wires to the axle, it is important to position the adjustment holes in one line (figure 6.1.2). Otherwise, the bottom plate will tilt.

By connecting both wires to one axle, only one motor is needed. Due to the pulley system, the motor only needs to handle half of the force needed. However, if the motor is not strong enough, a redesign could be made with two motors and two axles for one mechanism. Correct adjustments of the wire and the axle is then necessary to make sure that the bottom plate would not tilt. Pictures of the prototype of the vertical movement mechanism can be found below.



Figure 6.1.2 - Vertical movement mechanism prototype

6.1.2. Evaluation vertical movement mechanism

The prototype of the vertical movement mechanism works as intended. The prototype is able to push at least half of the crate out of the cool box. With this design, it would also be possible to push more than half of the crate out. This would however require a taller cool box. To make the embodiment more aesthetically pleasing and to not scare pedestrians on the sidewalk, I stayed with the design choice of only pushing half of the crate out of the cool box.

The speed of the vertical movement is also of great importance for the human-robot interaction at the doorstep. The popping-out interaction should be associated with a joyful interaction. If the crate pops out too slowly then this interaction might even be experienced as something annoying instead of joyful. People are used to fast interactions nowadays and will therefore expect the robot to pop out the crates within a few seconds. Some trial animations were done to test how fast the crates should pop out. Ideally, based on personal preference, the movement should not take more than 1.5 seconds.

How fast the mechanism will push the crate out is depending on the diameter of the axle and the Roots Per Minutes (RPM) of the motor. The larger the diameter and the more RPM the motor can provide, the faster the crates can be pushed out of the cool box.

The motor should be able to lift the crate with 15 cm by rotating a wire around an axle with a diameter of 1 cm (and therefore a circumference of π). Since the axle needs to rotate 5 times ($15/\pi \approx 5$), a motor of 200RPM is needed to lift the crate within 1.5 seconds. The motor should not only provide the right amount of RPM, but also provide a high torque. The mechanism should be able to lift a crate of 16kg. By making use of pulleys, the motor should only be able to lift 8kg. Taking the arm (0.5 cm) of the axle into account, the motor should at least have a torque of 0.4Nm. The prototype is making use of an electromotor which is normally used in car windows. This electromotor can lift 7 kg but rotates less than 200 RPM. More suitable motors for this design do exist, but were not feasible in this prototype, due to a long delivery time.

6.2 Prototype of sliding lid mechanism

The sliding mechanism (figure 6.2.1), is designed to move the lid, so the crates can be pushed out of the cool box. Both lids have their own sliding mechanism in order to function independently.

6.2.1 Working principle sliding lid mechanism

The sliding mechanism is making use of two tubes, four wires, two sets of decks, two axles and two electromotors. Each lid is attached to runners on both sides, and the runners are again connected with a wire. The wires and the runners are guided by the two tubes. At the end of the tube, both endings of the wire are connected with an axle. One ending is used to wind-up the wire and the other ending is used to unwind the mechanism. This is necessary for the lid to slide smoothly in both ways. A motor is used to rotate the axle with the result of a sliding lid.

6.2.2 Evaluation sliding lid mechanism

The sliding lid mechanism worked as intended. However, some struggles did occur with the runners within the tubes. Due to burrs in the tubes and the runner's ability to skid, the sliding did not always go smoothly. By creating a better tailored mechanism, I expect the mechanism to operate smoothly. To make the prototype run smoothly, extra metal bends were added at the ending of the tubes (figure 6.2.1) to make the wire with runners experience less tension.

In the prototype, the lid was made of some Styrofoam to make it easy for the motors to slide the lids. In the actual design this will be made of a hard plastic. To make the lid waterproof but still flexible, a combination of a plastic deck and plastic strips are used. The strips make it possible to slide across the bend and the deck will stop water from entering the robot. The rail for the lid is designed with a small slope, so the water will drip off. A trench is designed next to the rails, to drain the water even more easily. The deck will not only enable a waterproof, but also more shatter-proof and hygienic design.



Figure 6.2.1 - Sliding lid mechanism

6.3 Prototype of cool box and shell design Cool

The cool box is designed to cool and protect groceries. Since the two mechanisms are positioned within the cool box, the cool box will also protect those two mechanisms. The cool box is designed as compact as possible to make the robot not feel too massive to operate on the sidewalks. A shell is designed to integrate the cool box with the Husky robot and make it feel more like one design instead of combined parts.

6.3.1 Details cool box

The prototype of the cool box is pretty accurate. The cool box has sloping walls to have a less space-occupying look. One wall of the cool box can be disassembled to maintain the mechanisms and to reach the cooling system. A hatch is created to easily replace the cooling elements (figure 6.3.1). Both crates are actually able to fit within the cool box.

6.3.2 Details shell design

The shell is connecting the cool box with the Husky, while covering up the yellow surfaces of the Husky robot to create more of a unity. The shell is not only functional, but it also provides a friendly look. The triangles on the side of the robot can be associated with small arms that carry the cool box. The front shape of the shell can be associated with a face, which also makes the robot look more friendly and less just vehicle-like. With a little bit of fantasy, the bumper of the Husky can look a bit like a mouth in combination with the front shell.

6.3.3 Evaluation cool box and shell design

Even though the prototype of the cool box and shell are not made from the intended materials, the overall shape is accurate. The embodiment fitted perfectly on top of the Husky. The prototype did make me realize that extra details are needed in the shell to incorporate a hatch for charging, maybe some lights for battery indication and a stop button. Before placing the cool box on top of the Husky, I thought the robot with cool box might be experienced as too big and maybe even frightening (even though the cool box could not be designed more compact than this). However, after integrating the cool box with the Husky, it did not look too big at all. The cool box fits the Husky perfectly and it does not look too big for the platform. It might be a bit big for some sidewalks, but that is more caused by the width of the Husky robot. Either a different robot should be picked, or the robot should be used for different purposes with smaller goods and therefore a smaller embodiment.



Figure 6.3.1 - Cool box and shell embodiment

6.4.1 User test final prototype

A final user test was conducted to evaluate not only the embodiment in combination with the Husky robot, but also the human-robot interaction of retrieving groceries.

The embodiment was put on top of the Husky platform at the Marineterrein in Amsterdam. The robot was able to drive and use its mechanisms to pop the crate out of the cool box. In this user test, two participants were asked to retrieve the crates and to give their opinion about ergonomics, intuitive interaction, functionally looking appearance, aesthetics, and trustworthiness.

6.4.2 Key insights final user test

- **Ergonomics.** The interaction of retrieving groceries was experienced as comfortable. Since the embodiment is not designed all the way to the ground, the participants were able to place their feet underneath the embodiment, which ensured that they could keep their bodies as close to the weight of the crate as possible. The round-off on the side of the cool box was also used as support before lifting the crates, which makes the lifting interaction also more comfortable.
- **Intuitive interaction.** The sound of the mechanisms is a nice indicator to know when to retrieve the crates.

A small animation of the how the lids are going to move and how the crates will pop out in the app will help them make this interaction even more comfortable.

- **Functionally looking appearance.** Without a logo, it is clear that the robot is transporting something a bit bigger than small packages, but it would be even more clear that the robot transports groceries if a brand is attached to it.

- **Aesthetics** Especially the colours and the shell embodiment details (such as the yellow triangle arms) enables an aesthetically pleasing embodiment. Lights could be added to finish the look.

- **Trustworthiness** The wheels make the robot look trustworthy. The movement of the mechanisms also had a big influence on the trustworthiness of the robot. The more stable the movement of the mechanisms, the more confident the robot was experienced and the more trustworthy the robot looked.

Overall, the participants experienced the interaction of retrieving groceries from prototype as a pleasing joyful human-robot interaction.

6.5 Conclusion, main takeaways prototype

The prototypes did not only validate the working principles of the lid and crate mechanisms, but also other decision decisions to create a desirable human-robot interaction at the doorstep. Concluding, the vertical moment mechanism can be used to pop the crates out of the cool box. Speed turns out to be an important factor for the user to experience the handing over interaction as joyful. A motor with the right specifications should be used to enable this fast interaction. The sliding mechanism can be used to remove the lid of the cool box. For the user to experience the robot as trustworthy it is important to enable a smooth movement. The smoother and faster the mechanisms work, the more confident the interaction will be perceived. The embodiment is suitable for the husky platform. The shell design does ensure an integration between the cool box and the Husky. However, small adjustments in the embodiment need to be made to make sure that the stop button and the charge plug can easily be reached. Lights could be integrated with the shell design to make it look even more aesthetically pleasing. Overall, the human-robot interaction was experienced as joyful, ergonomic, and intuitive.

Conclusion prototype

7. Final Design

The final design of a grocery delivery robot is displayed in this chapter. A detailed description is provided about the implementation, possible future scenarios and the unique selling points of the robot.

Final design
Implementation
Future possible scenarios
Unique Selling Points





7.1 Implementation

- Order groceries on app
- Agrees on time slot
- Notification when robot is on its way
- Live location of delivery robot
- Robot calls you when arrived
- User press unlock button
- App explains what will happen
- User retrieve crates
- User puts back empty crates
- Robot checks with user if everything is set
- Robot drives back to dock-station

7.2 Possible future scenarios

The grocery delivery robot is part of a much larger process than just the moment of hand-over by the customers doorstep. But how will it be part of the larger process? And in what way could it be beneficial for the customer? By looking at the needs of the subgroups of the target audience (chapter 2.1), potential future scenarios were created.

Scenario 1. Modular robot

This scenario is often mentioned by other existing delivery robots' companies. A truck loaded with delivery robots and goods will drive to a specific area in the city centre. From there the robots will be loaded and send off to the customer.

After the robots dropped their loads off, they will find their way back to the truck to be loaded again or get a ride back to the dock station. In this scenario, the interaction of waiting at home for the groceries to arrive is not too different from the existing grocery delivery services with time slots. Accept the delivery robot can provide its location, so it is better estimable for the customer when to come back home again. The downside of this scenario is that still a lot of weight gets to be carried around. A loaded delivery robot can weight up to 125kg. For example, by leaving the robots in the city centre and only transporting the crates by truck, would already save some energy. This brings us to the following scenario.

Scenario 2. Neighbourhood robot

In this scenario, the delivery robot will be stored at a dock station somewhere in the neighbourhood. Since the delivery robot can actively cool the groceries, the robot would be able to stay at the dock station for a while, especially when the robot has access to a charger. The robot would, in this scenario, be able to wait for the customer to arrive home, instead of the other way around. To make this scenario a little bit more efficient, food storages could be integrated at those dock stations. The grocery delivery company could then just drop the crates off in the morning. The crates will be preserved at the right temperature and then the robot would be able to load itself once it gets a notification of the customer. Due to the design, the robot can easily retrieve the crates from above. It only needs to stand in the right position and open the cool box. In this scenario, the customer is more in control of the process and is more likely to create some kind of bond with their recurring neighbourhood delivery robot.

Scenario 3. Owning a robot

The third scenario is more applicable for more wide-spread neighbourhoods. In this scenario, the customer is owning the robot. The robot is for example parked in the garden and will drive towards the grocery truck, once the truck has arrived in the neighbourhood. In this scenario, the customer does not need to think about the grocery delivery process at all, since the robot can just go and get the products for you. Since the robot can charge itself at the customers house, the goods will stay preserved within the robot due to the active cooling system.

7.3 Unique Selling Points

Many considerations were taken into account when designing the grocery delivery robot. However, some of the design decision make this embodiment unique and are therefore highlighted in this paragraph.

User-friendly hand-over.

An autonomous interaction that ensures an effortless as joyful experience at the doorstep. The delivery robot mimics the hand-over interaction of the current grocery delivery process by autonomously pushing the crates out of the cool box. In this way, the user does not need to perform any more actions to retrieve the crates than with the current grocery delivery process. The interaction is intuitive, and the crates will be released at such a height that it is comfortable to retrieve by as many people as possible. The vertical movement also enables a joyful experience at the doorstep; an experience that the customer has never seen before.

Cool reliable transport.

An integrated cooling system that is always able to prove that the groceries were preserved at the intended temperatures. Due to the integrated compact and lightweight cooling system, the robot is able to continuously control the temperature within the cool box. This system will make it hard for other companies in the delivery supply chain to hold the delivery robot company accountable.

Lightweight, compact, and therefore sustainable design

The embodiment can carry and cool two crates with groceries, while weighting less than 43 kg. The less the robot weighs, the more sustainable the robot drives. The compacter the embodiment, the less frightening the robot will be perceived at the doorstep or at the sidewalk. Through an extensive investigation to light weight components and by incorporating all the mechanisms within the cool box, a compact, lightweight design is realized.

Design for integration and more control for the customer

The autonomous vertical movement mechanism makes it possible for the grocery delivery robot to be integrated within the entire delivery process. Other autonomous mechanism will be able to easily interact with the robot to enable a more automated process. The more automated the delivery process, the more efficient the delivery will eventually be and the more control the user eventually can have of the delivery process. A better integrated delivery robot will be able to adjust its schedule around the customer, instead of the other way around.

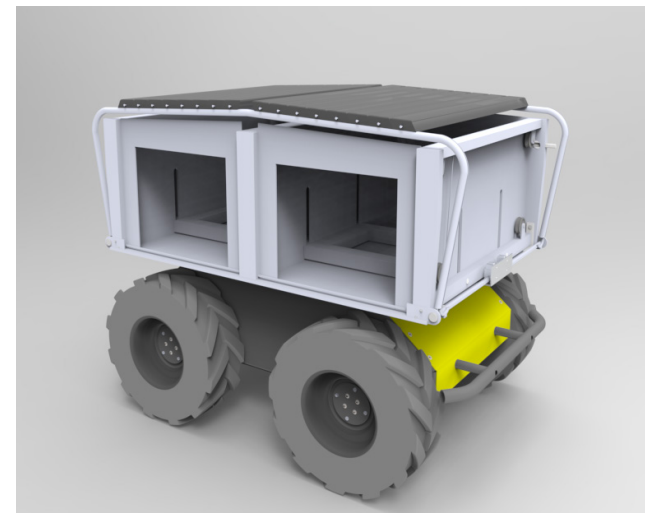
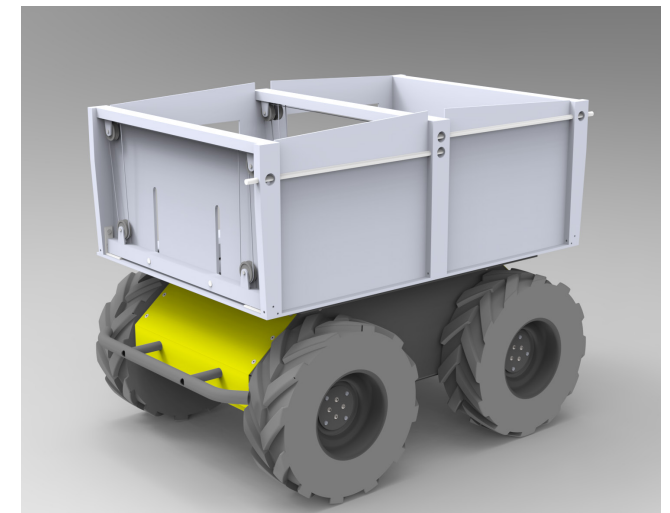


Figure 7.1 - Mechanisms within the cool box

8. Design Reflection

In this chapter, the final design is reflected based on the three lenses of innovation, the design goal, and the design vision.

Feasibility
Viability
Desirability
Reflection design goal
and design vision

8.1 Three lenses of innovation

The three lenses of innovation or in other words the feasibility, viability and desirability of the final design are discussed in this paragraph. All three lenses must be met for the grocery delivery robot to be a success. However, this thesis does mainly focus on the human-robot interaction at the doorstep. The three lenses of innovation will still help to reflect on the design and to make clear what still needs to be done in the future to make grocery delivery robots (with this fresh design) a success.

8.1.1 Feasibility

What is the feasibility of a grocery delivery robot? And how feasible is this embodiment design? The mechanisms within the cool box have been proven by the prototypes described in the previous chapter and the cooling system is already proved technology. The cool box is designed in such a way, that it could already be used. Of course, some adjustments are needed. The materials still need to be defined, a rain-drain system still needs to be designed and the design is not production ready yet, but I think it is safe to say that the embodiment is feasible.

The biggest question remains: when will it be allowed to have an autonomous vehicle operating on the sidewalk? Autonomous driving requires so many design choices combined with advanced technology. Besides, the autonomous driving itself, I think the biggest challenge is to create an embodiment that makes its intentions clear to the pedestrians.

Pedestrians have never experienced such an interaction before. In the embodiment design, lights are integrated to make the robot visible, but also to make the robot's intentions more visible. How these intentions should reflect in the lights or in the embodiment could still be investigated. However, existing delivery robot companies are doing a great job in their trial areas, so I have no doubt that a grocery delivery robot will not be feasible in the near future.

8.1.2 Viability

The delivery robot will only be viable if the entire delivery process starts thinking about integrating delivery robots. Only then can the robot delivery service be time and costs saving. With this embodiment design, I did take the possible integration of the entire delivery service process into account. With the vertical movement mechanism, the robot could be easily automatically loaded and unloaded by other systems. The delivery robot only needs to stand in the right position and other systems can vertically place the crates within the robot. An example of such a system can already be found in Ocado's warehouse (chapter 2.3). When the entire delivery process starts thinking about integrating delivery robots, the delivery robot would definitely be able to save a lot of time and costs. Last mile delivery is now still accountable for about 50% of all delivery costs.

8.1.3 Desirability

How desirable is this grocery delivery robot design? The analysis showed that the target audience would like to feel more in control of the delivery process. Due to possibly better integration of the robots in the entire delivery process and due to the access of the live location of the delivery robot, the customer will be able to feel more in control. For the customer it is especially important that the interaction of retrieving the crates does not take much more effort than with the current delivery process. The delivery robot will be something innovative, so the interaction must feel like that, or at least as something similar like to the current existing interaction. Due to the vertical movement mechanism, the user does not need to perform any extra actions to retrieve the groceries. They just need to wait and grab the handles once the robot hands over the crates. This intuitive interaction will create a desirable human-robot interaction at the doorstep.

8.1.4 Conclusion three lenses of innovation

Overall I would say that the embodiment is feasible, viable as desirable. The embodiment only needs some more elaborations to make it function long term. For viability and desirability, the most important steps to take will be the integration of the delivery robot with the entire delivery process. However, a start with the vertical movement hand-over has been made.

8.2 Reflection design goal and design vision

The goal of the project was to design and prototype an embodiment on top of the Husky, so the robot would be able to function as a grocery delivery robot in the near future, while establishing a desired human-robot interaction for the customer when retrieving goods from the robot at their doorstep. According to the design vision a desired human-robot interaction at the doorstep can be achieved by creating ergonomic, intuitive, functionally looking, trustworthy, aesthetically pleasing and environmentally friendly design that will empower the customer to feel in control of the delivery process.

With this design, the robot will be able to function as a grocery delivery robot, as it can deliver groceries on time and at a controlled temperature. The cool box design will not only ensure cool transport, but also enable a user-friendly hand-over. The vertical movement mechanism within the cool box does not only push the crate at a comfortable retrieving height (ergonomic design), but also enable an almost effortless retrieving interaction (intuitive design). The embodiment design is designed in such a way that it is easier for people to understand what the robot is transporting (functionally looking design). To create a desirable design, sustainability, aesthetics, and trustworthiness are incorporated in the shell design and the design of the mechanisms.

How much the customer will be empowered to feel in control of the delivery process is eventually depending on how the delivery robot will be integrated within the entire delivery process. For example, by owning the robot, the customer would have more control of the delivery process as when the robot is depending on when the truck with groceries arrives that day. I am glad to say, that I feel like I met the design goal (and design vision) determined at the beginning of the project. Of course, there is always room for improvement, but I think that this design of cool transport and a user-friendly hand-over can be a great start of a well-functioning grocery delivery robot in the near future.

9. Recommendations

In this chapter, some points of improvement, topics for further research and some final recommendations can be found

Points of improvement
Topics for further research
Final recommendations

9.1 Points of improvement

So many factors need to be taken into account when designing a grocery delivery robot, that is almost impossible to finish a production-ready embodiment design in 100 days. Even though I scoped down the project and only tried to focus on an embodiment design for a desirable human-robot interaction at the doorstep, it was hard to cover all design challenges in this time. Therefore, some points of improvements are highlighted in this paragraph.

9.1.1 Waterproof design

One of the still unsolved design challenges is about dealing with rain. As soon as the cool box slides the doors to the side, the crate and the inside of the cool box can be exposed to rain. Of course, this moment of exposure can be tried to be kept as short as possible, but some rain will eventually enter the cool box. Water and the ability of the cool box to freeze products, might not be a desired combination. You do not want to be scraping ice out of the cool box every time it rained. Some drain system still needs to be designed to drain the rain out of the cool box before it can turn into ice. Another solution could be to give the robot some sort of automatic umbrella for when it rains. However, this might interfere with the current ergonomic retrieving interaction.

9.1.2 Closing lid

Another still unsolved design challenge is about the mechanism of closing the lid. How will the lid know when to close? This is a topic needs some further elaboration. Should the lid close as soon as the crate has left the platform in the cool box? But what about fingers getting stuck? Can we implement some kind of laser light or movement detection that know when not to close the lid?

There are probably enough solutions, we only need to figure out which one will be the best for a grocery delivery robot to act autonomously.

9.1.3 Aesthetic lights

I found out that the aesthetics of the embodiment is to a great extent depending on details of the shell design. The lights have the potential to give the embodiment a designed look. Thereby, will they be able to clarify intentions of the robot at the sidewalk and at the doorstep. In this final design, the embodiment does not show that it is waiting for the customer to arrive. This might cause some confusion for pedestrians. A point of improvement would be to create a more aesthetically pleasing light, that is able to clarify its intentions with the pedestrians on the sidewalk (also about the moment of hand-over).

9.2 Topics for further research

Some topics, which I found interesting but did not fit within my project scope, and what I believe has potential for future research, are shown in this paragraph.

9.2.1 Delivery robot integration

Last mile delivery will only be more efficient, sustainable, and able to offer the customer more control of the delivery process if the delivery robots are integrated within the entire delivery process. If you take a look at for example Ocado's warehouse (chapter 2.3), you can see that so many innovations are already taking place in the grocery delivery sector. The entire process will be so much more efficient if all those sub-processes within the grocery delivery work together.

This final design already has a vertical movement mechanism of handing over the crates, which might make it easier to integrate the delivery robot with other automatic processes. How this integration should be embodied if you take a look at the bigger picture, could be a nice research topic to make the (robotic) grocery delivery more efficient.

9.2.2 Visibility delivery robot in traffic

The delivery robot will be operating on the sidewalks, but at some point, the robot needs to cross the street. To make the robot visible for car drivers, it is important that the embodiment is high enough for drivers to notice. Other existing delivery robots are using small little flags to make the robot visible in traffic. However, such a flag also brings some association with it. For me the flag feels a bit childish, which is for me not a desired association to have with a delivery robot. A design challenge and therefore research topic could be to find a way to make the robot visible in traffic without integrating such a childish flag. An add-on feature might also have great potential to enable desired human-robot interaction at the sidewalk.

9.2.3 Situation where the robot is waiting for the customer

As described in points of improvement, the delivery robot must wait at the doorstep for the customer to arrive. Since this interaction might take place on the sidewalk, it can probably cause some confusion for pedestrians. Is it broken? Does it want me to do anything? It might be interesting to investigate how to make clear that the robot is waiting for someone to arrive.

9.3 Final recommendations

This thesis is devoted to an embodiment design for a grocery delivery robot. Designing a robot specific for grocery delivery has been a challenge. Since the robot is dealing with food, many requirements must be met. Groceries need to be preserved at a certain temperature, the design needs to be hygienic, secluded and the groceries of different customers cannot be mixed. All these requirements resulted in having less design freedom to enable a desired human-robot interaction at the doorstep, then when you for example would design a package delivery robot.

It was a challenge to create a compact, lightweight design with an integrated cooling system, making use of universal crates to enable a desired human-robot interaction at moment of hand-over. My final recommendation would be that if you want to start a delivery robot business, it might be wise to start with a package delivery robot. A package delivery robot must comply with less (strict) laws, which might be easier to test with. Besides that, you will have more design freedom, and you can probably also reach more customers with one delivery robot. However, no grocery delivery robot that can operate on the sidewalk is designed yet. Even though it might be harder to launch a grocery delivery robot on the market, it can also be seen as an exceptional opportunity, and I think this embodiment design can be seen as a great start.

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