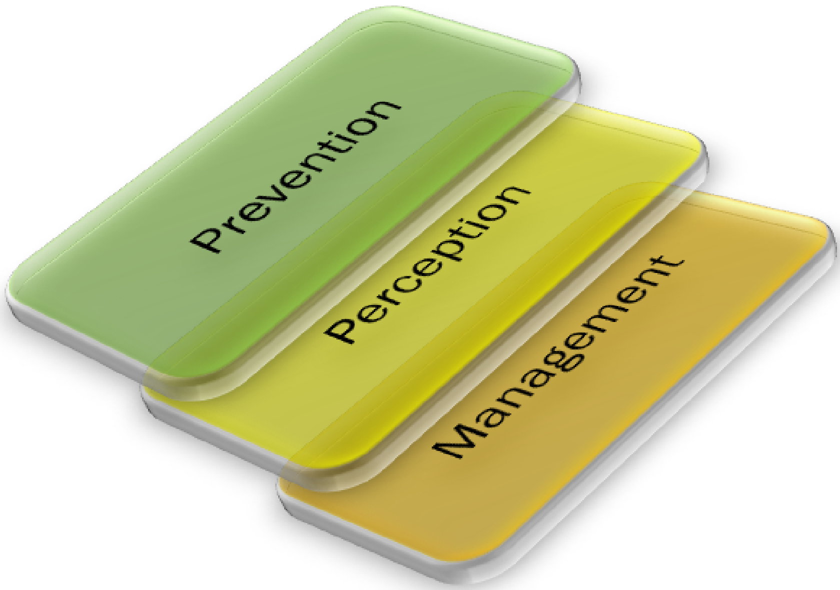
CHALMERS
UNIVERSITY OF TECHNOLOGY



Product development for retained newness with focus on cleanability & durability

Master thesis for CEVT

Dejan Lolic
Mehmet Esat Özel

Product Development
Chalmers University of Technology
Gothenburg, Sweden 2019

Master thesis

Product development for retained newness with focus on cleanability & durability

Dejan Lolic
Mehmet Esat Özel

Product Development
Department of Industrial and Materials Science
Chalmers University of Technology
Gothenburg, Sweden 2019

Dejan Lolic, 2019.
Mehmet Esat Özel, 2019.

Date: 2019-06-12

Supervisior: PhD Andreas Dagman, Department of Industrial and Materials Science
Examiner: Andreas Dagman, Department of Industrial and Materials Science

Cover:

Typesetting in LaTeX
Chalmers University of Technology
SE - 412 96 Gothenburg
Phone number +46 31 772 1000

Product development for retained newness with focus on cleanability & durability
DEJAN LOLIC
MEHMET ESAT ÖZEL
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

"Retained newness" can simplistically be described as: the grade of how well a products original attributes that generate the perception of new are preserved over time. In an attempt to use a car designed for conventional use in a car sharing service the term is of relevance for the consumer service satisfaction, market value of product and cost of maintenance. A car in a sharing service in comparison to a car in conventional use has an elevated frequency of use, which entails elevated scratching & abrasive wear, soiling in particle form and soiling in liquid form. The relevant attributes of a product is thereby the cleanability & durability, by an exploratory study the correlation with retained newness is defined. Furthermore the exploration continues by defining parameters & variables of interest and materials & technologies with sought for properties.

The knowledge gained in the exploration is used in a case study of a lower cover, by using the generic product development process the main output is concepts of interest for implementation in a sharing service. The winning concept entailing the addition of a modular feature that protects the lower cover from the exposure that implies decline in product appearance.

As a final part of the project some interesting solutions are assessed through proof of concept testing. These being protective films & coatings, the major conclusion is that they can be of relevance, but there is an inherent decline in product appearance that is hard to overcome.

Finally, the result is presented which contains a design guideline and proposal on updates to requirements & testing methods of today. The design guideline will help engineers reflect over the possibilities, since conclusively designing for this purpose concerns many disciplines. Furthermore, to validate design choices, among other both testing & requirements needs to reflect reality to a higher degree.

Acknowledgment

The master thesis **Product development for retained newness with focus on cleanablility & durability** has been performed during 19 weeks, January until June, 2019 at Chalmers University of Technology. The master thesis has been performed in collaboration with CEVT. Both of the master thesis members are students in the Product development master programme with a mechanical engineering bachelor from Chalmers University of Technology.

Initially we would like to thank our supervisor Andreas Dagman at Chalmers University of Technology for all his help, specifically for aiding us during periods of uncertainty and for always allocating time for among other answering our incredible amount of e-mails.

Furthermore we would like to thank our supervisors at CEVT for giving us the opportunity to perform this master thesis and for always being available. Another important part to the success of this thesis is the people from different departments at CEVT, specifically we would like to thank the people at the surface materials department.

Last but not least, we would like to thank our families and near beloved ones, without them and their support this would not have been possible.

Table of Contents

1. Introduction

Newness is an ambiguous expression, by definition the expression means something that has the quality of being "new, novel, original" or things that were "created, made, built or begun" a short time ago [1]. Furthermore "retained newness", can simplistically be described as: the grade of how well a products original attributes that generate the perception of new are preserved over time. Thereby to retain newness, implies defining the reason for the decline of these attributes and counteracting them. In many cases this entails improving the durability of a product, but durability alone does not capture the entire spectrum. The process of retaining newness and what it entails is based on the case, among other the use situation, the product and the type of offering. As of today there is knowledge and even guidelining methods to design for assembly, reliability, etc. Retaining newness and relevant elements on the other hand are not treated to the same degree. The relevance of the term will increase as future products are changing among other in terms of the need for resource efficiency and how they are offered to the consumer. This master thesis is performed to treat a part of retained newness and in the following chapter the project is introduced. A background to the problem initiates followed by the company from a product context, aim, deliverables and delimitations.

1.1 Background

The automotive industry is undergoing major changes in the coming future, the reason for this includes four major trends; electrification, autonomous drive, connectivity and shared mobility [2]. All of which bring their own type of challenges, shared mobility in specific refers to innovative ownership models where cars can be shared among users and the car can be owned through subscription services. As seen in Figure 1.1, the revenue stream from shared mobility services will have a distinct increase in the coming years [2]. This trend is welcomed, the ability of subscribing and sharing the car implies among other simplicity for users, but can also entail an elevated use of the product and a decreased feeling of ownership. The former implying environmental benefits but also increased wear & tear of the product and the latter furthermore implying that users can become somewhat careless in their use. The introduction of shared mobility among other increases the need for design & material choice for elevating cleanability & durability properties.

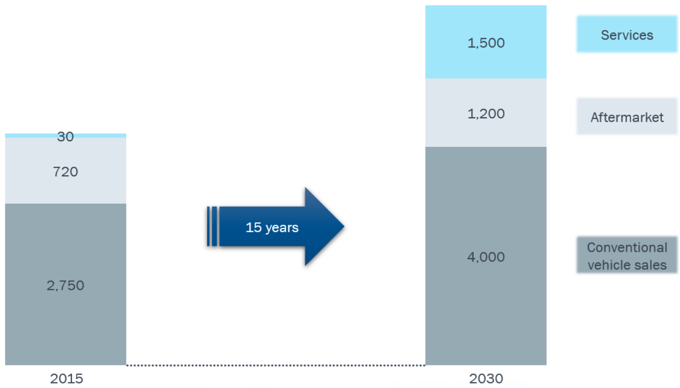


Figure 1.1: *Prediction of revenue changes in the autmotive industry in billions of dollars, data from McKinsey [2].*

This thesis is performed with the support of CEVT, which is an abbreviation for China Euro Vehicle Technology and is an innovation centre for Zheijang Geely Holding Group (ZGHG). CEVT develops automotive technology that will meet the demands of tomorrow's global markets [3]. The organization was created by ZGHZ in 2013 to develop a new modular architecture for Volvo and Geely compact cars, today the organization covers all aspects of passenger car development.

Figure 1.2: *Management structure of Zheijang Geely Holding Group*

A car brand within Geely Auto Group and developed by CEVT is Lynk & Co, as seen in Figure 1.2. Lynk & Co have a vision of providing consumers vehicles in a simple and modern way, among other by sharing [4]. The strategy is to keep Lynk & Co cars in the car sharing fleet for five years and after their effective use resell the car in the aftermarket. The inherent issues with the strategy is to provide the consumer a premium experience of that of an owned car while being used by the many and simultaneously ensuring high residual value at the end of the effective use within sharing.

There is different strategies to provide stated experience, one of which is to retain newness of the product. A disruption in offering and consumption generates a disruption in engineering decision-making. As mentioned by Johannesson [5], for producers of products in sharing the challenge is to develop it to be sustainable during it's life-cycle for the company. The scenario introduces new relevant requirements, for example customer adaptation and maintenance & serviceability [5]. Peter Holley [6], writes about a shareable electric scooter which has been launched in cities of the USA. The expectations from the consumers of the shareable service was that the scooters would hold, but the designers had not considered that the usage would change when in fleet usage. Instead, they had designed the scooters as it would be of individual usage, which lead to unreliability [6].

1.2 Aim and Deliverables

The interior of a passenger car is a challenging environment, it has to comply with requirements for complex functions while still fulfilling consumer needs regarding for example the products appearance. The interior includes systems like the instrument panel, floor console, door trim, seats which are essential for the main function of the car and the general experience. Today, cleanability & durability properties of products have been of less focus as the necessity of these during conventional use are minor in comparison to sharing. There is now a need to understand how to design for the use situation of sharing and thereby how to elevate cleanability & durability properties of products in the interior. The thesis aims to study the cleanability & durability of the interior of a car by analyzing & identifying:

- Currently used materials within the interior
- Feasibility of relevant other materials in comparison to materials used today
- Feasibility of technologies that can enhance performance
- Design & material parameters of interest

The study of cleanability & durability will be performed in coherence with development of a product that is a typical case of rapid decline in product appearance. Thereby, the data gained by the study is tested in a product development process, to further gain data about possible solutions to enhance cleanability & durability properties and to understand how to choose optimal solution. The thesis also aims to enhance understanding of retained newness and guideline future development, synthesized by the following deliverables.

1. Design guidelines & material database
2. Proposal on updates for current Design prerequisites (DPR) and Testing methods

1.3 Research questions

In continuation of the aim and deliverables the research questions below are formulated to guide data collection and creative problem solving activities.

- What are the important parameters & variables of a products characteristics to elevate cleanability & durability properties?
- What materials & technologies can be feasible for elevating cleanability & durability properties?
- How can retained newness be prolonged in comparison to today's products in the use situation of a shareable car?
- How can the current Design Prerequisites (DPR) & Testing methods be developed to achieve retained newness in future products?

1.4 Delimitations

The subject of retaining newness is broad and requires limiting to be feasible. Following below is limiting statements that guided the thesis.

- Focus on interior of vehicle
- Physical testing focuses on proof of concept
- Focus on knowledge gaining activities for the purpose of supporting creation of deliverables.
- Focus on generating ideas for refurbishment solutions

2. Theoretical framework

In this chapter, retained newness and how it correlates to subsequent areas is explained & described. The chapter aims to support the direction taken in the project and thereby support the results. Excluding retained newness, areas treated also include Product-Service system, Circular economy, Modular design and the Product development process, see Figure 2.1.

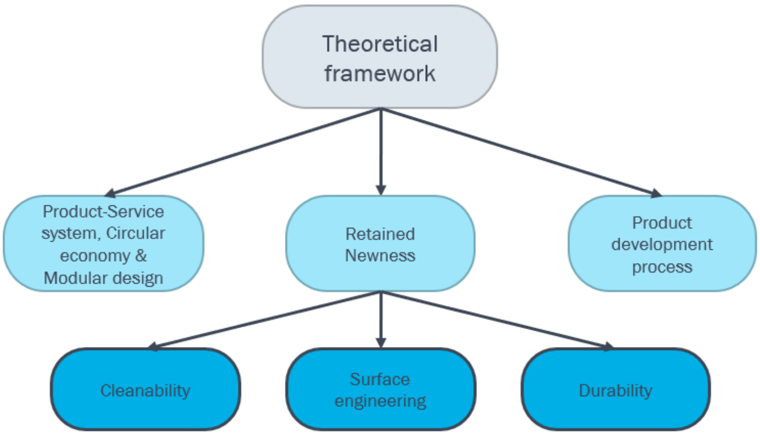


Figure 2.1: *Overview of theoretical framework content*

2.1 Product development process

The product development process is a set of steps used by engineers to design a product. The process is preferable as it is a form of structured problem-solving, a mix of synthesis and analysis [5]. This is important since design problems are often open and divergent, meaning that there is not only one single correct answer as for example in mathematics [5].The process initially includes a wide set of ideas which are subsequently narrowed down as the project progresses and knowledge is gained, as seen in Figure 2.2. The generic process contains six phases seen in Figure 2.2. The front-end of the development process is the more demanding part and is often iterative, at any stage new information can arise that require the development team to take a step back [7]. As mentioned by Johannesson [5] product development projects have different approaches and often treat the re-design or improvement of products already in use.

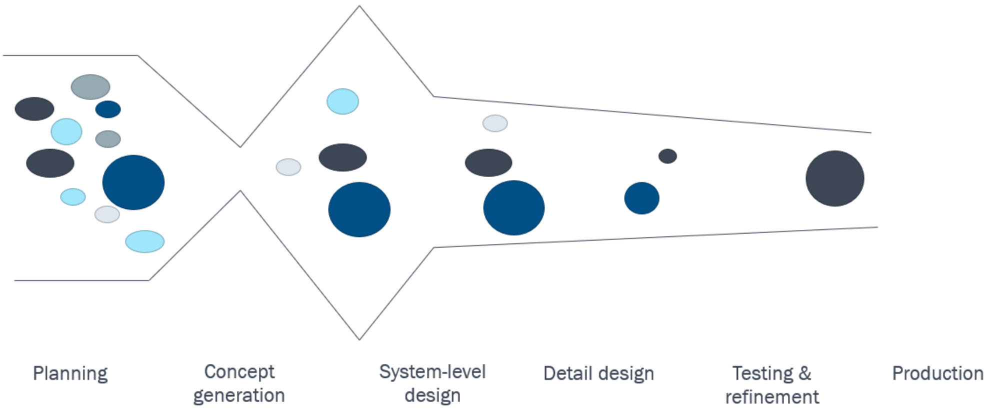


Figure 2.2: *The product development funnel, illustrating narrowing of ideas during phases, recreated from book [7].*

2.2 Product-Service system, Circular economy & Modular design

Service is about giving the customer what they need and maintaining what is delivered, it is defined as "the action of helping or doing work for someone" [1]. In the western world, selling service instead of selling products has increased in many industries [5]. Considering the design of a service, the important aspect is to ensure a positive experience and benefit for the customer. This by maintaining quality in the interactions between consumers and suppliers [5]. The action of moving from a product offering to a more service focused offering is defined as servization, servization considers the customer's problem as a starting point [8]. There are different levels to servization, the simplest form is the offering of maintenance services and the more developed form is when the service is the core offering & the product becomes the means to deliver it [8]. In an article by Michelini et al. [9], it is mentioned that Product-Service system offerings can be a way of promoting circular economy. Circular economy can be defined as the maximization of resources already in use. According to Esposito et al. [10] it is restorative and regenerative by design, structure and objective. Products in a circular economy are designed for the purpose of being able to continuously add, recreate and preserve value at all times [10]. This has entailed that developments within design for modularity has increased in fields as product life cycle and environmental management [11]. There are three different types of modularity, modularity in design, -in use and -in production. Modularity in use is driven by consumer demands with regard to different attributes. These attributes can be divided into two areas which are product performance and personalization. If and when a sub-part of a product loses its performance, modularity eases the procedure to change the part without affecting the rest of the product. Consequently, a positive effect with regard to maximizing resources already in use, since the part can be changed, maintained and re-used while the rest of the product is unchanged [12].

2.3 Retained newness

By definition, retained newness means: "to keep or continue to have (something)" that has "the quality of being novel, new, original" [1]. Continuously "new" means: "Things which were created, made, built or begun a short time ago" [1]. As seen in Figure 2.3, by assessing different theories a consequent based explanation of retained newness is presented, starting with consumption-value theory.

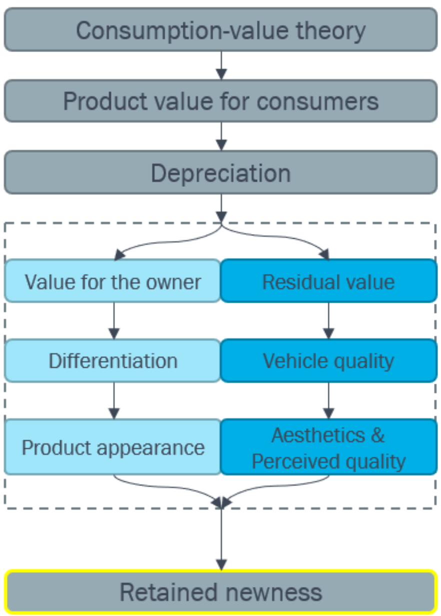


Figure 2.3: *Overview retained newness theory chapter.*

The Consumption-value theory, argues for which factors has an impact on the consumer choice of buying or not buying a product or service [13]. These factors are categorized as the functional-, social-, emotional-, epistemic- and conditional values.

- **Functional value**, is the type of value which is gained by fulfilling the function of the product [13].
- **Social value**, is the type of value that shows to which extent the consumer can connect with others by owning a product or engaging in a service [13].
- **Emotional value**, is the type of value which shows to which extent the consumers can express themselves or feel better by owning a product [13].
- **Epistemic value**, is the type of value which is connected to the knowledge desired. If it is motivated by curiosity or the seeking of novelty [13].
- **Conditional value**, is the type of value that reflects the fact that some market choices are dependent on situations that the consumers face [13].

The theory is based on three basic propositions which are: that the market choice is a function of multiple values, the type of values make different contributions in different situations and that the values are independent.
Another perspective on the product value for consumers, is that it depends on four dimensions which is performance, esteem, scarcity and retained value [14]. The author Mascitelli [14] writes that depending on who the customer is the different dimensions will have more influence on the purchase decision.

Depreciation is the decrease of value [15]. According to Donald et al. [15] value has several meanings and can be very ambiguous, in economic analysis for example it might mean market value or value for the owner. Depreciated market value is defined as residual value, Lucko [16] considers residual value as the price of an used asset at any point in time. Residual value is of major importance for automotive brands since it has influence on factors like new car sales and image perception [17]. An example of value to the owner is the dimension of retained value, which can be described by attributes like reliability, durability and resale value. Car manufacturers like BMW promote their products by asserting that their products have higher retained value, and consumers are known to justify expensive purchases because of the "higher retained value" [14]. Furthermore the newness of a product's appearance has been identified to be an effective means of differentiating and have positive effects on product sales [18]. According to Talke et al. [18] design newness is measured by the degree of distinction a product has to a reference product, the reference being for example a competing product or an older generation. Differentiation can include changes in for example color, material and dimension [18]. Hence, visual aesthetics are of importance as it is a way of creating value by sense and emotions. Consumers don't only buy products but also value and experience. According to Mumcu et al. [19] when a products design is appealing the sensitivity to price decreases and thereby enabling higher profit margins.

According to the thesis by Eriksson & Svanestrand [20] there are both controllable and uncontrollable variables that affect residual value. A controllable factor of interest is vehicle quality, quality is the the fitness of the product for meeting or exceeding its intended use as required by the customer [21]. The term quality can be defined by using the following eight attributes: performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality [21]. To retain newness or in other words retain value there is a interest to retain the qualitative attributes. The value in this case is in the attributes and dependent on situation some are more relevant than other, in the case of interior panels the main purpose is to cover a less appealing foundation. Consequently, the attributes of most relevance is the aesthetics and perceived quality, more so the rate of deterioration of these attributes.

2.4 Cleanability

The term cleanability is defined as "the ability to be cleaned, especially easily or without damage" [1]. In general, literature regarding cleanability differ in their definition, divided into three different areas: the cleaning agents ability of removing "soil" from a surface, the ability of reaching the "contaminated" area with a cleaning agent and the probability of a material/surface collecting "soil" [22] [23]. According to Ávila et al. [24] cleanability is the ability to clean a component to the required cleanliness level. This depends on the entire chain of events from design to service which are necessary to produce a part that satisfies performance, service life and cost requirements [24]. According to Marshall et al.[25] clean means free from dirt or impurities and the process of cleaning is the process of removing these impurities.

According to Mchardy [26], design for manufacturing is a good starting point when considering cleanability but when designing for cleanability there are specific guidelines that could be of use. Among the guidelines there are three that are of specific interest. The first one being material, which is fundamental when considering cleanability of parts, adhesion of particles on surfaces are dependent on material properties like hardness and material surface properties. Important to understand is that materials that have better performance when considering particle adhesion doesn't inherently simplify the process of cleaning, even if there theoretically is less particles to remove [26]. According to Avila et al. [24], the focus is on the ability of removing adhered and loose contaminants (impurities) from the surface, this includes the cleaning media after the cleaning process. Consequently the physicochemical, morphological and mechanical properties of the surface is of importance [24]. For example mechanical properties define the allowed force used for removal of impurities before the surface is damaged [24].

The second guideline is in regard to surface finishes and coatings, different types of coatings could enhance material performance with regard to preventive measures of particle allocation. The third being geometrical guidelines and specifically blind holes, which typically are a place where excessive allocation of particles is present [26].

Cleanability as an attribute is of importance, not necessarily for the fact that a customer would require it specifically, but other attributes like aesthetics are affected by the products ability to be cleaned. For example Marshall [25] divides reasons for industrial surface cleaning into three: preparation for fabrication processes, aesthetics or to ensure functionality of products.

2.4.1 Particle adhesion

According to Kohli et al. [27] the sources of contaminants can be divided into different categories, of interest for the thesis are indirect material and from people. The indirect materials include consumable supplies which could come in contact with a surface during a cleaning process or other, for example wipers, gloves and cleaning chemicals [27]. In regard to people the contaminants include human waste like skin and particles from for example clothes, according to Kohli et al. [27] humans are the biggest source of contaminants.

Kohli et al. [27] divides particle adhesion forces into the following four: van der Waals attraction, Electrostatic attraction, Capillary attraction and Chemical bonding.

- **Van der waal** forces happen whenever two objects approach each other, the attraction force increases. The van der waal force is considered to be the weakest of all particle attraction forces but should not be neglected, it is the most fundamental one [27]. If disregarding external forces, van der waals force is one that is always present [28].

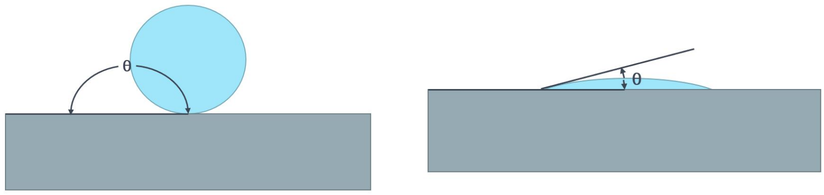
- **Electrostatic** attraction binds particles to non-conducting surfaces, charged particles are attracted by both neutral- and oppositely charged surfaces [27]. The acting force is coulombic attraction, in accordance to this the number of particles on a surface is dependent on: Particle charge and concentration, the electrostatic charge per area on the surface and the duration of exposure [27].

- **Capillary** attraction is a force that is based on the van der waals force attraction. The strength of the van der waal is dependent on the surface area of contact between the "objects, capillary attraction you could say exploits this. In capillary attraction a film is formed between the contaminant and the surface, increasing the surface area and by that increasing the adhesion forces [27].

- The final attraction force is called **chemical bonding** and in some cases is the strongest type of adhesion force. This because of chemical reactions that create bonds that make conventional cleaning processes ineffective, bonds that only can be "released" by finding an alternative chemical reaction [27].

2.4.2 Liquid adhesion

Wettability is the ability of a liquid to maintain contact with a solid surface [29]. When controlling surface contamination of materials, a rapid detection method is required that does not adversely affect the surface. The parameter defining the wettability is observed contact angle, a low contact angle results in high wettability. It can be stated as 0 degrees being completely wetting (hydrophilic), 0 to 90 degrees partial wetting, 90 to 180 degrees partial dewetting and 180 degrees completely dewetting (hydrophobic). The angle is measured between a tangent to the liquid surface where it meets the solid substrate and the plane of the solid substrate, which is measured inside the liquid phase and not in the vapor phase [27], see Figure 2.4. It can be influenced by the spreading history of the liquid drop, e.g. for a smooth, planer surface, the angle depends on the liquid surface tension, the surface free energy of the solid and the interactions between the two materials [27].



(a) *Superhydrophobic at θ =180 degrees.*

(b) *Superhydrophilic at θ =0 degrees.*

Figure 2.4: *Figure 2.4a and 2.4b illustrates a liquid drop in profile on a surface.*

2.5 Durability

Durability is one of the dimensions of quality as mentioned by Mitra [21]. In the most simple term durability can be explained as a measure of product life. According to Garvin [30] durability has both economical and technical dimensions, where the technical dimension can be defined as the amount of use of the product a consumer has before its inevitable decline. In the case of the economical dimension the attribute can be defined as the amount of use before it breaks down and a replacement product is more logical than continuous repair [30]. The latter definition implies that durability is closely connected to reliability, whereas a product that often fails will likely be replaced earlier than one that does not. In an article by Bakker et al. [31] they explore product life extensions by design. Product life spans have had a steady decline during the 21st century, consequently material throughput has elevated and by that the environmental impact is becoming critical. Bakker et al. [31] mentions that for product designers there are three strategies for addressing this problem, material efficiency, product life extension and product recycling. Designing for durability being one of the ways of extending product life. According to Ashby et al. [32] durability is a key material attribute but one of the more difficult attributes to characterize and use for material selection. This for example because of the fact that it is not just a function of the material but also of the environment that it operates in.

2.5.1 Wear

According to Basu et al. [33], wear can be defined as progressive damage leading to loss of material. The importance of wear in engineering is because of the inevitable costs, which is generated from the need of replacing parts, maintenance, etc. In essence, as mentioned by Garvin [30] the economical dimension of durability. A part that is either partially worn or fully worn will not surprisingly deteriorate with regard to performance, which includes among other lower quality and surface damage [33]. The wearing can be of different types, these are called wearing mechanisms and include among other abrasion, adhesion, erosion and fretting.

Abrasion is a type of wear that occurs when rough and hard objects slide over a softer surface, consequently causing plastic deformation at the interface of the softer material [33]. Important parameters to consider for the "attacked" material being hardness, toughness and brittleness. For example a key element of abrasive resistance is the elevated hardness of the "attacked material" in regard to the "attacking material" [33]. Abrasive wear is according to Dwivedi [34], the material loss from a functional surface of a component interacting with hard particles like rocks, sand and dust. According to Abdelbary [35], abrasive wear on polymers results in micro-machining which consequently generates wear grooves, tearing, scratching etc. The grade of wear is dependent on the hardness, toughness and size of the particles and the same properties of the surface material [34].
According to Abdelbary [35], the third significant wear mechanisms for wear of polymers is surface fatigue. The process of surface fatigue wear happens when a polymer is exposed to repeated stress in the form of rolling and sliding motion. The repeated exposure can lead to subsurface crack initiation and with continued exposure leads to propagation of the cracks. This finally because of stress concentration will lead to detachment of wear debris and of course will further decline the durability of the material.

2.6 Surface engineering

Surface engineering is the science and technology of modifying surface characteristics based on the needs of a certain application to enhance product life. Dwivedi [34] divides the need of surface engineering into the following four:

- Increased resistance to corrosion, wear, oxidation and sulfidation.
- Enhancing mechanical- and electrical properties etc.
- Reducing friction and improving lubrication characteristics
- Improving aesthetic characteristics

According to Batchelor et al. [36], there are two types of surface engineering, one being the application of protective coatings and the other being modification of the surface for critical characteristics.

Discrete coatings are coatings that have a clear border between it and the substrate, range from familiar paint to advanced coatings. All coatings have a unanimous goal of protecting the “vulnerable” substrate from a type of external damage [36]. According to Dwivedi [34], surface modifications like coatings are based on the simple principle of applying a good quality material on the functional surface of a substrate to achieve desired properties. The most well known type of coating, is the organic coatings which include paint,varnishes and epoxy resins. They are deposited on a surface in liquid form and then develop into a thin film by polymerization that could be initiated by for example UV light [36].

According to Arino et al. [37], the appearance of any object is usually described in terms of color, gloss and texture. They are the major perceptual attributes that stimulate human impression, their complexity create a need of human observation tests [38]. Appearance of an object is also very subjective and the need for finding a relationship between physical measures and perceived impression is of interest.

In regard to the perceptual attributes, surface texturing offer more than just visual feedback, they offer feel. The feel and the visual properties of a surface can be controlled by altering the surface roughness, hence the importance of surface texturing [39]. According to Gao et al. [40], textures except from enhancing look and feel also conceal surface damages and thereby retain visual appearance. The texturing of products also enhance a materials scratch resistance, this because of the fact that a textured surface allows for a smaller contact area than with smooth surfaces. According to Barr et al. [41], the ability of scratch resistance of a surface texture relies on the base material properties, specifically the deformation properties. The level of damage because of scratches is implicitly dependent on the mechanical behaviour of the material. In regard to surface texturing as a concealing strategy for scratches, visibility of scratch damages is limited to the visual capacity of our eyes and the governing parameter is changes in light intensity [41].

3. Methodology

The chapter presents methodology used in this project, furthermore how each individual method is adapted is explained. The methodology is inspired by the product development process, see chapter 2.1, although front-loaded to support the aim of the project. In Figure 3.1, the methodology is visualized and where respective phase can be positioned in the product development process.

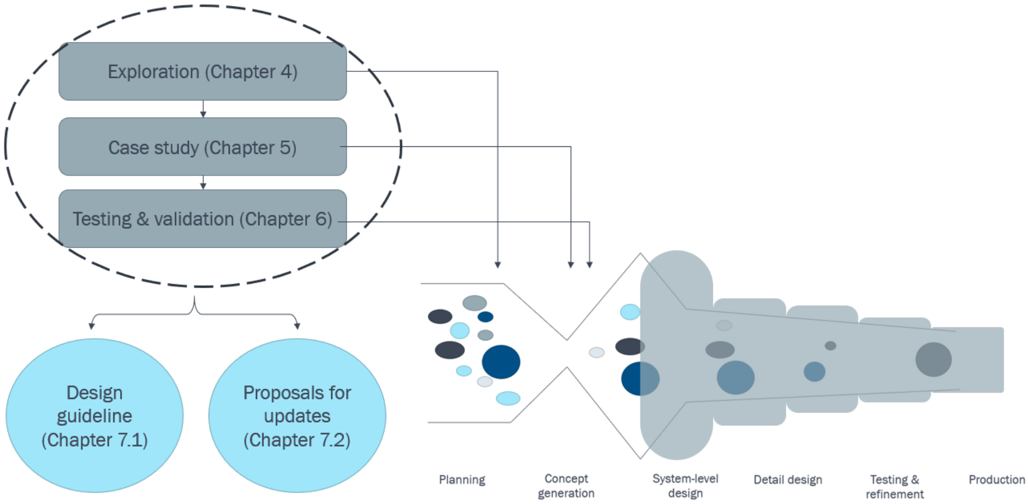


Figure 3.1: *Visualization of the methodology for this project*

The exploratory research generates the knowledge base of the subject firstly from a holistic perspective and then more specifically with focus on cleanability & durability, see chapter 4. The generated knowledge is then used in a case study of a typical problem area, see chapter 5. Finally, possible solutions are tested in the proof of concept phase to assess their feasibility, see chapter 6. These three phases are finally synthesized by the development of the design guideline and proposals of updates to the design prerequisites & testing methods, see chapter 7.

3.1 Exploration of Retained newness

For a generic product development process the initial phase is planning. It's the preparation for development of a new found opportunity. As Ulrich et al. [7] explains in the context of product development an opportunity is an idea for a new product, a newly sensed need. An effective method to categorize opportunities is to analyze them in terms of "knowledge of need" and "knowledge of solution". As seen in Figure 3.2, categorization reflects different levels of risk and uncertainty.

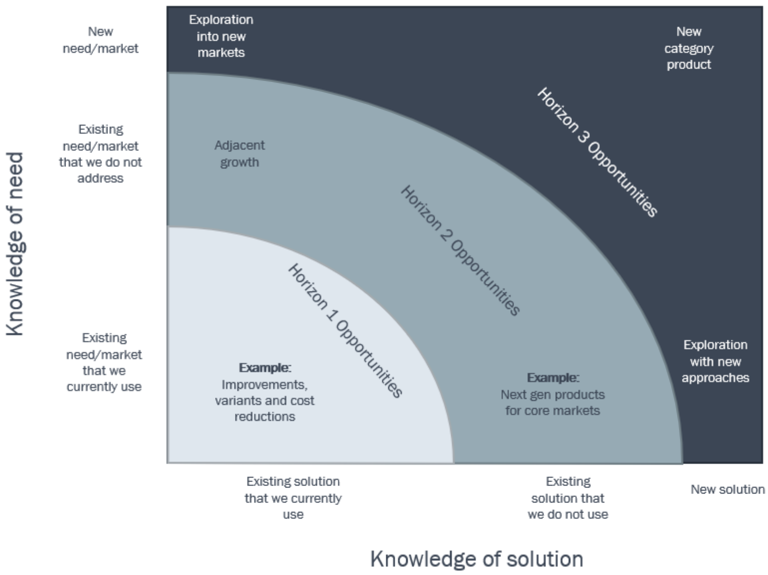


Figure 3.2: *Opportunities categorization from Ulrich et al. [7]*

For this project there is a new need/market, thereby the knowledge of the need is relatively low. Furthermore the knowledge of solutions is even more modest, even for the solutions that are currently used there is a lack of knowledge of how they could be used to satisfy the new need. A part of the project is to explore this spectrum. Exploratory research is a research method used when the researchers have low or no knowledge of the situation/problem, although the researchers have a reason to believe that there is information worth discovering [42]. In the subsequent chapters methods to support the exploratory research is described.

3.1.1 Data collection & Qualitative research

There are two different types of data, primary and secondary. The primary data is collected directly from its source, e.g. interviews, phone calls, e-mails etc. The secondary data is information that is collected from someone else's work, e.g. literature, articles, internet search and studies [43].

The primary data can be collected in two different ways, qualitatively and quantitatively. The difference between the two types is the amount of people used and specificity of questions. During qualitative research, the primary tool is interviews with individuals or groups and allows for more elaborate questions [44]. During quantitative research, the common method of use is surveys, the aim being quantity of subjects and thereby less elaborate questions [44].

In this project a qualitative research methodology is used. The inherent specificity of questions for a fairly low treated subject supports in enhancing understanding. The quantitative research as mentioned is based on quantity of subject, therefore it would require questions decomposed to a lower level where simple answers like yes or no is feasible and valuable.

3.1.1.1 Interview

Interviews can be performed with three different techniques, structured-, semi-structured- and unstructured interviews [45]. In a structured interview, all the questions are determined and organized before the interview [45]. In a semi-structured interview, the area which is in focus is determined but the questions are asked depending on the reaction and answers gained from the interviewee [45]. In an unstructured interview, nothing is determined and and the questions asked are dependent on the subject and answers gained by the interviewee [45].

In this project the interviews are performed in a semi-structured manner. Interviewees includes a wide span of people, mainly experts of fields relevant for the knowledge of how to retain newness, see Figure 3.3 & 3.4. The interviewees are introduced to the project and depending on their background questions are formulated to generate value adding discussion, furthermore the discussion is controlled by the project members to ensure quality.

The interviews are performed mainly to confirm the information gained during the pre-study. This is done by taking notes during the interviews and comparing it with the information gained in other sources.

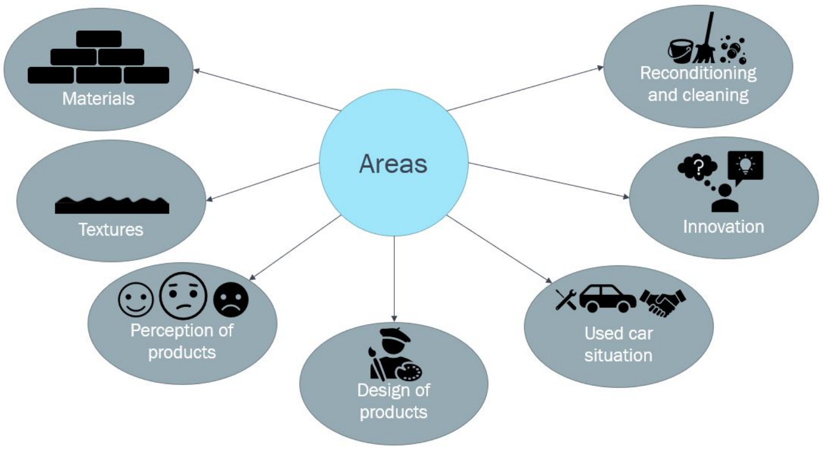


Figure 3.3: *Illustrating the different areas of knowledge of the interviewees.*

The stakeholders interviewed within the company include the following departments:

- **Innovation department**, has the mission to strengthen the innovation capacity at CEVT. They support the organization by identifying, promoting and managing innovation initiatives within the field of mobility and with focus on customer's present and future needs.
- **Business**, implies representatives from Lynk & Co, function that control the business strategies and are interested in sales of the vehicle. Develop the service and the strategy for vehicle throughput.
- **Surface Materials**, representatives working with among other textures, colors and gloss.
- **Styling**, design department for Lynk & Co, decision-makers regarding appearance.
- **Design**, the mission provider working with design of components and manufacturing.
- **Perceived Quality**, developing requirements for among other the appearance and feel of products.

In Figure 3.4 each stakeholder is defined including their respective knowledge base.

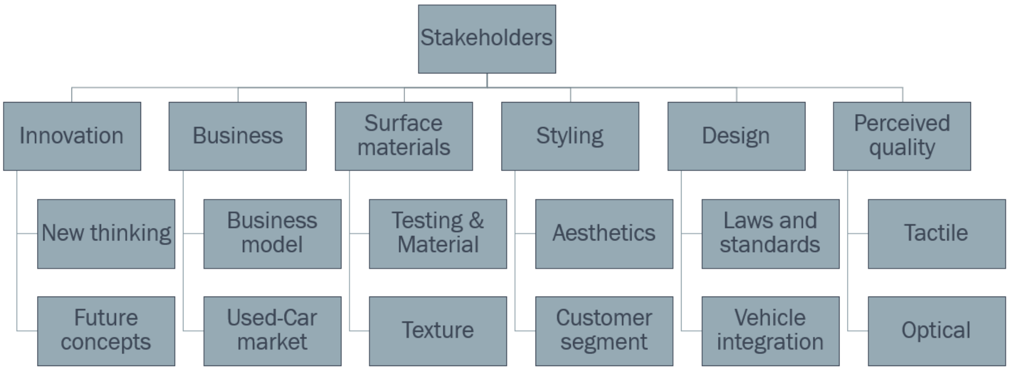


Figure 3.4: *Visualization of stakeholders included in analysis.*

3.1.1.2 Literature review/study

A literature review has many different definitions and more often than not many purposes. Two purposes that often is the case for a thesis project, is for the writer to learn about the literature and to play a role in arguments [46]. A theoretical literature reviews centre of attention is the theory accumulated of a certain topic. The review establishes what theory's exist, how well they have been investigated, their relationship and thereby new hypotheses are generated [47].

In this project the review of literature is instrumental for a knowledge basis, and to aid in development of project deliverables. The initial purpose is to explore the subjects newness, cleanability and durability. Furthermore review of literature regarding design for service, forces of adhesion, testing procedures etc.

3.1.2 Stakeholder mapping

Stakeholders, is the people or groups of people that have a stake in the project. For a product development project stakeholders can be defined as a group of people that are impacted by the products failure or success. This consequently means that a stakeholder entails different people, among other the user, the retailer, the service center etc. In short the success of a product development project can be defined by the profitability of the developed product. The profitability itself is dependent on among other product quality and product cost, hence there is different interests dependent on stakeholder [7].

A way of mapping stakeholders is by analyzing them based on their influence and power regarding the development project. As seen in Figure 4.4 stakeholders based on these terms can be plotted on a 2 by 2 grid, the grid can furthermore be used for understanding what stakeholders are of most interest to keep engaged or in some cases to please [48].

In this project the method is used to understand what stakeholders are impacted by a proposed change in design, furthermore the tool acts as a excellent support for understanding trade-offs in decision-making. Furthermore the interviews with stakeholders aids in development of a requirements specification.

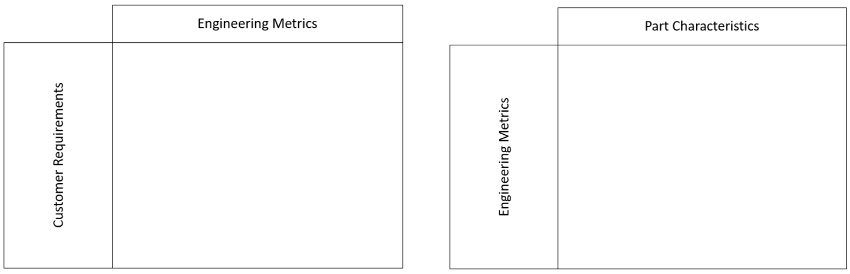
3.1.3 Needs list

A need can be defined as an attribute of a potential product that is desired by the customer [7]. A customer is defined as the individual or organization that purchases the product. In development projects there is often high focus on the product and less on the product in a context. Expanding of the spectrum incorporates more people that are of interest when developing a product, these are among other users, consumers and stakeholders. The identification of customer needs is a basic part to a product development process as the needs are tools for engineers to define a product specification. **In this project** a needs list is generated from interviews with stakeholders, this entails six engineering functions and an external party that can be equaled to maintenance personnel. The needs list is the primary output that aids in development of the requirements specification.

3.1.4 QFD

Quality function deployment (QFD) is a structured method used to translate customer requirements into design specifications [49]. It is also helpful when producing more accurate decisions with regard to several aspects and criteria based on the customers needs [50]. QFD is usually associated with the house of quality and part development. These relate the customer requirements, engineering metrics and part characteristics, see Figure 3.5a and 3.5b [49]. The QFD has many benefits as identification of customer needs and expectations, planning, communication and uncertainty reduction [50].

The center of the QFD is where the relationship between the different customer requirements, and engineering metrics parameters and part characteristics are stated. This can be done in different scales e.g. 0-1-3-9 correlation



(a) *Customer requirements and engineering metrics [49].*

(b) *Engineering metrics and product characteristics [49].*

Figure 3.5: *The two different QFD matrix, Customer requriements and engineering metrics to the left and engineering metrics and part characteristics to the right.*

scale or 0-10 scale. Usually and also in this project, the 0-1-3-9 scale is used where 0 means none correlation, 1 is small correlation, 3 is somewhat correlated and 9 is highly correlated [49].

In this project the QFD is used to correlate customer needs to part characteristics. This differentiates from the generic process but effective in generating understanding of how the needs can be fulfilled. The reason can be correlated to that the customers in this project entails engineers, whom thereby are very clear in their definition of need.

3.1.5 Problem decomposition

A problem decomposition is used when the problem treated is to complex, by decomposing into various simpler sub-problems the process of generating concepts can be simplified. There are many strategies to decomposing problems among other is decomposing by function. A function-means tree is thereby a strategy to decompose by function. In contrast to a generic functional decomposition, the function-means tree connects the functions to a certain mean/several means. The principle is similar to that of axiomatic design where a Functional requirement (FR) is connected to a specific Design parameter (DP), beginning with functional requirements on a total system level ending with sub-solutions on a detailed level [5].

In this project the tool is used for two purposes, one of which is to generate an understanding of the lower cover which is used as a design case in this project. The second purpose is to decompose retained newness and to understand where the function of retaining newness belongs in the overall system.

3.1.6 Requirement specification

In a requirement specification, also known as product specification, all the requirements that describes what the product should fulfill is stated [7]. This represents an unambiguous agreement on what should be done to satisfy the customer needs [7]. What is not mentioned in a requirement specification is how to address the customer need [7].

It takes more than one iteration to gain the final requirement specification. There is one established in the beginning of the project when all the customer needs are specified [7]. Then there is one that is established after the concept selection since some of the needs will not be met or that some exceed what is expected [7].

When establishing the requirement specification, there is four steps that is followed. The first step is to prepare the list of metrics which reflects to which degree the product satisfies the customer needs. The second step is to collect competitive benchmarking information. This to gain an understanding of what values are reasonable to set and also to be competitive on the market [7].

The third step is to set ideal and marginally acceptable target values [7]. The ideal value is the best result to hope for and the marginally acceptable value is the lowest result that can be achieved [7].

The fourth step is to reflect on the result and process to ensure that the results are consistent with the goals of the project [7].

In this project two main requirement specifications is generated. One generic which treats the requirements that are of relevance when designing for elevated cleanability & durability. The second is generated for the case study, it incorporates the relevant generic requirements and additionally requirements valid for the specific case. This is performed by following the first and second step which is mentioned earlier. The requirements specification generated are mainly composed by wishes, as the goal of the project is to identify parameters & variables of interest.

3.2 Case study of lower cover for elevating cleanability & durability

To further research how to develop for retained newness a case study is performed on a part of the interior. It aims to support the development of deliverables and simultaneously explore ideas for the part treated. The case study will follow the generic product development process, see chapter 2.1, until the point of system-level design. Hence, concepts developed are to guide possible future development projects and do not aim to be further developed to finished concepts. The following subsequent chapters describe methodology for analysis of current situation, for generation & screening of ideas and furthermore describe how they are used in the project. Furthermore problem decomposition, quality function deployment and requirement specification are also used in this phase but are treated in chapter 3.1.

3.2.1 Benchmarking

Benchmarking is a systematic method used to analyze solutions that competitors on the market use compared with the company's own solutions [51]. Scott Cheney [52] writes in his book that benchmarking can be defined as the process which enables managers to perform company-to-company comparisons of different aspects as processes, products and practices. The aim with this is to identify which company has the best solutions of the problem and why it is the best [52].

One benefit that follows by performing a benchmarking is that achievable goals are easier to set. This by analyzing the customer demands and how the demand is meet by the products on the market. By having this in mind the company can develop a measurement to meet and exceed the needs today to become competitive on the market [52].

There are internal and external benchmarking that can be performed. Internal benchmarking is basically that comparisons are done on different units within the company. External benchmarking consists of three different types which are competitive, cooperative and collaborative benchmarking [52]. Competitive benchmarking is when the competitors within the same industry are analyzed. Cooperative benchmarking is when an organization in another industry that uses some technology to solve a common problem is analyzed. Collaborative benchmarking is when companies team up and exchange statistics and information [52].

In this project, internal benchmarking and external benchmarking (competitive and cooperative) is performed. The internal benchmarking is performed to get an understanding of how the problem is solved today or if the issue is considered within the company. The external benchmarking with regard to competitors is performed by analyzing data from the database A2mac1 [53]. The cooperative benchmarking is performed to gain new creative ideas on how other industries has solved the problem which could be implemented in the car industry. This is performed by searching for technologies and materials on the internet by using different key-words which is of relevance with regard to retained newness, cleanability and durability.

3.2.2 SWOT-analysis

SWOT-analysis is a strategic tool used to pinpoint and evaluate a projects strengths, weaknesses, opportunities and threats [5]. The aim with a SWOT-analysis is to identify the internal and external factors that has high importance to achieve the objective [54]. The internal factors is strengths and weaknesses and the external factors is opportunities and threats [54]. The result of the analysis is presented in a matrix [54], see Figure 3.6 for the layout of the SWOT-analysis.

Figure 3.6: *The SWOT-analysis matrix layout which is used.*

In this project, the SWOT-analysis is used to evaluate the lower cover of the door panel with regard to "cleanability and durability in sharing pools" and the "sharing and subscription" business model. The data gathered in the benchmarking, technology and material research is used in the SWOT-analysis.

3.2.3 Brainstorming

Brainstorming is a method used to gain creative ideas within groups of 5-15 people. A large part of performing the brainstorming session is to not criticize other group members ideas, because the aim with the method is to gain as many ideas as possible, quantity before quality [5], which is the two out of the three fundamental principles for a group brainstorming [55]. The third principle is to encourage new and wild ideas [55]. The ideas that are generated can also be combined to create new ideas or upgrade the current ones [5].

Usually, brainstorming sessions consists of five phases [5]. During the first phase, simple and common ideas are brought up. In the second phase, a silence emerges around the participants and the idea development lowers its pace. The third phase is when the brainstorming starts. In the fourth phase, the pace decreases again and in the fifth phase the outstanding ideas emerges [5].

In this project, employees from different departments at CEVT which are related to the different subjects is asked to join the brainstorming session. This is done to gain a larger amount of people with different backgrounds which will entail that the ideas brought up will have different focus areas. E.g. an employee from the materials department will have ideas regarding materials and an employee from the door panel department will have ideas about the door panel. Each department has an own session, and the amount of people is two to three per department. A brainstorming session is also performed within the project group.

Further on, the brainstorming session is performed by introducing two different customer segments. For each segment, questions with focus on different areas of the project is asked to gain specific ideas. See Appendix E for segments and questions. The brainstorming session with the CEVT employees is lead to a discussion during each question, with guiding help from the project group. All the ideas that needs to be visualized to elevate the understanding of the idea is sketched by the project group. The brainstorming session within the project group is performed by sketching and writing down ideas which is later on discussed to develop further.

3.2.4 Attribute listing

Attribute listing is a systematic idea generation tool where a product is decomposed into basic/low level components [56]. Decomposing the component renders the ability to identify negative aspects with each low level component, and thereby aid in generation of ideas to address the issues [56]. **In this project** the technique is used to separate by example the surface texture from the surface color. The technique is mainly used during the idea generation performed by the project group.

3.2.5 Concept generation

For the concept generation a modified Morphological matrix is used to categorize and combine ideas systematically. All the sub-ideas which solves the same sub-function/problem are put on the same row in the matrix, which entails that it will be easier to see which sub-functions that needs more sub-ideas [5]. Later on, one sub-idea from each row is selected and combined to a concept which is visualized by drawing a line between the sub-ideas [5]. The modified part which differs from the original Morphological matrix is that the columns are divided into different sub-areas depending on how the issue can be solved. This modification is done to easier categorize the solutions, see Figure 3.7.

Modified Morphological Matrix																
		Sub-Function	Texture		Film		Additives	Material	Coating		Gloss	Colour	Other			
			Texture roughness	Texture type	Film type	Film purpose	Additives with purpose	Material choice	Coating type	Coating purpose			Modularity	Semi Modularity	Modularity-feature	Semi-Modularity-feature
Probability	1	Resist scratching and abrasive wear									-	-				
	2	Resist adhesion of liquid									-	-				
	3	Resist adhesion of particles									-	-				
Identification	4	Disallow for identification of wear									-	-				
	5	Disallow for identification of liquid									-	-				
	6	identification of particle									-	-				
Refurbishment	7	Allow for easy maintance of wear									-	-				
	8	Allow for easy maintance of liquid									-	-				
	9	Allow for easy maintance of particle									-	-				

Figure 3.7: *The modified Morphological matrix without solutions.*

In this project the modified morphological matrix is used to structure ideas of interest and to aid in generation of concepts for the lower cover, see chapter 5. The combinations chosen are based on knowledge gained during the pre-study.

3.2.6 Elimination matrix

The elimination matrix is a method used to eliminate ideas that do not fulfill basic criteria [5]. This is performed early in the development phase to minimize unnecessary time spent and work performed [5].
The criteria that are considered in an elimination matrix is:

- Does it solve the base problem?
- Does it fulfill the basic requirements?
- On which level is the technology readiness level?
- Is the cost within the given specifications?
- Is it an advantage from a environmental, safety or ergonomically aspect?
- Does it match the company product program?
- Is the information required available?

[5] [57].

Each question is answered by a plus (+) if it fulfills the criteria, minus (-) if it does not fulfill the criteria and a question-mark (?) if more information is needed to answer the question [5][57]. If an idea gets a plus (+) on every criteria, it will continue to the concept generation phase. When an idea gets one minus (-), the idea will be eliminated. If an idea gets a question-mark (?), a search to gain more information about the idea will be performed until the information needed to answer with a plus or minus is collected [5][57].

In this project, the elimination matrix is performed in the steps mentioned before. It is performed to eliminate the ideas that do not fulfill the basic criteria.

3.2.7 Pughs matrix

In this project, the Pugh matrix is used to narrow down the number of concepts systematically. By comparing each concept versus the reference for the desires or requirements which are to be over-fulfilled, a value is gathered which shows in total if the concept is better, worse or same as the reference product. This by applying a (+) for better than, (-) for worse than or (0) for equal as [5]. After the comparison is complete, a sum of all (+), (-) and (0) is calculated and the result of this sum becomes the value for each concept. The concepts are then rated, and the ones with the lowest rating are eliminated [7]. Initially the existing product is used as a baseline reference which in the matrix consists of only zeros (0) [5]. During the second iteration, the concept with highest rating from the first iteration is set as the reference and the eliminated concepts are not included in the comparison. This is performed to evaluate if the other concepts still are good enough to be evaluated further in the next phase.

3.2.8 Weighted Pughs matrix

In this project, the weighted Pughs matrix is used to evaluate with more precision which concept is the better one/ best one. This is done by adding a weighting element to the matrix for each criterion [7]. The weighting score for each concept is determined by multiplying the weighting value, 1-5 where 5 is high importance and 1 low importance, for a specific criterion and the rating which is from 1-5 depending on how well the concept is fulfilling the criterion, where 5 is that it fulfills the criterion very well [7]. The result is compared with a reference which is an ideal solution with only 5:s on the rating value which will entail the highest possible score [7], which will be stated as 100 %. When all the concepts have been evaluated, their final score is divided by the ideal score in order to identify the amount of percentage every concept got in comparison with the ideal solution [7].

3.3 Testing & validation of interesting solutions

The former phases (chapter 3.1 & 3.2) introduce interesting possible technologies that can enhance performance. To assess these technologies/possible solutions with regard to feasibility a proof of concept testing is performed. As the name suggest the method proof of concept (POC) is used for validating ideas & concepts. POC is used to determine feasibility for real world application. The extent to which POC is performed can range from full scale prototypes to small computer simulations, this since the main output is to verify feasibility. **In this project** proof of concept is performed by applying these technologies to firstly test plates with different material composition and texture, secondly one possible solutions is tested on the same product that is used in the case study. The result is subjectively evaluated by the project group based on mainly performance and possibility to implement.

3.4 Results

The final part of the project is the synthesizing of results gained from former phases, this is done by the creation of two distinct deliverables. A design guideline and an analysis of both design prerequisites & testing procedures.

A **design guideline** is a tool to guide designers in a specific problem solving activity. According to Filippi et al. [58], the main characteristics of a design method is: helpful in determining optimal solutions, inciting creativity and understanding, allow for the electronic formalization and elaboration of information among other. Furthermore when design methods are specific for a part of the product lifecycle they become DfX methods, for example design for assembly. **In this project** the design guideline is created in a PowerPoint document to ensure accessibility to all whom may gain from it and to simplify use by making it interactive. The design guideline is specific for the use part of the product lifecycle, and in this case the use during sharing.

In this project the analysis is made based on three documents, the design prerequisites of different systems, the technical regulations and the testing methods. The aspects of relevance that has been treated in these documents are requirements & testing treating specifically "retained newness" and other that treat either the "cleanability or durability of the factors of interest" mentioned in chapter 4.3. The main goal of the analysis is to identify what changes to the existing design prerequisites & testing methods can be of relevance to achieve retained newness of future products.

4. Exploration of Retained newness

The development of the design guideline and the proposals for requirements & testing are based on knowledge gained by the exploratory research and case product development. In the following chapter results from the exploratory research is presented and in chapter 5 the case study is presented.

4.1 Retained newness design definition

Initially there is a need for a clear definition of what retaining newness requires and what the objective for an engineer is. Retaining newness as explained in chapter 2.3 is the process of retaining qualitative attributes over time, as for the case of the interior of a vehicle the qualitative attributes of interest is the perceived- and aesthetic quality, in essence the product appearance. To support engineering design the model in Figure 4.1 is created, and is what we call the controllable newness.

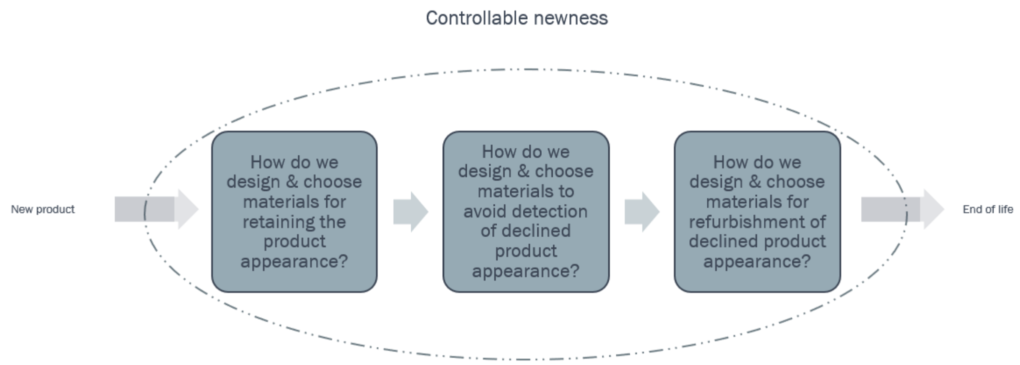


Figure 4.1: *Definition of controllable newness.*

The model incorporates three distinct questions that treat retaining newness during the product life, the questions are formulated as follows:

1. How do we design & choose materials for retaining the product appearance?
2. How do we design & choose materials to avoid detection of declined product appearance?
3. How do we design & choose materials for refurbishment of declined product appearance?

The first questions treats the intended decrease of the probability for any factor that would decrease product appearance to arise, here **Prevention**. The second question treats tactile and optical identification of said factor, here **Perception**. Finally the third question treats the restoration of the product appearance and thereby possibly the removal of said factor, here **Management**. In optimizing design & material choice following this procedure the decrease of newness over time is believed to be minimal. In Figure 4.2 the concept is visualized, where each graph represent one of before mentioned questions.

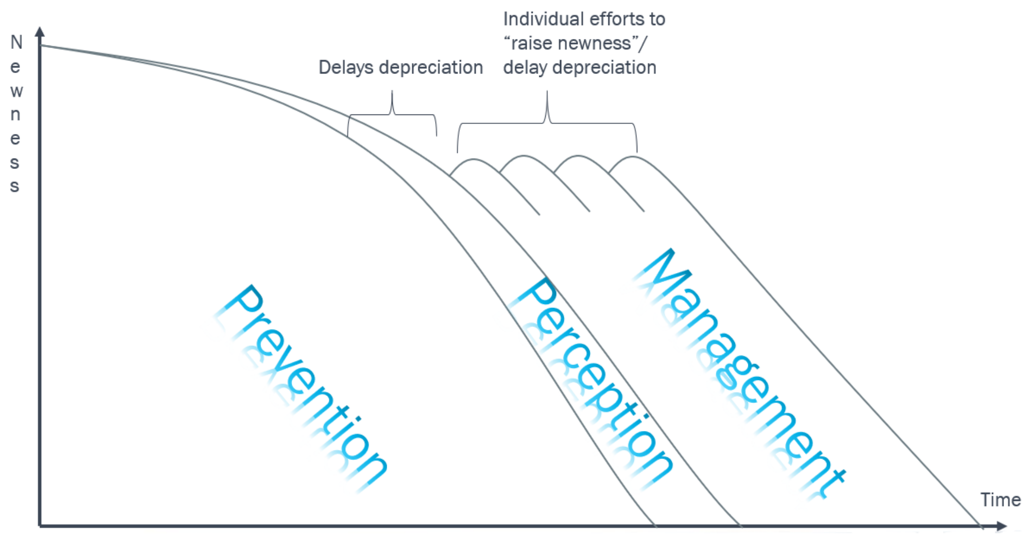


Figure 4.2: *Newness development over time considering the three questions.*

In considering the first question the decrease of newness is dependent on the time/cycles required for an abnormality (factor of interest) to occur, as soon as repeated abnormalities occur the newness grade will decrease. If continuing and considering the second question as well, the degree of newness will also be dependent on the users optical and tactile sensitivity. Thereby making decisions that make these abnormalities less identifiable the depreciation could be delayed. Finally, by considering designing for the effectiveness of individual efforts like for example cleaning procedures, the newness degree could be restored with even instances and thereby further delay the depreciation.

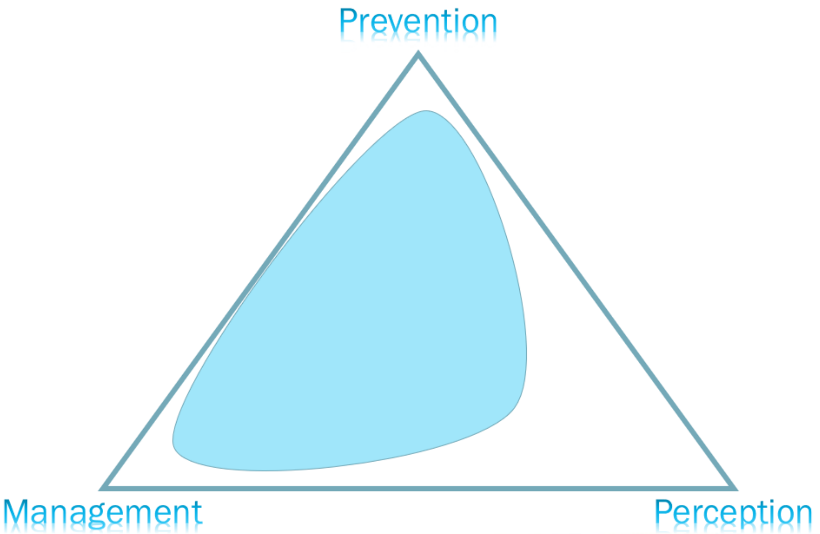


Figure 4.3: *Illustrating the need to consider solutions to all three questions.*

In any attempt to design for retained newness by neglecting either of the three question will consequently generate the need of more solutions treating the remaining questions, see Figure 4.3. For example by neglecting solutions to avoid detection will thereby render that resistance to the occurrence of abnormalities and ability to restore have to be more advanced, this simply to counter the ease of detection.

4.2 Need of definition

In order to understand why retaining newness is of interest for the organization and what their needs are a stakeholder analysis is performed. The result shows based on interest & power that the stakeholders of most importance is the mission provider and surface materials department, closely followed by the business representatives from Lynk & Co. The results correlates with both power & interest for project deliverables and power & interest of a possible solution. In Figure 4.4, the results is visualized in a 2 by 2 matrix, for methodology see chapter 3.1.2.

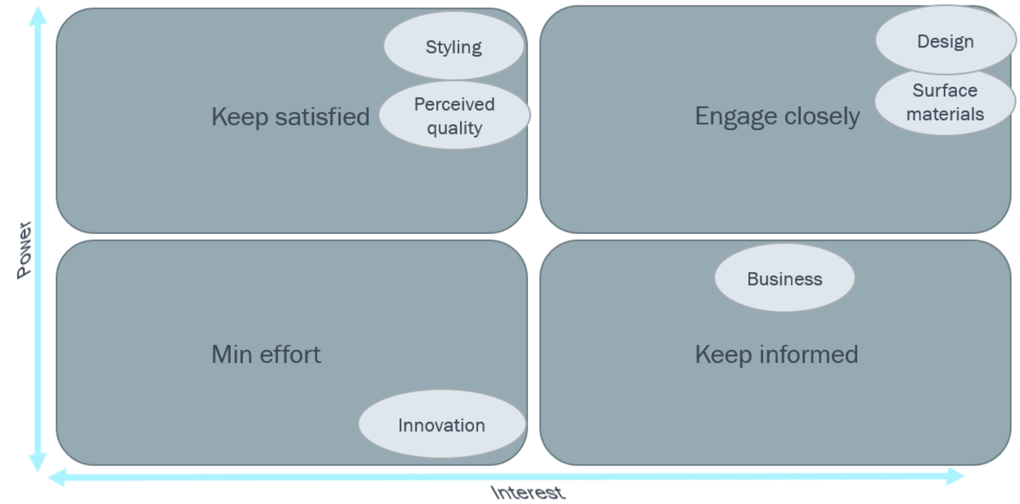


Figure 4.4: *Stakeholder Map visualizing the results from the stakeholder analysis.*

Interestingly, the stakeholder analysis conveys that any solution that would be feasible has to comply with the requirements of Styling & Perceived quality. The same trade-off is often experienced in product development projects, where conflicting needs by departments limit the solution spectrum.
The stakeholder analysis further results in a definition of the need for retained newness and more specifically an understanding of the why of the problem. Three distinct areas is repeatedly mentioned in stakeholder interviews, areas where a possible solution would have a positive impact.

- **Consumer service satisfaction**, a conclusion is that the satisfaction is partly based on the degree of newness of the interior.
- **Market value of product**, a conclusion is that the degree of newness of the interior will have an impact on the residual value of the car after the shareable cars period.
- **Cost of maintenance**, a conclusion is that designing for newness would in direct effect require less amount of maintenance.

Furthermore, based on the why, the how of the problem is formulated to support the goal of the design process. The how of the problem is seen as the holistic needs for a possible solution, and are formulated as follows:

- The product appearance of a interior part shall be as close to initial as possible **during use/sharing period**.

- The product appearance of a interior part shall be as close to initial as possible **after a five year period of use in sharing.**

- The product appearance of a interior part shall be as close to initial as possible **without requiring extensive & frequent action.**

4.3 Factors of interest

To further understand the need, a definition of "what is to be treated" to fulfill the holistic needs is defined. The initial part is to define what differentiates a car used in sharing to a car used conventionally, in form of factors that impact product appearance. The defining difference and the reason for this project is the elevated frequency of use, therefore the factors that have a higher impact on the product appearance relative to conventional use is as follows:

- **Scratching & abrasive wear**, the bi-effect of an object hitting a surface, given that the object has higher relative hardness and sufficient force to generate plastic deformation. Abrasive wear is in this thesis compared to scratching as the repeated minor occurrence of scratching.

- **Soiling particle form**, particles in the form of example dust that adhere to surfaces by adhesion forces mentioned in chapter 2.4.1.

- **Soiling liquid form**, liquids in the form of example coffee that adhere to the surface by capillary attraction or chemical bonding.

For example UV-light which is a relevant factor for retaining product appearance, is not relevant to consider in this case, as the design for UV-light resistance of today's product is sufficient. The transfer from using the car conventionally to in a sharing service does not entail elevated exposure of UV-light. Although, scratching for example is often generated by user movement, thereby an elevated frequency of use implicates elevated user movement. These factors of interest are abnormalities that differentiate the product appearance from its initial state.

4.4 Design for retained newness perspectives

To further understand the what of the problem retained newness is divided into two different perspectives. Firstly as a redesign of an already existing product and secondly as the implementation of a new function. To an already existing part there is three basic elements that could be treated to elevate cleanability & durability properties, hence designing for retained newness. The **three elements** are as follows:

- **Geometry**, the geometry of a product is the shape and size of features.
- **Base material**, the material that constitutes the majority of the product.
- **Surface**, the surface of a product which in this case concerns the texture, color and gloss.

If considering the second perspective, retained newness is seen as a supportive function to the main function of the existing product. A supportive function is as according to Johannesson [5], a function that supports and simplifies the product use without being critical of the main function. Supportive functions raise the products use value and can be necessary for good sales and acceptance [5]. This means that designing for retained newness can among other include solutions that treat the three questions mentioned in Figure 4.1 with minimal change of the products three elements. A vehicle in a simplistic manner has the main function of transporting a person from point A to point B. This function entails the need of storing the person inside the vehicle, the unwanted effect of this in our case is the allocation of human waste. Furthermore a sub-function to this main function is the need of a door to enable the human to enter & exit the vehicle. The unwanted effect from this is that the interior environment is exposed from the hence less clean exterior environment, and the door entails moving parts which elevates the risk of impact. This type of decomposition can be done in the direction of other parts as well. The main outcome is the macro understanding of what can be treated to retain newness, in Figure 4.5 retained newness is visualized as a supportive function to the main function of a particular case. In this project the case as explained further in chapter 5, is the lower cover of the door panel where the unwanted effects are scratching and adhesion soil.

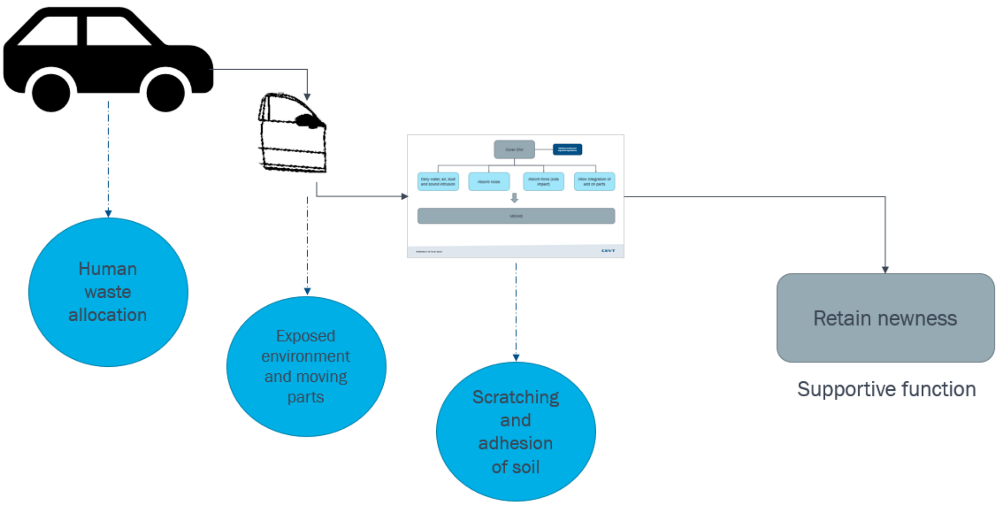


Figure 4.5: *Visualizing function effect and retained newness position.*

Hence, to eliminate the unwanted effects the product can be treated based on the three elements or by developing a supportive function. **In this project** the main focus has been on treating an existing product and thereby guideline for design of the three elements, from a solution perspective considerations of supportive functions can sometimes be more effective both in regard to cost and performance.

4.5 Needs & Characteristics

The needs regarding design for retained newness are treated iterativley starting from the holistic needs mentioned in chapter 4.2. The following needs are depicted from the holistic needs in combination of knowledge gained from the exploratory research.

- Abnormalities **shall not occur on the surface.**
- Any occurrence of abnormalities **shall not be easily visible/distinguished**
- Any occurrence of abnormalities **shall be restorable/removable with relative ease.**

Continuing on the same thought the needs are depicted further to differentiate factors/abnormalities mentioned in chapter 4.3. For example combining the need of abnormalities that shouldn't occur and the factor of scratching, the need becomes "resistant to scratching". The needs are divided in the three categories which follow the same principle as the questions mentioned in chapter 4.1. The needs can be seen in Figure 4.6 below the heading customer need, where the categories are illustrated by dotted lines.

Furthermore these needs are used in a quality function deployment (QFD) to find the correlation between them and the product characteristics. This results in an overview of where the fulfillment of these needs can be treated, as seen in Figure 4.6.

		Product characteristics						
Customer need	Rank (1-5)	Surface texture	Colour	Gloss	Geometrical features	Base material	Integration	Relation
Resistant to scratching & wear	X	9	1	1	3	9	1	1
Resistant to particle adhesion	X	3	1	1	9	3	1	1
Resistant to liquid adhesion	X	3	1	1	9	3	1	1
Ensure difficult identification of scratching & wear	X	9	9	9	1	3	1	9
Ensure difficult identification of adhered particles	X	3	9	9	3	1	1	9
Ensure difficult identification of liquid adhesion	X	1	9	9	3	1	1	9
Allow for easy restoration of scratching & wear	X	3	1	1	9	3	3	1
Allow for easy removal of particles	X	9	1	1	9	3	3	1
Allow for easy removal of liquids	X	3	1	1	9	3	3	1

Figure 4.6: *Quality function deployment visualizing the correlation between needs and product characteristics.*

For example the correlation between the need of having a product that is "resistant to scratching & wear" to the "surface texture" is high. Conclusively, when treating any product, one product property of most interest for elevating scratch resistance is the surface texture. Although, this does not entail that it is the only characteristic of relevance, surface textures have other functions that may be prioritized. Furthermore in Figure 4.6 there are no rankings of the needs, this since the ranking is dependent on the case. For example a product in the baggage space relative to a product in the drivers view will have a lower ranking overall. As seen in Figure 4.6, two more properties which are not mentioned in chapter 4.4 are added to the QFD, specifically relation and integration. The properties themselves can not be defined as a property of the product although they are properties of the system. Consider relation, which refers to the difference/similarity of the product to the adjacent product. The importance of relation becomes clear when considering identification of abnormalities. Identification is based on contrast, by having one product which is close to the initial state and another which is degraded, the realization that the other is degraded is easier to achieve. Furthermore integration is of relevance when considering restoration, if a theoretical solution requires decoupling of the product from its system, a higher grade of integration correlates with difficulty of maintenance.

4.6 Function means decomposition

The functional decomposition is used to decompose retained newness as a function and thereby generate an overview of the solution spectrum, seen in Appendix C.1. The main function is to "retain newness of product" the means to that is to ensure new/good product appearance during shareable cars use. The four secondary functions to that mean is as follows:

- **Resist** scratching and abrasive wear
- **Resist** adhesion of liquids & particles
- **Disallow** for identification of lowered/declined product appearance
- **Allow** for easy maintenance of product appearance

The secondary functions are furthermore decomposed into means, which are the same as the product characteristics from the QFD, seen in Figure 4.6. Additionally each mean is decomposed to illustrate the primary function of that mean in that situation. For example the surface texture has the main function of "Ensuring minimal contact area with incoming object", this since scratch resistance is dependent on the objects ability to stay in contact with the surface. Note that the decomposition has green boxes marked with question marks, these are the means which are not present in today's product. This will be treated further in both chapter 4.10 and 5.

4.7 Parameters & variables

To further understand why customer needs are correlated with product characteristics as in chapter 4.4, in this chapter parameters & variables of interest are explained, and the physics behind it. Subsequent chapters are divided according to the factors of interest, explained in chapter 4.3.

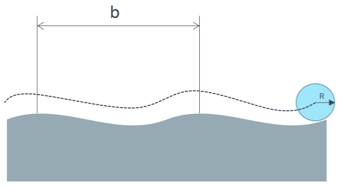
4.7.1 Scratching & wear

The needs **regarding scratching and wear** can be seen in Figure 4.6 and are the first in each category. The meaning of wear and the mechanism are explained in chapter 2.5.1.

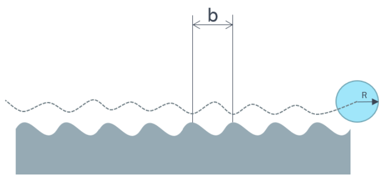
4.7.1.1 Prevention

Let consider **resistant to scratching**, the need is correlated to three characteristics, see Figure 4.6.

The surface texture correlates with resistance to scratching & wear for one main reason; to ensure minimal total contact area with the object that generates the abnormality. The object can come in contact with the surface for different reasons, for example the accidental contact with a key or the repeated contact because of user movement. Surface texture is the topography of a surface and is composed of small variations from that of an ideal surface. The texture can be generated because of the manufacturing process or purposefully designed as a value adding feature. They can be used for functional purposes, as for example a rougher texture to improve scratch resistance. The physics behind it is that a rougher texture will minimize the total contact area with the incoming object and thereby minimize the friction. Simply explained, the goal is to maximize the possibility of slip of the incoming object, if there is no contact with the surface the scratch cannot occur, principle visualized in Figure 4.7.



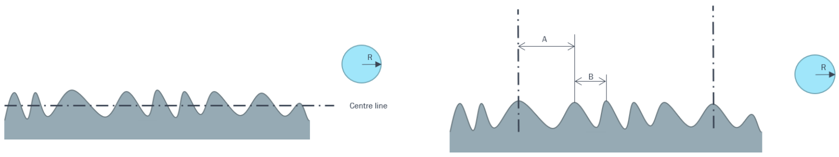
(a) *A relatively smooth surface texture where resistance to scratching is comparatively low.*



(b) *A relatively rough surface texture where resistance to scratching is comparatively high.*

Figure 4.7: *Scratch resistant texture physics.*

This concept assumes that designer has knowledge of the incoming objects radius, where the width between asperities is desired to be maximum double the radius of the object. A more accurate perspective is to consider the parameters of ISO 4287, Ra and RSm. **Ra** is defined as the "arithmetical mean deviation of the assessed profile", in English this refers to the mean roughness value in relation to a set centre line. As seen in figure 4.8a, the mean roughness value is the quota of "the mass above the centre line" and "the absence of mass below the centre line". **RSm** is defined as "mean width of the profile elements" and this within a specified length, simplistically can be explained as the frequency of asperities.



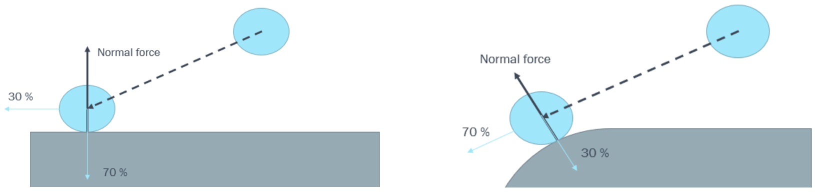
(a) *Visualizing definition of parameter Ra.*

(b) *Visualizing definition of parameter RSm.*

Figure 4.8: *Parameters for defining surface roughness and designing for optimal scratch resistance.*

As seen in Figure 4.8b, RSm is the sum of widths divided by amount of widths measured within a set sampling length. These parameters are relevant since textures are often not as uniform as in Figure 4.7, and for example the parameter b in that figure is thereby not accurate as it fluctuates. The two parameters combined can articulate both shape and frequency of the asperities, which thereby can be used for optimal design of texture. Another standard than ISO 4287, is ISO 25178 which can be used instead as it better represents the different properties of a surface texture.

The geometry of the product correlates to scratching for two reasons: one is to maximize possibility of slip and the other to avoid the incoming object. Geometry is the **form and shape** of the the treated product, scratching & wear is localized plastic deformation that occurs when an incoming object generates a compressive force at the surface that is larger than that of the materials inherent opposing force. The compressive force acting on the surface is the vector that is acting normal to the surface, the other vector is the tangential force. In design, avoiding sharp corners and similar features can be efficient when the goal is to avoid scratching in a certain region, the idea is visualized in Figure 4.9. This of course assumes that the designer is aware of the direction that the objects is coming from.



(a) *Geometry with comparatively low slip, compressive force larger than the moving force.*

(b) *Geometry with comparatively high slip, compressive force lower than the moving force.*

Figure 4.9: *Visualizing object hitting surface with associated force components.*

The same principle is in regard to avoiding contact completely, if there is knowledge of where the object is coming from, design the product or system to avoid it if possible. A self-evident and seemingly simple idea, although still worth considering as focusing on technically advanced solutions is not always the most efficient.

The base material correlates with resistance to scratching & wear for one reason: ensuring integrity by minimizing localized plastic deformation. The hardness of a material is by definition "the resistance to localized plastic deformation" and by choosing a material with comparatively high hardness values an increased product scratch resistance can be achieved, more about this in chapter 2.5.1.

4.7.1.2 Perception

Lets consider ensure difficult **identification of scratching & wear**. The need correlates highly with four characteristics and partly with the choice of base material, see Figure 4.6.

The surface texture is relevant for the purpose of human perception. Texturing can be an effective way of masking an occurred scratch, by considering the parameter **directionality**. A simple way of explaining is by considering bike trails, if all but one bike trails follow the same path, identification of the one that stands out is instant. Although if all bike trails follow different paths, to distinguish one from another becomes a more challenging task, see Figure 4.10.

(a) *Visualizing scratching in a texture that is "directional".*

(b) *Visualizing scratching in a texture that is "random".*

Figure 4.10: *Principle of scratching visibility in different texture types.*

The **base material** is relevant for the case of scratch depth, the **elastic (young's) modulus** of materials is the amount of stress needed to generate a certain amount of strain, the material stiffness. The property correlates with scratch depth, with a higher young's modulus the plastic deformation occurs at relatively low strain of the material, thereby a shallower scratch. According to barr et al. [41], a high elastic modulus limit the elastic recovery possible and the scratch depth increase rapidly only at a certain limit which is dependent on the objects sharpness. The optimal choice is therefore a material slightly above this limit.

The relation is relevant as scratch identification as mentioned in the beginning of this chapter is based on human perception. The relation of products to adjacent products is therefore of importance, in similar principle as in Figure 4.10 the visibility of a worn product among other non-worn products is self-evidently higher.

4.7.1.3 Management

Lets finally consider allow for easy **restoration of scratching & wear**. The need correlates with four product characteristics, see Figure 4.6. In this case correlation is strongly dependent on what restoration implies, is it "the reparation of the scratch" or "the replacement of the product" or other.

The surface texture is relevant for the ease of maintenance. There are different procedures to restoring scratching, the texture has two main goals which is to ensure access to the occurred scratch and to ensure that the process requires little effort. An example of the latter is that some methods include the process step "restoration of texture", the texture type can therefore be a factor for the ease of this process step.

The geometry is relevant for the ease of maintenance. Any solution that would require restoring, replacing or other, can be impacted by the **complexity** of the geometry. Lets consider replacement as a solution, the complexity of the geometry can correlate with ease of modular design. Furthermore the complexity level can be a factor when considering restoring scratch damage, or other solutions like application of protective films.

The base material is relevant for two reasons, the cost of the material and the materials ability to be treated by scratch restoring procedures. The material cost is very relevant for replacement solutions as this would entail a larger amount of products. Furthermore by defining the method used for restoration of the scratch, additional material properties of relevance can be defined. In short the choice of material "shall not add to amount of process steps and the existing process shall require little effort".

The integration degree is of relevance for maintenance methods that would require decoupling of the product from the system. The higher degree of integration implies more challenging and thereby time-consuming disassembly.

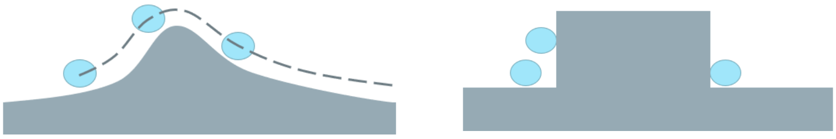
4.7.2 Particles

The needs regarding particle adhesion can be seen in figure 4.6 and are the second in each category. The mechanism of particle adhesion is explained in chapter 2.4.1.

4.7.2.1 Prevention

If considering **resistance to particle adhesion** the need is correlated to three product characteristics, see Figure 4.6.

The surface texture correlates with the need for three reasons: ensure minimum active van der waals forces, electrostatic attraction forces and mechanical interlocking. Electrostatic charge can occur on a surface when two surfaces are rubbed against each other. The charge generated by rubbing increases because of two variables, one being the pressure between the two surfaces and the other being the increase of the parameter **RSm**, explained further in chapter 4.7.1.1. By designing surface texture to minimize electrostatic attraction amount of particles adhering to the surface would theoretically minimize. Furthermore the texture type can be a factor in adhesion & removal of particles, specifically the grain shape, as visualized in Figure 4.11.



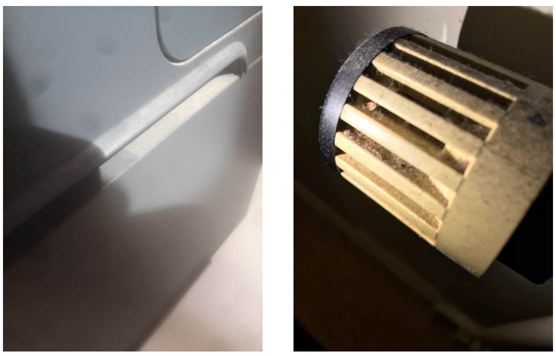
(a) *Visualizing particles moving across what can be seen as a smooth grain type.*

(b) *Visualizing particles locking in the corners of what can be seen as a rough grain type.*

Figure 4.11: *Principle texture type for particle adhesion.*

For a texture with a relatively smooth grain type the probability of particles lodging in the creases of the texture (see Figure 4.11b) is minimized.

The geometry is of relevance for one specific reason, the avoidance of typical geometries that are known to allocate particles. The core principle is the same as in Figure 4.11, the mechanical locking of particles because of sharp corners, holes with a high depth to radius ratio, and other geometrical features that would stop the movement of particles generated by for example wind or gravity. Examples of these types of geometries can be seen in Figure 4.12.



(a) *Visualizing typical particle allocation geometry.*

(b) *Visualizing typical particle allocation geometry.*

Figure 4.12: *Principle geometries that allocate particles.*

The base material is of relevance in this case based on the material properties regarding anti-statics, meaning for the purpose of minimizing electrostatic attraction. A materials anti-static property is defined by the ability of the material to conduct charge away, polymers are insulators and the build of charge on the surface is therefore as the name suggests static. The parameters used to determine this is among other the materials volume resistivity (electrical resistivity) which is the inverse of the materials electrical conductivity. In article by Zhang et al. [59], materials are combined that are both positivley- and negativley charged against a reference surface to generate a non charging surface.

4.7.2.2 Perception

If considering difficulty of **identification of particles** adhered to surfaces, the correlating characteristics can be seen in Figure 4.6.

The surface texture is of relevance for the same principle as in chapter 4.7.1.2, although in this case can be arguably slightly less effective. This because of the fact that with particles it implies the addition of material on to the surface, only if the particles have no distinct colour or gloss difference the texture can be an effective means. Although, considering the tactile sense texturing can arguably be effective, a smoother surface would allow for users to identify particles that contrast to that of the expected surface.

The geometry is of relevance for the same principle as in chapter 4.7.2.1, if there is features that have a tendency of allocating particles. The population of particles will be distinctively higher at these features than anywhere else on the product, thereby identification of particles will be comparatively rapid. This of course implies that the feature is visible, the same argument can be made for delayed identification in any other case.

The relation is of relevance for the same principle as mentioned in chapter 4.7.1.2.

4.7.2.3 Management

If considering easy **removal of particles** the correlating product characteristics are as follows.

The surface texture is of relevance for the purpose of reaching & detaching the adhered particles with respective cleaning procedure. The texture should preferably be designed to be smoother, in the sense of peak frequency, valley depth and grain shape. The parameters of relevance are therefore **Ra**, **RSm** and the texture type. Another possibility with texture is to design for elevated wettability of the surface, as higher wettability would imply improved spreading of cleaning agents (if liquid).

The geometry is of relevance for the same principle as mentioned in both chapter 4.7.2.1 & 4.7.2.2, geometrical features that have a tendency of allocation particles. The geometrical features are negative both from the prevention and perception of particle adhesion, in this case it is not as explicit. It is dependent on the removal/cleaning procedure, a localization of particles can be effective for cleaning if the cleaning procedure actually can access the particles feature. In similar fashion, if the procedure cant access the particles the localization is consequently negative for easy removal of particles.

The base material is of relevance in this case primarily for ensuring the integrity of the product during removal/cleaning procedure. The parameters of interest is strongly dependent on the procedure, but parameters that could be of interest is the materials **chemical resistivity** and the **hardness**. This for the reason of ensuring that any procedure performed does not subsequently generate damage to the product, for example scratching generated by tool used in procedure, hence the hardness property. Another relevant parameter is the wettability/surface energy of the material, as a material that would allow for high wettability could allow for more efficient removal of particles through cleaning liquids.

The integration is of relevance primarily for the purpose of any easy removal of particles that would imply replacement of the product. The degree of integration today is a parameter that illustrate how easy it is to redesign for modularity. This of course only relevant when we are considering redesign of an existing product, in the design of a new product that intends to be modular the integration should already be considered.

4.7.3 Liquids

The needs regarding liquid adhesion can be seen in Figure 4.6 and are the last in each category.

4.7.3.1 Prevention

If considering **resistance to liquid adhesion** the correlating product characteristics can be seen in Figure 4.6.

The surface texture is of relevance for the wettability of the surface, by designing texture types that treat the contact angle of liquids, a hydrophobic surface can be achieved and thereby minimizing amount of liquid adhering to the surface, see Figure 4.13. The governing parameter is thereby the **tex-**

ture type, more about this in chapter 4.10.

(a) *Illustrating surface texture that allows for wettability.* (b) *Illustrating hydrophobic surface texture.*

Figure 4.13: *Illustrating two different texture types with regard to liquid adhesion.*

The geometry is of relevance for the same purpose as in chapter 4.7.2.1. A feature that has the tendency of allocating particles will have a similar effect on liquid contaminants.

The base material is of relevance to ensure minimal wettability of the surface. The material parameter of relevance is the **surface energy (Dyne/cm)**. The lower amount of surface energy of a material the lower the wettability of the surface, and thereby the ability of liquid contaminants adhering to a surface is decreased.

4.7.3.2 Perception

If considering ensuring difficult **identification of adhered liquid** the correlating product characteristics can be seen in Figure 4.6.

The geometry and the relation is of relevance for the same purpose as in chapter 4.7.2.2.

4.7.3.3 Management

If considering allowing for easy **removal of liquids** the correlating product characteristics can be seen in Figure 4.6.

The surface texture is of relevance for the same principle as in chapter 4.7.2.3, to allow respective cleaning medium to reach the contaminated area.

The geometry, base material and integration of relevance for the same purpose as in chapter 4.7.2.3.

4.8 Requirement specification

As a conclusion of the exploratory research regarding what designing for retained newness entails a requirements specification is created. The requirements are categorized based on the product property they treat and the need they fulfill, seen in Appendix B.1. Each requirement is correlated with a specific value/metric to illustrate what parameter is of relevance. The product properties in this case including, texture, geometry and base material. For the case of identification properties that also should be included is the colour and gloss. This is not included in this case for the reason of lack of knowledge, although very relevant since it treats contrast sensitivity. The requirements list is generic and for the purpose of redesigning an existing product without the addition of new features, a further developed requirements list can be seen in the case study, chapter 5.

4.9 Material research

To understand what materials can be of relevance for the purpose of elevatning cleanability & durability a benchmarking of materials & additives used for relevant applications is analyzed. To support the benchmarking an additional analysis is performed with a material database, the analysis is performed based on knowledge gained of important parameters during the initial part of the exploratory study.

4.9.1 Base material

The material search is based on finding materials resistant to the factors of interest mentioned in chapter 4.3.

4.9.1.1 Scratch & wear

For material properties of interest and why see chapter 4.7.1.1. The two properties of comparison in the database analysis is the hardness (Vickers) and the young's modulus. Furthermore an initial limiting of the search is done by the following limitations:

- Price, 10 - 50 Sek/Kg
- Young's modulus 1,5 - 4 GPa

- Water(fresh), in use resistance is acceptable or excellent
- Water(Salt), in use resistance is acceptable or excellent

The first chart visualizes a set of possible material choices, the more often used materials in the interior (PP and ABS) are not the optimal choice with the above limiting and comparative properties.

To further filter the materials visualized, the two axial properties are limited. The hardness set to a minimum 10 HV to match the hardness property of materials used today. Furthermore, the young's modulus is set to a minimum 2 GPa based on that sensitivity to scratch depth changes is deemed by Barr et al [41] to be higher for materials with values below 2 GPa.

Table 4.1: *Materials of interest for scratch resistance application in automotive interior, data from software CES [60].*

Materials	Hardness(Vickers)	Youngs modulus (GPa)	Price(Sek/kg)
PP – (GF reinforcement)	12 – 18	2,6 -5	16 – 20
PA6 (66) –(MD reinforcement)	16 – 18	2,2- 4,51	20 – 24
PBT	17 – 18	1,9-3	21,3 – 22,2
PC-(GF reinforcement)	18 – 24	3,1 – 4,14	22,3 – 26,4
(PC+PET) – GF10	18 – 20	3,1 – 4,83	23,8 – 27,1
POM(Co) & POM(Co) -L	15 – 22	2,3 – 3,2	20 – 31
PTT & PTT-GF15	20 – 41	2,4 – 6,5	18 – 34
ABS	5,6 -15,3	1,1 – 2,9	23,8 – 24,2
(ABS + PC)	7 - 15	2,41 – 2,62	27,2 – 29,3
(ASA +PC)	14 – 18	2,3 – 2,6	26,3 – 28,6

In Table 4.1 a collection of materials relevant for scratch resistant applications are proposed. The materials are filtered based on earlier mentioned limiting properties and educated guessing, for example PC-L is filtered because of the relatively high cost in comparison to materials used today (even if the cost is within the limiting maximum). The proposed materials are also filtered based on application today, this in an attempt to ensure that use in automotive interior is relevant. Although this can not be confirmed as each application has the need of different material properties which are not considered in this analysis.

The benchmarking for scratch resistant base materials results in similar materials as in Table 4.1, although often with different types of additives or fibers. From a pure materials perspective the benchmarking resulted mainly in two types of advanced materials that can be of relevance, although their feasibility is questioned as there is today very limited use of these. These are self-healing materials, which are theoretically not scratch resistant, in fact its the materials inherent ability to restore damage that is of interest. The materials are based on the concept of management rather than the concept of prevention.

- **Self-healing polymers** recovers lost material through some type intrinsic or external stimuli. The polymer "senses" that the damage has occurred and through for example nanoparticles release an healing agent that closes the occurred scratch. Applications today include for example glasses and the exterior of vehicles.
- **Shape memory polymers(SMP)**, materials that have two defined shapes where the initial is defined by the manufacturing process and the second shape is defined by a process called programming [61]. The polymer is designed to be able to return to the initial shape by an external stimuli for example heat [61]. The possibility of returning to the initial shape after scratching can be of interest for application, although research suggest that only using SMP is not sufficient [61], can be due to the reason that SMP can only recover strain and not recover lost volume.

4.9.1.2 Particles

The overall conclusion is that materials build up triboelectric charges by rubbing, the type of charge and amount is dependent on what material they are rubbed against. The buildup is what we know as static electricity, is the build of electric charge at the surface (hence static), to minimize the buildup the material needs to be able to conduct the charge away from the surface. Materials that could be of interest can be seen in Table 4.2.

Table 4.2: *Materials of interest with preferable particle adhesion properties relevant for application in automotive interior, data from software CES [60].*

Materials	Electrical resistivity (µohm.cm)
PP-Me10	6,75e8 - 4,33e9
PC-Me5	1e6 – 1e7
ABS	
Nitrile rubber(NBR-CD30-P)	1e10-1e16

4.9.1.3 Liquids

The material property of relevance for the purpose of resisting adhesion of liquids is the surface energy which is measured in Dyne/cm. The polymeric materials that can be of interest can be seen in Table 4.3.

Table 4.3: *Materials of interest with preferable liquid adhesion properties relevant for application in automotive interior.*

Material	Surface energy (Dyne/cm)
PTFE (Fluoropolymer)	18
Polyvinyl fluoride	28
PP(Polypropylene)	29
PE (Polyethylene)	31

The results is based on the categorization of surface energy by 3M [62]. In general polymers have a lower surface energy than other materials like metal, meaning that the wettability of polymers is relatively low.

4.9.2 Additives

The benchmarking regarding materials resulted in mainly additives that can elevate the base material properties of interest, properties of interest are based on the factors in chapter 4.3 and are mentioned in chapter 4.7. The benchmarking resulted in the following collection of additives.

- **Hydrophobic additives**, lowers the wettability of the base material.
- **Anti-static additives**, enhances the resistance to particle adhesion due to electrostatic attraction.
- **Anti-stick additives**, same principle as the hydrophobic additives.
- **Anti-whitening additives**, for example silicone-based pellets used to prevent the scratch from being visible by minimizing its whitening effect.
- **Anti-scratch additives**, for example glass fibres, silica nanoparticles or minerals among other elevates the materials hardness property.

The use of additives in materials can be efficient although consideration of possible loss of performance in other material properties is of importance.

4.9.3 Discussion

From a materials perspective the materials used today are not necessarily of inferior performance than that of "new materials" and "materials used in other industries", this if considering that the materials of use today are chosen based on many other requirements of relevance. A driving factor is often the cost of the material and by that there is no surprise that the materials more often used are ABS and PP. In regard to strictly material performance regarding cleanability & durability there are some materials and additives that could be considered, although even in these cases there should be consideration regarding added cost in comparison to added value for the owner & user. Furthermore the addition of additives & material changes correlate with many more requirements than that of other product characteristics, thereby even if the material is the foundation of the product, changes to materials should be done with caution. Instead, design should focus on on possible changes to geometry and the elements of the surface, as there at least as many if not more possibilities to elevate cleanability & durability properties.

4.10 Technology research

The technologies can be divided in three categories, films, coatings and texture. In this chapter the three categories will be discussed and why their application could be of interest.

4.10.1 Films

Films refers to a layer of a material that can be applied on to a surface for a certain purpose. Films range from short term application like transport films, to long term applications like purpose made scratch resistant films. They can also range in color, gloss, opacity, material and some are used purely for decorative purposes. The advantage of films is that they are changeable, can elevate product properties without altering the three basic elements mentioned in chapter 4.4. The disadvantages are that the product appearance has distinct changes and the usage of material becomes higher (specifically if they are more temporary).

4.10.2 Coatings

Coatings refer to a layer of a solution applied on top of the base material, coatings in regard to films are not solid during application but can generate a thin film after application. The advantages discovered is that coatings are normally cheaper than films and can in some case have a lower effect on product appearance. The disadvantage is that application can require extensive industrial processes and the coatings are more permanent. Coatings as with films can be designed to have functional purposes, and there are several coatings that can be useful for cleanability & durability.

4.10.3 Texture

Textures as mentioned in chapter 4.7 is of interest for all factors of interest. In regard to technology research, the use of textures have developed further than the basic idea of roughness, direction and type. A recent trend is to research the possibility of using biomimicry to elevate cleanability & durability properties. The two main biological phenomenons treated is: the lotus flowers ability to disallow liquid adhering to the leafs, also called the lotus effect or "self-cleaning" effect and the similar ability with gecko feet which have a tendency of always staying clean. For example a European union sponsored project called NANOCLEAN treated the possibility to mimic the "self-cleaning" effect of the lotus leaf surface texture on injection molded plastic for large scale applications like automotive [63]. In a PHD thesis by E Søgaard [64], its concluded that its possible to manufacture superhydrophobic surfaces through polymer injection molding and based on the research there are at least two different texture types that can be used effectively. The application of these surfaces in the automotive interior have great potential, some consideration to however the performance of these textures change over time, specifically when the surfaces are exposed to scratching & wear. Another point to consider is that these textures allow for "self-cleaning" of a specific surface, the liquid does not disappear and the relevant questions to ask is where is it finally accumulated. The advantage to functional textures like these is that there is no addition of material or chemicals to achieve a certain property.

5. Case study of lower cover for elevating cleanability & durability

5.1 Lower cover & Functional analysis

The lower cover is a subsystem to the Door trim, which consist of different parts that include among other the armrest, interior door handle and the lower cover. The lower cover is the panel on the bottom of the door trim, see Figure 5.4. To understand the system a simple functional decomposition is made based on the DPR, as seen in Figure 5.1.

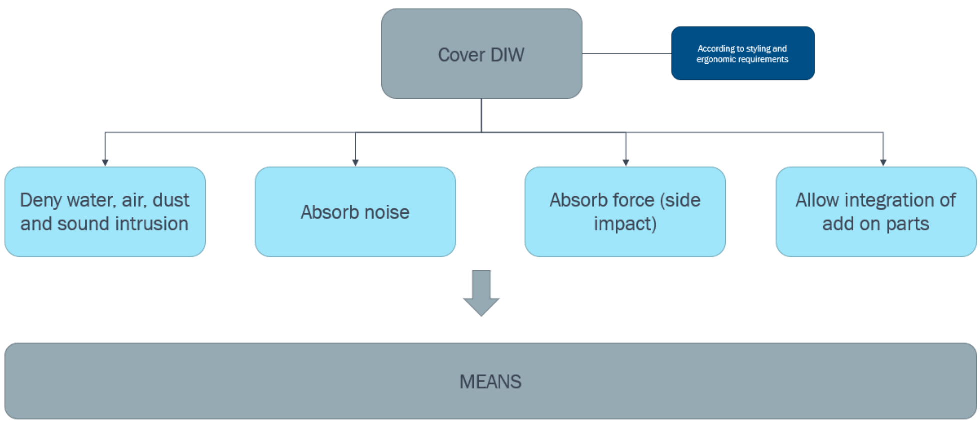


Figure 5.1: *Functional decomposition of Door trim.*

The main function is to "Cover DIW", as it is situated on the sheet metal door (Door in white) the main purpose is to "hide" the less appealing door behind it. The function is furthermore to be fulfilled according to the requirements stated by the styling- and ergonomic department. "Cover DIW" is decomposed into four sub-functions that in summary include the denial of substances from the exterior environment entering the interior, the improvement of safety from impacts and finally allowing integration. The lower cover is thereby one of the means for the door trim to fulfill these functions. The lower cover itself is a critical system in regard to design for retained newness, the product is a typical example of a part that is exposed to relatively high abrasive wear & scratching and particle adhesion in the form of dirt. This among other an effect because of impact by shoes during entry & exit of vehicle. The lower cover is often the first part of the interior that is identified as worn or dirty, thereby identified as "used" and consequently "old". The lower cover treated in this case study is composed of black ABS and texturing that can be described as mid range roughness & the mimicking of sand. If considering the means of the lower cover the part can be divided into the three elements mentioned in chapter 4.4.

5.2 Benchmarking lower cover

The material selection on the lower cover is analysed on 16 car brands and 31 different car models. See all the car brands in Table 5.1.

Table 5.1: *A table of the 16 car brands which are benchmarked.*

Cars brands which are benchmarked			
Audi	Jeep	Mitsubishi	Tesla
BMW	Land Rover	Opel	Toyota
Chevrolet	Mercedes	Porsche	Volkswagen
Ford	Mini Cooper	Renault	Volvo

The material selection of the lower cover for different car brands are documented in the diagrams shown in Figure 5.2 and 5.3. The diagrams show that ABS and PP is the most common materials used for the lower cover. More specifically, for premium cars ABS is the most common, for off-road cars PP, for segment C SUV cars PP and for the shareable cars PP. Materials that is less frequently used and that stand out from the general is PVC and PE.

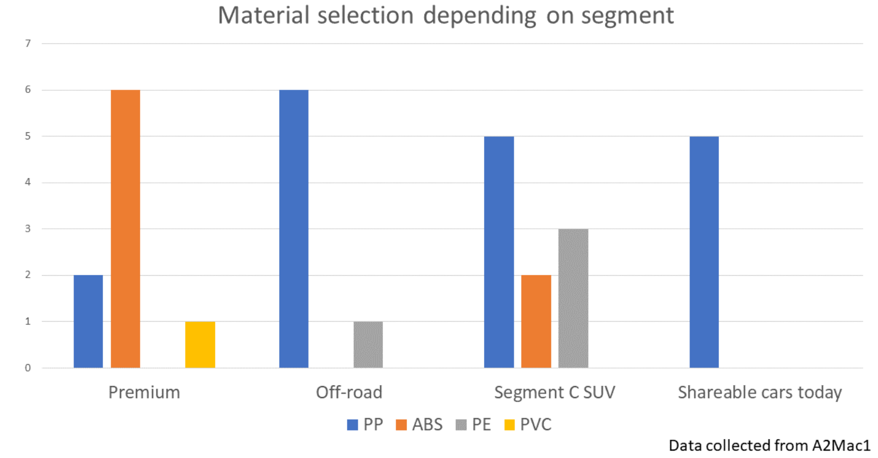


Figure 5.2: *The figure illustrates a diagram which shows the material selection for the lower cover (of the door-panel) depending on different car segments [53].*

As seen in Figure 5.3, during recent years (2015-2019) ABS is becoming a more frequently used material. PP is still the material of choice, although ABS use is elevating. The reason for this can be argued for by the elevated hardness of ABS in comparison with PP, as the resistance to wear is strongly correlated with the material property.

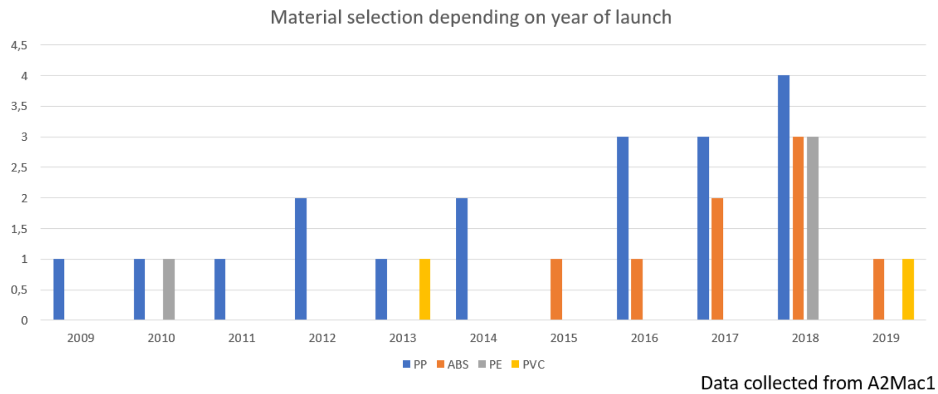


Figure 5.3: *The figure illustrates a diagram which shows the material selection for the lower cover (of the door-panel) depending on which year it has been launched [53].*

The lower covers which are analyzed are generally designed in two different manners. One way is to have a whole merged part for the panel carrier and the lower cover, see Figure 5.4. The other way is to have a less integrated product, this by having one part (only the lower cover) which is mounted to the panel carrier in a later stage, see Figure 5.5.

The most common design with regard to the analyzed cars is to have a whole merged part, twenty that has whole merged part and eleven that has one part which is mounted in a later stage.

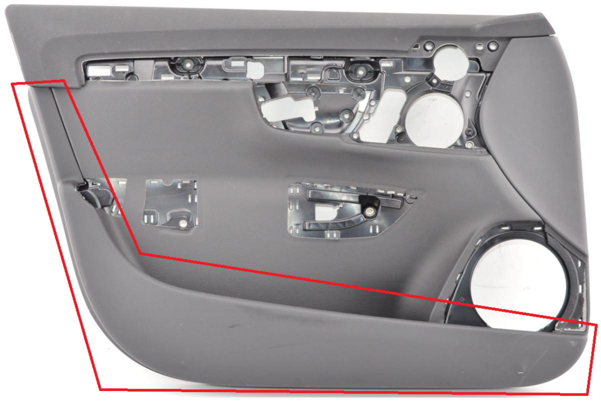


Figure 5.4: *The lower cover for Volvo S90. It is designed as a merged part with the panel carrier and the lower cover. (The red marked part is the lower cover). Copyright A2Mac1 [53].*

Figure 5.5: *The lower cover for the car model BMW X1. It is designed as one part (only the lower cover) which is mounted to the panel carrier in a later stage. Copyright A2Mac1 [53].*

5.3 Materials

Material choice is dependent on situation in chapter 4.9 generic materials & additives for an automotive interior are presented. The base material choice is dependent on requirements that are not considered in this project, for example heat resistance, with regard to the materials proposed in chapter 4.9 there is no apparent reason to why a material could not be used. Although as the case for the lower cover is more prone to scratch & wear and particle adhesion, materials suggested for preventing liquid adhesion are less relevant. Thereby in this case the material choice is limited to the first two collections of proposed materials mentioned in chapter 4.9. In similar fashion additives of interest are also limited based on relevant factors of interest that the lower cover is exposed to.

5.4 Technology

In this chapter, the technologies which are feasible for the lower cover is presented. The technologies are divided into films, coatings and textures.

5.4.1 Films

Films are covered in chapter 4.10, the films of interest for this case are primarily the following based on the same principle as the material choice.

- Scratch & wear resistant films that support in preventing the occurrence.
- Temporary films that support the <u>management</u> of occurrence.
- Anti-static films that support in <u>preventing</u> the occurrence.
- Decorative films that support in <u>perception</u> of said occurrence.

5.4.2 Coatings

Coatings are covered in chapter 4.10, the coatings of interest for this case have similar function as the films mentioned in chapter 5.4.1. In difference from the films coatings can be applied with a slightly more discrete effect on the product appearance.

5.4.3 Texture

Texturing as mentioned in chapter 4.10 exist with functional purposes like the "self-cleaning" texture. There also texture types that are designed with less advanced techniques, textures that are supposedly easier to clean and more scratch resistance than other textures, the basics behind this is mentioned in chapter 4.7. In the case of the lower cover a texture should be designed with the exposure of scratching & wear or/and particles in mind, and optimized based on this. Hence, trade-offs may occur, for example to design a texture for management of particles and prevention of scratching & wear would imply that the goal is to achieve a "smooth" texture and "rough" texture simultaneously. In Figure 5.6, the trade off is presented in an Euler curve where the optimal solution would be somewhere on the line illustrated with yellow color.

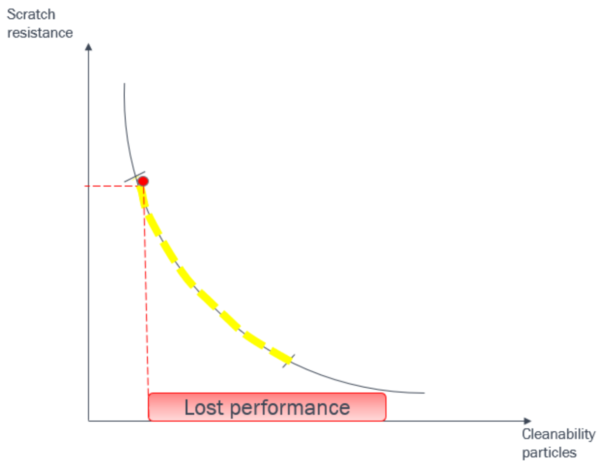


Figure 5.6: *Euler curve illustrating the trade off with scratch resistance texture and "cleanable" texture.*

Important to consider in these trade-offs is: where else is there a possibility to impact respective need. If there is a possibility to enhance the cleanability of particles in another way (e.g material choice) and furthermore if the prevention & perception (see chapter 4.1) of particles is well designed, the texture can be designed for scratch resistance and the lost performance of cleanability is recovered by other solutions.

5.5 SWOT-analysis

The SWOT-analysis resulted in an analysis of the benchmarked lower covers and the material and technology research. This with regard to how well the lower cover and the car which is going to be used in a sharing pool would perform.

The points that could be stated in the SWOT-analysis is that the material choice for the lower cover today (ABS) is a strength. This can be stated with regard to the material properties since it has a higher hardness than PP which is the most common used material for sharing pool cars. Another strength which can be seen is that since the car has not been launched to the market, changes can be done to better meet the requirements.

Further on, there are a lot of opportunities with regard to materials and surface texture, e.g. there are studies on how to gain a hydrophobic texture by using biomimicry technologies as mimicking the lotus flower leaf. But the technology readiness level is low which elevates the uncertainty level and becomes a weakness for today and an opportunity for the future. This brings us to the other weaknesses, e.g. it is not adapted for usage in a car sharing pool since the requirements stated are for a regular usage car.

The biggest threat mentioned could be that the car industry is a rapidly changing industry which is moving towards autonomous cars. This can entail large changes with regard to the design of the entire car. See Appendix D for the performed SWOT-analysis.

5.6 Requirements specification for Case

The generic requirements specification is presented in chapter 4.8, for the case study it is further developed, see Appendix B.2. The added requirements treat other aspects than the three elements mentioned in chapter 4.4, this is to among other ensure that solutions that would entail additional "means" (see green boxes in Appendix C.1 and C.2) are considered. For example requirement **A.5** is defined as "Maximal resource efficiency", which implies that any solution shall not for example imply the use of "changeable films" that are changed in a daily rate. Furthermore, requirement **A.2** is defined as "minimal impact on Perceived- and Aesthetic quality", hence if redesigning an existing product, the goal to design for retained newness shall not imply a radical change of the product appearance if not approved. In addition to the added requirements, all requirements are now ranked based on the location and the relevant factors of interest (see chapter 4.3).

5.7 Idea and concept generation

The brainstorming sessions with the CEVT employees and within the project group resulted in 33 different sub-ideas and 13 whole concepts.
The sub-ideas can be seen in the morphological matrix, see Appendix F.2. The materials that are found are grouped depending on their properties of interest, e.g. higher hardness than the baseline and lower surface energy than the baseline. These materials can be seen in chapter 4.9.1. The sub-ideas are combined in the morphological matrix to 35 concepts, including the 13 from the brainstorming, see Appendix F.1. These concepts can be categorized based on following:

- **Baseline** - entailing no change of the three sub-elements (surface, geometry and base material).
- **Redesign** - entailing change to at least one of the three sub-elements.
- **Additional feature** - addition of a feature (e.g. coatings) on to either the baseline or redesigned product.
- **Macro ideas/concepts** - ideas and concepts which could for example control the source that causes the damage and/or dirt, or help refurbish the product, e.g. by having a air cleaning system, particles will not be present in the car.

These concepts and description of them can be seen in Appendix F.1 & G.

5.8 Concept screening and selection

In this chapter the results from the elimination matrix, Pughs matrix and weighted Pughs matrix will be presented.

5.8.1 Elimination matrix

The basic problem is the decline in product appearance of the lower cover. There by the concepts that are not eliminated in the eliminations matrix are those that mainly treat the lower cover, e.g. air cleaning is eliminated. The basic requirements are the requirements used today with regard to scratch & wear resistance, adhesion of particles and liquids resistance. The evaluation depending on the technology readiness level is based on what is found in the pre-study about the technologies used. For example hydrophobic textures have proven functionality but has not been implemented in the automotive interior, thereby eliminated in the matrix. Furthermore, there is no cost specified which entailed that all the concepts generated fulfills the criterion. The environmental criterion is based on if the concept uses an unnecessary amount of material, e.g the changeable films without any cleanability or durability elevating properties, the absence will render the need to change the film more frequently. The criterion regarding the company product program was evaluated depending on if the concept considers the sharing concept or not. The last criterion is evaluated depending on if the information needed about the concept is sufficient to advocate for the use of it.

In the Elimination matrix, 17 concepts are eliminated and 18 concepts fulfill the criterion's. The concepts which continue to the next phase can be seen in Figure 5.7. The 17 concepts eliminated, fail because they either don't solve the base problem, don't fulfill the requirements, the Technology readiness level is too low or the environmental impact is to high. To see the whole Elimination matrix, see Appendix H.1.

1	+	+	+	+	+	+	+	+
3	+	+	+	+	+	+	+	+
6	+	+	+	+	+	+	+	+
7	+	+	+	+	+	+	+	+
8	+	+	+	+	+	+	+	+
9	+	+	+	+	+	+	+	+
10	+	+	+	+	+	+	+	+
11	+	+	+	+	+	+	+	+
14	+	+	+	+	+	+	+	+
15	+	+	+	+	+	+	+	+
16	+	+	+	+	+	+	+	+
18	+	+	+	+	+	+	+	+
20	+	+	+	+	+	+	+	+
21	+	+	+	+	+	+	+	+
22	+	+	+	+	+	+	+	+
23	+	+	+	+	+	+	+	+
25	+	+	+	+	+	+	+	+
26	+	+	+	+	+	+	+	+

Figure 5.7: *The Eliminations matrix with the concepts that is further analyzed in the Pughs matrix.*

5.8.2 Pughs matrix

The Pughs matrix is performed twice, see Appendix I for the two matrices. The first iteration of the Pughs matrix, contains 18 concepts that are compared with the baseline(baseline explained in chapter 5.1). This resulted in further analysis of 13 concepts including the baseline, see Figure 5.8. The evaluation is based on criterion's generated from the concept of prevention, perception and management (see chapter 4.1 & 4.5). Additional to these, criterion regarding cost, perceived quality, implementation, environmental impact and weight are considered.

The 6 remaining concepts are eliminated, this based on their rating compared to the further analyzed concepts. Furthermore all of them had a lower rating than the baseline, which entails a final "score" of lower than 0.

Criterion	Baseline	1	6	8	9	10	14	16	20	21	22	23	25
Scratching and abrasive wear resistant		-	+	+	+	+	0	+	0	+	0	+	+
Ensure resistance to adhesion of liquid		-	+	0	0	-	+	0	+	0	0	+	0
Ensure resistance to adhesion of particles		-	+	0	0	0	+	0	0	0	0	0	0
Disallow identification of scratches and wear		+	0	0	0	+	0	0	0	0	0	+	+
Disallow identification of adhered liquid		0	0	0	0	0	0	0	0	0	0	0	0
Disallow identification of adhered particles		+	0	0	0	0	0	0	0	0	0	0	0
Allows easy maintance of scratches and wear		+	0	+	+	+	+	0	+	+	+	+	0
Allows easy maintance of adhered liquid		+	+	+	+	+	+	+	+	+	+	+	0
Allows easy maintance of adhered particles		+	+	+	+	+	+	+	+	+	+	+	-
Ensure minimal addition to service life cost		0	+	-	-	-	0	0	-	0	-	-	0
Oblige to styling and ergonomics requirements		-	-	-	0	-	-	0	-	-	0	0	0
Enable simple maintenance		+	+	+	+	+	+	0	+	+	+	+	0
Allow for easy implementation		-	-	-	-	-	-	-	-	-	-	-	-
Inflict minimal environmental impact		0	-	-	-	-	-	-	-	0	-	-	0
Ensure minimal weight impact		0	0	0	0	-	0	0	0	0	0	0	0
SUM (+)	0	6	7	5	5	6	6	3	5	5	4	7	2
SUM (0)	0	5	5	6	6	3	6	10	6	8	8	5	11
SUM (-)	0	5	3	4	3	6	3	2	4	2	3	3	2
Net value	0	1	4	1	2	0	3	1	1	3	1	4	0
Ranking	5	4	1	4	3	5	2	4	4	2	4	1	5
Further development (YES/NO)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Figure 5.8: *The winning concepts of the first iteration of the Pughs matrix.*

The second iteration of the Pughs matrix resulted in further analysis of 9 concepts, see Figure 5.9. There is 2 concepts (concept 9 and 22) which is further analyzed even tho they have a final score of negative one. These are further analyzed since there is a short range between the concepts which had the highest score, which is 1. The concepts which are eliminated has -3 and -4 which is too low to be further analyzed.

Criterion	23	1	8	9	10	14	20	21	22
Scratching and abrasive wear resistant		-	0	-	+	-	-	0	-
Ensure resistance to adhesion of liquid		-	0	-	-	+	+	-	-
Ensure resistance to adhesion of particles		-	0	0	0	+	0	0	0
Disallow identification of scratches and wear		-	-	-	+	-	-	-	-
Disallow identification of adhered liquid		0	0	0	0	0	0	0	0
Disallow identification of adhered particles		+	0	0	0	0	0	0	0
Allows easy maintance of scratches and wear		0	0	0	0	0	0	0	0
Allows easy maintance of adhered liquid		+	+	+	+	+	+	+	+
Allows easy maintance of adhered particles		+	+	+	+	+	+	+	+
Ensure minimal addition to service life cost		+	-	0	0	-	0	0	0
Oblige to styling and ergonomics requirements		-	-	0	-	-	-	-	0
Enable simple maintenance		+	+	+	+	0	+	+	+
Allow for easy implementation		0	0	0	0	0	0	0	0
Inflict minimal environmental impact		+	0	-	-	0	-	+	-
Ensure minimal weight impact		0	0	0	-	0	0	0	0
SUM (+)	0	6	3	3	5	4	4	4	3
SUM (0)	0	4	9	8	6	7	7	8	8
SUM (-)	0	5	3	4	4	4	4	3	4
Net value	0	1	0	-1	1	0	0	1	-1
Ranking	2	1	2	3	1	2	2	1	3
Further development (YES/NO)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Figure 5.9: *The winning concepts of the second iteration of the Pughs matrix.*

5.8.3 Weighted Pughs matrix

The Weighted Pughs matrix resulted in one winning concept which is Concept 10, see Figure 5.10. It has comparatively good resistance to scratches & wear. If a damage occurs or dirt gets attached to the surface it will not camouflage and delay detection, but since it is modular, it can be changed and maintained. Further on, it is a extra part on the original lower cover. This will entail that the lower cover will be protected and product appearance will be retained until the sharing period is over. This may have a negative affect on the product appearance during the sharing period, since it entails styling changes and a wish being avoid major changes to the styling of the lower cover.

Criterion	Weight (1-5)	Reference	Rating 9	9	Rating 10	10	Rating 22	22	Rating 23	23
Scratching and abrasive wear resistant	5	25	5	25	5	25	3	15	4	20
Ensure resistance to adhesion of liquid	1	5	1	1	3	3	2	2	3	3
Ensure resistance to adhesion of particles	3	15	1	3	3	9	2	6	2	6
Disallow identification of wear	5	25	3	15	3	15	3	15	4	20
Disallow identification of liquid	1	5	2	2	2	2	3	3	2	2
Disallow identification of particle	3	15	2	6	2	6	3	9	2	6
Allows easy maintance of wear	5	25	5	25	5	25	5	25	5	25
Allows easy maintance of liquid	1	5	5	5	5	5	5	5	3	3
Allows easy maintance of particle	3	15	5	15	5	15	5	15	3	9
Ensure minimal addition to service life cost	4	20	2	8	3	12	2	8	3	12
Oblige to styling and ergonomics requirements	5	25	5	25	2	10	5	25	4	20
Enable simple maintenance	3	15	5	15	5	15	5	15	5	15
Allow for easy implementation	4	20	3	12	4	16	3	12	3	12
Inflict minimal environmental impact	3	15	1	3	3	9	2	6	2	6
Ensure minimal weight impact	2	10	5	10	3	6	5	10	5	10
Weighted Value		240		170		173		171		169
Net value				0,70833		0,72083		0,7125		0,70417
Ranking			3		1		2		4	

Figure 5.10: *The Weighted Pughs matrix that is performed with the top 4 best concepts.*

The three following concepts which are Concept 22, 9 and 23 are all modular which is the reason for the high rating. This since it eases the maintenance of the part which entails that the product appearance can be kept high. See Appendix J for the entire Weighted Pughs matrix.

5.9 Concepts & ideas of interest

There are a lot of concepts which could be considered in addition to concept 10, which was the winning concept in the Weighted Pughs matrix.

For example, a similar concept with regard to modularity is concept 9, 22 and 23 which are in the top 4 in the Weighted Pughs matrix. For these ideas, there is not an extra part which is implemented to the lower cover, but the part itself is modular and can be changed when the product appearance declines. These concepts could be of interest since they do not require changes to styling and entail the ability of customization. Furthermore concepts like these will allow adaption of the lower cover based on use, for example implementing one for sharing and another one for conventional use. Primarily these types of concepts does not entail retained newness of the lower cover, but retained newness of the interior, as the purpose is to replace when decline of product appearance reaches a critical point. The important question thereby being, is the goal to retain newness of the part or the system.

Concepts that do not require extensive changes to styling that also can be of relevance, are concepts that elevate the performance of the product by changing material. Although, this should be done with caution, see chapter 4.9.3.

There are concepts which do not solve the base problem but they have among other the ability to control the source that generates the factors of interest. These are mentioned in chapter 5.7 as macro ideas/concepts. For example the gull-wing door (concept 35) and autonomous turning seat (concept 28), which both aim to minimize the possibility of shoe contact with the lower cover, thereby eliminating the need for the lower cover to be designed for cleanability & durability to the same degree. Furthermore concepts that provide the users the ability of trowing trash in a purpose made container, hence garbage-can (concept 29), which aims to minimize the allocation of particles and liquids at unwanted locations in the interior. The remaining macro concepts can be seen in Appendix F.1, and furthermore description of these in Appendix G.

6. Testing and Validation of interesting solutions

6.1 Test plates

The tests are performed on four different test plates with different material and textures, see Table 6.1. Another test is also performed on a prototype door trim, where feasibility of one promising solutions is tested.

Table 6.1: *The number for each test plate and their materials and texture type.*

Test Plate	Material	Texture
1	PP 40% LGF	1.1 leather, 1.2. leather, 1.3 directional , 1.4 leather , 1.5 no texture, 1.6 no texture
2	PP 25% GF	Mid-random
3	PP-EPDM 20% GF	Softfeel
4	PP 25% GF	Softfeel

As can be seen in Table 6.1, three of the plates have PP and one have PP-EPDM as the base material and all four have either long glass fibre (LGF) or short glass fibre (GF) as an additive with different percentages to elevate the hardness of the material. As mentioned in chapter 4.7, the hardness property should in theory elevate the resistance to scratching & wear. Although what has been emphasized during the exploratory research is that this is very dependent on how well the fibre migrates to the surface during the manufacturing process. The test plates also have different types of textures with different levels of the values Ra and RSm (see chapter 4.7), the texture types can be seen in Table 6.1. The reason for using these test plates, is both to "test feasibility of solutions on different textures" and to evaluate visibility of occurred scratching & wear on solutions in comparison to material that it is applied on.

6.2 Solutions which are tested

The solutions tested can be categorized according to the modified morphological matrix (see Appendix F), changeable coatings and changeable films.

The following solutions are tested where the initial two are categorized as changeable films and the final two are changeable coatings.

- **Temporary tape**, developed among other for the protection of interior automotive surface like dashboards and doors. The main application is protection during storage and transportation. The tape is composed by a transparent Polyethylene film, with the main features being versatility in regard to application surfaces, simple & low cost application and easy disposal.
- **Scratch & wear resistant tape**, developed for permanent protection of surfaces against among other corrosion and mechanical damage by scratching & abrasion (wear). The main application is exterior painted surfaces, for example use today can be seen at the intersection of the wheelhouse and side skirts.
- **Paint**, a strippable paint based on water developed for protection against dirt and scratching of furniture and other surfaces. Two types of paints were tested that either generate a glossy surface or a mat surface, both being transparent.
- **Spray plastic**, developed for protection of for example rims. The spray is a paint that generates a solid rubber-like surface that is removable by peeling, the one used in this testing generates a black mat color. The paint has no specific property other than that it creates a barrier between the surface and the environment.

6.3 Test results

The performed test can be divided into three stages following below, in this chapter the results from these are treated in the same order.

- Changeable films on four different test plates
- Changeable coatings on different textures
- One changeable film on a prototype

The **temporary tape** shows that there are challenges in achieving good adhesion to surfaces with any type of texture, see Figure 6.1a. The tape is easy to remove from the surface, although most of the tests imply that the visibility of that there in fact is a tape applied to the surface is high. The latter of importance as any solution should still portray a premium perception and comply with styling requirements. To simulate a situation similar to that of the lower cover, a shoe was dragged across the surface. The temporary tape performed in general fairly good with regard to visibility of any decline in product appearance because of the shoe, as seen in Figure 6.1b. Subjective results for the temporary tape applied to different test plates can be seen in Appendix K.2 to K.5.

(a) *Temporary tape applied to test plate 1.* (b) *Temporary tape applied to test plate 2.*

Figure 6.1: *Temporary tape applied to test plates in light D65. D65 light mimics daylight.*

The **scratch & wear resistant tape** shows that where there are more rough and randomized textures adhesion could be an issue. In general for surfaces with relatively low roughness it was harder to distinguish that there in fact was a tape applied, as seen in Figure 6.2a. The only distinguishing factor was that the surface became more "glossy" and by touch more "sticky"(increased friction). During testing with the shoe, particles from the shoe adhered to both the part of the surface with the tape and the one without. In essence, the decline of product appearance was equal, although removal of the occurred particles from the tape was fairly simple, see Figure 6.2b. Subjective results for the scratch & wear resistant tape applied to different test plates can be seen in Appendix K.6 to K.9.

(a) *Scratch & resistant tape applied to test plate 1.*

(b) *Scratch & wear resistant tape applied to test plate 3.*

Figure 6.2: *Scratch & wear resistant tape applied to test plates in light D65. D65 light mimics daylight.*

The **spray plastic** is applied on both a smooth and rough surface, the results shows that it is possible to achieve a relatively good product appearance, see Figure 6.3a. Although, very dependent on even application of the paint, since in some failed tests the paint allocated to form an uneven surface. The paint used gave the test plates a darker color, and identifying that a substance has been applied was comparatively easy, since the surface upon touching felt like rubber. From an advantageous point of view the paint if applied correctly was relatively simple to remove, issues with removal occurred when applied to rough texturing, but the paint merged with the texturing comparatively well, see Figure 6.3.

(a) *Spray plastic applied to a test plate.*

(b) *Spray plastic during process of removal.*

Figure 6.3: *Spray plastic applied to evaluate feasibility.*

The **paint** is applied on both a smooth and rough surface, the results shows that it is possible to achieve even better product appearance than for any of the tested solutions before, see Figure 6.4a. Although, very dependent on even application since in some cases the paint allocates to corners. Furthermore the process of applying the paint is very challenging, requires around 24 hours to dry and repeated layers. The advantage is that the paint when applied correctly merges well with the texturing and is easy to remove from the surface as seen in Figure 6.4b.

(a) *Paint applied to test plate 2 (above split line).*

(b) *Paint in the process of removal from test plate.*

Figure 6.4: *Paint applied to test plates to evaluate feasibility.*

Finally the **scratch & wear resistant tape** is applied on a prototype door trim, the tape adheres even if the prototype has features with sharp corners. Although there is clearly a collection of air bubbles, meaning that it does not entirely merge with the texture. Furthermore even with the level of transparency the tape is easily distinguished, see Figure 6.5.

Figure 6.5: *Scratch & wear resistant tape applied to a prototype lower cover.*

6.4 Discussion of test results

Initiating with the conclusion that sooner or later an abnormality will occur on the surface, there is a benefit to having a protective layer that can be changed when the decline of product appearance has reached an undesired point. In regard to the testing the one solution that can be feasible is the scratch & wear resistant tape. It has some disadvantages but with regard to ease of application, removal and overall integrity it ranks higher than the other tested solutions. This and all other solutions tested have one combined disadvantage, which is that by applying them there is already a decrease in product appearance (some more than other). Consequently, by choosing this type of solution there should be some reflection regarding if the initial decrease is justifiable. An advantage is that after a 5 year period the lower cover below the protective film will have a minimal decline, see Figure 6.6, since the exposure is limited to the time between tape change.

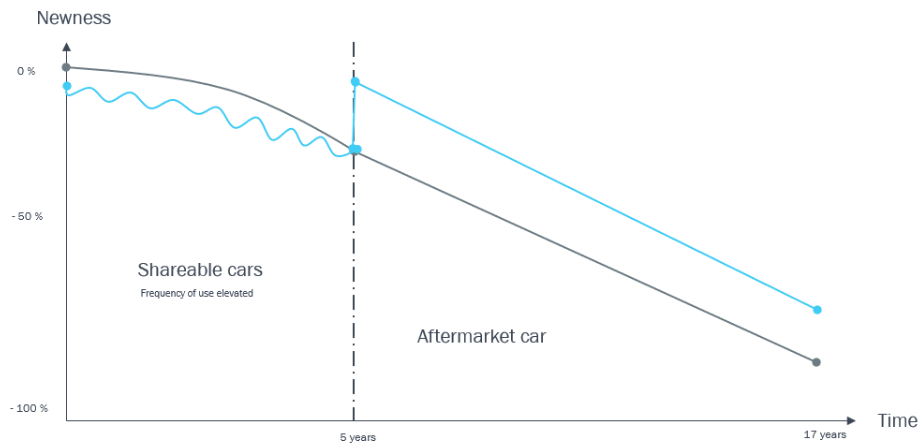


Figure 6.6: *Visualizing the decrease in newness of baseline lower cover (starting from 0%) and of lower cover with a protective layer (starting from -10%).*

Furthermore, another disadvantage to these solutions is the environmental impact the use of them render. If the protective layer requires frequent change, the use of resources will elevate and considering that there is minor possibilities of reuse the probable end destination is landfill(depending on the material). Therefore use of these solutions are only proposed, if by an Lifecycle assessment it can be assured that the rate of material throughput is advantageous compared to the environmental impact by alternate solutions.

7. Results

In this chapter the main result from the project is presented with respective deliverables, these are based on knowledge gained by generating the results in chapters 4 & 5.

7.1 Design guideline

The design guideline is a summary of the work performed during the project, it contains the projects definition of what retained newness entails and furthermore a step by step process that aids in design & material choices for the cleanability & durability of a product.

The first part of the guideline is the introduction, which contains among other a definition of retained newness, problem definition and abbreviations. The info in the introduction aims to provide user an understanding of the basics behind the guideline and why it is structured in this way.

The second part is the actual guideline, initiated by supporting questions to help define where the part treated is situated in the vehicle interior and what it is exposed by. These question are there to support the user in ranking of the needs/requirements, the rankings are used in a QFD where the need is correlated to product characteristics of relevance as seen in Figure 4.6. For example if "resistant to scratching" is ranked highly, the user will know that treating the surface texture, geometrical features and base material is of more relevance than the remaining characteristics.

Furthermore, when the user has generated an understanding of what characteristics are of relevance, the user is introduced with limiting questions. These limiting questions treat the design freedom the user has, based on the three elements mentioned in chapter 4.4. For example "is there a possibility to change base material", if the answer is "no" the user will understand that the sections mentioning base material are of no relevance. Finally the user is introduced to questions regarding the source of the external impacts, for example is the scratch induced because of restricted user movement. The questions regarding the source will not only improve ability to design for prevention, perception and management of the problem at the product level, but also generate a type of macro thinking of the problem.

The questions mentioned before will aid in defining to what degree the part treated is to be designed for retained newness and what areas of the guideline that is of interest. The remaining guideline is divided in three sections (Perception, Prevention and Management) and each section has three subsequent sections (Scratching, Particles and Liquids) which furthermore treat the three elements, see Figure 7.1. This is interactive in the design guideline, meaning that the user can by "clicking" the mouse button orientate themselves through the different levels. Furthermore abbreviations are used to indicate at what level the user is situated at a certain moment.

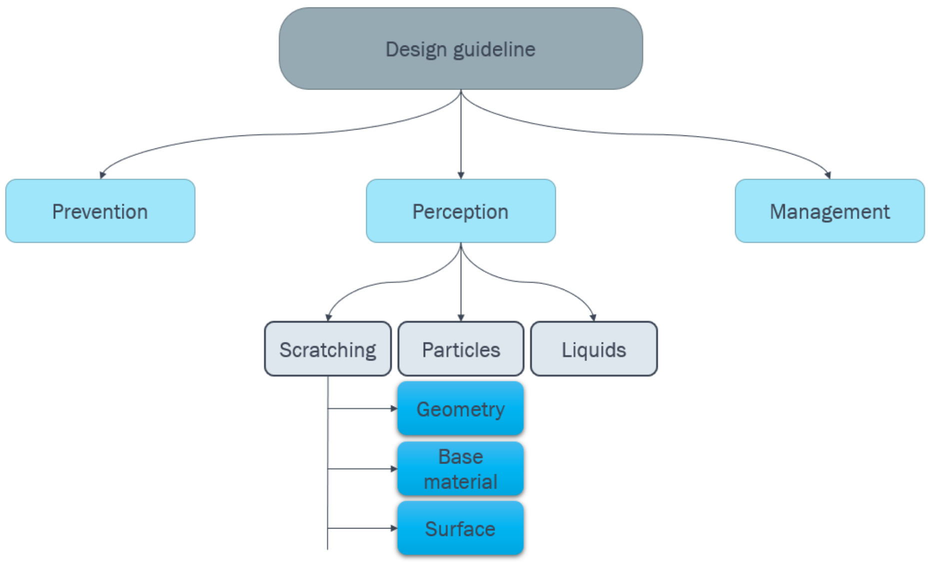


Figure 7.1: *The structure of the design guideline.*

For example a user may wonder how do i design & choose materials for preventing scratching, the user will then be directed to subsection **P.S** which is an acronym for "prevention scratching". In this section the user is guided to possible solutions and/or parameters of interest. For example in Figure 7.2, geometrical solutions to the problem of scratching is proposed by supporting questions and parameters that could be of interest. The question itself is there to guide the user in pattern of thinking, therefore proposed "solutions" is not the only possible solution. Another example can be seen in Figure 7.3, where both relevant information & examples regarding base material and additives are presented to the user.

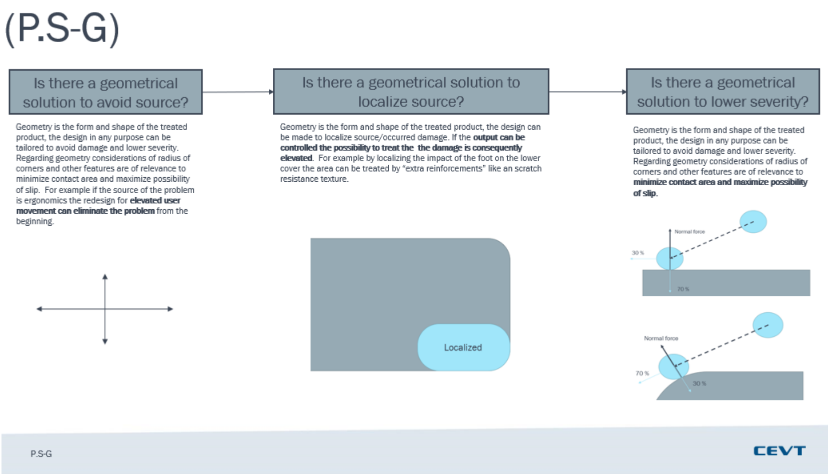


Figure 7.2: *Design guideline section Prevention of scratching based on geometry.*

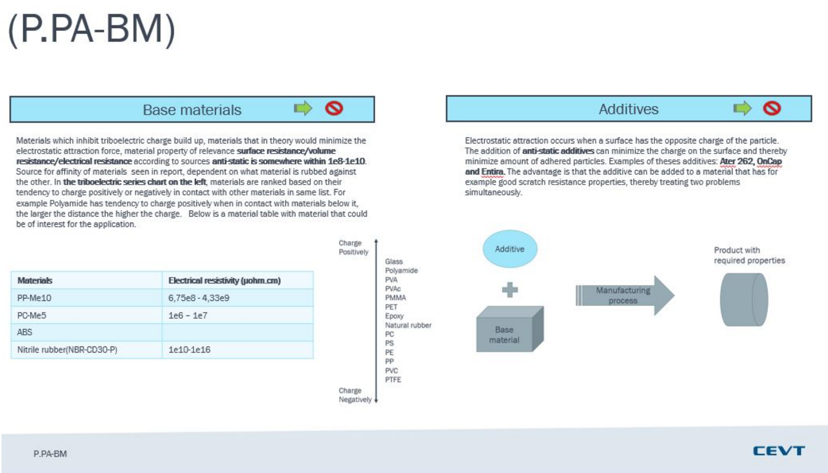


Figure 7.3: *Design guideline section prevention particle adhesion with regard to base material.*

Finally the design guideline concludes by highlighting possible trade-offs between solutions in each section. For example **P.LA** and **M.PA** are contradictory to a certain extent, proposals include both generating the hydrophobic and hydrophilic effect for example. The user can then in a matrix (see Figure 7.4) see where trade-offs can occur and consider if there is another approach that is more effective.

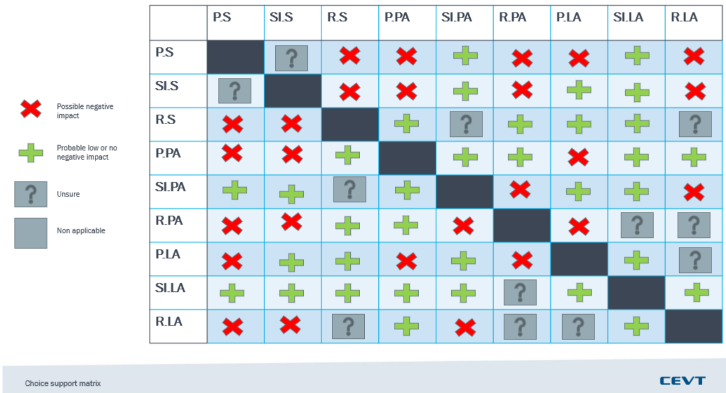


Figure 7.4: *Design guideline support matrix that illustrates compatibility with solutions from each section.*

In summary the guideline is a tool for guiding the thought process of a designer while simultaneously proposing solutions where applicable & discovered by the project. Consequently, the guideline does not include all possible solutions but based on the content the user is aided in identifying possible solutions.

7.2 Proposal for updates to DPR & Testing methods

To define a product based on how well it retains newness there is a need to both define requirements but also ensure that validation of these requirements is done with the best possible method. This chapter includes proposals for updates and the respective reason for these proposals. Initiating with the general knowledge gained during this thesis, requirements and testing because of the need to be repeatable & uniform tend to fail to mimic reality. This does not necessarily entail that the testing results will not portray reality to some extent, although with the goal to elevate the cleanability & durability of products there are some apparent opportunities for elevated accuracy. The proposals in subsequent chapters mainly treat the following:

- Type of evaluation of requirements
- Test frequency
- Test process

7.2.1 Retained newness

Firstly lets consider the requirements regarding retained newness, all of the DPRs mention it in a subsequent chapter to durability. Although, there is no content defining any type of requirement. The definition of newness we have defined, is the retainment of qualitative attributes, this since one aspect of value by consumer is the vehicle quality. There are many qualitative attributes, in that the durability as well, since of course if the product does not fulfill its main purpose the product cannot be classified as new. There are also other attributes like performance, features, aesthetic and perceived quality. To retain newness is then to minimize the delta between the "initial state of these attributes" and the "state after use". For example, there is requirements for ageing effects and retaining newness can in some cases entail being proactive of ageing effects. The newness grade is dependent on the qualitative attribute that declines at a faster rate, its the abnormality from the products initial state, for example a car that has a faulty engine after one year but still has a good appearance cannot be classified as new. There is consequently a need to understand what each product is subjected to and what qualitative attribute that will thereby decline faster. The proposed definition of the requirement for retained newness is the following: "**Any consumer critical attribute shall be designed to stand the test of time**", if possible design for ability to adapt in the form of customization and for uncontrollable factors like competition, legislation and technology push. This is to be evaluated based on testing that mimics both the type of exposure, frequency of exposure and management of exposure.

7.2.2 Durability

The abrasion testing is performed by cyclic loading with for example an abrasion wheel according to ISO 5470-1. The primary identified issues with these is the subjectivity of measurement data and the cycles used. The cycles are specified for an amount based on the use of a conventional car, if the same car is used in car sharing the amount of wear will be reached faster. Conclusively, any requirement that entails cyclic loading test should be increased to mimic the elevated frequency of use car sharing entails. The increase should be based on amount of conventional cars a shared car replaces, for example if a shared car replaces four cars then the cyclic loading shall be increased to mimic the wear of four cars combined. Furthermore, the requirement is among other defined as no major changes to the visual appearance. As newness, this statement is very ambiguous and dependent on the subject that performs the evaluation, to acquire better accuracy this can be supported by some type of indication of what major entails.

The scratching test are performed by two different methods with the use of similar tools, an ERICHSEN pen that is the object that induces the scratch. The two methods are differentiated based on material tested, PP is the material that stands out as it is tested by the creation of a grid pattern with what is called an ERICHSEN cross hatch cutter. The tests have two ways of defining scratch resistance the generic test defines it as "no visible scratch marks allowed at 3N", while the PP test defines it as maximum deviation of δL (delta lightness value) being 1,5 and having a set load of 10N . The reason to why the testing method differs can be because of the ease of scratching PP or that PP is often used in areas where scratching is more prone to occur. The proposal is to first and foremost find a better categorization than material, for example based on type of exposure. The PP test in comparison to the generic test have a less subjective evaluation and can therefore be advantageous. Also some consideration to why the load limits are 3N & 10N, are they mimicking reality and should the load be based on location(exposure).

7.2.3 Cleanability

The requirements regarding cleanability can be primarily defined as "resistance to chemicals, soiling and cleanability". In general the evaluation of these test is performed in a repeatable manner, as they are evaluated among other based on greyscale changes (color tone changes). The tests are in general defined very well in process steps, soils applied, cleaning agents used etc. The major possibility to improve is with regard to frequency, mixture and time of cleaning. Frequency entails the cyclic testing on the same test plate, as today testing is performed on a new test plate once. Incorporating frequency in the test can help in generating understanding of how materials perform after repeated exposure to both particles & liquids, and thereby how effective cleaning agents are after for example five years of use. Furthermore the test today are performed on a test plate with one specific "soil" for example ketchup, some consideration should be taken to mixing of the soils as there is a possibility that soils will mix during use. Finally, cleaning agents are tested after 24 hours, in reality and especially for the case of a car used in car sharing this is not necessarily the case. Incorporating these three proposals into testing can improve the tests accuracy in comparison with reality, thereby material choice can become more accurate.

8. Discussion

The thesis studies both from a general perspective what retaining newness entails and during the project decomposes the term to more specific elements, cleanability & durability, and further. The result is a guideline and proposed updates to DPR & testing methods which aims to aid among other engineers in designing for retained newness in the interior of car.

The **scope of the project** was relatively open, a project intended for project members with background in materials adapted to fit members with background in product development. This entailed that knowledge of areas of relevance only increased as the project progressed, delimitations where therefore enforced to fit the time frame of a thesis among other limiting the type of testing, the solutions tested and the plan of the case study. In retrospect more limiting of the scope would have been preferable, as the complexity of the initial phase directly affected the quality of the generated result in sequential phases.

The project initiates with an **exploratory research** that aims to grasp the whole picture, as it is imperative for understanding what retaining newness for this case entails. This process is challenging, it requires continuous communication with both stakeholders within the company and between the project group. The phase is performed through data collection of different kinds, the inherent complexity of newness and its elements contributes to challenges in finding relevant data. Thereby some elements are left untreated and the validity of the definition of newness can be affected. Furthermore uncertainty regarding cleanability & durability and what **parameters & variables** that are of relevance, contributed to the need of extensive literature searching and discussions with people with relevant knowledge. The latter of which contributed to delays as people with relevant knowledge were difficult to locate and furthermore not always in a position to share information. This also contributed to that parameters & variables identified does not necessarily capture all of interest and some assumptions had to be made which might affect the validity of the result of the project. An example of parameters & variables mentioned but not treated further are the products gloss and color, which is identified as interesting for "delaying identification of declined product appearance". The **materials & technology research** is performed to create an overview of which that can be of interest, thereby any that can elevate cleanablility & durability. In retrospect the material & technology research mainly focused on preventive measures and this furthermore for polymers. In any future research there should be considerations of materials other than polymers and technologies that include other than those that elevate the products cleanability & durability properties. This referring to materials like metals and technologies regarding for example cleaning process.

The **case study** and **testing & validation** phases aims to contribute to the understanding and thereby to the creation of the deliverables. The major contribution is seen in the creation of the design guideline, as the case study among other aids in identifying trade-offs. The case study followed a generic product development process where methods are adapted according to the result generated in the exploratory research. In retrospect this can have had an impact on the grade of creativity as the solutions spectrum is limited, furthermore possible solutions include around 268 000 and only 35 are generated. This because of time constraints, but also since many of the possible solutions can be eliminated based on the knowledge gained during the exploratory study.

The **design guideline** and the analysis of **requirements & testing methods** are created based on the knowledge gained in preceding phases among other the exploratory research. Thereby some consideration could be made on the validity of the results, as they both are based on the project members definition of controllable newness. The design guideline in specific is therefore quite complex in its structure, and to use it effectively the user has to understand this. Thereby, considerations of creating a more compact guideline is therefore of interest for future use. The proposals for updates on **requirements & testing methods** are from a holistic point of view, the analysis is based on information in documents and from interviews with stakeholders. There was no participation in any testing and thereby the validity of the proposals might be affected, since there is no confirmation that the method stated in the documents is actually the method used. Furthermore some requirements states certain test conditions, among other amount cycles and amount of force applied. Information regarding the reason for this is not found and thereby no specific values is proposed.

From an **ethical perspective** the result of this project, specifically the design guideline can be questioned to some degree. The information in the guideline contains proposals of solutions that can have an impact on human well being, more specifically the implementation of coatings, films and additives. The project members ethical duty is to illustrate as many solutions as possible to elevate cleanability & durability properties in coherence with the aim. Although to propose solutions that can have an impact on for example the environment can be questioned since implementation of these solutions can be morally wrong. Simultaneously, the implementation of these solutions are not something that the project members can control, more than illustrating the disadvantages of said implementation.

9. Conclusions

The future of the automotive industry will have a distinct increase in the type of offering refereed to as shared mobility. Shared mobility entails the divided use of a car between multiple users over a certain period of the vehicles life. This type of offering entails positive developments including environmental benefits because of resource efficiency as cars in conventional use are parked more than 90 % of the product life. Although, the new type of offering entails new use situations to consider and a change in ownership. This contributing to the elevated relevance of retained newness and more specifically the cleanability & durability properties of a product. There is thereby a need to reassess these aspects and treat them more extensively than before. This thesis has treated these aspects with the goal of enhancing understanding and thereby guideline future development. This by performing three distinct phases, whereas the first phase contains an extensive literature study and interviews that results in a design guideline & proposals on updates to requirements and testing methods. This followed up by a case study and testing of interesting solution to further complement the deliverables.

- To enhance understanding a model is created called controllable newness, stating that the retained newness can be prolonged by:
    - **Preventing** the degradation of product appearance caused by wear and/or soiling
    - Controlling the **Perception** of degraded product appearance
    - **Managing** degraded product appearance

  Furthermore retained newness is also believed to be prolonged by controlling the amount of exposure to wear & soiling and enabling replacement of products.

- The first phase of the thesis contained an extensive search to understand the concept of retained newness but also identification of relevant parameters & variables. The realization being that the amount variables are extensive and case specific. As their relevance are defined by aspects like the products use situation, amount of exposure to wear & soil and the products characteristics. Therefore the search is limited to those relevant for elevating cleanability & durability properties, and with the goal of aiding in the process of design rather than proposing definite solutions. This is summarized and synthesized by the creation of a design guideline, which is to act like an aid for designers to generate an understanding of where to start the problem solving and by that also illustrate possible trade-offs. The guideline is constituted by an intro explaining the concept of retained newness, followed up by an interactive question based structure that aims to guide the user to relevant sections with parameters & variables to consider.

- Technologies to elevate cleanability & durability are mainly coatings, films and textures. They often have the specific purpose of elevating relevant property for example resistance to scratching, but their use in most cases would imply a negative effect to the intended product appearance. The use of them could be preferable given that it is considered early in the development process, thereby including it as a part of the product appearance rather than a change to already defined product appearance.

- Based on interviews and the use of material databases it is concluded that materials of relevance include those that elevate cleanability & durability properties, for example optimized electrical resistivity. Although there is no ultimate material, rather there is a collection of materials that have different advantages & disadvantages. Furthermore, a change in material would not imply changes to product appearance, although their feasibility depend on the materials ability to fulfill requirements other than those relevant for cleanability & durability. This is for example requirements regarding cost and mechanical strength.

- Testing today is performed in a manner that does not include among other mixture of soils and frequency. For example scratching is tested separately from coffee and thereby the test regarding the ability to clean does not include testing on products after some time of use. Furthermore the testing is performed once on a new test plate meaning that results is based on the probable best performance, thereby disregarding repeated exposure to any factor of interest. The introduction of shared mobility will imply the need to develop these test to better portray the reality that this use situation will entail.

- The case study concludes that the more promising concepts are those that imply the addition of a modular feature, entailing the ability to customize and replace. The winning concept entails the addition of this on top of the existing baseline, elevating the cleanability & durability and simultaneously enabling retained newness of the baseline product when the car re-enters the conventional use stage.

10. Future recommendations

It is clear that for any attempt to design for retaining newness with focus on cleanability & durability there is a need for cross-functional teams, as it is dependent on many different disciplines. The design guideline aims to ease this work by in addition to providing basic information that can aid in understanding, providing the user an idea of what discipline that can be of help. An example of this is that many of the solutions that exist would entail a change to the product appearance, this not necessarily a decline, but still requires communication with e.g. styling. Furthermore with regard to retained newness, there are more aspects than the product alone. As discovered by the project group by expanding the solution search to a macro level the problem solving can be simplified. An example being considering the service model alone, by implementing penalties or/and rewards, Uber like rating of users or other, the amount of exposure to the factors of interest can be controlled. In essence as consumption changes there is a need to change what the product entails, a car is no longer just a car...

To design for retained newness there is a need to understand the specific product treated. This since each product is among other composed by different elements, exposed by different factors of interest (see chapter 4.3) and located differently with respect to the user. For example a product located in the baggage space in comparison to a product located in the drivers view can be argued to need less extensive design efforts. Thereby in future efforts to design for retained newness start with the product in question, as parameters & variables of interest will vary.

Include retained newness early in the design process, by treating the redesign of a product there is already many limitations that restrain the ability of elevating cleanability & durability. For example solutions that entail the application of protective films are dependent of among other the base material, this with regard to the ability of the film to adhere to the product.

Finally, testing & requirements should in the future be reassessed, this with the goal of mimicking reality to a better extent and by that also consider the new use situation.

Reference list

[1] *The free dictionary By Farlex*. 2019. Available: https://www.thefreedictionary.com.

[2] G. Paul, K. Hans-werner, M. Detlev, and W. Dominik, *Disruptive trends that will transform the auto industry*, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry, accessed:2019-04-29.

[3] *What we do (refining automotive engineering)*, https://www.cevt.se/what-we-do/, accessed: 2019-04-29.

[4] *More than a car*, https://www.lynkco.com/cars, accessed: 2019-04-29.

[5] H. Johannesson, J.-G. Persson, and D. Pettersson, *Produktutveckling*, Second edition. Liber, 2013.

[6] P. Holley, *A sharable 'sit down' electric scooter company is launching in texas*, 2019. Available: https://search-proquest-com.proxy.lib.chalmers.se/docview/2166304884?accountid=10041#center.

[7] K. T. Ulrich and S. D. Eppinger, *Product Design and Development*, Fifth edition. McGraw-Hill, 2012.

[8] C. Linz, G. Muller-Stevens, and A. Zimmermann, *Radical business model transformation*. New York : Kogan Page Ltd, 2017.

[9] G. Michelini, R. N. Morales, R. N. Cunha, J. M. H. Costa, and A. R. Ometto, "From linear to circular economy," *Procedia CIRP*, vol. 64, 2017.

[10] M. Esposito, T. Tse, and K. Soufani, "Introducing a circular economy: New thinking with new managerial and policy implications," *California Management Review*, vol. 60, 2018.

[11] M. Sonego, M. E. S. Echeveste, and H. G. Debarba, "The role of modularity in sustainable design: A systematic review," *Journal of Cleaner Production*, vol. 176, 2017.

[12] M. Sako and F. Murray, "Modules in design, production and use: Implications for the global automotive industry," *IMVP Annual Sponsors Meeting, University press*, 2000.

[13] R. Sánchez-Fernández and M. Á. Iniesta-Bonillo, "The concept of perceived value: A systematic review of the research.," *Marketing Theory*, vol. 7, p. 427–451, 2007.

[14] R. Mascitelli, *Lean Product Development Guidebook - Everything Your Design Team Needs to Improve Efficiency and Slash Time-to-Market*. Northridge : Technology Perspectives, 2007.

[15] D. G. Newnan, T. G. Eschenbach, and J. P. Lavelle, *Engineering Economic Analysis*, 11th Edition. Oxford University Press, 2015.

[16] G. Lucko, *A Statistical Analysis and Model of the Residual Value of Different Types of Heavy Construction Equipment(Doctoral dissertation)*. Virginia Tech, 2003.

[17] A. Jost and A. Franke, "Residual value analysis," *In 23rd International Conference of the System Dynamics Society*, 2005.

[18] S. M. Katrin Talke and J. E. Wieringa, "A matter of perspective: Design newness and its performance effects.," *International Journal of Research in Marketing*, vol. 34, 2017.

[19] Y. Mumcu and H. S. Kimzan, "The effect of visual product aesthetics on consumers' price sensitivity.," *Procedia Economics and Finance*, vol. 26, p. 528–534, 2015.

[20] D. Eriksson and F. Srvanestrand, *Residual value and media: a comparative study in the automotive industry based on predicted future residual values*. Göteborg : Chalmers tekniska högskola, 2007.

[21] A. Mitra, *Fundamentals of Quality Control and Improvement*, 4th ed. New York : John Wiley Sons, Incorporated, 2016.

[22] J. G. Detry, P. G. Rouxhet, L. Boulangé-Petermann, C. Deroanne, and M. Sindic, "Cleanability assessment of model solid surfaces with a radial-flow cell," *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 302, 2007.

[23] D. Arbelaez, M. Avila, A. Krishnamurthy, W. Li, Y. Yasui, D. Dornfeld, and S. McMains, "Cleanability of mechanical components," *Proceedings of 2008 NSF Engineering Research and Innovation Conference, Knoxville, Tennessee*, 2008.

[24] M. Ávila, J. Gardner, C. Reich-Weiser, S. Tripathi, A. Vijayaraghavan, and D. Dornfeld, "Strategies for burr minimization and cleanability in aerospace and automotive manufacturing," *SAE International*, 2005.

[25] J. P. Marshall and H. Wilcox, *Developments in Surface Contamination and Cleaning*. Elsevier, 2015, ch. How green and does it clean: Methodologies for assessing cleaning products for safety and performance, p. 1–69, ISBN: 9780323299619.

[26] J. McHardy and S. P. Sawan, *Supercritical Fluid Cleaning - Fundamentals, Technology and Applications*. Westwood, N.J. : Noyes Publications, 1998.

[27] R. Kohli and K. L. Mittal, *Developments in Surface Contamination and Cleaning: Fundamentals and Applied Aspects*. Amsterdam: William Andrew, 2008.

[28] K. Reinhardt and K. Werner, *Particle Deposition and Adhesion. In Handbook of Silicon Wafer Cleaning Technology*, 3rd ed. Elsevier, 2018.

[29] H.-J. Lee and K. Park, "Variable wettability control of a polymer surface by selective ultrasonic imprinting and hydrophobic coating," *Colloid & Polymer Science*, vol. 294, 2016.

[30] D. A. Garvin, ".competing on the eight dimensions of quality," *Harvard Business Review*, vol. 65, p. 101–109, 1987.

[31] C. Bakker, F. Wang, J. Huisman, and M. den Hollander, "Products that go round: Exploring product life extension through design," *Journal of cleaner production*, vol. 69, p. 10–16, 2014.

[32] M. Ashby, H. Shercliff, and D. Cebon, *Materials : engineering, science, processing and design*, 3rd ed. Oxford : Butterworth-Heinemann, 2014.

[33] B. Basu and M. Kalin, *Perspective for Designing Materials for Tribological Applications*, 3rd ed. John Wiley & Sons, 2011.

[34] D. K. Dwivedi, *Surface Engineering : Enhancing Life of Tribological Components*. Springer eBooks, 2018.

[35] A. Abdelbary, *Wear of polymers and composites*. Cambridge, MA : Woodhead Publishing, an imprint of Elsevier, 2014.

[36] A. W. Batchelor, M. Chandrasekaran, and N. L. Lam, *Materials degradation and its control by surface engineering*. Singapore : Imperial College Press, 2011.

[37] I. Arino, U. Kleist, L. Mattson, and M. Righdal, "On the relation between surface texture and gloss of injection molded pigmented plastics," *Polymer Engineering and Science*, vol. 45, 2005.

[38] M. Hamdi and H. J. Sue, "Effect of color, gloss, and surface texture perception on scratch and mar visibility in polymers," *Materials & design*, vol. 83, 2015.

[39] L. Vepsäläinen, P. Pääkkönen, M. Suvanto, and T. A. Pakkanen, "Frequency analysis of micropillar structured surfaces a characterization and design tool for surface texturing," *Applied Surface Science*, vol. 263, 2012.

[40] M. W. Gao, L. Wang, J. K. Coffey, and F. Daver, "Understanding the scratch behaviour of polymeric materials with surface texture," *Materials & design*, vol. 146, 2018.

[41] C. J. Barr, L. Wang, J. K. Coffey, and F. Daver, "Influence of surface texturing on scratch/mar visibility for polymeric materials," *Journal of materials science*, vol. 52, 2017.

[42] S. R. A, *Qualitative Research Methods: Exploratory research in the social sciences*. SAGE Publications, Inc., 2001, doi: 10.4135/9781412984249.

[43] P.-G. Svensson and B. Starrin, *Kvalitativa studier i teori och praktik*. Lund : Studentlitteratur, 1996, ISBN: 91-44-39851-4.

[44] R. M. Thomas, *Blending Qualitative & Quantitative Research Methods in Theses and Dissertations*. 2003, ISBN: 9781412983525.

[45] Björklund and Paulsson, *Seminarieboken- att skriva, presentera och opponera*. Lund: Studentlitteratur AB, 2000.

[46] M. R, *How to write a thesis*, Third edition. Maidenhead : McGraw-Hill/Open University Press, 2011.

[47] J. Dudovskiy. (2019). Types of literature review, Available: `https://research-methodology.net/research-methodology/types-literature-review/`. (accessed: 24.04.2019).

[48] Smith, K. Richard, S. David, R. Skelsey, and Dan, *Effective Change Manager's Handbook Essential Guidance to the Change Management Body of Knowledge*, 182-197. Kogan Page Publishers, 2015.

[49] R. A. Hunt and C. P. Killen, *Best practice quality function deployment (QFD) Part I: Cases*. Bradford : Emerald Publishing Limited, 2004, ISBN: 9781845441999.

[50] S. Natee, S. P. Low, and E. A. L. Teo, *Quality Function Deployment for Buildable and Sustainable Construction*. Springer, 2016, ISBN: 978-981-287-848-9.

[51] M. Coers, C. Gardner, L. Higgins, and C. Raybourn, *Benchmarking: A Guide for Your Journey to Best-Practice Processes*. Houston : American Productivity Quality Center, 2001, ISBN: 9781928593249.

[52] S. Cheney, *Benchmarking*. 1998, ISBN: 87559269.

[53] *A2mac1*, https://portal.a2mac1.com/, accessed: 2019-03-30.

[54] C. James, P. Debra, and T. Paul, *Business Analysis Techniques - 99 Essential Tools for Success*, Second edition. BCS The Chartered Institute for IT, 2014, ISBN: 978-1-78017-273-6.

[55] C. Wilson, *Brainstorming and Beyond: A User-Centered Design Method*. Amsterdam : Morgan Kaufmann, 2013, ISBN: 9780124071575.

[56] Thomas, P. Philipa, C. Debra, and James, *Human Touch - Personal Skills for Professional Success*. London : BCS The Chartered Institute for IT, 2012, ISBN: 9781628702552.

[57] G. Pahl, W. Beitz, J. Feldhusen, and K.-H. Grote, *Engineering Design: A Systematic Approach*, Third edition. Springer Ebooks, 2007, ISBN: 9781846283192.

[58] S. Filippi and I. Cristofolini, *The design guidelines collaborative framework*. Springer, 2010, ISBN: 9781848827714.

[59] Z. Xuan, H. Xu, K. W. Sen, and S. Siowling, "Designing non-charging surfaces from non-conductive polymers," *Advanced materials*, vol. 28, 2016.

[60] *Cambridge engineering selector (ces)*, Software, accessed: 2019-05-10.

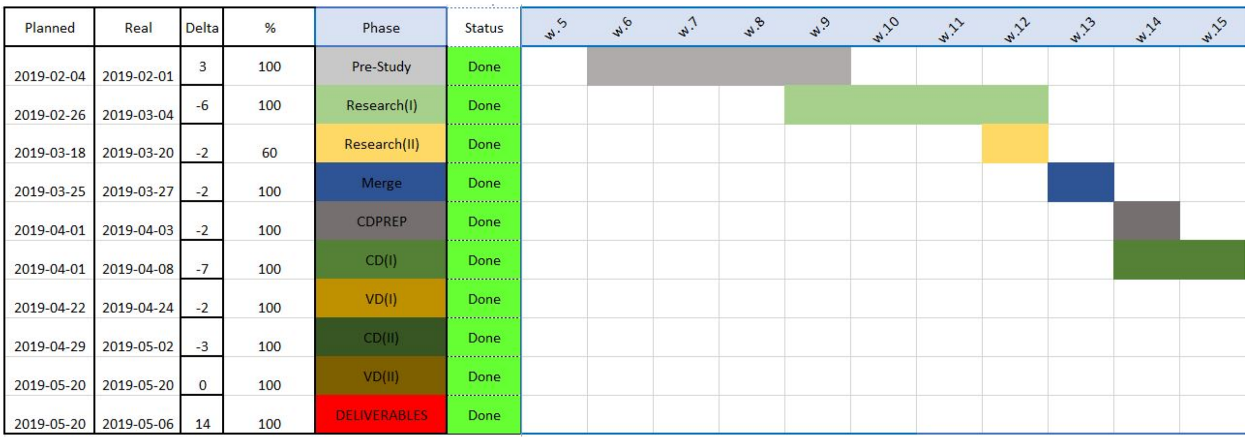
[61] A. Lazauskas, D. Jucius, V. Baltrušaitis, R. Gudaitis, I. Prosyčevas, B. Abakevičienė, and V. Grigaliūnas, "Shape-memory assisted scratch-healing of transparent thiol-ene coatings," *Materials*, vol. 12, 2019.

[62] *Categorizing surface energy*, https://www.3m.com/3M/en_US/bonding-and-assembly-us/resources/science-of-adhesion/categorizing-surface-energy/#, accessed: 2019-05-13.

[63] *Optimisation and upscaling of self-cleaning surfaces for automotive sector by combining tailored nanostructured machined injection tools and functional thermoplastic nanocompounds*, https://cordis.europa.eu/project/rcn/92201/factsheet/en, accessed: 2019-05-13.

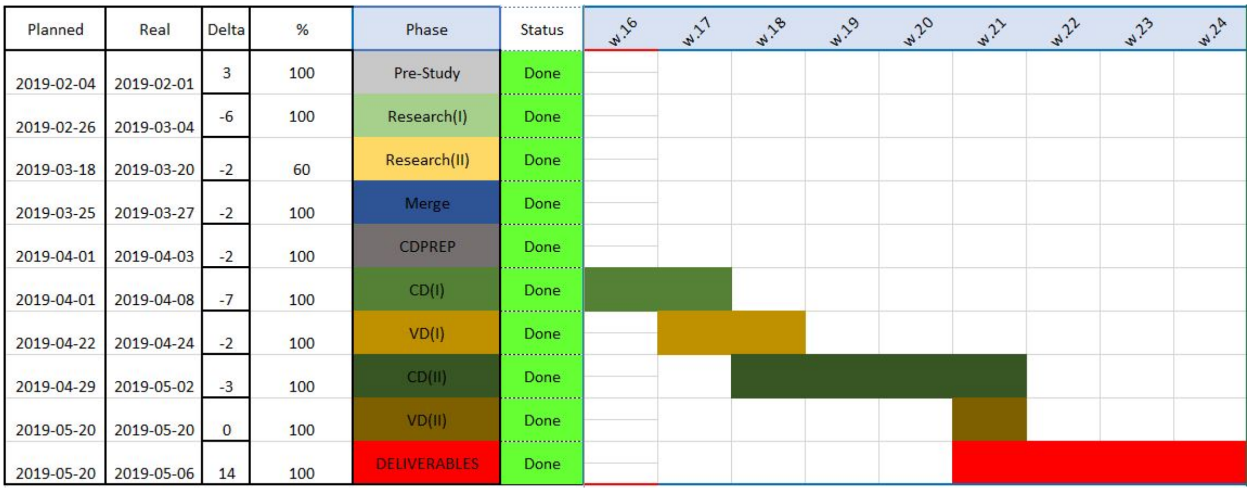
[64] E. Søgaard, "Injection molded self-cleaning surfaces," *DTU Nanotech (PHD thesis)*, 2014.

A. Gantt-chart



Planned	Real	Delta	%	Phase	Status
2019-02-04	2019-02-01	3	100	Pre-Study	Done
2019-02-26	2019-03-04	-6	100	Research(I)	Done
2019-03-18	2019-03-20	-2	60	Research(II)	Done
2019-03-25	2019-03-27	-2	100	Merge	Done
2019-04-01	2019-04-03	-2	100	CDPREP	Done
2019-04-01	2019-04-08	-7	100	CD(I)	Done
2019-04-22	2019-04-24	-2	100	VD(I)	Done
2019-04-29	2019-05-02	-3	100	CD(II)	Done
2019-05-20	2019-05-20	0	100	VD(II)	Done
2019-05-20	2019-05-06	14	100	DELIVERABLES	Done

Figure A.1: Gantt-Chart for week 5-15.



Planned	Real	Delta	%	Phase	Status
2019-02-04	2019-02-01	3	100	Pre-Study	Done
2019-02-26	2019-03-04	-6	100	Research(I)	Done
2019-03-18	2019-03-20	-2	60	Research(II)	Done
2019-03-25	2019-03-27	-2	100	Merge	Done
2019-04-01	2019-04-03	-2	100	CDPREP	Done
2019-04-01	2019-04-08	-7	100	CD(I)	Done
2019-04-22	2019-04-24	-2	100	VD(I)	Done
2019-04-29	2019-05-02	-3	100	CD(II)	Done
2019-05-20	2019-05-20	0	100	VD(II)	Done
2019-05-20	2019-05-06	14	100	DELIVERABLES	Done

Figure A.2: Gantt-Chart for week 16-24.

B. Requirement Specifications

Need	Category	Requirement	Rank	Value/metric	RQ #
Ensure resistance to scratching & wear	Texture	Surface texture be designed to minimize contact area between indenting object and surface. Rougher surfaces preferable	X	RSm, number of peaks & Ra, mean roughness	PT.1
Ensure resistance to scratching & wear	Texture	Surface texture be designed to minimize contact area between indenting object and surface. Rougher surfaces preferable	X	Texture Type	PT.2
Ensure resistance to liquid adhesion	Texture	Surface texture be designed to enable high contact angle of liquid droplets.	X	Texture Type	PT.3
Ensure resistance to particle adhesion	Texture	Surface texture be designed to minimize van der waals force and build up of triboelectric charging.	X	Texture Type	PT.4
Ensure resistance to particle adhesion	Texture	Surface texture be designed to minimize van der waals force and build up of triboelectric charging. Preferable smoother surfaces.	X	RSm, number of peaks & Ra, mean roughness	PT.5
Ensure resistance to liquid adhesion	Texture	Surface texture be designed to minimize mechanical capillary attraction. Preferable smoother surface.	X	RSm, number of peaks & Ra, mean roughness	PT.6
Ensure resistance to scratching & wear	Geometry	Geometry designed for minimizing contact possibility and maximizing probability of slip.	X	Size, shape, depth, radius	PG.1
Ensure resistance to liquid adhesion	Geometry	Geometry designed for minimizing possibility of liquid allocation	X	Size, shape, depth, radius	PG.2
Ensure resistance to particle adhesion	Geometry	Geometry designed for minimizing possibility of particle allocation	X	Size, shape, depth, radius	PG.3
Ensure resistance to particle adhesion	Base material	Base material chosen to minimize electrostatic attraction	X	Electrical resistance/conductivity	PM.1
Ensure resistance to scratching & wear	Base material	Base material chosen to minimize possibility of localized plastic deformation.	X	Hardness	PM.1
Ensure resistance to liquid adhesion	Base material	Base material chosen to minimize capillary attraction.	X	Surface energy	PM.1
Ensure low identification of scratching & wear	Texture	Surface texture be designed to minimize depth, width and contrast of an occurred scratch	X	Texture type	PET.1
Ensure low identification of particles	Geometry	Geometry designed for minimizing possibility of particle allocation	X	Size, shape, depth, radius	PEG.1
Ensure low identification of liquids	Geometry	Geometry designed for minimizing possibility of liquid allocation	X	Size, shape, depth, radius	PEG.2
Ensure low identification of scratching & wear	Base material	Base material chosen to minimize depth and size of occurred scratch. Also consideration of whitening effects.	X	Youngs modulus	PEM.1
Allow for easy removal of adhered particles	Texture	Surface texture be designed to minimize depth of valleys, sharpness of grain, to allow for reaching adhered particles with cleaning medium. Preferable smoother surface	X	RSm, number of peaks & Ra, mean roughness	MT.1
Allow for easy removal of adhered liquid	Texture	Surface texture be designed to minimize capillary attraction forces and enable reaching adhered liquid.	X	Texture type	MT.2
Allow for easy restoring of occurred scratch	Texture	Surface texture be designed to minimize amount of process steps	X	Texture type	MT.3
Allow for easy restoring of occured scratch	Geometry	Geometry designed for minimizing amount of process steps	X	Simplicity - Complexity	MG.1
Allow for easy removal of adhered particles	Geometry	Geometry designed for reachability of cleaning medium	X	Simplicity - Complexity	MG.2
Allow for easy removal of adhered liquid	Geometry	Geometry designed for reachability of cleaning medium	X	Simplicity - Complexity	MG.3
Allow for easy restoring of occurred scratch	Base material	Base material chosen for minimizing amount of process steps	X	Compliance with method	MM.1
Allow for easy removal of adhered particles	Base material	Base material chosen to minimize active electrostatic forces and adapted for cleaning procedure	X	Electrical resistance/conductivity, High surface energy, High hardness	MM.2
Allow for easy removal of adhered liquid	Base material	Base material chosen to minimize capillary attraction	X	Low surface energy, high hardness	MM.3

Figure B.1: Requirement specification generic

Need	Category	Requirement	Rank	Value/metric	RQ #
Ensure resistance to scratching & wear	Texture	Surface texture be designed to minimize contact area between indenting object and surface. Rougher surfaces preferable	5	RSm, number of peaks & Ra, mean roughness	PT.1
Ensure resistance to scratching & wear	Texture	Surface texture be designed to minimize contact area between indenting object and surface. Rougher surfaces preferable	5	Texture Type	PT.2
Ensure resistance to liquid adhesion	Texture	Surface texture be designed to enable high contact angle of liquid droplets.	1	Texture Type	PT.3
Ensure resistance to particle adhesion	Texture	Surface texture be designed to minimize van der waals force and build up of triboelectric charging.	3	Texture Type	PT.4
Ensure resistance to particle adhesion	Texture	Surface texture be designed to minimize van der waals force and build up of triboelectric charging. Preferable smoother surfaces.	3	RSm, number of peaks & Ra, mean roughness	PT.5
Ensure resistance to liquid adhesion	Texture	Surface texture be designed to minimize mechanical capillary attraction. Preferable smoother surface.	1	RSm, number of peaks & Ra, mean roughness	PT.6
Ensure resistance to scratching & wear	Geometry	Geometry designed for minimizing contact possibility and maximizing probability of slip.	5	Size, shape, depth, radius	PG.1
Ensure resistance to liquid adhesion	Geometry	Geometry designed for minimizing possibility of liquid allocation	1	Size, shape, depth, radius	PG.2
Ensure resistance to particle adhesion	Geometry	Geometry designed for minimizing possibility of particle allocation	3	Size, shape, depth, radius	PG.3
Ensure resistance to particle adhesion	Base material	Base material chosen to minimize electrostatic attraction	3	Electrical resistance/conductivity	PM.1
Ensure resistance to scratching & wear	Base material	Base material chosen to minimize possibility of localized plastic deformation.	5	Hardness	PM.1
Ensure resistance to liquid adhesion	Base material	Base material chosen to minimize capillary attraction.	1	Surface energy	PM.1
Ensure low identification of scratching & wear	Texture	Surface texture be designed to minimize depth, width and contrast of an occurred scratch	5	Texture type	PET.1
Ensure low identification of particles	Geometry	Geometry designed for minimizing possibility of particle allocation	3	Size, shape, depth, radius	PEG.1
Ensure low identification of liquids	Geometry	Geometry designed for minimizing possibility of liquid allocation	1	Size, shape, depth, radius	PEG.2
Ensure low identification of scratching & wear	Base material	Base material chosen to minimize depth and size of occurred scratch. Also consideration of whitening effects.	5	Youngs modulus	PEM.1
Allow for easy removal of adhered particles	Texture	Surface texture be designed to minimize depth of valleys, sharpness of grain, to allow for reaching adhered particles with cleaning medium. Preferable smoother surface	3	RSm, number of peaks & Ra, mean roughness	MT.1
Allow for easy removal of adhered liquid	Texture	Surface texture be designed to minimize capillary attraction forces and enable reaching adhered liquid.	1	Texture type	MT.2
Allow for easy restoring of occurred scratch	Texture	Surface texture be designed to minimize amount of process steps	5	Texture type	MT.3
Allow for easy restoring of occured scratch	Geometry	Geometry designed for minimizing amount of process steps	5	Simplicity - Complexity	MG.1
Allow for easy removal of adhered particles	Geometry	Geometry designed for reachability of cleaning medium	3	Simplicity - Complexity	MG.2
Allow for easy removal of adhered liquid	Geometry	Geometry designed for reachability of cleaning medium	1	Simplicity - Complexity	MG.3
Allow for easy restoring of occurred scratch	Base material	Base material chosen for minimizing amount of process steps	5	Compliance with method	MM.1
Allow for easy removal of adhered particles	Base material	Base material chosen to minimize active electrostatic forces and adapted for cleaning procedure	3	Electrical resistance/conductivity, High surface energy, High hardness	MM.2
Allow for easy removal of adhered liquid	Base material	Base material chosen to minimize capillary attraction	1	Low surface energy, high hardness	MM.3
Ensure minimal addition to service life cost	All	Require minimal amount of maintenance sessions	4	Cost of use	A.1
Oblige to styling and ergonomics requirements	All	Minimal impact on Perceived- and Aesthetic quality	5	Degree of change to product appearance	A.2
Enable simple maintenance	All	Shall not require special tools or methods to retain or restore functionality	3	Complexity of process	A.3
Allow for easy implementation	All	Shall not require special methods for assembly	4	Complexity of process	A.4
Inflict minimal environmental impact	All	Maximal resource efficency	3	Kg/1000Km	A.5
Ensure minimal weight impact	All	Optimized with regard to weight	2	Kg	A.6

Figure B.2: Requirement specification for the Case study Lower cover. Used in the Pughs matrix and Weighted Pughs matrix.

C. Functional decompositions

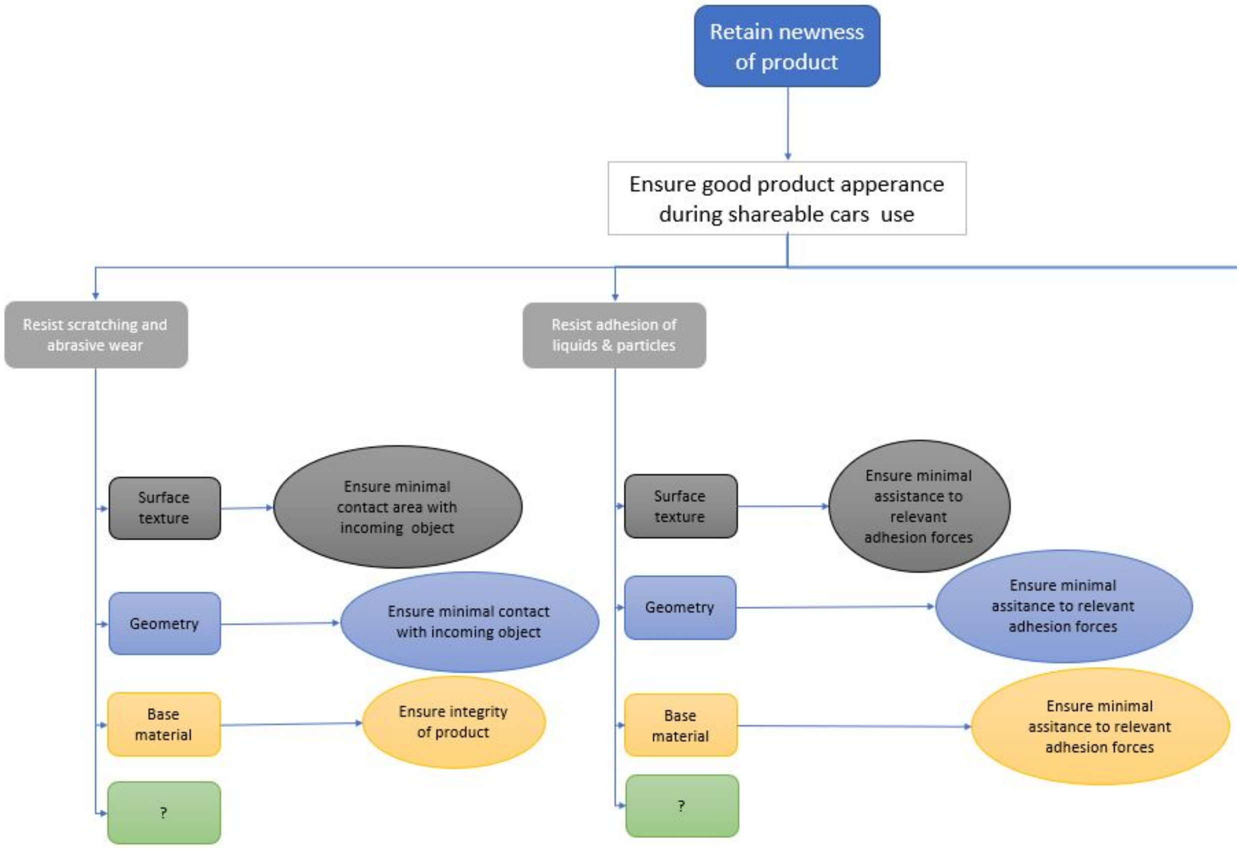


Figure C.1: Functional decomposition generic part 1

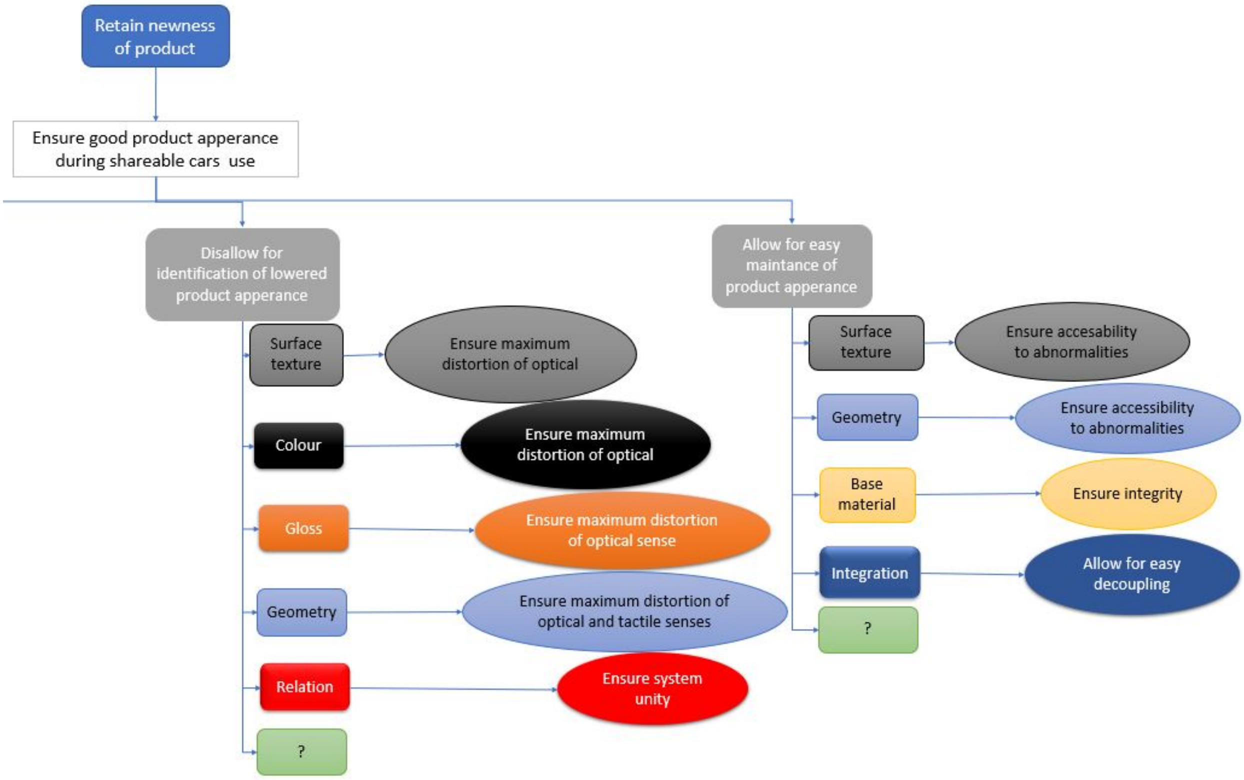


Figure C.2: Functional decomposition generic part 2

D. SWOT-analysis

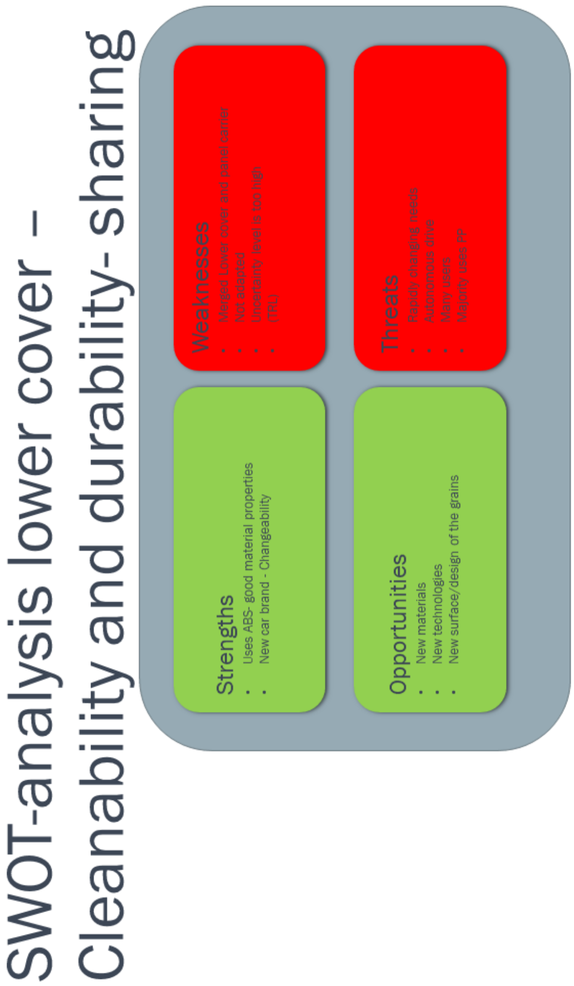


Figure D.1: SWOT-analysis on lower cover, with regard to cleanability and durability in sharing

Figure D.2: SWOT-analysis on the car, with regard to sharing and subscription

E. Segments and questions used during brainstorming session

E.1 Scenarios/Segments

- George is a 25 year old man who is very interested in fashion and strives to have the latest and newest of everything. He is a very modern person with a high interest for new technologies.
  When something new is released, he is one of the first to buy it.
  George doesn't take the car that often, only if he is in a rush and needs to get to work quickly. His reason for not taking the car often is because of environmental aspects.
- Peter is a 45 year old man with 3 kids. Peter takes the car wherever he goes, to work, the children's football trainings etc.
  Peter has no interest in technologies or fashion, the only thing that is important for him is that the car will take him from point A to B.
  Peter is a little bit messy, in other words he doesn't care if the car gets dirty, and his wife is the opposite which creates a conflict since they use the same car.

E.2 Questions

- Since George has an interest for fashion, how should the interior be designed to be kept new and updated?
- George is always in a rush, how could the cleaning of the car interior be solved? Or, how could it be kept clean?
- Since George has an interest in fashion, the car interior shouldn't be worn, how could this be solved?
- Since George has an interest in fashion, the car interior shouldn't be worn, but if a scratch occurs, how could this be solved?
- Since Peter is a little messy and has 3 kids, keep the car interior clean becomes tricky, how could this be solved?
- Peter doesn't mind that the car gets worn but his wife does. How could wear be prevented?

F. Modified Morphological matrix

Modified Morphological Matrix

		Sub-Function	Texture roughness	Texture type		Film type	Film purpose	Additives		Material	
Probability	1	Resist scratching and abrasive wear	Rough texture	-	-	-	Scratch and wear resistant film	Elevating Hardness	-	ABS (baseline)	Higher hardness than the baseline
	2	Resist adhesion of liquid	Smooth texture	Hydrophobic texture	-	-	Hydrophobic film	Elevating Hydrophobicity	Anti-stick	Lower surface energy than the baseline	
	3	Resist adhesion of particles	Smooth texture	-	-	-	Anti-static film	Elevating Anti-static	Anti-stick	ABS (baseline)	Higher electrical resistance than the baseline
Identification	4	Disallow for identification of wear	-	Random texture	-	-	Decor film	Anti-whitening	Elevating Youngs modulus	Higher Young's modulus than the baseline	
	5	Disallow for identification of liquid	-	Random texture	-	-	Decor film	-	-	-	-
	6	Disallow for identification of particle	-	Random texture	-	-	Decor film	-	-	Textile	-
Refurbishment	7	Allow for easy maintance of wear	Smooth texture	-	-	Changeable film	-	Elevating Hardness	-	Self-healing	Shape memory
	8	Allow for easy maintance of liquid	Smooth texture	Directional texture	-	Changeable film	-	-	-	-	-
	9	Allow for easy maintance of particle	Smooth texture	Directional texture	Hydrophilic texture	Changeable film	-	-	-	-	-

Figure F.1: The Modified Morphological matrix, first half.

Modified Morphological Matrix										
		Sub-Function	Coating type	Coating purpose	Gloss	Colour	Modularity			
Probability	1	Resist scratching and abrasive wear	-	Anti-scratch	-	-	-	-	-	-
	2	Resist adhesion of liquid	-	Hydropobic	-	-	-	-	-	-
	3	Resist adhesion of particles	-	Anti-static	-	-	-	-	-	-
Identification	4	Disallow for identification of wear	-	-	-	-	-	-	-	-
	5	Disallow for identification of liquid	-	-	-	-	-	-	-	-
	6	Disallow for identification of particle	-	-	-	-	-	-	-	-
Refurbishment	7	Allow for easy maintance of wear	Changeable coating	Self-healing	-	-	Modularity	Semi-modularity	Modularity-feature	Semi-Modularity-feature
	8	Allow for easy maintance of liquid	Changeable coating	-	-	-	Modularity	Semi-modularity	Modularity-feature	Semi-Modularity-feature
	9	Allow for easy maintance of particle	Changeable coating	Hydrophilic	-	-	Modularity	Semi-modularity	Modularity-feature	Semi-Modularity-feature

Figure F.2: The Modified Morphological matrix, second half.

F.1 Concepts generated

1. Baseline – Textile – Modularity feature
2. Baseline – Scratch and wear resistant film – ABS – Changeable film (Electrically)
3. Rough texture – Random texture – ABS – Hydrophobic coating – Décor film – Semi-modularity
4. Baseline – Changeable film - Décor film
5. Hydrophobic texture – ABS – Semi-modularity
6. Rough texture – Random texture – ABS – Anti-stick additive
7. Rough texture – Random texture – NBR-CD30
8. Smooth texture – Random texture – ABS – Scratch and wear resistant film – Changeable film
9. Rough texture – Random Texture – Higher hardness than baseline (ABS+PC) – Modularity

10. Smooth texture – Random texture – Higher Young's modulus than baseline (Aluminum) – Modularity-feature

11. Smooth texture – Random texture – Higher Young's modulus than baseline (Aluminum) – Semi-modularity-feature

12. Baseline – Changeable film

13. Rough texture – Random texture – Higher surface energy than the baseline (PP) – Anti-whitening additive

14. Smooth surface – Random texture – ABS – Changeable film – Anti-static film

15. Rough texture – Random texture – Higher hardness than baseline (PC-GF) – Elevating Young's modulus additive – Anti-static + Hydrophilic coating

16. Rough texture – Random texture – ABS – Elevating hardness additive

17. Smooth texture – Hydrophilic texture – Higher hardness than baseline (ASA+PC) – Elevating anti-static additive – Semi-modularity

18. Smooth texture – Random texture – Higher hardness than baseline (PC+PET-GF10) – Hydrophobic coating – Changeable coating

19. Rough texture – Random texture – ABS – Décor film

20. Rough texture – Directional texture – ABS – Elevating Young's modulus – Changeable coating – Hydrophobic coating

21. Smooth texture – Directional texture – Higher surface energy than the baseline (PP) – Changeable film – Scratch and wear resistant film

22. Rough texture – Random texture – ABS – Modularity

23. Rough texture – Random texture – Higher hardness than baseline (PP-GF) – Semi-modularity

24. Rough texture – Random texture – ABS – Self healing coating

25. Rough texture – Random texture – Higher hardness than baseline (PBT)

26. Rough texture – Random texture – Lower surface energy than the baseline (PE)

27. (**Macro thinking**) Autonomous doors
28. (**Macro thinking**) Autonomous turning seat
29. (**Macro thinking**) Garbage-can
30. (**Macro thinking**) Air-cleaning
31. (**Macro thinking**) Whole system modularity
32. (**Macro thinking**) Light (personalizing/decor)
33. (**Macro thinking**) Penalty and reward
34. (**Macro thinking**) Accessible cleaning
35. (**Macro thinking**) Gull-wing door

G. Sketches of concepts from the brainstorming

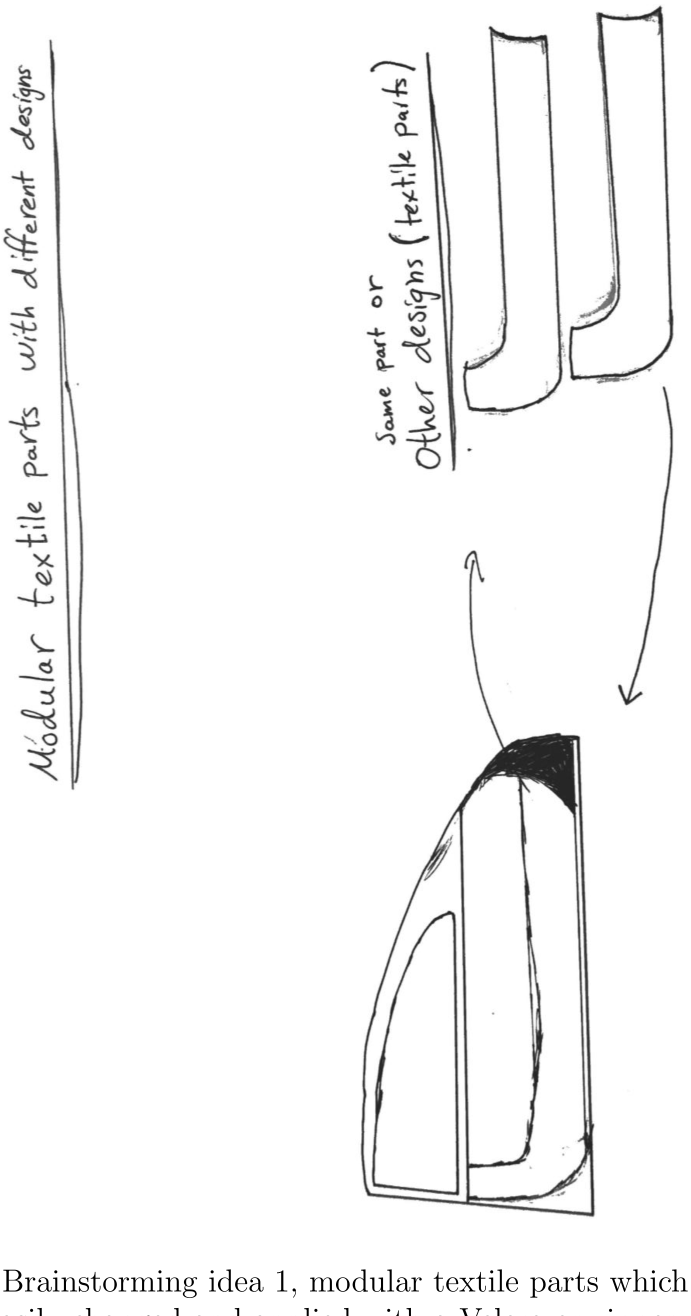


Figure G.1: Brainstorming idea 1, modular textile parts which has different designs. Is easily changed and applied with a Velcro or zipper

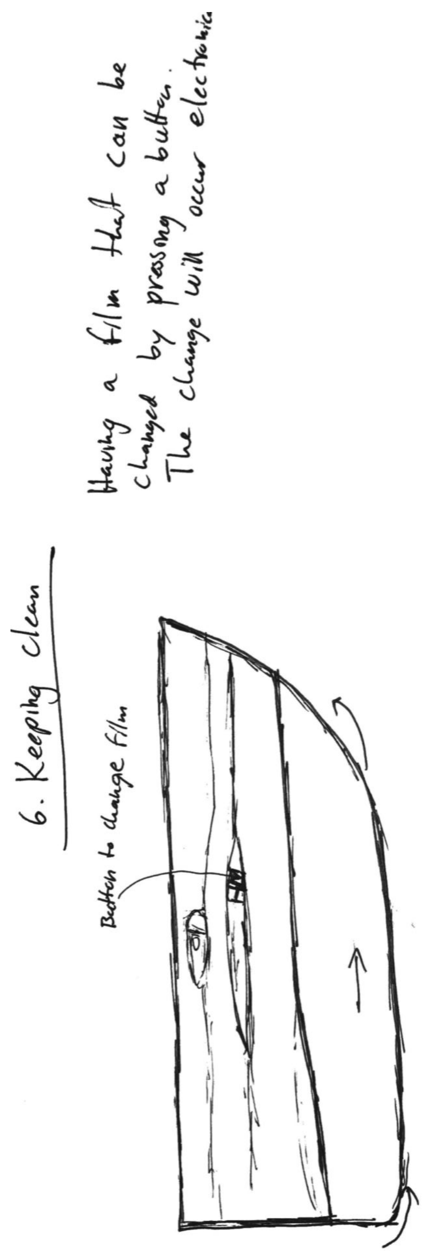


Figure G.2: Brainstorming idea 2, an electrically driven change process of the film which is changed by pressing a button.

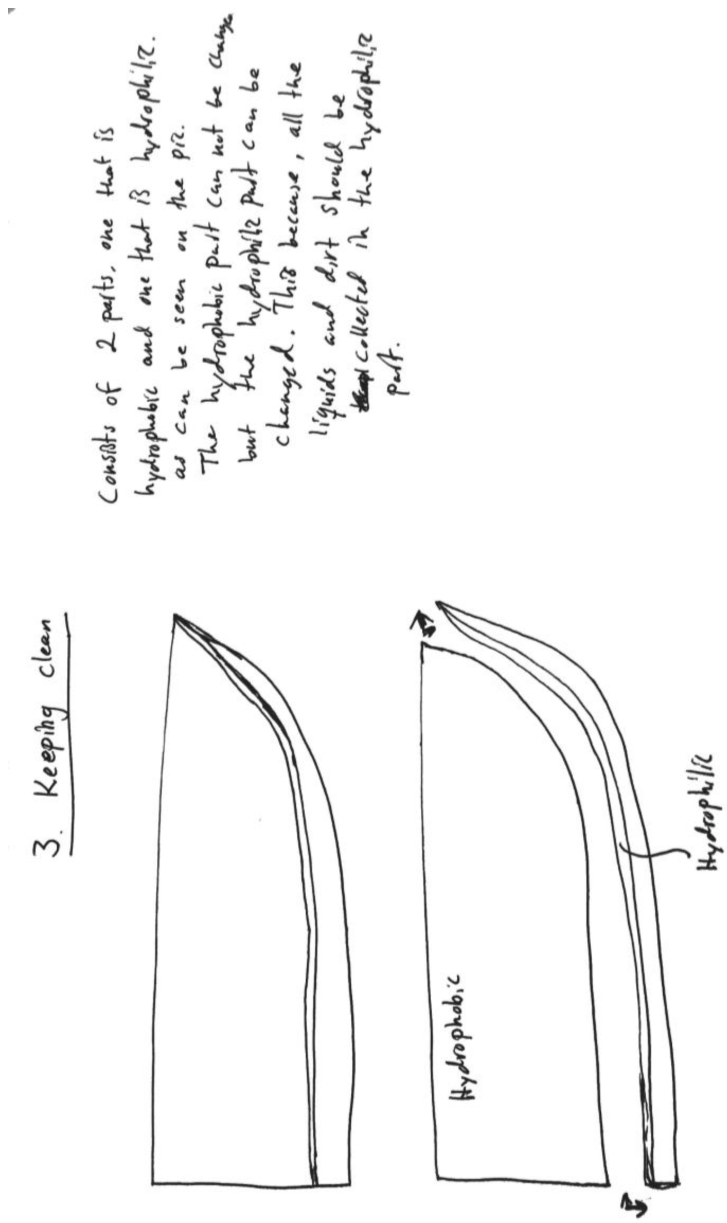


Figure G.3: Brainstorming idea 3, a hydrophobic lower cover designed with a modular container which will pick up the soil and has hydrophilic properties to ease cleaning the surface. There is a decor film on the container and it is hydrophilic on the inside for easier cleaning.

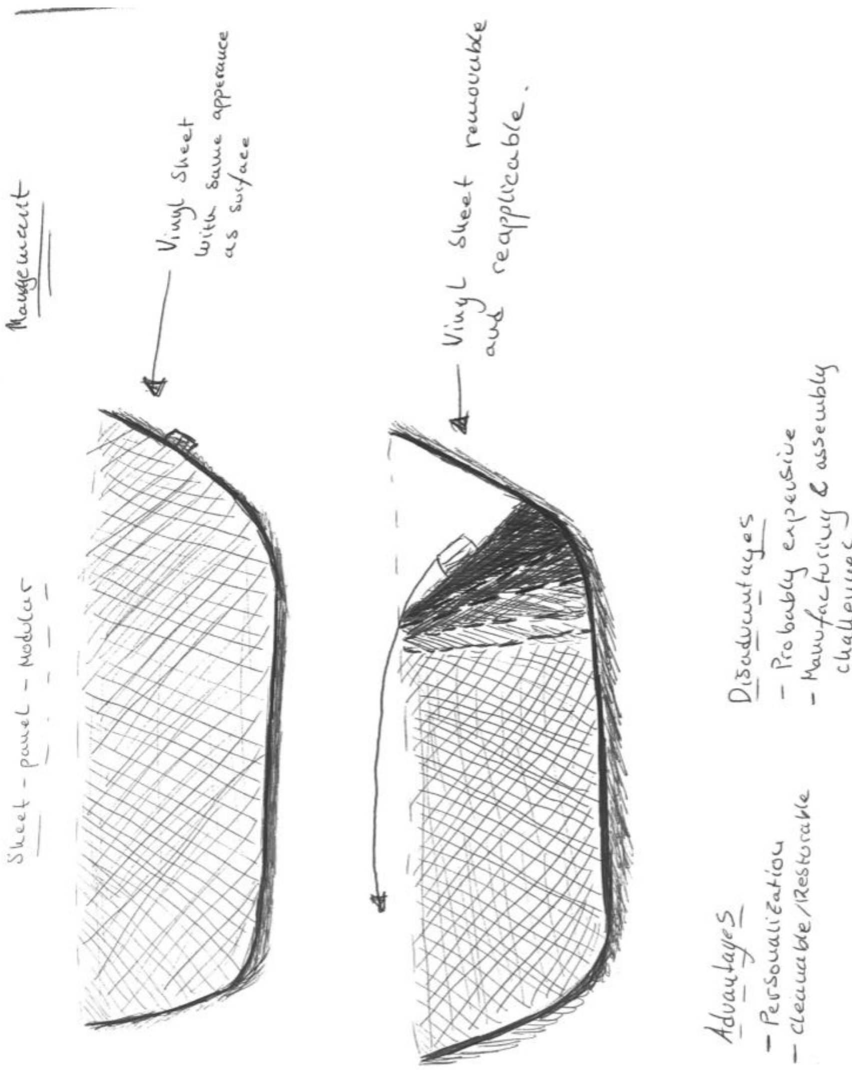


Figure G.4: Brainstorming idea 4

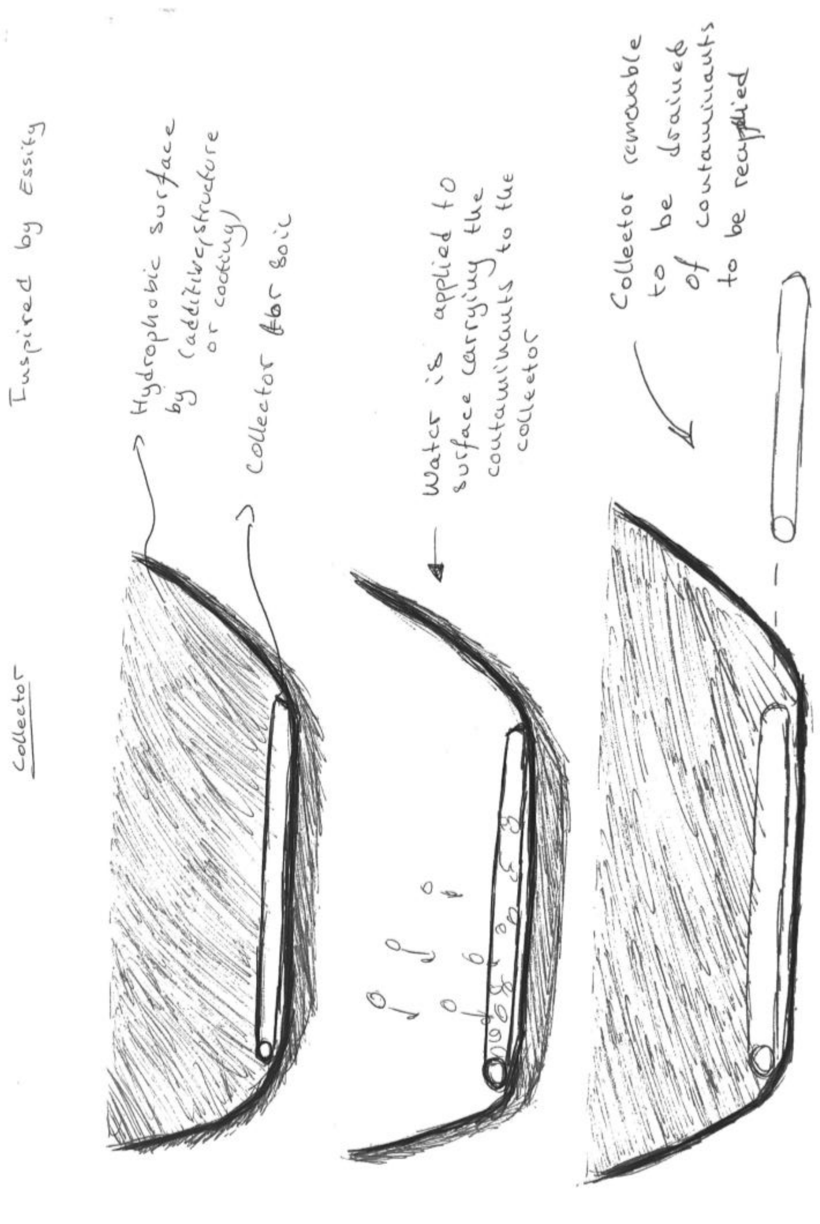


Figure G.5: Brainstorming idea 5, a hydrophobic lower cover designed with a modular container which will pick up the soil.

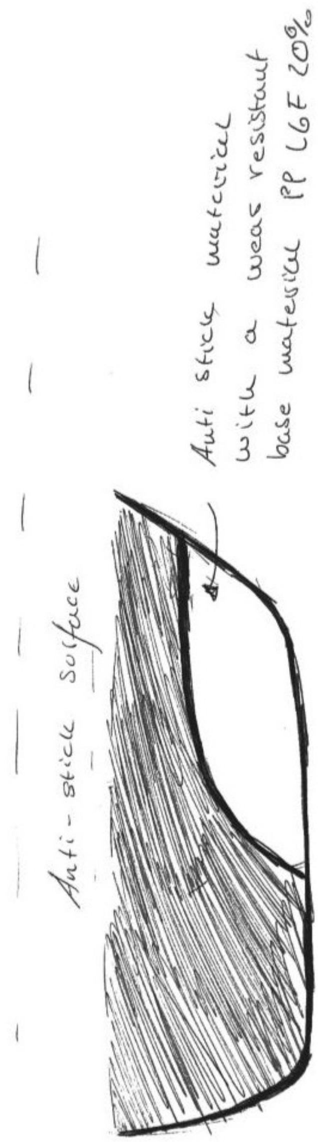


Figure G.6: Brainstorming idea 6, Anti-stick surface and scratch resistant base material (PP-GF20).

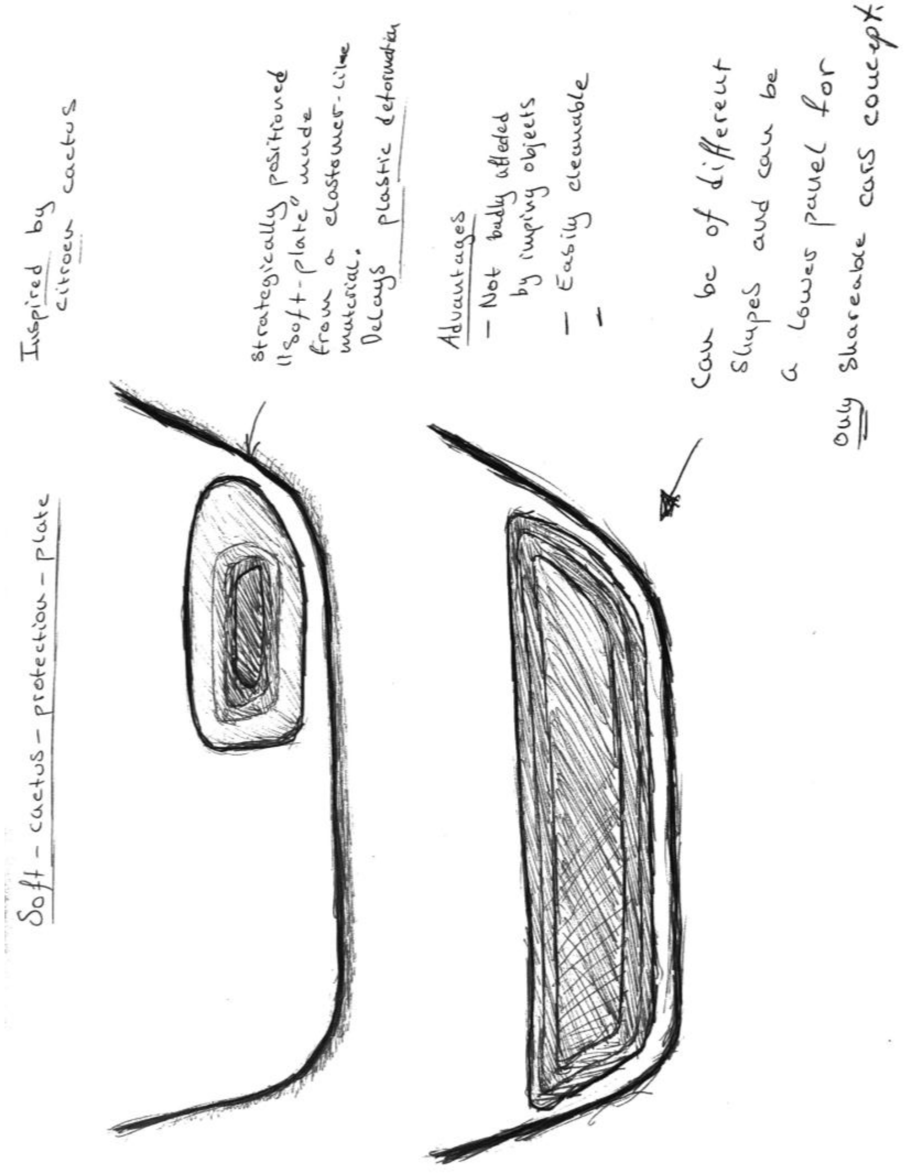


Figure G.7: Brainstorming idea 7, a design and material choice which delays plastic deformation.

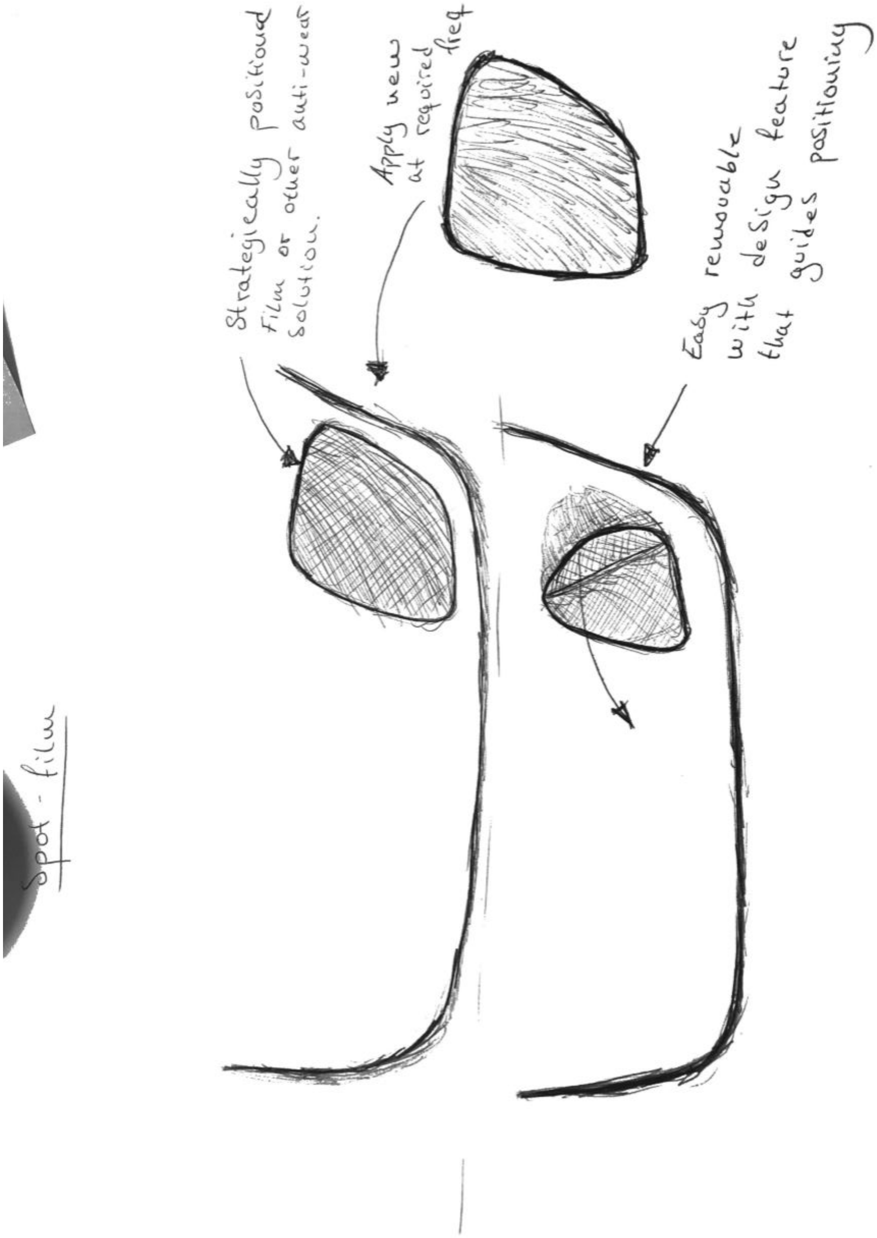


Figure G.8: Brainstorming idea 8, strategically positioned film or other anti-wear solution on the lower cover which is easy to remove. Has designed features that guides position of film or other anti-wear solution.

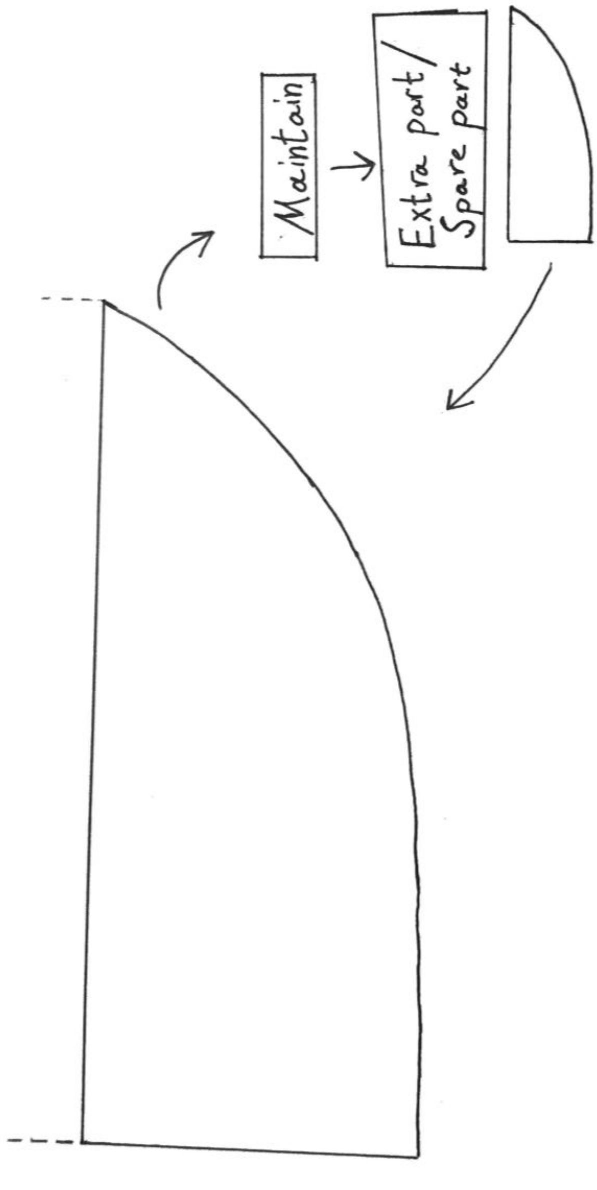


Figure G.9: Brainstorming idea 9, Modular part that has spare parts which can replays the damaged/dirty part during maintaining.

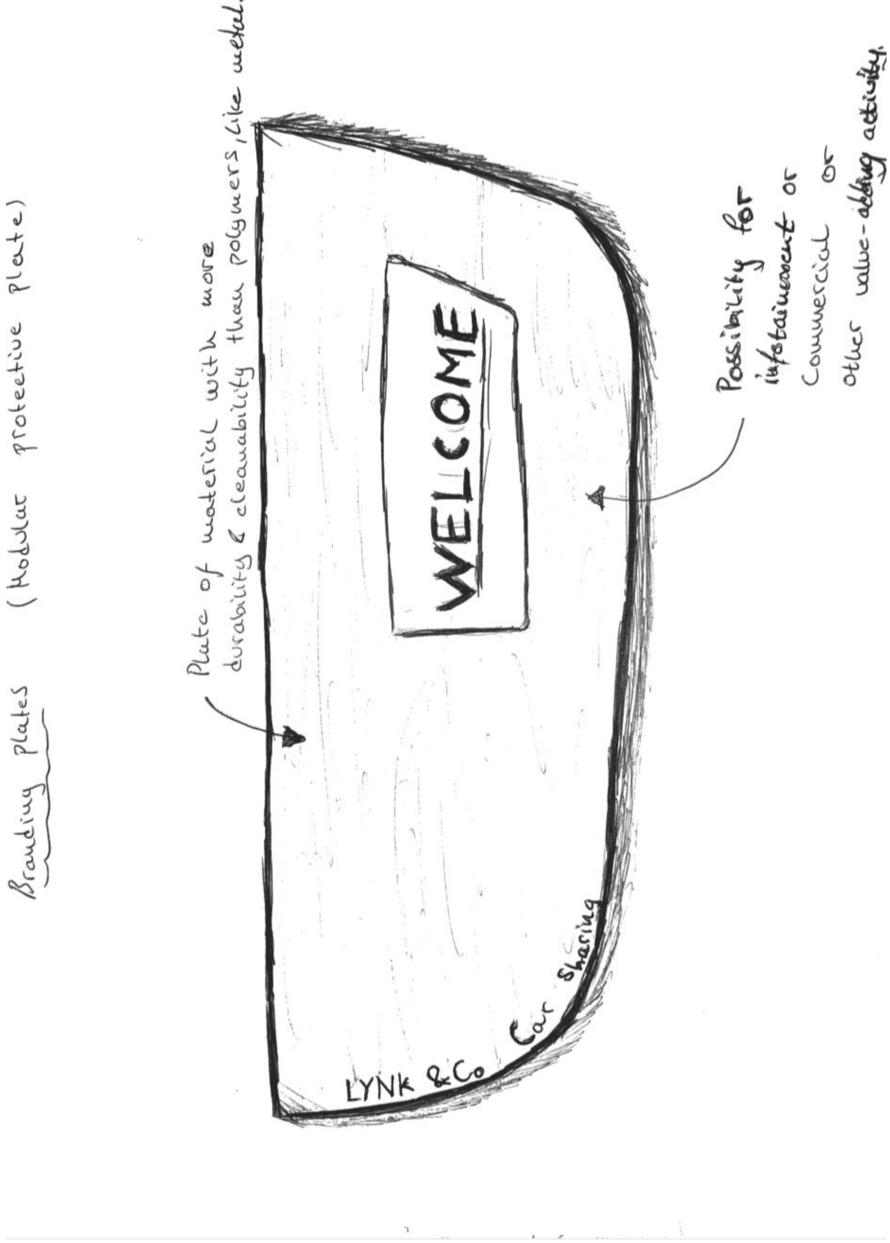


Figure G.10: Brainstorming idea 10, Concept branding which will brand the car manufacturer and owner of the sharing pool.

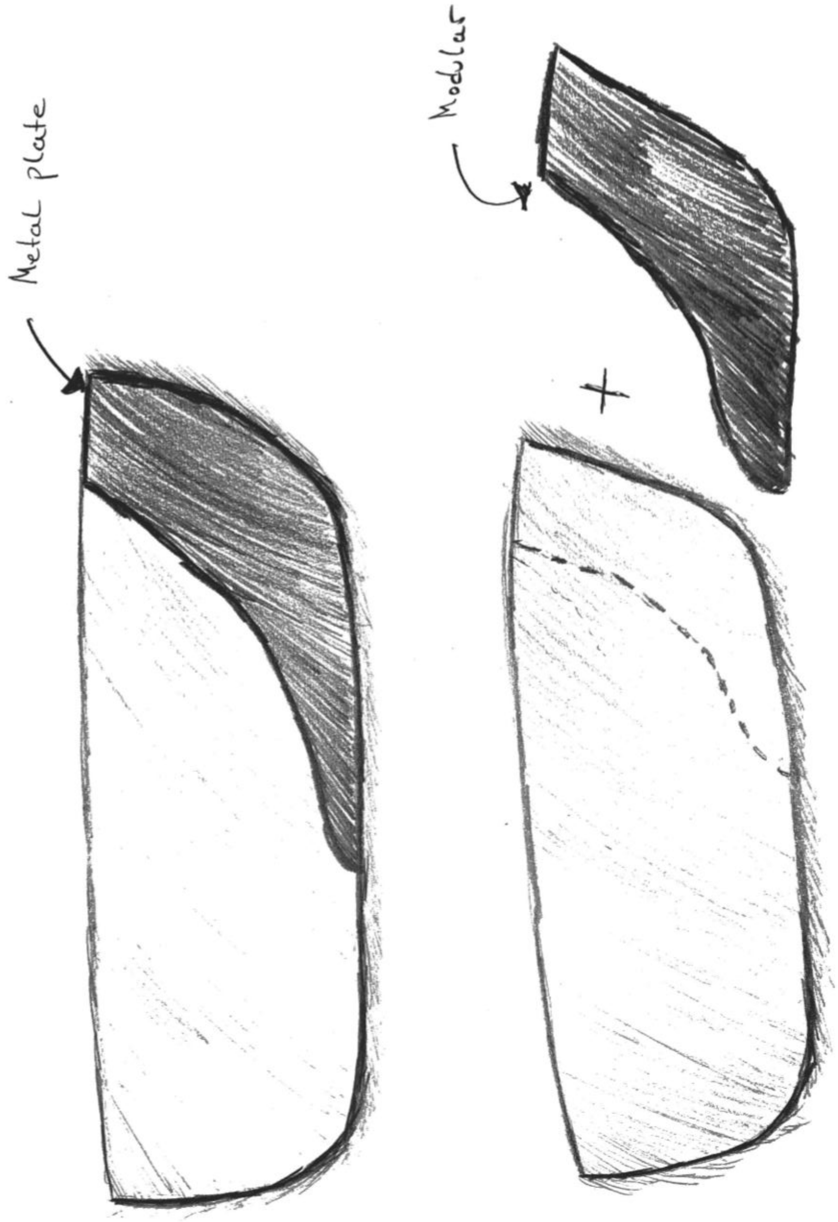


Figure G.11: Brainstorming idea 11, foldable protection plate.

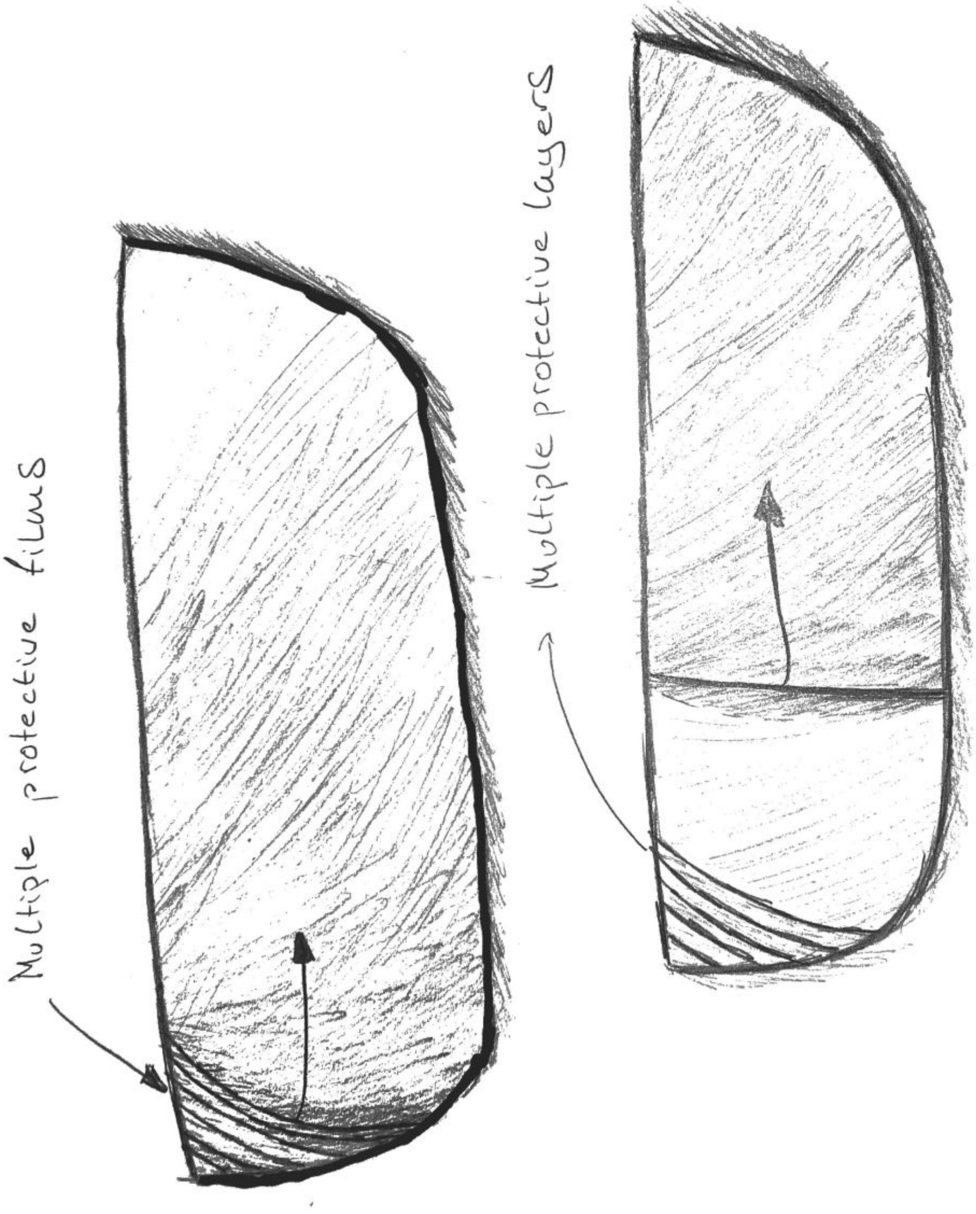


Figure G.12: Brainstorming idea 12, multiple tape entailing ease of changing by having multiple layers of tape on each other.

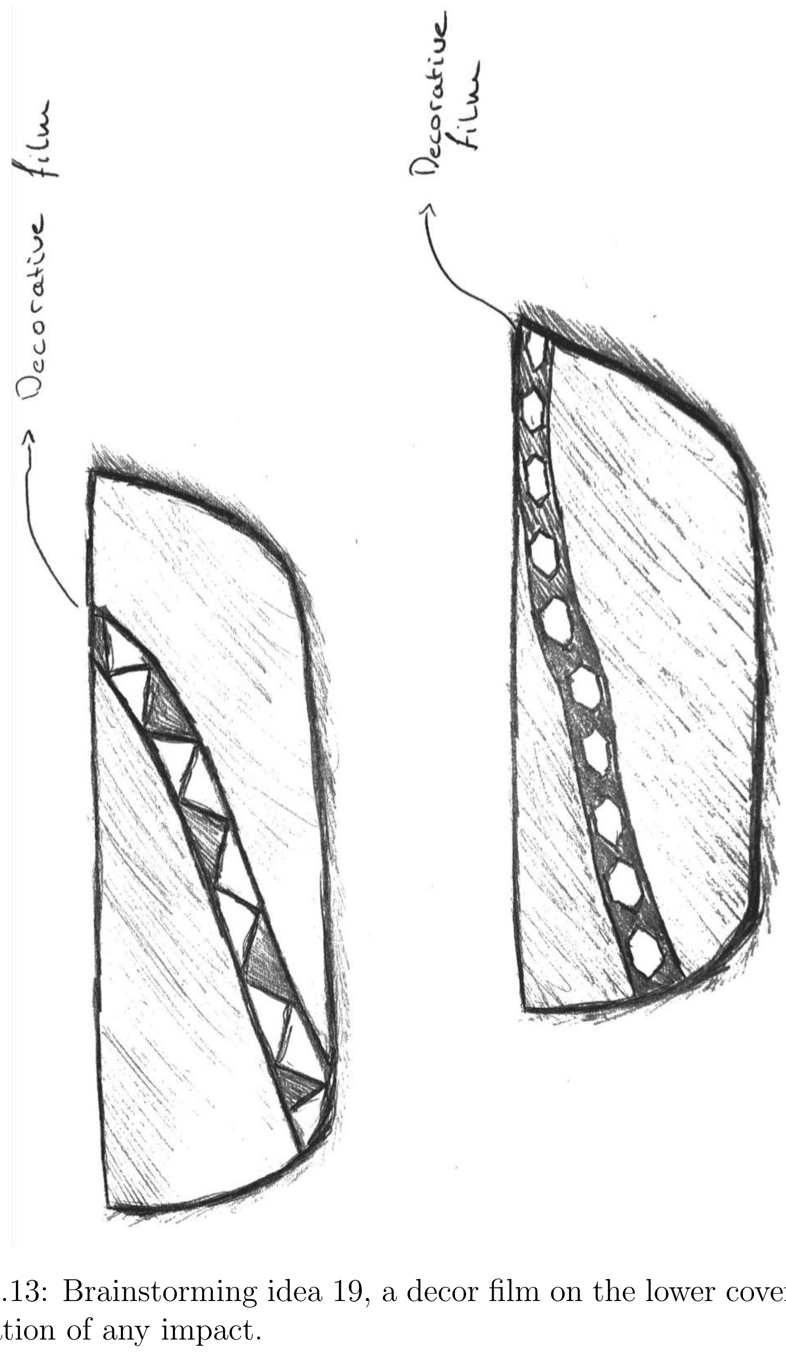


Figure G.13: Brainstorming idea 19, a decor film on the lower cover to lower identification of any impact.

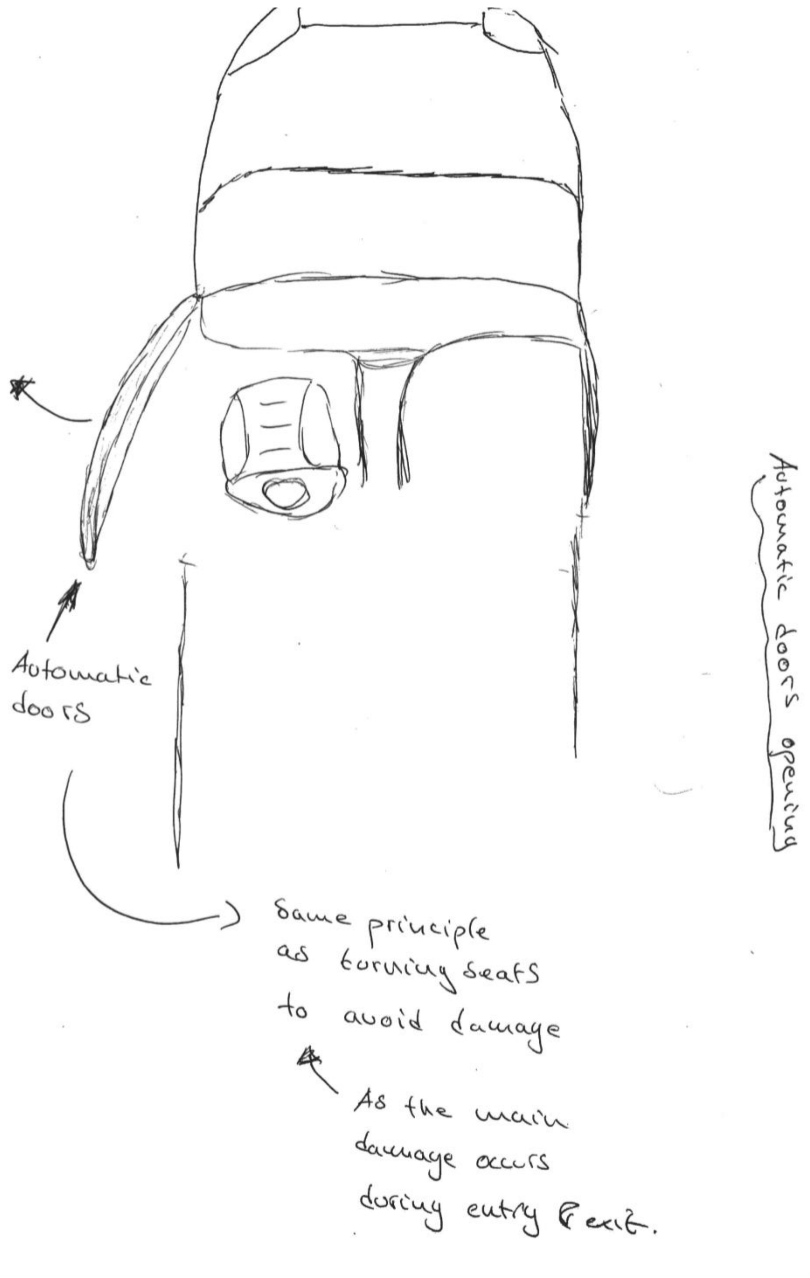


Figure G.14: Brainstorming idea 27, Concept autonomous doors

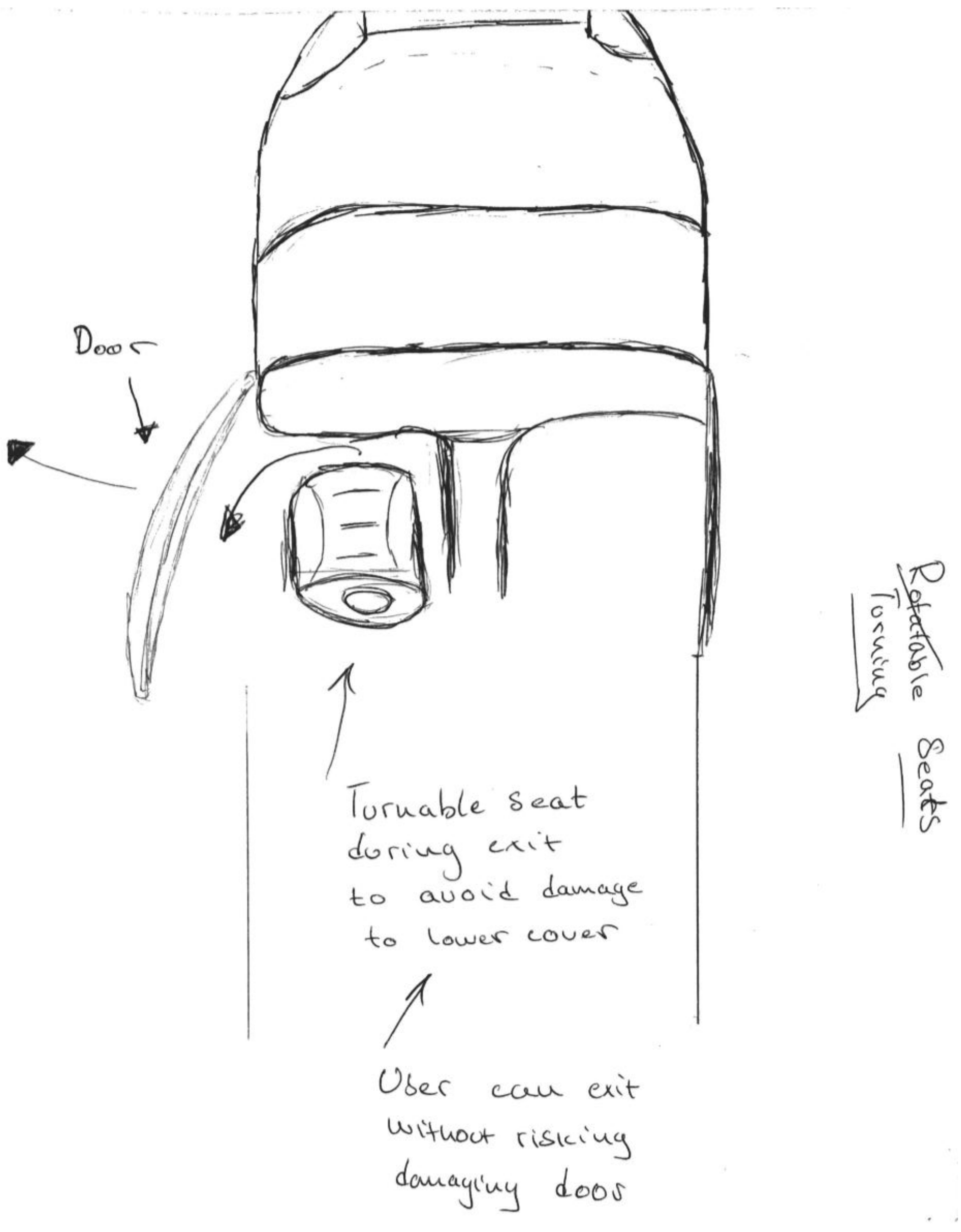


Figure G.15: Brainstorming idea 28, autonomous rotating seat

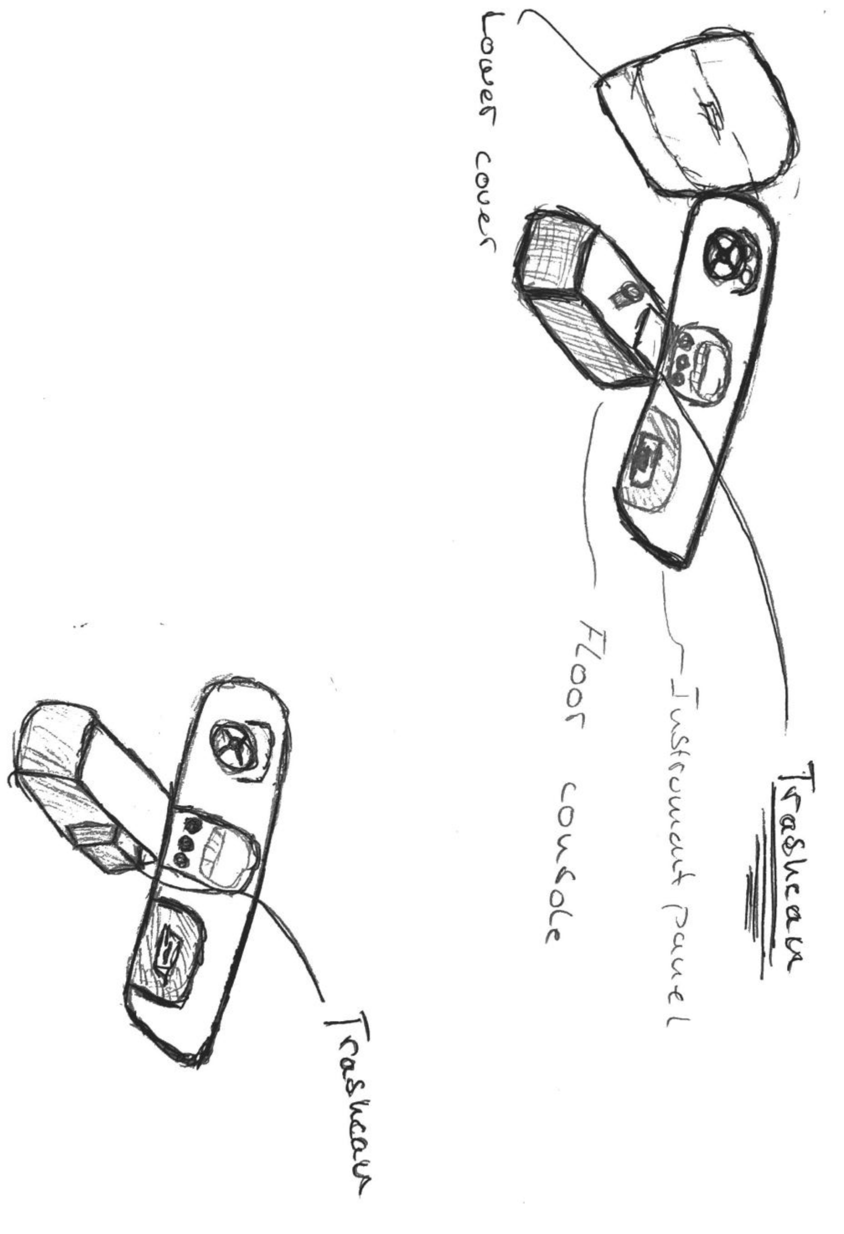


Figure G.16: Brainstorming idea 29, implementing a garbage-can in the car.

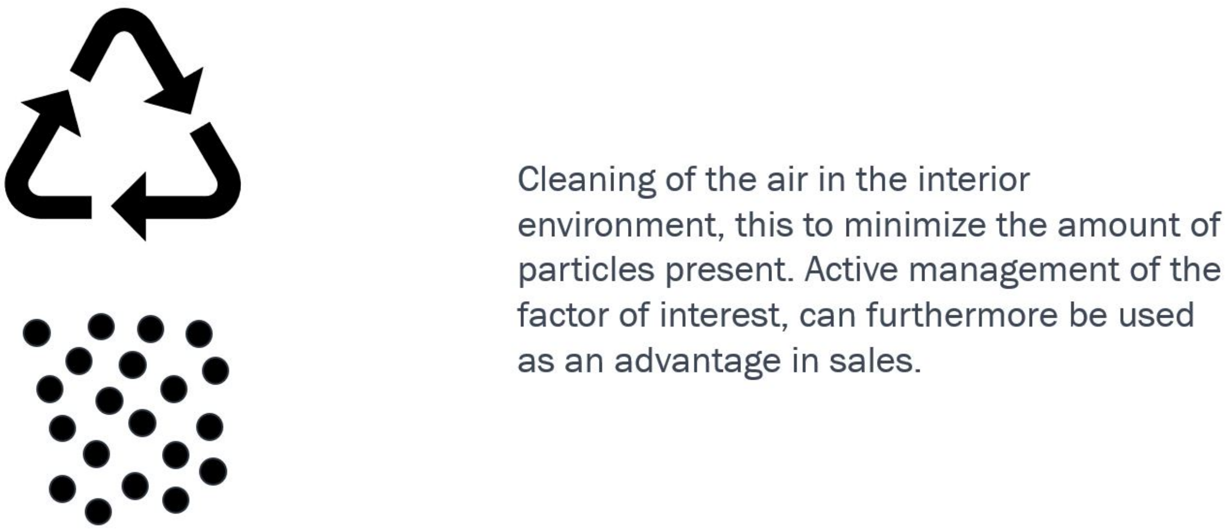


Figure G.17: Brainstorming idea 30, implementing a air-cleaning system to the car.

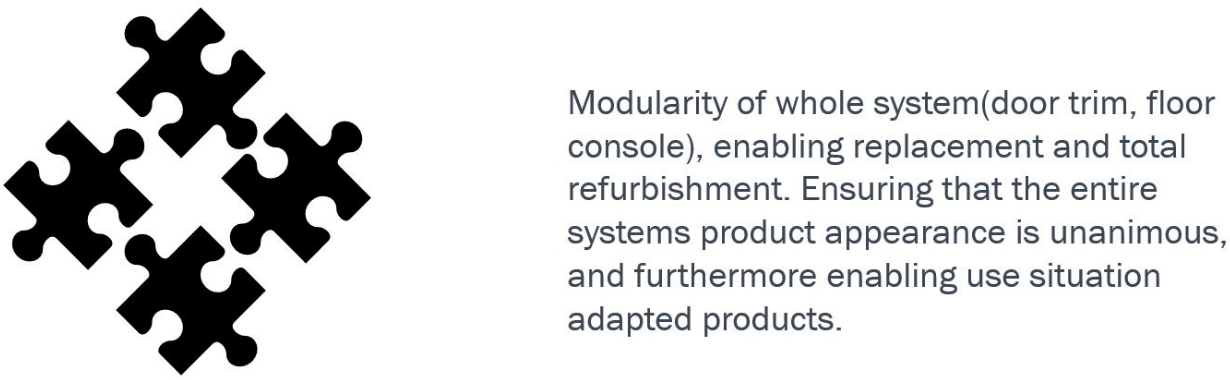


Figure G.18: Brainstorming idea 31, Whole system modularity.

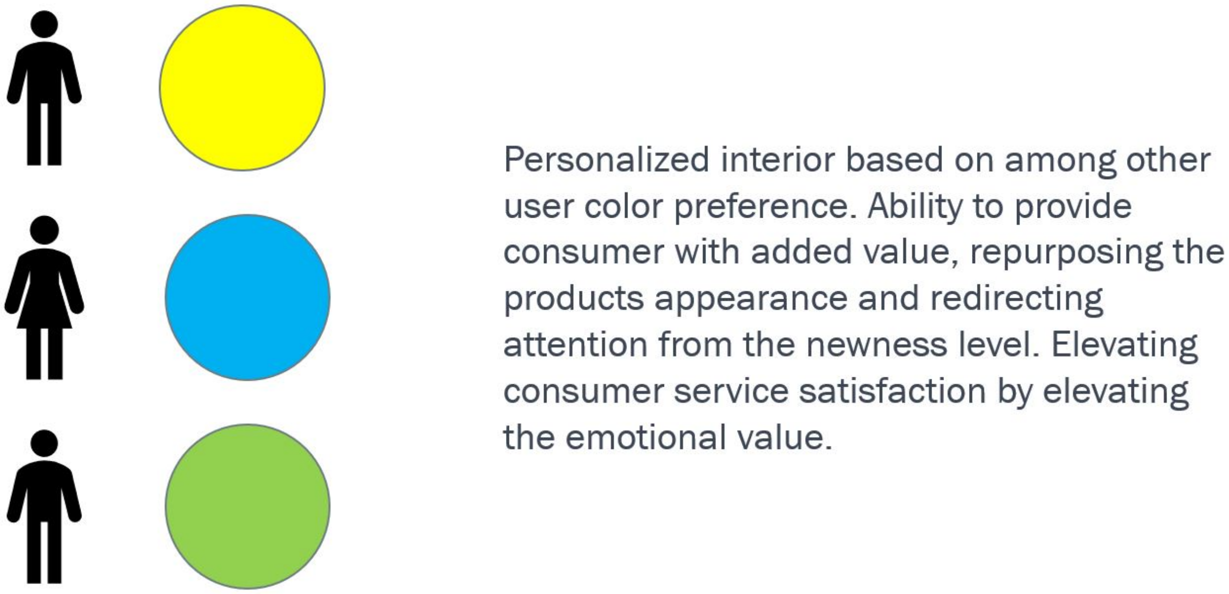


Figure G.19: Brainstorming idea 32.

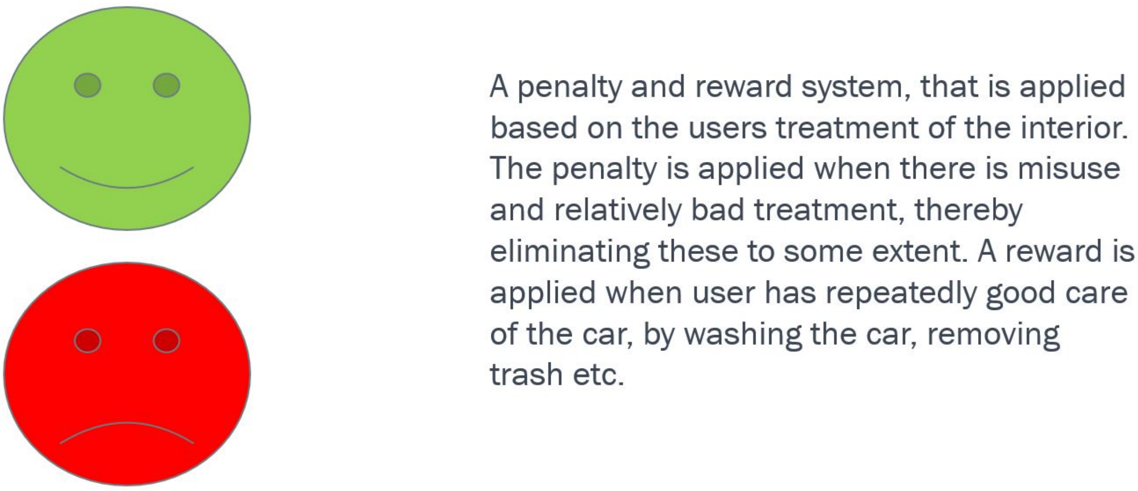


Figure G.20: Brainstorming idea 33.

Accessible cleaning possibilities, providing the consumer with cloths and other cleaning tools. This to enable quick cleaning of the interior by the consumer, furthermore enabling the consumer comfort by providing them the ability to clean surfaces that are of concern.

Figure G.21: Brainstorming idea 34.

Gull-wing doors, redesign of the door to ensure minimal impact to lower cover. Enabling simplified exit & entry of vehicle and eliminating the unwanted effect of todays exit & entry.

Figure G.22: Brainstorming idea 35.

H. Elimination matrix

Elimination criterions/decision

(+) Yes

(-) No

(?) More info is needed

Solution	Does it solve the base problem?	Does it fulfill the basic requirements?	Is the technology readiness level high enough?	Is the cost within the given specifications?	Is it an advantage from a environmental, safety or ergonomically aspect?	Does it match the company product program?	Is the information required available?	Decision
1	+	+	+	+	+	+	+	+
2	+	+	-					-
3	+	+	+	+	+	+	+	+
4	+	+	+	+	-			-
5	+	+	-					-
6	+	+	+	+	+	+	+	+
7	+	+	+	+	+	+	+	+
8	+	+	+	+	+	+	+	+
9	+	+	+	+	+	+	+	+
10	+	+	+	+	+	+	+	+
11	+	+	+	+	+	+	+	+
12	+	+	+	+	-			-
13	+	-						-
14	+	+	+	+	+	+	+	+
15	+	+	+	+	+	+	+	+
16	+	+	+	+	+	+	+	+
17	+	+	-					-
18	+	+	+	+	+	+	+	+
19	+	-						-
20	+	+	+	+	+	+	+	+
21	+	+	+	+	+	+	+	+
22	+	+	+	+	+	+	+	+
23	+	+	+	+	+	+	+	+
24	+	+	-					-
25	+	+	+	+	+	+	+	+
26	+	+	+	+	+	+	+	+
27	-							-
28	-							-
29	-							-
30	-							-
31	-							-
32	-							-
33	-							-
34	-							-
35	-							-

Figure H.1: The whole Eliminations matrix which is performed.

I. Pughs matrix

Criterion	Baseline	1	3	6	7	8	9	10	11	14	15
Scratching and abrasive wear resistant		-	-	+	0	+	+	+	+	0	+
Ensure resistance to adhesion of liquid		-	+	+	0	0	0	-	-	+	-
Ensure resistance to adhesion of particles		-	0	+	-	0	0	0	0	+	+
Disallow identification of scratches and wear		+	0	0	0	0	0	+	+	0	+
Disallow identification of adhered liquid		0	+	0	0	0	0	0	0	0	0
Disallow identification of adhered particles		+	+	0	0	0	0	0	0	0	0
Allows easy maintance of scratches and wear		+	-	0	0	+	+	+	0	+	-
Allows easy maintance of adhered liquid		+	-	+	+	+	+	+	0	+	+
Allows easy maintance of adhered particles		+	+	+	+	+	+	+	0	+	+
Ensure minimal addition to service life cost		0	-	+	0	-	-	-	-	0	-
Oblige to styling and ergonomics requirements		-	-	-	-	-	0	-	-	-	-
Enable simple maintenance		+	-	+	0	+	+	+	0	+	0
Allow for easy implementation		-	-	-	-	-	-	-	-	-	-
Inflict minimal environmental impact		0	-	-	0	-	-	-	-	-	-
Ensure minimal weight impact		0	0	0	0	0	0	-	-	0	0
SUM (+)	0	6	4	7	2	5	5	6	2	6	5
SUM (0)	0	5	3	5	10	6	6	3	7	6	4
SUM (-)	0	5	8	3	3	4	3	6	6	3	6
Net value	0	1	-4	4	-1	1	2	0	-4	3	-1
Ranking	5	4	8	1	6	4	3	5	8	2	6
Further development (YES/NO)	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No

Figure I.1: The first iteration of the Pughs matrix which is performed, first half.

Criterion	Baseline	16	18	20	21	22	23	25	26
Scratching and abrasive wear resistant		+	+	0	+	0	+	+	-
Ensure resistance to adhesion of liquid		0	+	+	0	0	+	0	+
Ensure resistance to adhesion of particles		0	0	0	0	0	0	0	0
Disallow identification of scratches and wear		0	+	0	0	0	+	+	-
Disallow identification of adhered liquid		0	0	0	0	0	0	0	0
Disallow identification of adhered particles		0	0	0	0	0	0	0	0
Allows easy maintance of scratches and wear		0	-	+	+	+	+	0	0
Allows easy maintance of adhered liquid		+	-	+	+	+	+	0	0
Allows easy maintance of adhered particles		+	0	+	+	+	+	-	0
Ensure minimal addition to service life cost		0	-	-	0	-	-	0	0
Oblige to styling and ergonomics requirements		0	-	-	-	0	0	0	0
Enable simple maintenance		0	-	+	+	+	+	0	0
Allow for easy implementation		-	-	-	-	-	-	-	-
Inflict minimal environmental impact		-	-	-	0	-	-	0	0
Ensure minimal weight impact		0	0	0	0	0	0	0	0
SUM (+)	0	3	3	5	5	4	7	2	1
SUM (0)	0	10	5	6	8	8	5	11	11
SUM (-)	0	2	7	4	2	3	3	2	3
Net value	0	1	-4	1	3	1	4	0	-2
Ranking	5	4	8	4	2	4	1	5	7
Further development (YES/NO)	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No

Figure I.2: The first iteration of the Pughs matrix which is performed, second half.

Criterion	23	1	6	8	9	10	14
Scratching and abrasive wear resistant		-	-	0	-	+	-
Ensure resistance to adhesion of liquid		-	-	0	-	-	+
Ensure resistance to adhesion of particles		-	+	0	0	0	+
Disallow identification of scratches and wear		-	0	-	-	+	-
Disallow identification of adhered liquid		0	0	0	0	0	0
Disallow identification of adhered particles		+	0	0	0	0	0
Allows easy maintance of scratches and wear		0	-	0	0	0	0
Allows easy maintance of adhered liquid		+	-	+	+	+	+
Allows easy maintance of adhered particles		+	-	+	+	+	+
Ensure minimal addition to service life cost		+	+	-	0	0	-
Oblige to styling and ergonomics requirements		-	-	-	0	-	-
Enable simple maintenance		+	-	+	+	+	0
Allow for easy implementation		0	+	0	0	0	0
Inflict minimal environmental impact		+	+	0	-	-	0
Ensure minimal weight impact		0	0	0	0	-	0
SUM (+)	0	6	4	3	3	5	4
SUM (0)	0	4	4	9	8	6	7
SUM (-)	0	5	7	3	4	4	4
Net value	0	1	-3	0	-1	1	0
Ranking	2	1	4	2	3	1	2
Further development (YES/NO)	Yes	Yes	No	Yes	Yes	Yes	Yes

Figure I.3: The second iteration of the Pughs matrix which is performed, first part.

Criterion	23	16	20	21	22	25	Baseline
Scratching and abrasive wear resistant		0	-	0	-	-	-
Ensure resistance to adhesion of liquid		0	+	-	-	-	-
Ensure resistance to adhesion of particles		0	0	0	0	0	0
Disallow identification of scratches and wear		-	-	-	-	-	-
Disallow identification of adhered liquid		0	0	0	0	0	0
Disallow identification of adhered particles		0	0	0	0	0	0
Allows easy maintance of scratches and wear		-	0	0	0	-	-
Allows easy maintance of adhered liquid		-	+	+	+	-	-
Allows easy maintance of adhered particles		-	+	+	+	-	-
Ensure minimal addition to service life cost		+	0	0	0	+	+
Oblige to styling and ergonomics requirements		0	-	-	0	0	0
Enable simple maintenance		-	+	+	+	-	-
Allow for easy implementation		0	0	0	0	+	+
Inflict minimal environmental impact		+	-	+	-	+	+
Ensure minimal weight impact		0	0	0	0	0	0
SUM (+)	0	2	4	4	3	3	3
SUM (0)	0	8	7	8	8	5	5
SUM (-)	0	5	4	3	4	7	7
Net value	0	-3	0	1	-1	-4	-4
Ranking	2	4	2	1	3	5	5
Further development (YES/NO)	Yes	No	Yes	Yes	Yes	No	No

Figure I.4: The second iteration of the Pughs matrix which is performed, second part.

J. Weighted Pughs matrix

Criterion	Weight (1-5)	Reference	Rating 1	1	Rating 8	8	Rating 9	9	Rating 10	10	Rating 14	14
Scratching and abrasive wear resistant	5	25	2	10	5	25	5	25	5	25	2	10
Ensure resistance to adhesion of liquid	1	5	2	2	3	3	1	1	3	3	4	4
Ensure resistance to adhesion of particles	3	15	2	6	3	9	1	3	3	9	4	12
Disallow identification of wear	5	25	3	15	1	5	3	15	3	15	2	10
Disallow identification of liquid	1	5	3	3	1	1	2	2	2	2	2	2
Disallow identification of particle	3	15	5	15	1	3	2	6	2	6	2	6
Allows easy maintance of wear	5	25	5	25	5	25	5	25	5	25	5	25
Allows easy maintance of liquid	1	5	5	5	5	5	5	5	5	5	5	5
Allows easy maintance of particle	3	15	5	15	5	15	5	15	5	15	5	15
Ensure minimal addition to service life cost	4	20	3	12	2	8	2	8	3	12	3	12
Oblige to styling and ergonomics requirements	5	25	1	5	2	10	5	25	2	10	2	10
Enable simple maintenance	3	15	5	15	5	15	5	15	5	15	5	15
Allow for easy implementation	4	20	3	12	4	16	3	12	4	16	3	12
Inflict minimal environmental impact	3	15	4	12	3	9	1	3	3	9	3	9
Ensure minimal weight impact	2	10	5	10	5	10	5	10	3	6	5	10
Weighted Value		240		162		159		170		173		157
Net value				0,675		0,6625		0,7083333		0,7208333		0,6541667
Ranking			5		7		3		1		8	

Figure J.1: The whole Weighted Pughs matrix, first part.

Criterion	Weight (1-5)	Reference	Rating 20	20	Rating 21	21	Rating 22	22	Rating 23	23
Scratching and abrasive wear resistant	5	25	2	10	5	25	3	15	4	20
Ensure resistance to adhesion of liquid	1	5	5	5	2	2	2	2	3	3
Ensure resistance to adhesion of particles	3	15	3	9	2	6	2	6	2	6
Disallow identification of wear	5	25	2	10	2	10	3	15	4	20
Disallow identification of liquid	1	5	2	2	2	2	3	3	2	2
Disallow identification of particle	3	15	2	6	2	6	3	9	2	6
Allows easy maintance of wear	5	25	5	25	5	25	5	25	5	25
Allows easy maintance of liquid	1	5	5	5	5	5	5	5	3	3
Allows easy maintance of particle	3	15	5	15	5	15	5	15	3	9
Ensure minimal addition to service life cost	4	20	3	12	3	12	2	8	3	12
Oblige to styling and ergonomics requirements	5	25	2	10	2	10	5	25	4	20
Enable simple maintenance	3	15	5	15	5	15	5	15	5	15
Allow for easy implementation	4	20	3	12	3	12	3	12	3	12
Inflict minimal environmental impact	3	15	2	6	2	6	2	6	2	6
Ensure minimal weight impact	2	10	5	10	5	10	5	10	5	10
Weighted Value		240		152		161		171		169
Net value				0,6333333		0,6708333		0,7125		0,7041667
Ranking			9		6		2		4	

Figure J.2: The whole Weighted Pughs matrix, second part.

K. Tests and Validation Results

Table K.1: The tests performed with no applied feature.

Test plate	Light	Applied test feature	Test type	Comment
1 (all)	D65	None	Check in light	Some dust particles are visible on the surface
1 (all)	TL84	None	Check in light	Some dust particles are visible on the surface
2	D65	None	Check in light	Some dust particles are visible on the surface
2	TL84	None	Check in light	More dust particles are visible than in D65 light
3	D65	None	Check in light	Some dust particles are visible on the surface
3	TL84	None	Check in light	More dust particles are visible than in D65 light
4	D65	None	Check in light	Some dust particles are visible on the surface
4	TL84	None	Check in light	More dust particles are visible than in D65 light

Table K.2: The tests performed on test plate 1 with the temporary tape.

Test plate	Light	Applied test feature	Test type	Comment
1.1	D65	Temporary tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach. Some air bubbles visible. More glossy and sticky tactile feel relatively without the tape.
1.1	TL84	Temporary tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach. Some air bubbles are visible. More glossy and sticky tactile feel relatively without the tape. The tape is more visible relatively D65 light.
1.2	D65	Temporary tape	Check in light and tactile feel	Not very clear that it is a tape on the surface, but the surface is more glossy and sticky tactile feel relatively without the tape.
1.2	TL84	Temporary tape	Check in light and tactile feel	Very clear that it is a tape on the surface. The surface is more glossy and sticky tactile feel relatively without the tape.
1.3	D65	Temporary tape	Check in light and tactile feel	Not very clear that it is a tape on the surface, but the surface is more glossy and sticky tactile feel relatively without the tape.
1.3	TL84	Temporary tape	Check in light and tactile feel	Very clear that it is a tape on the surface. The surface is more glossy and sticky tactile feel relatively without the tape.
1.4	D65	Temporary tape	Check in light and tactile feel	Not very clear that it is a tape on the surface, but the surface is more glossy and sticky tactile feel relatively without the tape.
1.4	TL84	Temporary tape	Check in light and tactile feel	Not very clear that it is a tape on the surface, but the surface is more glossy and sticky tactile feel relatively without the tape.
1.5	D65	Temporary tape	Check in light and tactile feel	Very clear that it is a tape on the surface, still looks good where there is no air bubbles. Attaches very well to the surface. The surface is more glossy and sticky tactile feel relatively without the tape.
1.5	TL84	Temporary tape	Check in light and tactile feel	Very clear that it is a tape on the surface, still looks good where there is no air bubbles. Attaches very well to the surface. The surface is more glossy and sticky tactile feel relatively without the tape.
1.6	D65	Temporary tape	Check in light and tactile feel	Looks very good on the surface but there are some air bubbles which makes it look worse. No major change in tactile feel and gloss relatively without tape.
1.6	TL84	Temporary tape	Check in light and tactile feel	Looks good but worse than in D65 light. No major change in tactile feel and gloss relatively without tape.

Table K.3: The tests performed on test plate 2, 3, 4 with the temporary tape.

Test plate	Light	Applied test feature	Test type	Comment
2	D65	Temporary tape	Check in light and tactile feel	Not clear that it is a tape. The texture makes the air bubbles look planned. The surface is more glossy and sticky tactile feel relatively without the tape.
2	TL84	Temporary tape	Check in light and tactile feel	Not clear that it is a tape. The texture makes the air bubbles look planned. The surface is more glossy and sticky tactile feel relatively without the tape.
3	D65	Temporary tape	Check in light and tactile feel	Not clear that it is a tape. The surface is more glossy and sticky tactile feel relatively without the tape. Better look than the other test plates.
3	TL84	Temporary tape	Check in light and tactile feel	Not clear that it is a tape. The surface is more glossy and sticky tactile feel relatively without the tape. Better look than the other test plates. More visible that it is a tape than in D65 light.
4	D65	Temporary tape	Check in light and tactile feel	Not clear that it is a tape. The texture makes the air bubbles look planned. The surface is more glossy and sticky tactile feel relatively without the tape.
4	TL84	Temporary tape	Check in light and tactile feel	Not clear that it is a tape. The texture makes the air bubbles look planned. The surface is more glossy and sticky tactile feel relatively without the tape.

Table K.4: The scratch tests performed on test plate 1 with the temporary tape.

Test plate	Light	Applied test feature	Test type	Comment
1.1	D65	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.1	TL84	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.2	D65	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.2	TL84	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.3	D65	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.3	TL84	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.4	D65	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.4	TL84	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.5	D65	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.5	TL84	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.6	D65	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.
1.6	TL84	Temporary tape	Scratch test and check in light	There is no visible scratch on the surface after 3 hits with a shoe on the tape.

Table K.5: The scratch tests performed on test plate 2, 3, 4 with the temporary tape compared with the texture without the tape.

Test plate	Light	Applied test feature	Test type	Comment
2	D65	Temporary tape	Scratch test and check in light	The scratch is not visible from distance. More visible from near close.
2	TL84	Temporary tape	Scratch test and check in light	The scratch is not visible on the tape but it is visible on the texture without tape.
3	D65	Temporary tape	Scratch test and check in light	The scratch is not visible on the tape but it is visible on the texture without tape.
3	TL84	Temporary tape	Scratch test and check in light	The scratch is not visible on the tape but it is visible on the texture without tape.
4	D65	Temporary tape	Scratch test and check in light	The scratch is not visible on the tape but it is visible on the texture without tape.
4	TL84	Temporary tape	Scratch test and check in light	The scratch is not visible on the tape but it is visible on the texture without tape.

Table K.6: The tests performed on test plate 1 with the scratch and wear resistant tape.

Test plate	Light	Applied test feature	Test type	Comment
1.1	D65	Scratch and wear resistant tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach. Some air bubbles are visible. More glossy and sticky tactile feel relatively without the tape.
1.1	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach. Some air bubbles are visible. More visible that it is a tape on the surface relatively D65 light. More glossy and sticky tactile feel relatively without the tape.
1.2	D65	Scratch and wear resistant tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach, but attaches better than 1.1. Some air bubbles are visible. More glossy and sticky tactile feel relatively without the tape.
1.2	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach, but attaches better than 1.1. Some air bubbles are visible. More visible that it is a tape on the surface relatively D65 light. More glossy and sticky tactile feel relatively without the tape.
1.3	D65	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape on the surface. Attaches better than 1.1 and 1.2. More glossy and sticky tactile feel relatively without the tape.
1.3	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape on the surface. Attaches better than 1.1 and 1.2. More visible that it is a tape on the surface relatively D65 light. More glossy and sticky tactile feel relatively without the tape.
1.4	D65	Scratch and wear resistant tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach, but attaches better than 1.1. Some air bubbles are visible. More glossy and sticky tactile feel relatively without the tape.
1.4	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Clearly visible on some places that the tape doesn't attach, but attaches better than 1.1. More visible that it is a tape on the surface relatively D65 light. Some air bubbles are visible. More glossy and sticky tactile feel relatively without the tape.
1.5	D65	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape. Attaches very well to the surface. More glossy and sticky tactile feel relatively without tape.
1.5	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape, but more visible than in D65 light. Attaches very well to the surface. More glossy and sticky tactile feel relatively without tape.
1.6	D65	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape. Attaches very well to the surface. More glossy and sticky tactile feel relatively without tape.
1.6	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape, but more visible than in D65 light. Attaches very well to the surface. More glossy and sticky tactile feel relatively without tape.

Table K.7: The tests performed on test plate 2, 3, 4 with the scratch and wear resistant tape.

Test plate	Light	Applied test feature	Test type	Comment
2	D65	Scratch and wear resistant tape	Check in light and tactile feel	Very clear that it is a tape on the surface. More glossy and sticky tactile feel relatively without the tape.
2	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Very clear that it is a tape on the surface. More glossy and sticky tactile feel relatively without the tape.
3	D65	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape on the surface. Doesn't attach to the surface that well. More glossy and sticky tactile feel relatively without the tape.
3	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Not clear that it is a tape on the surface. Doesn't attach to the surface that well. More glossy and sticky tactile feel relatively without the tape.
4	D65	Scratch and wear resistant tape	Check in light and tactile feel	Very clear that it is a tape on the surface. More glossy and sticky tactile feel relatively without the tape.
4	TL84	Scratch and wear resistant tape	Check in light and tactile feel	Very clear that it is a tape on the surface. More glossy and sticky tactile feel relatively without the tape.

Table K.8: The scratch tests performed on test plate 1 with the scratch and wear resistant tape compared with the texture without the tape.

Test plate	Light	Applied test feature	Test type	Comment
1.1	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.1	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.2	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.2	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.3	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.3	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.4	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.4	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.5	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.5	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.6	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.
1.6	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture.

Table K.9: The scratch tests performed on test plate 2, 3, 4 with the scratch and wear resistant tape compared with the texture without the tape.

Test plate	Light	Applied test feature	Test type	Comment
2	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture. Some scratches are visible on the texture.
2	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture. Some scratches are visible on the texture.
3	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture. Some scratches are visible on the texture.
3	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture. Some scratches are visible on the texture.
4	D65	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture. Some scratches are visible on the texture.
4	TL84	Scratch and wear resistant tape	Scratch test and check in light	Particles sticks to both the film and the textured surface. The particles on the tape can be removed but there are particles left in the texture. Some scratches are visible on the texture.