Streamlining of NKT´s cleaning procedure of the conductor in high voltage cables before splicing

Degree project for Master of Science in Mechanical engineering
with focus on innovation and sustainable product development

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The author declare that he is the sole author of this thesis and that he has not used any sources other than those listed in the bibliography and identified as references. He further declares that he has not submitted this thesis at any other institution to obtain a degree.

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ABSTRACT

For several hundred years there has been a great deal of emphasis on how industries and businesses may encourage excellent production work that does not harm the environment or the working individual. NKT is a world leader company in cable technology and designs, manufactures, and installs voltage cables. The company includes a department where splicing is performed on cables to extend or repair them. To complete the splicing process, however, the inner most structures of the cable must first be cleaned from a substance called compound. Today, this cleaning process is carried out manually by the workers. Despite the efficient operation of NKT's splice department, various risks have been identified that might have a negative impact on both the worker and the environment. On one hand, there is a risk that the cleaning agent containing a certain amount of unhealthy chemicals will encounter the worker and cause health risks, and on the other hand, chemical leakage may occur on the work surface, resulting in a contaminated work area, and unnecessary material waste. This material waste also adds to less cost-effective operations, since bigger amounts will be required to accomplish the intended work, this in relation to the fact that the process requires a considerable time. Thus, the aim of this degree project is to investigate if streamlining the procedure of cleaning the compound from the conductors in high voltage cables before splicing is possible by developing a mechanical device or replacing the current used solvent or both.

The methods used for this project were a combination of the design thinking strategy and participatory action research and to deeply understand the methods, a literature review was also performed.

The results obtained were a well-detailed virtual simulation in SolidWorks, a functional alpha prototype, and results from a conductivity measurement for PF-Solvent and Strovels Smådelstvätt 100. Although the first laboratory tests showed equivalent effects for PF-Solvent and Strovels Smådelstvätt 100 regarding the solubility of the compound, PF-Solvent's good conductivity properties were confirmed while Strovels Smådelstvätt 100 proved not to be suitable for this cleaning procedure due to the big difference in the values.

The results obtained from the sustainability template provided the project with useful guidelines for refining the concept into a long-term solution. Many of the components of the physical product will be built from stainless steel, which will make it simpler to recycle at the end of its useful lifespan.

In conclusion, it requires a development of a device that cleans the conductor from the compound. The device / machine can keep the solvent in a special place and at the same time, the worker has more control over how much solvent is used. According to the laboratory tests, the solvent Strovels Smådelstvätt 100 had an equivalent effect on the compound during the same time interval as PF-Solvent. It was also milder from the environmental and health aspects.

Furthermore, the development of a mechanical device can contribute to reduced waste of various materials, such as brushes, gloves, and spray bottles, during the procedure. Finally, investing in such a machine can be expensive, but in the long run this investment leads to savings in materials used today. However, a machine procedure involves a large transition that requires a lot of time, resources and planning as it shall be developed through collaborations with different industries.

Keywords: Streamlining, cleaning procedure, compound, SolidWorks, design thinking strategy

SAMMANFATTNING

I flera decennier har olika branscher och företag lagt stor vikt på att erhålla ett utmärkt produktionsarbete som inte skadar miljön eller den arbetande individen. NKT är ett världsledande företag inom kabelteknik och design. De tillverkar och installerar spänningskablar. Företaget innefattar en avdelning där skarvning utförs på kablar för att utöka eller reparera dem. För att slutföra skarvningsprocessen måste dock kabelns inre struktur rengöras från ett ämne som kallas för compound. Idag utförs denna rengöringsprocess manuellt av arbetarna. Trots det effektiva arbetet vid NKT:s skarvningsavdelning har olika risker identifierats som kan ha en negativ inverkan på både arbetaren och miljön. Å ena sidan finns det en risk att arbetarna utsätts för rengöringsmedel som innehåller en viss mängd ohälsosamma kemikalier och orsaka hälsorisker, och å andra sidan kan kemiskt läckage uppstå på arbetsytan, vilket resulterar i ett förorenat arbetsområde, och onödigt materialavfall. Detta materialavfall bidrar också till mindre kostnadseffektiva procedurer, eftersom högre kostnader kommer att krävas för att utföra det avsedda arbetet, detta i förhållande till det faktum att processen kräver en betydande tid. Således är syftet med detta examensarbete att undersöka huruvida det är möjligt att effektivisera den befintliga rengöringsproceduren av compound från koppartrådarna i ledaren i högspänningskablar innan skarvning. Detta genom att utveckla en maskinell lösning eller ersätta det befintliga lösningsmedlet, eller de båda.

Metoderna som användes för detta projekt var en kombination av design thinking strategin och participatory action research samt genomfördes även en litteraturgenomgång för att på djupet förstå dessa metoder.

Resultaten som erhölls var en väl detaljerad virtuell simulering i SolidWorks, en funktionell alfa-prototyp, och resultat från en konduktivitetsmätning för PF-Solvent och Strovels Smådelstvätt 100. Trots att det första laboratoriska testet visade likvärdiga effekter för PF-Solvent och Strovels Smådelstvätt 100 avseende lösligheten av compoundet, bekräftades PF-Solvents goda konduktivitetsegenskaper medan Strovels Smådelstvätt 100 visade sig inte vara lämplig för denna rengöringsprocedur på grund av den stora skillnaden i värdena.

Ur hållbarhetsaspekten gav resultaten från hållbarhetsmallen projektet användbara riktlinjer för att förfina konceptet till en långsiktig lösning. Många av komponenterna i den fysiska produkten kommer att byggas av rostfritt stål, vilket kommer att göra det enklare att återvinna i slutet av sin livslängd.

Sammanfattningsvis kräver det en utveckling av en maskinell lösning som rengör ledaren från compoundet. Maskinen kan bevara lösningsmedlet inom ett begränsat område och samtidigt har arbetaren mer kontroll över hur mycket lösningsmedel som används. Enligt testerna hade lösningsmedlet Strovels Smådelstvätt 100 en likvärdig effekt på compoundet under samma tidsintervall som PF-Solvent. Det var också mildare ur miljö- och hälsoaspekterna. Vidare kan utvecklingen av en mekanisk anordning bidra till minskat slöseri av olika material, såsom penslar, handskar och sprayflaskor, under rengöringsproceduren. Slutligen kan det bli dyrt att investera i en sådan maskin, men i längden leder denna investering till besparingar av engångsmaterial som idag används och bortkastas. En maskinell procedur innebär dock en stor omställning som kräver mycket tid, resurser och planering då den ska utvecklas genom samarbeten med olika branscher.

Nyckelord: Effektivisering, Rengöringsprocess, Compound, SolidWorks, Design thinking strategi

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1 INTRODUCTION

Today, society is completely dependent on electricity. Electricity, more than anything else, keeps the modern existence going. Furthermore, the population is rapidly growing, as is the need for a contemporary lifestyle. As a result, there will be a larger need for energy. Due to the constant and advancing technological development, electricity thus becomes an essential cornerstone for a functioning society. The reason is that the countries' infrastructure is based on a functioning electricity system to be able to have functioning products, services and living conditions. [1]

This electrical energy can thus be extracted from renewable energy sources and undergo a conversion to electricity to finally be able to be used in practical everyday life. For this process to be possible, voltage cables are thus required that can carry out this transportation of electricity. In addition, these cables must be able to withstand high voltages while not being affected by the surrounding environment.

NKT is one of the companies that manufactures these high-voltage cables of the desired length. However, there are limitations in the manufacture of these cables, i.e., they cannot be manufactured in infinite lengths. As a solution, cables can undergo a so-called splicing process where they are joined, which results in a longer cable. Prior to splicing, however, these cables, mostly cables containing copper, must be pre-treated using a cleaning process that involves manually cleaning the cable ends from the rubber-like and sticky substance, compound, which is located on the conductor. This cleaning procedure is perceived to be very energy and time consuming and therefore a deeper investigation of how this cleaning process can be made more efficient in terms of time, environment. and the economic aspect contributes to the transformative solution to this current problem. This degree project has thus been carried out to investigate how the cleaning process in the company's splice department can undergo the desired efficiency.

1.1 NKT – The multinational corporation

NKT is a multinational corporation with operations in more than 14 countries with headquarters in Denmark. The company has today over 3,400 employees and had a total revenue of 1.3 billion EURO in 2019 [2]. NKT was founded in 1891 during the second industrial revolution and today takes on the fourth industrial revolution with its expertise in energy transport and cost-effective production facilities of the latest technical standards. [2]

NKT is a world-renowned company that is working to supply the need for energy [3]. They provide ready-made cable solutions for both direct current and alternating current (DC / AC). Thus, they are also a world leader in cable technology and help to the global transition to renewable energy. They are always innovating since the development of cable solutions is the foundation of today's contemporary society, which necessitates that we continually be on the cutting edge. As a result, they are always working to simplify the different processes used for, among other things, conductor cleaning. [4]

The company has vital power supply connections across the world. Sweden, Germany, the Czech Republic, Poland, Norway, and Denmark all have manufacturing plants. NKT designs, manufactures, and installs voltage cables. Cable networks connect countries, and the company has great knowledge connecting offshore wind turbines to the onshore electricity grid. Renewable energy is thus incorporated into society in this manner. Integration is economical, and clean energy is essential for reducing carbon dioxide emissions and combating climate change on a national and worldwide scale [5]. The company considers itself responsible for ensuring that the way they generate, deliver, and use electricity is also in the interest of future generations. They consider themselves to play the important role of forming the link between the power source and the users [1].

1.2 High voltage cables

High voltage cables are electrical cables that are designed to be able to transmit high voltage power. This therefore poses special safety risks due to the high amount of energy involved. High-voltage electricity is available in electrical transmission lines for delivery to homes and businesses, as well as certain types of high-voltage wiring systems, such as certain forms of industrial machinery.

NKT designs, produces, and installs high voltage onshore and offshore cables. The high-voltage cables can be used for land- and sea-based power transmissions, connections for offshore wind turbines, power distribution on land and to transmit power from land to the platform [6]. The company has world leadership in offshore high-voltage cable systems where the first high-voltage cable link (DC) was developed in 1945. As for the land-based cables, these power transmission cable systems are designed, manufactured, and installed directly from power plants to primary distribution networks. The company always strives to design each part of their solutions in a way that meets all specific customer requirements, everything from densely populated to environmentally sensitive areas [6].

1.3 The splicing process

Splicing is a process that is performed on the cables to extend them, repair any defect and if there has been a production error that must be rectified. The process involves removing the outermost metal cover to expose the insulation. Then this polyimide insulation is removed to finally expose the conductor which in this case consists of copper wires, see figure 1 below. Then the copper wire ends are scaled to the desired geometries for splicing. Afterwards, joints, factory joints, installation joints or, for example, repair joints, are used to connect the machined cable ends [7].

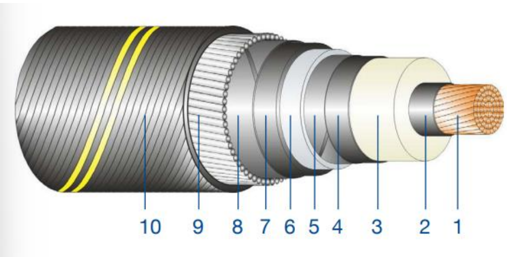

Figure 1: Some of the components that the cable includes 1) The conductor (Al or Cu), 2) The inner semi-conducting layer, 3) The DC-XLPE insulation and 4) The outer semi-conducting layer. [8]

To have a successful splicing, however, the substance compound must be removed from the copper wires. This is done by folding up the copper wires and manually removing the compound that is present on all surfaces of the wires, see figure 2. After all the compound has been removed, welding of the conductors can be performed.

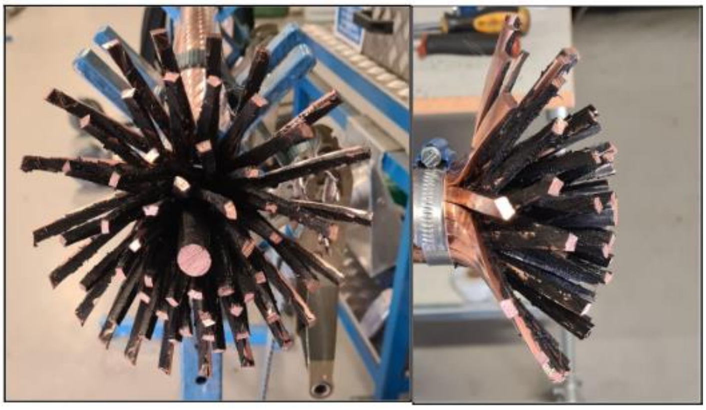

Figure 2: Upfolded copper wires before the initiation of the cleaning process.

1.4 The cleaning process of HV-Cables containing compound

The company operates in accordance with set criteria for numerous divisions. However, it is almost always feasible to enhance current procedures even more. Employees in the company's splice department work efficiently to splice cables and manually clean the conductor, from the compound, see figure 3, before the splicing process takes place [5].

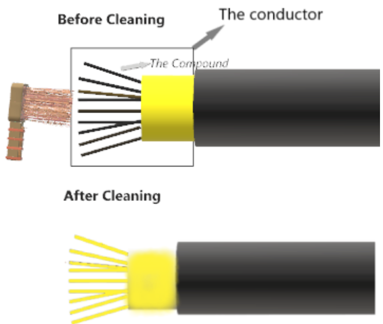

Figure 3: High voltage cable´s conductor coated with compound before cleaning and compound-free after cleaning.

1.5 The impact of working conditions on the individual and environment

There are various research projects that contain the goal of transitioning from an unhealthy way of working to a healthier way of working in terms of both the environment and the individual. The relationship between excessive exposure to chemicals and human health has long been a cause of controversy. According to Chun et al. [9], chemicals can have a severe influence on an individual's health if they are exposed to it in high amounts, mostly through skin contact but also through inhalation. As a result, efforts are being made to further research in the sector to determine whether it is feasible to replace or minimize the spread of harmful chemicals that expose workers by inventing creative techniques for each work activity.

There are still some firms or companies where employees in certain areas perform manual labor. This might be because new working techniques or materials that can replace old processes have yet to be created. It is possible that you will need to design a long-lasting and robust machine capable of doing the task in a safe, efficient, and controlled manner [10]. Some employees at NKT's splice department attempted to streamline the abovementioned procedure, but the results were unsatisfying. The reason for this might be lack of in-depth understanding of how several factors will contribute to a functional system.

1.6 PAR – Participatory Action Research

The participatory action research is a methodology that aims to actively involve the specific stakeholder throughout the research process. The goal of participatory action research is to share information between the involved organization and the researcher to obtain favorable outcomes and new experiences that may be used in future applications for both parties. The researcher is involved into the organization to understanding its internal dynamics and system circumstances, and the organization is integrated into the activities of the researchers to contributing to the established knowledge throughout the process [11].

A common start to the participatory action research process is the identification of the problem that the organization is perceived to have. Furthermore, a collaboration is established between both parties to target the problem and solve it. Once the problem has been identified, the first step is to conduct an information search in the literature with a subsequent hypothesis formulation. A prerequisite for the PAR process to be successful is that the researcher seeks his information in the literature to carry out further specifications of the problem and the purpose. Finally, the researcher finds an organization that allows the researcher to conduct his research [12].

For the PAR method to be implemented, the researcher must ensure that it is a participatory based process, which means that the involved parts on whom the research is based must be given the opportunity to participate in, among other things, problem definition. Furthermore, the approach must be participatory controlled, which implies that the organization must be allowed to select which actions to take [13]. Figure 4 below summarizes the various aspects of this methodology. Goals are established following the definition of the problem, while working techniques are decided. Following that, important data are collected to be studied further. Finally, a reflection of the obtained results is made, which are evaluated. Simultaneously, the researcher is continually striving to include the organization in the process to get the intended result of new information and new problem solutions [14].

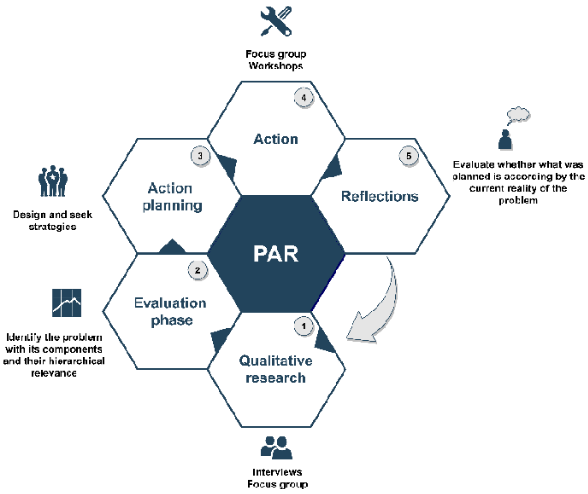

Figure 4: The different steps in PAR [14]

1.7 Design Thinking Strategy

In the customer's eyes, designing and developing a product can be considered simple. The customer can easily overlook the time-consuming planning process as well as the procedure for producing a particular product. The design thinking process is demanding and critical for a successful outcome. The phrase itself describes two overlapping concepts with the meaning that this process describes a unique way of looking at the world and that it is a process of methods and activities that reflect and support the way of thinking. The focus of this methodology is problem solving based on some type of empathetic discovery, problem definition, idea generation, creation, and evaluation (figure 5). [15]

To solve a problem, it is important to understand that the problem exists, which takes place in the first phase of the strategy where empathetic discovery takes place. In this phase, patterns, and problems as well as goals are identified through human centered techniques which, by seeing things from the users 'and customers' perspective, emphasize an empathetic understanding. Various methods and tools are used to help, such as personas and expectation maps to understand the user in order to be able to further frame the problems [16] [15].

The next phase in the strategy is to identify and define specific problems that need to be solved. This examines, among other things, difficulties that a user encounters when, for example, using a product, service or during work, to then be able to focus on how these problems can be solved [16] [15].

The third phase in the design thinking strategy is the idea generation which is dependent on divergent thinking to generate most ideas for possible solutions. Here, ten to several hundred potential solutions are brainstormed, mind-mapped or sketched where no ideas are considered wrong at this stage. The question "what if?" is kept in mind to be able to imagine new, futuristic solutions even though they may not be completely feasible.

After the processing phase of the various ideas, it also becomes relevant to create prototypes for testing ideas and collecting more feedback before the complete development of the solution takes place. The prototypes can be developed both virtually and physically and are the first iteration of what is to be designed. The prototypes do not have to be complete, they can be informal, poor in detail and of a simple form, consisting of, for example, paper or other material that requires lower investment.

In the final phase, the final solution is tested by the users to obtain feedback. In this phase, most techniques and methods can be used, such as interviewing users to gather relevant feedback. This feedback may contribute to new problems coming to the surface, which further contributes to the need for further solutions.

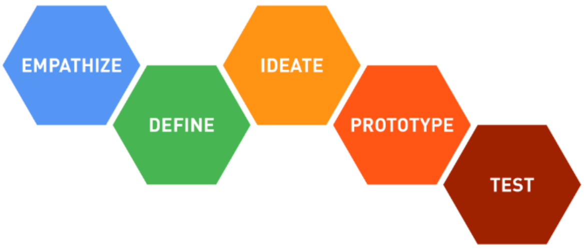

Figure 5: Stages in the design thinking strategy. [17]

1.7.1 Implementation of the design thinking strategy on the cleaning process

The compound is a material with, among other things, sticky properties which also consists of rubberlike materials. This further contributes to the advantages and disadvantages of the cleaning procedure since the material's properties contribute to time-consuming and energy-intensive work. Due to this, it becomes very helpful to work according to the design thinking strategy to accomplish a good solution. The five above-mentioned steps in the design thinking strategy can thus be implemented to find the best solution to the current problem in the splice department in NKT.

1.8 The relevance of the project

Despite the efficient operation of NKT's splice department, various risks have been found that might have a negative impact on both the worker and the environment. On one hand, there is a risk that the cleaning agent containing a certain amount of unhealthy chemicals will encounter the worker and cause health risks, and on the other hand, there is a risk that chemical leakage will occur on the work surface, resulting in a contaminated work area, and unnecessary material waste. This material waste also adds to less cost-effective operations, since bigger amounts will be required to accomplish the intended work, this in relation to the fact that the process requires a considerable time.

The issues above are particularly essential since, according to present regulations and circumstances governing areas of work and employees, it is critical that there are no substantial risks for the worker while a job is performed [4]. Simultaneously, there is continual technical and sustainable growth that permits the simplification of some operations to further ease a procedure inside a workspace. In this situation, the goal is to make cable cleaning more effective while splicing, from an environmental, social, and economic standpoint, with a focus on minimizing material waste and increasing time efficiency in proportion to costs.

1.9 Purpose, goals, and research questions

The purpose of the thesis is to streamline the cleaning of the substance compound on conductors in some high voltage cables before splicing. The focus will be on developing a mechanical product that contributes to this efficiency from an environmental, time, cost, and health standpoint. Depending on the outcome, new guidelines may also be established if the solvent currently used to clean the conductor can be replaced by another solvent and if the mechanical device turns out to be an efficient solution.

The following research questions are expected to be answered:

- How can the leakage and the amount of solvent be reduced when cleaning the conductor?
- What alternative solvents available at NKT can replace today´s used solvents in terms of environmental friendliness, time efficiency and health?
- What can the development of a mechanical device contribute to in terms of time and cost efficiency?

The key performance indicators that are of interest to be analyzed are:

- Time efficiency:
    - How quickly the different solvents dissolve the compound
    - How quickly the mechanical device cleans the compound from the conductor compared to the manual cleaning process.
- Cost efficiency
    - How much solvent is saved in a mechanical procedure compared to the manual one.
    - How robust the mechanical device will be and the life cycle of the device.
    - If the device will contribute to the workers using less protective equipment, including disposable gloves.
- Sustainability
    - If the materials that will be used to develop the mechanical device are durable and environmentally friendly, i.e., have a long service life but can also be recycled and replaced if necessary.

1.10 Limitations and risk management

The limitations of this work are that preliminarily only one virtual program will be used, Solidworks. The focus will be on transforming the process from manual to mechanical by developing a mechanical device. During this procedure, the delimitation will be that only an alpha prototype will be developed for economic reasons and time. The project is carried out for a limited time, which makes it difficult to get a fully developed physical mechanical device.

Another limitation in this thesis is that when choosing suitable solvents for the laboratory tests, the selection will only consist of solvents available at the company and are approved for use in accordance with current policy. The reason is that they are quality assured and approved for transport to other countries and easily accessible in the respective countries.

Risks that may arise during the work are primarily as follows:

- Inadequate component and material selection for the development of the mechanical device. This risk can be avoided by making careful and safe choices by avoiding choosing materials that have a negative impact or are negatively affected by the solvent, heat or other parameters involved in the mechanical device.
- Laboratory sources of error that can occur are, for example, that not the exact same amount of compound is placed in the beaker. To avoid this problem, the material can be weighed using an accurate scale available at the company before it is placed in the beaker.
- When heating the solvent, any changes in the composition and properties may occur. Here, it is therefore important that a preliminary investigation of the solvent's reaction to heat is carried out, above all by searching for information.

1.11 Hypotheses

The results that are expected to be obtained are a time and cost-efficient cleaning process through the development of a mechanical device. The expectations are also that the procedure will be able to be carried out in a less risky way from the health and environmental aspect.

Regarding the expected results from the laboratory tests, the outcome may be that current solvent may be replaced by a milder variant. With the help of the mechanical device the solvent can be reused, which hopefully contributes to less waste of the solvent. If the tests also show that one of the solvents simplifies the removal of the sticky compound, this, in combination with the pressure properties of the mechanical device and maybe by heating the compound or the solvent, will contribute to the conductor being cleaned faster in time.

The results that are expected are of interest because they contribute to increased sustainability of the procedure from both the individual and environmental aspect. The workers benefit in such a way that they do not have to perform an equally heavy and relatively risky work. At the same time, the company benefits since the process is streamlined. This contributes to increased benefits from the economic aspect by reducing working hours while increasing productivity. At the societal level, the above expected results mean saving resources as the procedure becomes more controlled and focused.

2 THEORY

This chapter presents some theory about the high-voltage cable, cleaning procedures for the compound, the chemicals chosen for this project, and the role of sustainability to enable the reader better comprehending the role of the chosen factors for this thesis.

2.1 The structure of the high-voltage cable

The high-voltage cable consists of a conductor that can be made of, for example, aluminum, copper and other metals. On the other hand, copper conductors are more expensive than aluminum in terms of how much current the conductor can handle. Despite this difference, copper is used for most cables in that it allows a smaller cross section. This means that less material needs to be used around the conductor. It is therefore important to make an individual assessment of the different areas of use, as aluminum, for example, may be preferable in certain situations.

Each individual conductor must then be packed in an insulator that can consist of a variety of plastic, rubber, and paper products. In high-voltage cables, cross-linked polyethylene (XLPE) is most used as this material can withstand high operating temperatures up to 90 degrees C [18] [6]. The advantages of having such an insulating material are that the crosslinks make the material very stable and resistant to, for example, ambient stresses that can contribute to fractures in the material. Other properties that the material has are flame resistant and that it has an excellent dielectric strength and a low dissipation factor for all frequencies. This means that such high-voltage cables can be used both on land but also in the sea [19] .

Each individual copper wire in the conductor is enclosed by the compound inside, which is exposed during folding up, see figure 2. This unique material that the company uses consists of a mixture of different substances to achieve the desired properties [20].

2.1.1 Composition of the compound

The most extensive components in the compound are graphite and rubber. Graphite is a mineral that is a modification of carbon which is an element. Unlike, for example, diamond, which is another crystalline modification of carbon, graphite is very soft that easily allows itself to be split into plastically bendable blades or scales. This property has a direct relation to the crystalline structure of the substance, which is made up of a hexagon-patterned layer. Within the layers, the bonding forces are greater compared to the bonding forces that exist between the layers, which means that the layers can slide over each other. The consequence of this slippage is then that the substance has, among other things, a lubricating effect, see figure 6 below [21].

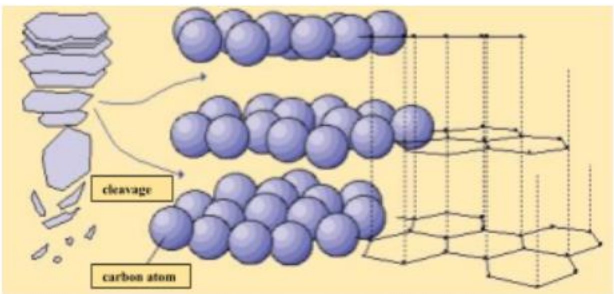

Figure 6: Graphite structure, image taken from NE.SE [21]..

As far as the rubber content is concerned, it is mainly butyl rubber and polyisobutylene that the compound consists of. Butyl rubber is a synthetic elastomer with low elasticity at room temperature. This is produced by a combination of isobutylene and isoprene where these two substances react quickly at low temperatures. The effect that isoprene has is the creation of double bonds, which leads to crosslinking of the material via so-called vulcanization. In short, vulcanization is a thermosetting process that binds all rubber molecules together, forming a large single molecule. The property of this molecule is that it does not melt at high temperatures while it does not break down at low temperatures [22]. To keep all the substances together, wax is also used, which has a high melting point [23]. Finally, this composition of the substance means that it works excellently as a sealing material in the conductors of high-voltage cables, including submarine cables, to prevent penetration of external fluids and contaminants to the cable's interior [23].

2.2 Cleaning techniques for the compound

A manual cleaning technique is currently applied to the company's splice department. The procedure involves the workers scrubbing off the substance with a cleaning brush. To help, the solvent PF-Solvent is used to dissolve the substance a little and to be able to scrub it off more easily. So far, only PF-Solvent has been used in the cleaning process, which has been effective against the compound. However, there are other solvents in the company that may have the same effect on the substance while its positive properties outweigh the negative ones in comparison with PF-Solvent [24].

2.2.1 PF-Solvent

PF-SOLVENT is a liquid that can be used for cleaning, professionally and industrially. The workers in the splice department at NKT use this agent to clean the compound from the raised copper wires. The liquid contains> 90% of Hydrocarbons, C11-C13, isoalkanes, <2% aromatics and <2% Orange sweet extract which according to the CLP Regulation, the Regulation on Classification, Labeling and Packaging is classified as environmentally hazardous, where the latter is the main toxic component. The solvent can cause allergic skin reactions, be fatal if swallowed if it passes through the respiratory tract and be toxic to aquatic organisms as it contributes to long-term effects, hence the hazard pictograms in Table 1 below. To prevent these negative effects, it becomes essential for workers to use protective equipment in the form of goggles, clothing that provides sufficient protection for the skin, such as rubber and cotton, and suitable protective gloves consisting of nitrile rubber or polyvinyl alcohol. The substance must also be handled in an environmentally friendly way by not encountering soil, groundwater, or sewage [25].

2.2.2 Other chemicals that may be suitable for the cleaning process

NKT has a wide range of chemicals available that fulfill different functions depending on the subject area. In addition to PF-Solvent, three additional compounds piqued the researcher's curiosity due to their unique features. These chemicals are "STROVELS SMÅDELSTVÄTT 100," "Ethanol" and "Ecosolv" and are discussed in further depth in the subsequent paragraphs.

2.2.2.1 STROVELS SMÅDELSTVÄTT 100

STROVELS SMÅDELSTVÄTT 100 is a low-viscosity and colorless liquid containing 60-100% Hydrocarbons, C11-C14, n-alkanes, isoalkanes, cyclic, <2% aromatics. This product is used for professional purposes only. The most serious harmful effect of this product is, just like PF-SOLVENT lethal if swallowed if it enters the respiratory tract. In addition, this agent can also contribute to skin irritation in the form of cracks and dry skin, which makes it necessary for the user to wear protective equipment in the form of goggles or face shield at risk of splashes, suitable protective clothing as needed and chemical resistant protective gloves. Like PF-SOLVENT, this product must be treated as hazardous waste as it is classified as environmentally hazardous, see table 2 [26].

2.2.2.2 Etanol absolut AnalaR NORMAPUR Reag. Ph. Eur., Reag. USP, ACS

Ethanol absolute, also called Ethyl alcohol, is a liquid and colorless liquid with a wide range of uses, including as a solvent, antifreeze and as a disinfectant [27] [28]. This liquid is classified as highly flammable and can also cause severe eye irritation, see table 1. It thus becomes very important to store the liquid in a well-ventilated place, cool and far from heat and that the user protects himself with protective clothing and other equipment such as gloves and visors. This means that work processes involving this liquid must always be organized in a way that contributes to low risks of inhalation, skin contact, eye contact and that storage of the liquid and preventive measures are considered [28].

2.2.2.3 ECOSOLV A

Ecosolv, like ethanol, is a colorless, liquid with a characteristic odor consisting of 60-70% Ethanol and 30-40% Isopropanol. This liquid has been identified as being relevant as a solvent for industrial purposes and even here there may be dangers in using this agent. The identified dangers are that you can become drowsy or dizzy, get serious eye irritation and that it is very flammable, see table 1. To prevent these possible risks, the recommendations are to use eye protection, keep the substance cool and use other protective equipment to minimize the risk of skin contact. The reason is that the composition of the agent is irritating, which can result in the contact area becoming more exposed to the uptake of, for example, allergens that are harmful substances, hence the recommendation to use nitrile or butyl gloves, for example [29].

2.2.2.4 Paraffin oil

Paraffin oil is another agent that is colorless, has a faint odor and is tasteless [30]. This oil is part of the product group synthetic technical white oil and has been identified as relevant for use as, among other things, cutting fluid, solvents, buoyancy aids and drilling fluid. The composition of the oil consists of synthetic white oil, consisting chemically of saturated hydrocarbons, which is made from synthesis gas in a catalytic process. The synthesis gas itself is produced from residual gases and natural gases. In terms of content, there are also paraffins, which are alkanes, which have a boiling point of about 220-360 degrees C. Another chemical property that the product has is that it is biodegradable. Like the other agents, dangerous properties of paraffin oil have been identified where the main danger is that it can be fatal if swallowed if it enters the respiratory tract. To handle the paraffin oil in the safest way, the instructions are to use protective gloves made of leather. It is also important that the product is stored correctly at room temperature so as not to risk heating and further exploding [31].

Table 1: Warning symbols for the solvents

PF-Solvent	Strovels S.	Ethanol	Ecosolv	Paraffin oil
Harmful		Harmful	Harmful	Harmful
Harmful for the environment				
Serious health hazard	Serious health hazard			
		Flammable	Flammable	

2.3 Conductivity measurement

Most materials have the natural property called electrical conductivity, also called conductivity. Depending on how conductive the materials are, they can be categorized as highly conductive, low conductive or anything in between. The lower the conductivity of the material, the better it is as an insulator. Examples of low conductivity insulators are glass and ceramics [32].

The conductivity of a material is measured with a so-called conductivity meter which consists of a measuring unit and a conductivity probe. Sometimes the probe may also include a temperature sensor. When measuring, the resistance of the solution will be measured by sending an alternating current between the probe poles, see Figure 7. Since the area of the poles and the distance between them is constant and they are defined in the cell constant of the probe, this results in a measurement of the sample resistivity and thus conductivity. Before the measurement is carried out, an automatic calibration of the equipment takes place by measuring resistance in a solution with known conductivity, which contributes to obtaining a cell constant. [32]

The reason why the conductivity of different materials is measured is to be able to control the content of these. For example, the conductivity of the water is measured to check the purity of the water. If a low conductivity is obtained, this means that the water has a low content of dissolved salts. If, on the other hand, the conductivity is too high, this may be an indication that the water is polluted from discharges [33].

In addition to the conductivity measuring the purity of water, a connection has been found between conductivity and concentration. Most often, this relationship is linear at a certain concentration range, which means that conductivity can be used to determine the concentration of many solutions with known content. [32]

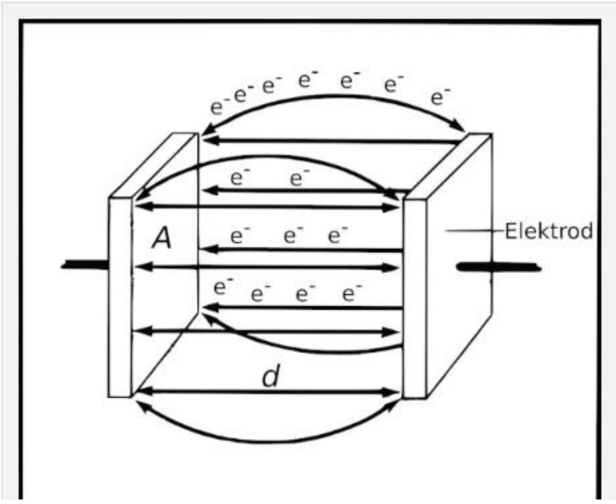

Figure 7: Conductivity cell; two poles with the area (A) with a separating distance (d). [32]

2.4 The role of sustainability

The term "sustainability" has become increasingly important and debated today. This is because it has been demonstrated that continuing in the same manner generates a significant environmental burden. As a result, several researchers have attempted to analyze the problem and define the concept of sustainability. Simplified, the definition of sustainability is that society should be able to fulfill their needs without affecting future generations' capacity to meet their needs. To accomplish this, a set of methods and concepts have been created to serve as guidance for businesses and society in product creation and consumption. Table 2 below illustrates the various sustainability principles which includes the environmental aspect as well as the human health aspect. [34]

Table 2: Sustainability principles; 1-3 for environment, 4-8 for health. [35]

Principle:	**Description: In a sustainable society, nature is not exposed to systematically increasing:**
1	Concentrations of substances from the bedrock such as: • fossil coal • oil • metals
2	Concentrations of substances from society's production such as: • nitrogen oxides • brominated flame retardants • hormone-like chemicals
3	Degradation in a physical way such as: • deforestation • depletion
	Description: There are no structural barriers to human:
4	Health, for example through: • dangerous working conditions • insufficient rest from work
5	Influence, for example by: • suppressing freedom of expression • neglecting opinions
6	Competence, for example through: • obstacles to education • insufficient opportunities for personal development
7	Impartiality, for example through:

	• discrimination • unfair elections to positions
8	Meaning, for example by: • suppressing culture • obstacles to co-creation of meaningful conditions

To optimize a product's lifecycle while combining environmental aspects in the procedure, the designer can use different design strategies. Design for remanufacturing (DfRem) and recycling are two examples of design strategies. Design for remanufacturing implies that the developer should make it simple to disassemble the product if it breaks. This is because only the broken part may be replaced by a new one, which saves resources compared to repairing numerous pieces or the entire product since they can't be separated. Recycling design is comparable to remanufacturing, except that instead of replacing defective parts, they are recycled. It indicates that the developer should attempt to create products in which the various elements can be simply separated to promote recycling. It is also advantageous to develop a product with fewer material variants since fewer components must be separated [36].

2.4.1 Sustainability Criteria identification with Knowledge Maturity

Understanding the project from a sustainable viewpoint is one of the most crucial parts of project implementation. As a result, it is vital for teams to reflect on and disentangle disparate concepts and assumptions to improve selection visibility and highlight the user's needs and objectives. The goal will therefore be to find a way to create stronger processes and data analysis for, among many other things, the creation of sustainable goods. Techniques that contribute to improve provenance and accessibility of, along with other things, the decision of sustainability considerations must be supplied to fulfill this in the right direction. Understanding the design's life span is important to determine strengths and weaknesses in the solution which contribute to its increased durability. [37]

The capacity to make decisions and prepare for sustainability demands the development of essential skills and competencies by individuals and organizations from all different disciplines [38].

Group model building is an example of a well participative system modeling technique in which members co-create a common understanding of control checks and how the behavior of the model may be changed using system dynamic simulations and causal modeling. This type of modeling may aid in learning and strategizing in complicated systems, as well as leading efficient, and strategic, decision-making [38]. Members in the team model building exercise may design a causal loop diagram to show the interconnectedness of participants in the social - ecological systems, which they may then utilize as the framework for debate to be ready at a sustainable option [38].

Causal Loop Diagrams is a significant method for System Analysis because they allow for system modeling. They allow for the map of the complexities of a problem of interest [39]. A causal loop diagram aids in understanding correlation and causation rather than assuming a straight proportionality between system features [39]. It helps us to identify how a behavior has shown itself in such systems so that we may develop techniques to operate with and against the behavior. We'd also like to figure out how and to what extent the problem is related to other systems. Developing a causal loop diagram helps one to observe and therefore better understand the feedback processes involved in a system. Consequently, they allow for an examination of both the design and the activities of a system [39].

3 METHOD

For this thesis, a combination of the design thinking strategy and the participatory action research methodology was used, which is illustrated in figure 8 below. Given the purpose of this work, it was considered appropriate to combine these two methodologies to fulfill the purpose of the work. The work aims to conduct research on the substance compound and its properties. It also aims to investigate the composition and properties of various chemicals at the company. Furthermore, to take advantage of the acquired knowledge to develop solutions for how the compound can be removed from the conductor in the gentlest way. The project thus consists of two separate approaches which in combination contribute to the answering of the research questions. At the same time, this methodology contributes to creating a framework that meets both elements that are of interest. The reason for this is because using only one of the research methodologies does not include product development and vice versa, hence the decision to combine them both.

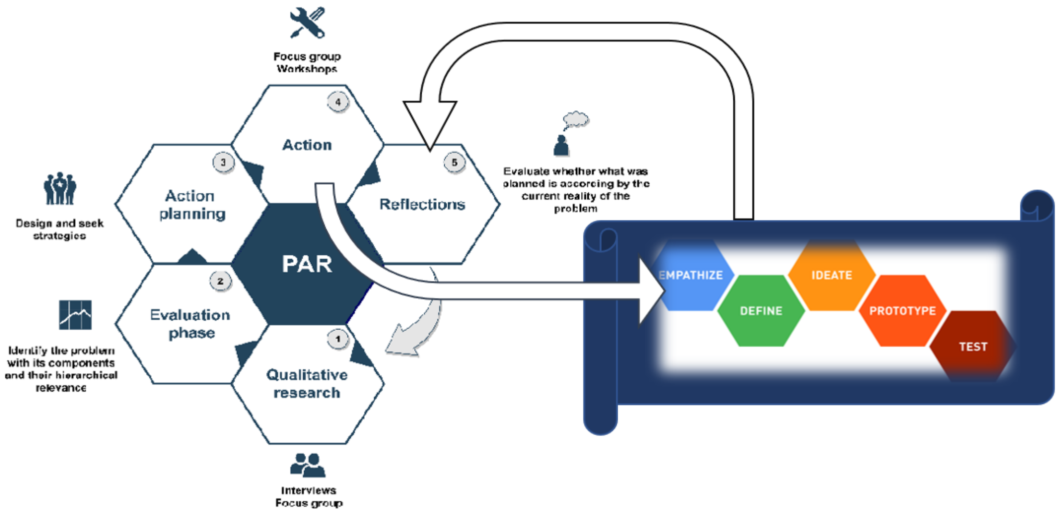

Figure 8: A combination of PAR and Design thinking strategy.

As the figure shows, the process begins with identifying and formulating the problem with the subsequent specification of research questions, which is in line with the initiation phase. The next phase includes planning and determination of different goals and working methods, which is also relatively in line with the initiation phase. After that, scientific data is obtained, which is also linked to, among other things, the needs of the customer. In the fourth step, the collected data is analyzed and then, to the greatest extent possible, some of the research questions will be answered. In addition, an additional problem definition is carried out to further proceed to the preparation and implementation of solutions, which is done with the help of the other embedded methodology. The process ends with reflections, critical thinking, and interpretation of all achieved results to find any weaknesses and to suggest future work.

3.1 Problem formulation – The initiation stage

The project was initiated by the researcher being in contact with workers in the splice department in the company NKT to be able to formulate an initial problem definition. After defining the problem, preliminary thoughts were discussed with those responsible for the construction of the scope. Discussions about the various identified problems took place and each person who was included in the discussion had the chance to contribute with their own suggestions. After the meeting, an agreement was reached between both parties that the idea presented by the researcher was relevant to proceed with. For further investigation of the problem area, information about what has already been done to solve the problem and the methods used was collected. After such knowledge was established, goals and issues were established for this project to further carry out investigations of the problem identified in the splice department.

3.1.1 Business Model – Team Canvas

A team canvas is a version of the business model canvas customized for collaboration. It's a way for a new team members to begin an organized discussion, plan their work together, and make sure that all are on the same track. Therefore, the team canvas is structured into nine sections to guide the discussion. As a result, there are several sub-sections, such as: mission, people and roles, shared objectives, individual goals, strengths, values, expectations, and so on. As a result of using the tool, the team members' most important characteristics and the project's guiding principles are summarized. To keep the team on track, the results of the tool may be utilized as a constant reminder so that one can go back to it if problems throughout the process occurs [40].

For this project, a customized version of the team canvas was utilized and was used as a base in the early phases of the project. This is to optimize the discussions to further describe the mutual aims and expectations of the project. The reason for the modification of the team canvas was largely because it is not a regular project group, but it was just a partnership with the company that was founded to be able to carry out the project. Thus, some parts in the standard team canvas were unnecessary for this task, thus the adjustment since the researcher will carry out the work while NKT will be present to support and be participating in discussions of results and other relevant topics throughout the project. This meant that, for example, the section that mentioned the members' strengths and flaws was no longer applicable. In designing the concept, the researcher began by mapping relevant components for each segment based on what was discussed with NKT in the final phase. Representatives from NKT were then called and the results were further discussed with the team members to verify that everyone agreed on the results and approved. The representatives were given the ability to adjust and alter the screen, and throughout the debate, few improvements to the tool were offered and mapped.

3.2 Planning of the project – Empathize

At this stage, a detailed project plan was created containing descriptions of intended activities as well as implementation and evaluation of these. Possible risks were identified and discussed to avoid them as much as possible. The project plan was implemented in a separate document prior to the establishment of the exact problem to be investigated and will thus not be reported in this essay.

3.3 Data collection – Inspire and Define

At this stage, as much data as possible was collected using various tools and techniques to then be able to study the collected material further. Here it was important to create a deep understanding of the main problem from the stakeholder aspect. To help, a stakeholder analysis was conducted as well as interviews to gather enough data for the next phase.

3.3.1 Understanding of the compound

The first thing that was of interest to explore deeper was what Compound really was. The reason for this is that the researcher has limited knowledge regarding the chemical and functional properties of the material. To obtain more information about the compound, the supervisor at NKT was asked if detailed information could be disclosed to the researcher, which was accepted. Furthermore, individual components that this subject consists of were actively studied through active research in literature digitally, to, among other things, evaluate possibilities and limitations regarding approaches to problem solving. After a complete information search about the compound was completed, practical investigations were also carried out to be able to visually assess how the material reacts with different solvents, which is described in section 3.8.

3.3.2 Stakeholder Analysis

When the sufficient information of the cleaning procedure and the substance compound was collected, a stakeholder analysis was carried out to determine which stakeholders would be interested in interviewing and collecting requirements from to get awareness and an understanding of the problem. First, all relevant stakeholders who may be involved by the solution were identified. The power/interest matrix was then used to map the various stakeholders (see figure 9). This tool is divided into four areas, and a stakeholder's placement is determined by their ability to create change as well as their level of interest in the outcome and the project. A stakeholder with significant power and interest should be closely managed, which implies that it should be integrated and included in the process and decision-making on a frequent basis. If the stakeholder's power level is reduced, the stakeholder will be assigned to the keep informed area, which indicates these should be updated but not as frequently. The last two sections are titled "keep satisfied" and "monitor," with the first implying that stakeholders should be continually updated, and the solution should try to meet their requirements. Stakeholders in the monitor field are given minimal importance and are frequently excluded. When conducting the stakeholder analysis for this project, all the stakeholders involved were positioned in the matrix based on knowledgeable assumptions, with inspiration drawn from previous experiences on how it usually seems in companies. Following that, just a few stakeholders were chosen to be interviewed depending on their placement. [41]

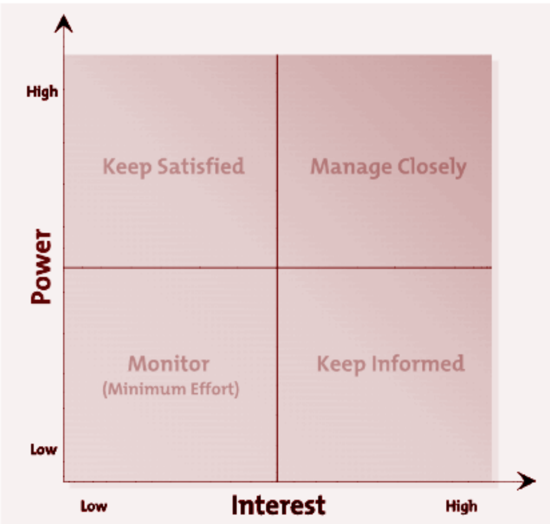

Figure 9: Stakeholder Matrix. Adapted from: [41]

3.3.3 Interviews

To gain a broader understanding of the problem, interviews were conducted with ten workers in the splice department. With the help of the interviews, information could be gathered, and needs identified with the workers, who in this case are also the stakeholders. Interviews are qualitative research methods that can be conducted in three different ways depending on what the interviewer is looking for. The first strategy is that the interview is structured like a questionnaire which each informant must answer [42]. During this type of interview, a strict structure is followed that does not change, which differs from an unstructured type of interview, which is another form of interview. In the unstructured interview, the informant is the one controlling the interview, while the interviewee's role is to listen to the different stories that are told. Finally, there is an interview format that combines both the above mentioned, hence the name semi-structured interview. During such an interview, an interview guide with, for example, two major opening questions is created by the interviewee to frame a theme for the interview. Thereafter, the informant is free to answer the questions and the interviewer can ask follow-up questions and direct the interview a little to get information that is considered relevant. In this way, the informant can also reflect on the questions asked and provide additional relevant information [42].

The chosen interview type for data collection was structured interview. An interview guide was created and used as a basis during the interviews conducted. The interview guide consisted of seven main questions that concerned the current cleaning procedure with some subsequent and supplementary questions, see appendix 1. In some of the questions, the 5-whys method could also be used to obtain further reasoning and to find the real root cause of the informants' perceived problems.

3.4 Analysis of collected material before the ideation stage

At this stage, all the data that were collected from the previous stages were analyzed to create a more concrete picture of what goals should be achieved in the next stages. The tool that was used for the analysis was personas, which is described below.

3.4.1 Personas

All the material gathered from the interviews with the key stakeholders was compiled and mapped in distinct personas to provide an overview of the basic demands from the respective departments. A persona is a fictional figure who represents a group of actual individuals, including their needs, objectives, and experiences. Personas are frequently used to assist designers in understanding the individuals for whom the solution will be built, as well as to make the design work in question less difficult by directing the ideation process [43].

After the implementation of all personas, the interview material was analyzed in more detail to gain a more detailed understanding of the informants' real needs by interpreting their opinions. In the interpretation, the various statements given by the informants were structured into more technical and simple terms that simplify the understanding of these sentences. Thus, designers and engineers based on these personas can develop concepts based on the statements of the informants. When the personas were completed, they were presented to the people interviewed to confirm that everything written was correctly interpreted so that they could then move on to the next step in the process.

3.5 Ideation of different concepts

At this stage, the focus was on generating solution proposals for the various identified problems. Here, it was also important to keep the identified needs of the stakeholders in mind while answering the questions.

3.5.1 Brainstorming

To generate most ideas that can contribute to good solution proposals, brainstorming was carried out using three different approaches. The first way was that the researcher ignored various limitations that the cleaning procedure could have to highlight creative thoughts. Based on this technology, various solution proposals were highlighted which, despite their unreasonableness, could contribute to other further developed proposals and lines of thought.

At the beginning of the brainstorming, the researcher planned how this activity could most effectively contribute to several different thoughts, hence the establishment of a time interval where the researcher brainstormed as many creative and innovative solutions as possible for three minutes and then took a 1-minute break to reflect on the ideas as brainstormed. The procedure was performed three times on four different occasions, one of which was performed together with the workers in the splice department. All ideas that the researcher managed to generate were written down digitally in a document to both document everything and be inspired by them before the next brainstorming interval. The ideas that the workers brainstormed were also collected and digitally documented in the same document. This procedure was carried out on several occasions where the first occasion took place at NKT with the workers and the remaining occasions were carried out at two-day intervals. The reason for this was so that the brain would not feel a lot of pressure and could slowly gather new creative thoughts with the previously brainstormed thoughts in memory.

To generate further ideas, the researcher used another technique that involved a form of thematization based on different industries. This technology aimed to identify industries that could have the slightest connection to the topic that this project touches on. Furthermore, the idea was that new ideas related to the different industries would be generated. Prior to this new idea generation, 4 different industries were first determined; dental care, car industry, cleaning company and construction industry where these were written down in a new digital document and the brainstorming, without any restrictions, was carried out according to the above technology a total of 4 times at one and the same time.

Finally, another brainstorming variant was carried out which was inspired by existing products on the market. The starting point for this technology was, among other things, the above industries, given that some form of cleaning is carried out in all these industries. Internet search was performed to build a foundation for the brainstorming and then the idea generation was carried out a total of four times at one occation. All the brainstorming ideas were written down digitally in a document and then used as a starting point when sketching the most suitable ideas collected from each brainstorming procedure to be able to visually see the ideas.

3.5.2 The Pugh Matrix – Selection

The decision had been made using a Pugh matrix to identify and thereafter exclude concepts with poor potential. A Pugh matrix is a table in which several criteria are given in the first column and various ideas are listed in the first row. Each concept is then evaluated against the criteria by assigning it a single numerical score or a single grading [44]. After all criteria have been met, the numbers or ratings are totaled together to determine which ideas obtained the best or worst score. The criteria were developed in response to some of the material's requirements and constraints. Each notion was then scored on a scale of -1, 0 and +1, with +1 representing “better than baseline”, 0 representing “about the same” and -1 representing “worse than baseline” [45] . All concepts with a total score of -2 or above were chosen for additional review to choose one concept to continue ahead with. To avoid selecting a solution with a poor outcome, the final evaluation included the sustainability aspect as well as a relatively low complexity in implementation.

3.5.3 Sketching and Prototyping

After the implementation of the Pugh matrix, the best ideas with the highest ranking were chosen to be sketched and prototyped. The sketching of the ideas was carried out both virtually in the program Paint 3D and physically on paper. Then small prototypes were built with the help of hand tools where they consisted of simple and easily accessible materials, such as paper, wood, and plastic. The prototypes were then tested with a subsequent assessment of their functionality. Finally, a selection was made where the least functional prototypes were excluded from proceeding in the process.

3.6 Concept selection

To choose which concept is the most winning, the tools six thinking hats and the “Sustainability KM GMB WS” template were used, where these are described in more detail in the sections below.

3.6.1 Six thinking hats

Six thinking hats is a great technique that may be utilized in a variety of circumstances, particularly when discussing various ideas within a team. Given that people may think in a variety of ways and from a variety of viewpoints, this frequently leads to lengthy conversations regarding discovering unique ideas. That strategy becomes effective because it requires thinking in a specific way while wearing a specific hat. Each of the six hats has one color, and each hat symbolizes a distinct philosophy. If you're wearing a white hat, it suggests you're searching for and analyzing accessible data and information. In this case, it is also essential to examine previous patterns and capitalize on a lack of understanding about the given issue. Thus, the white hat represents analysis and objectivity which means that one must be objective in his or her thoughts while wearing that specific hat. [46]

The red hat represents the exploration of emotions toward the concept. The emotional factor is at the forefront in this case, i.e., how one does feel about the concept and if one likes or dislikes it. The red hat encourages one to listen to the gut instincts and then make an evaluation based on the feelings that have been developed because of the concept. However, it is equally critical that one does not entirely submit to the red hat, and to maintain emotional balance. [46]

The optimistic mentality is activated when wearing the yellow hat. At this stage, all the positive aspects of the concept should be considered, and an examination of what may be functional and beneficial with the concept is carried out. When everything appears to be difficult or even impossible, this hat helps with moving forward despite the obstacles. [46]

The purpose with the black hat is to make one think in negative ways. This is further allowing reasoning out potential bad occurrences that can occur if one chooses to pursue an idea. Having this hat in focus, discussions about what may go wrong with the notion can take place, and one is forced to consider the disadvantages of the idea. This is particularly significant since it highlights the concept's flaws, allowing for the processing of these flaws, which adds to a stronger idea. [46]

The green hat, on the other hand, indicates inventiveness. It includes looking outside the box to see if there are any better ideas or approaches to the concept itself. This hat focuses on coming up with innovative solutions to issues or ideas for them to prosper. [46]

Finally, the blue hat symbolizes control of the process. When wearing this hat, one can choose which of the other hats is best for making decisions. For example, you may remark beneath a blue hat, "now, it is time shifting the focus by using the green hat instead." With the blue hat, summarizations, forming the conclusions, and deciding the ultimate option for the concept. [46]

The concepts outlined and pretotyped in the previous activity were analyzed by the researcher and four employees from the department at NKT using six thinking hats. The first stage was to use the white hat to analyze the concepts. The concepts were next examined through the red hat, from an emotional standpoint. Following that, utilizing the yellow hat, the ideas were discussed, and the benefits and good features of the concepts were highlighted. The ideas were then assessed by donning the black hat, which emphasized negative qualities and faults in the concepts. The next phase was to examine the ideas via the green hat, which highlighted the creative component, i.e., the concepts were viewed from a broader viewpoint, and ideas outside the box being recommended to improve the answers. Lastly, the blue hat was picked, and the procedure was examined, i.e., which hats were appropriate for deciding which thought would be the most suited. After the analysis, each concept was ranked by the respective individuals involved. The ranking numbers were 1, 2 and 3 as well as -1, -2 and -3 where each one gave both a positive and a negative number. At the end of the process, the positive and negative scores for each idea were added together, which further resulted in a final sum for the purpose of implementing a comparison between the various concepts.

3.6.2 Sustainability template

The "Sustainability KM GMB WS" template was utilized to get the sustainable element of the concept (see Appendix 6). The first stage was to define what the solution needed to be to fit within a sustainable society. Material, sources, end of life, and so on might be decided via guided questions so that the answer meets the sustainable perspective. The present preconditions for creating and supplying these features were then examined. Strengths and limitations might be discovered by looking at raw goods, production, distribution, as well as maintenance and then connecting them to ecological, social, and economic elements. In the third stage, certain criteria that might steer the solution toward a sustainable solution were established. Six leading sustainable criteria (LSC) were developed for the solution as a result of these three processes. The LCS were assessed in terms of weight (how significant the criteria are) and maturity, in addition to the requirements identified through needfinding (how certain you are about the grade). Appendix 6 shows the indicated weight and maturity level. The voting process was repeated multiple times.

3.7 Prototyping

After choosing the winning concept based on the various tools above, both a virtual prototype as well as a physical alpha prototype were implemented.

3.7.1 Solidworks

For the virtual prototyping, the program Solidworks was used, which is a program for two- and three-dimensional CAD [47]. The focus of the software is mechanical design and is thus relevant to this project. Based on the sketching that was carried out and the dimensions that were taken on the conductor where the copper wires were already raised before cleaning, the development of the virtual prototype in Solidworks began. In the program, only the most complicated concept was implemented because this concept could not be physically built up and tested optimally. In the program, the machine was dimensioned where the material type, design and component parts were included in the model, see appendix CAD. An important feature that was implemented when simulating the various parts of the machine was "sheet metal" which enables sheet metal bodies to be created very quickly [48]. After the simulation was completed, it was decided that an alpha prototype would be built to physically test the idea. Before the final model was established, it underwent several iterations where the company could give its opinion and suggestions for improvements.

3.7.2 Alpha Prototype

The alpha prototype that was constructed was based on the virtual model but in a simpler way. The materials used for the prototype were readily available and were available at BTH as well as at the researcher's home. However, hoses with the connected nozzles from Biltema were bought. The box that is supposed to surround the conductor was made of wood with plastic inside and rubber at the edges to prevent leakage of the solvent. The box consisted of two parts that were assembled and then a round entrance hole with a diameter of 47 mm was created specifically for the test pieces. Holes were created in the upper part for the nozzles, see figure 10, and the hoses were connected to a small diaphragm pump which was placed in the solvent to pump up the agent via the hoses to the nozzles which then clean the copper wires. The prototype was tested at the company on a sample of a copper conductor containing coated with compound.

Figure 10: Nozzles attached to the box

3.7.3 Beta Prototype

Prior to the physical prototype, an information search was conducted about the components that the beta-prototype is intended to consist of. First, the company Telfa AB’s customer support was contacted to obtain information about the various pumps sold and for advice on which pump is most recommended due to the large selection available in the company. At the same time, the company PNR's customer support was contacted to get information about the various nozzles as well as advice about the most proper nozzle to be selected for the prototype.

3.8 Laboratory tests of the chemicals

The selected chemicals mentioned in the theory part were tested laboratory at NKT to decide whether the current solvent, PF-Solvent can be replaced with a milder variant. The laboratory manager was first contacted to undergo a short introductory course for this specific department to gain further access to the laboratory. After that, a careful selection of solvents was carried out where they would meet specific requirements which was that they would not have more hazard pictograms than PF-Solvent. After the careful selection, 20ml of the solvents PF solvent, Strovels, Ethanol, Ecosolv A and paraffin oil were filled into various beakers. Then 2g of the substance compound was added in the respective beaker and at the same time a timer of 60 minutes was started, see figure 11. The beaker was gently stirred every three minutes to facilitate dissolution of the compound. For the sake of accuracy, the test was performed for each solvent separately and not simultaneously. After obtaining results, a conductivity measurement of the solvent was performed which gave the best results.

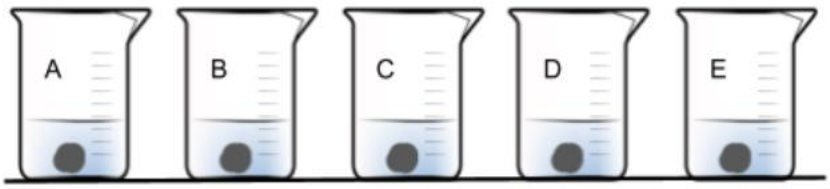

Figure 11: The beakers containing the compound and the respective chemical: A) PF-Solvent, B) Strovels Small parts wash 100, C) Ethanol, D) Ecosolv, E) Paraffin oil.

3.8.1 Conductivity measurement

The test procedures for the conductivity measurement of the selected chemicals PF solvent and Strovels Smådelstvätt 100 were performed in parallel. First, the XLPE plate sample was placed on top of the bottom electrode. Then 10-15 ml of the solvent was poured on XLPE sample. Then the contaminated sample was covered by an aluminum foil to protect the top electrode. The diameter of the aluminum foil was about 170 mm to be large enough to cover the prepared XLPE hot press sample. The next step was to place the top electrode on the sample and finally the measurement was started. This procedure was made for both solvents separately but at the same time.

4 RESULTS AND ANALYSIS

In this chapter, the most relevant results are presented.

4.1 Planning of the project

Figure 12 shows the results from the team canvas. The team consisted of four main members, including the researcher/author of this thesis, two supervisors, and the department manager for the splice department, as seen in the figure. The personal goals and the needs and expectations shown in the canvas are primarily relevant to the researcher, but the purpose, common goals, values, rules, and activities presented in the canvas are shared viewpoints across the entire team. The overall aim of the project is to streamline the cleaning procedure from the health, environment, and sustainability aspects by suggesting different solutions. The common goals are proposing an implementation plan to be implemented later, obtain circularity in the cleaning procedure, and acquire and share knowledge. The results should be of high quality, and they should be delivered on time, according to the researchers' time schedule. To do this, the researcher needs reviewing documents related to the procedure as well as getting the final work reviewed, interview workers at the department and other employees to gain relevant information and identify their needs and getting access to materials and relevant departments at the company. Lastly the values were communication and teamwork where the communication was decided to take place mainly over e-mail and teams since it has been a good strategy during the pandemic and will hopefully still be.

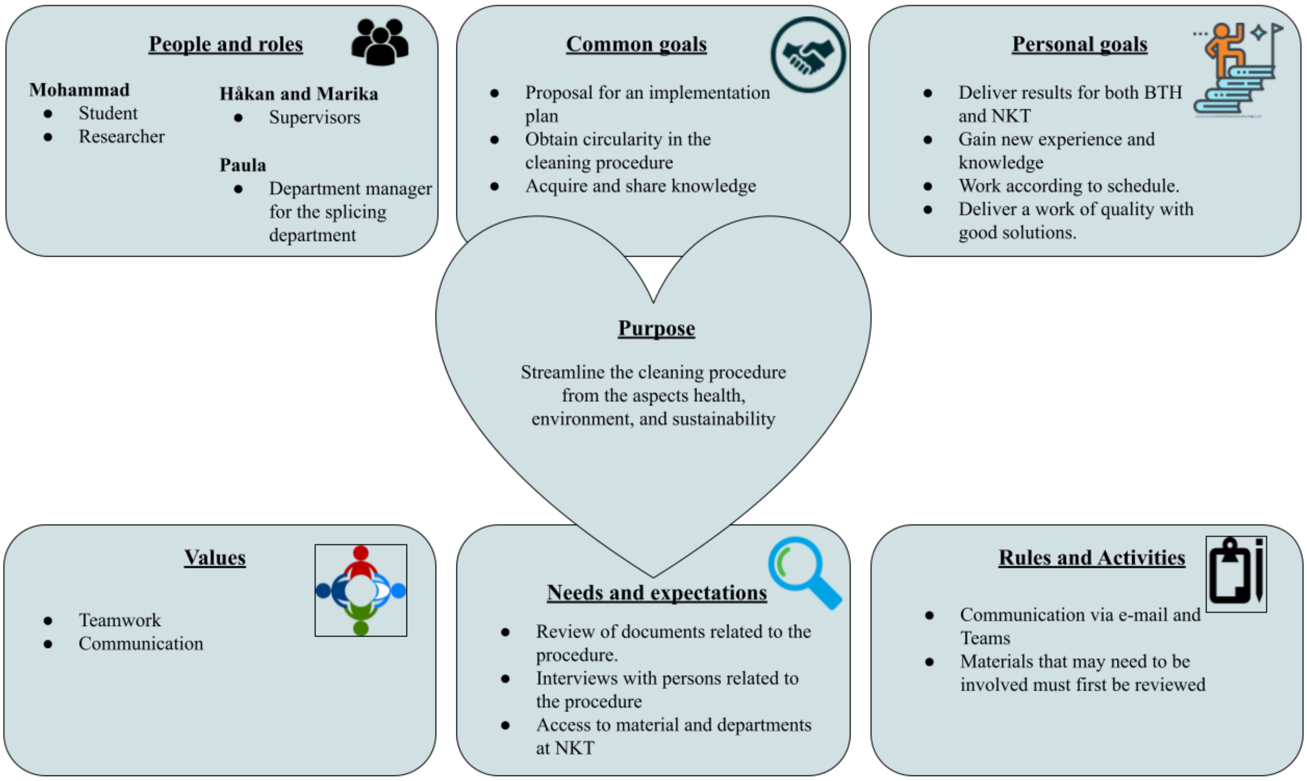

Figure 12: Team Canvas - A modified version created with NKT.

4.2 Analysis of the collected data

This chapter present all of the results from the data acquisition and analysis stages, as well as the inspiration phase from the design thinking methodology.

4.2.1 Understanding of the compound

After a literature search and information search in the company NKT, it turned out that the compound consisted of wax. This wax has a very high melting temperature, which means that heat treatment cannot be applied in the cleaning procedure. This rejects the hypothesis that heat can be included in cleaning the conductor.

4.2.2 Stakeholder analysis

Figure 13 shows the stakeholders selected and their placement in the matrix, where the findings are based on assumptions and prior experiences of what it used to seem like in other companies with whom the researcher has previously worked. The management stakeholder gained the most power, yet interest in this project was low due to other priorities. Consumers were the stakeholder with the least power and interest since it is doubtful that customers will be able to focus on all sub-processes that are conducted during the production of high voltage cables, but they are primarily interested in receiving a high-quality completed product, they are still considered a stakeholder, though, because the solution has the potential to affect customer long waits. The Materials Action Department was supposed to have a low power but a strong interest in the project or what it may accomplish. This is due to increased awareness of sustainability and quality development, and many people desire to be more sustainable. The material suppliers were also considered to have a low power and a low interest rate since they are likely to be negatively affected when the number of materials ordered from them by the company decreases, and so they may find the outcomes of this thesis uninteresting for their own production. The remaining stakeholders acquired average power since these departments have the knowledge and expertise to improve manufacturing and the corporate strategy. These stakeholders are also thought to be the ones most related to concerns of simplifying work procedures and sustainability, therefore their interest in this activity is strong. However, relevant stakeholders (workers, production development department, and splice department) were chosen to be interviewed, updated on a regular basis, and collaborate more closely with.

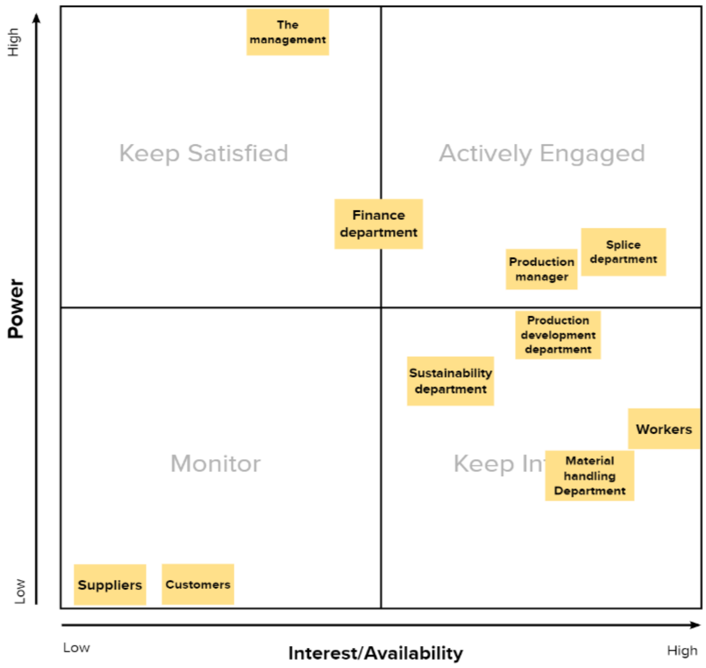

Figure 13: Stakeholder Analysis.

4.2.3 Interviews

The information obtained from the interviews was the time it takes to clean the compound from each cable end, which was stated to be about 3-4 hours. In addition, the informants talked about the tools used in the cleaning, which included PF-Solvent, brushes and spray bottles made of plastic. Furthermore, more information was obtained about the amount of chemicals used and then there were between 1 to 2 bottles of the solvent for each end. Finally, the informants stated that their attitude to the existing procedure is negative since it is a very demanding procedure that takes both a long time as well as a lot of energy, see Appendix 2. The following statement was made by one of the workers at the department:

> *"When cleaning the ends, a brush is needed for each end that is cleaned, sometimes more brushes because they can be destroyed during the process".*

This quote indicated that most tools and materials are used and destroyed during the procedure which was not appreciated by the workers. Appendix 2 shows the attitude of the workers towards the current procedure where 100% of the respondents had a negative attitude to the cleaning procedure.

4.2.4 Personas

Figures A1-A3 in Appendix 3 shows the findings of all three personas and shows that all departments are linked and rely on each other to establish a more sustainable work environment and develop new sustainable working techniques. A linear business model is being replaced by a circular one, and these divisions want to learn about sustainable practices and devulcanization technologies in the process. Because of this, it is important to exchange as much relevant information as possible and to include a circular style of thinking for all components while gathering ideas and generating solutions.

Researchers were able to identify the specific cleaning requirements of the conductor for the splice department employees using the various personas that were created. Some of the most pressing demands were to speed up the cleaning process and reduce the danger of exposure to the chemicals used in the process, as well as to reduce the amount of time spent cleaning each conductor. It was possible to identify many goals based on the personas created for other stakeholders, such as finding a milder chemical that can be used in lieu of the chemicals now in use and decreasing expenses, including the reduction of disposable materials and the usage of less solvents.

4.3 Ideation

As a result of all the previous phases' activities, tools, and analysis, it became apparent what to do in the next stages. Investigating how several concepts may be useful in establishing an acceptable solution for the identified problem, for example, became clear. From the needs, it was also clear what cleaning approach should be used to streamline the process. It was because of this that these upcoming stages have been dedicated to addressing research questions related to determining which cleaning procedure is most effective in meeting the needs and challenges of the methods used today.

4.3.1 Brainstorming

The result obtained from the brainstorming was the ideation of 40 where 20 of those ideas were chosen to be sketched, see figures 11-13 below. Each individual idea in the figures was assigned a unique code where the number before the full stop represented the brainstorming technique described in the theory and the number after instead represented the idea generated from the brainstorming procedure, se table 3. From the first technique, 10 different ideas were generated. The second technique, on the other hand, contributed to 6 different ideas and finally 4 different ideas were obtained from the last technique. All the ideas were then given a unique name representing its functionality, which is seen in table 3.

Table 3: The 20 chosen ideas named and described.

Concept	Description
1.1: SprayBrush	A cleaning tool consisting of a brush part and a container with solvent. There is a button on the container that makes liquid leak out to the brush part.
1.2: SuperCloth	The cloth is dipped in a strong solvent and absorbs this. The cloth is swept on the copper wires with a moderate force and the solvent helps to dissolve the compound.
1.3: UltraCCleaner	Rotating head that automatically sprays the solvent triggered by the contact with the compound as it rotates around each copper wire.
1.4: HeatAndClean	The conductor is heated in a closed box and the compound is then removed with a rotating brush.
1.5: CompoundScratcher	The compound is scraped off with a coarse reusable brush.
1.6: MeltAndClean	The compound is melted down with a cylindrical machine that radiates heat inside on the compound on the copper wires. The machine is used individually on each copper wire.
1.7: UltimateInsulator	The compound is replaced with another material that has a composition that is easier to handle.
1.8: SteamAndClean	The compound is exposed to chemical vapor in a steam engine and is then scrubbed off with a brush after the steam treatment.
1.9: 360Rotater	Small device with a 360-degree rotating head. The head is cylindrical, and the copper wire is placed inside the cylinder so that the head can rotate around all the surfaces of the copper wire.

1.10: CompoundEd.2	The composition of the compound is revised to facilitate the handling of it.
2.11: PressureCleaner	Battery-powered cleaning tool with a rotating brush head. The solvent is pumped upwards towards the brush head by means of a pumping effect
2.12: WashingBox	A mechanical cleaning apparatus with several components. Cleans the entire conductor at once.
2.13: MagicSponge	Sponge that absorbs solvents and then is pushed out when scrubbing the compound.
2.14: RotatingSteelWoolB	Brush consisting of steel wool which secretes chemicals when moistened.
2.15: 360MovingB	Hand machine attached to the end of the copper wire. It has a moving part that moves along the entire copper wire and cleans it from the compound.
2.16: ScrubAndClean	A similar machine as described in 2.15 but a scraping effect instead where the scraping starts from the inside and out towards the outermost point of the copper wire.
3.17: ConductorC	Electric toothbrush-like device but with a larger motor that is stronger and a larger cleaning head.
3.18: PressAndClean	A small drill but with a specially adapted brush head.
3.19: ConductorWash	Machine with brushes as in car wash but in a smaller variant as a box.
3.20: AutoClean	A bottle containing detergent that is automatically sprayed using a small motor. Built-in brush.

4.3.2 The Pugh Matrix – Concept selection

The results from the Pugh matrix showed how the top 20 ideas from the brainstorming process ended up in the rankings. Figures 14-15 shows that the four best concepts according to ranking received a score that was between -2 and 5. Other concepts received a total value of -3 or lower. The winning concept according to this matrix was concept 12 (figure 15), or 2.12 according to table 3, with a score of 5 points. The second winning concept was the 11th one, with a score of 3. The third winning concept was the 17th one with a total score of 3 and lastly, concept 1 (figure 14) was ranked at the fourth place with a total score of -2.

Pugh Matrix - A Decision Matrix

Problem/Situation: Streamlining of the cleaning procedure of the conductor.

	Criteria	Baseline	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10
			Alternatives									
1	Safe	0	–	–	0	0	0	0	0	–	–	–
2	Sustainable	0	0	–	0	+	–	–	0	–	–	0
3	Weight	0	+	+	+	0	0	–	0	0	+	0
4	Easy to assemble	0	0	+	0	–	+	–	–	–	+	–
5	Reliable	0	–	–	–	0	–	0	–	0	–	0
6	Cost	0	0	–	–	–	–	–	0	0	0	–
7	Effectiveness	0	–	–	0	–	–	–	0	–	–	–
8	Manufacturing Ease	0	+	0	–	0	+	0	–	–	0	–
9	Evironmentally friendly	0	–	–	–	–	–	0	0	0	–	0
		Totals	-2	-4	-3	-3	-3	-5	-3	-5	-3	-4
		Rank	4	6	5	5	5	7	5	7	5	6

Figure 14: Ranking of concepts 1-10.

Pugh Matrix - A Decision Matrix

Problem/Situation: Streamlining of the cleaning procedure of the conductor.

	Criteria	Concept 11	Concept 12	Concept 13	Concept 14	Concept 15	Concept 16	Concept 17	Concept 18	Concept 19	Concept 20
		Alternatives									
1	Safe	+	+	–	0	+	0	0	0	0	0
2	Sustainable	+	+	–	–	0	0	–	–	0	–
3	Weight	0	0	+	0	0	–	+	–	–	–
4	Easy to assemble	–	–	0	–	–	–	0	+	–	+
5	Reliable	0	+	0	0	0	0	0	0	0	–
6	Cost	+	+	–	–	–	0	0	–	–	0
7	Effectiveness	+	+	–	0	–	–	–	–	+	–
8	Manufacturing Ease	0	0	0	0	0	0	0	0	0	+
9	Evironmentally friendly	0	+	–	–	–	0	0	0	–	–
		3	5	-4	-4	-3	-3	-1	-3	-3	-4
		2	1	6	6	5	5	3	5	5	6

Figure 15: Ranking of concepts 11-20.

4.3.3 Sketching

The results obtained from this activity were simple virtual models of the four winning concepts, as shown in Figures 16-19 below. The fourth winning concept, the SprayBrush, is a cleaning tool that consists of a brush part and a container that contains the solvent, see figure 16. There is a button on the container that makes liquid leak out to the brush part.

The third winning concept, the ConductorC, 2 is a battery-powered cleaning tool with a rotating brush head. The solvent is pumped upwards towards the brush head by means of a pumping effect, see figure 17.

The second winning concept, PressureCleaner, is a mechanical cleaning tool consisting of different components; a removable and rotating brush head, adjustable rubber components that close the cavity during the cleaning process, containers for solvents, motor and pump and nozzles, see figure 18.

Finally, the first winning concept, the WashingBox (figure 19) consists of a mechanical cleaning apparatus which consists of several components and has the function of cleaning the entire conductor at one and the same time. The device is designed in such a way that the raised wires all fit in the square cavity of the machine. The entrance to the cavity is made by folding up the upper half of the square. The circle on one side of the square, shown in the figure to the right, is also divided into two so that it too can open and close with the square. However, this part is made of rubber, which differs from the other squares, which are instead constructed of another more durable material. The white container shown in the figure includes the solvent and a warming effect. The solvent is pumped up by means of a special pump and then carried upwards (in the blue hose), passes a filter, and moves on to the nozzles located in the walls of the cavity. These nozzles have a rotating function (like those for watering grass) to ensure that the solvent reaches all surfaces of the conductor. The floor of the square cavity is also designed with a slight slope to collect the solvent used. The agent will then be returned to the white container via the red hose. As for the blue hose, it is placed at a distance from the bottom of the container so as not to inflate impurities when reusing the product. The function of the filter is to filter out any impurities and thus protect the nozzles from being destroyed.

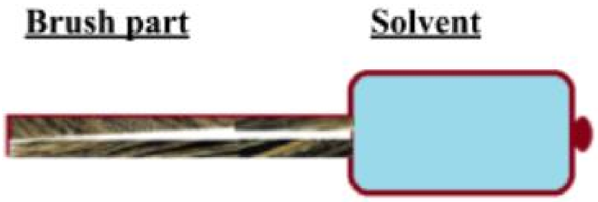

Figure 16: Concept 1 – The SprayBrush

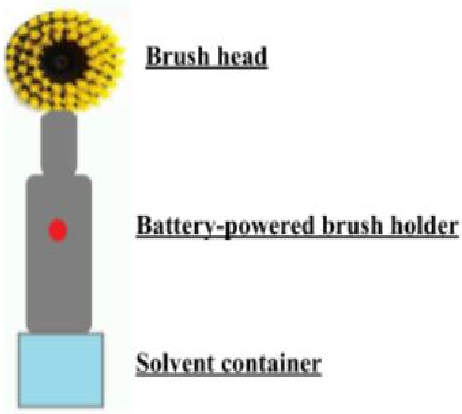

Figure 17: Concept 2 – The ConductorC

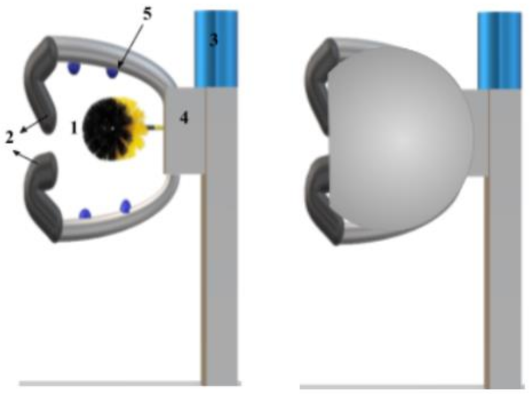

Figure 18: Concept 3 – PressureCleaner. Image on the left shows the components of the machine, the image on the right shows the appearance of the machine. 1) removable, rotating brush head, 2) Adjustable rubber components, 3) solvent containers, 4) motor and pump, 5) nozzles.

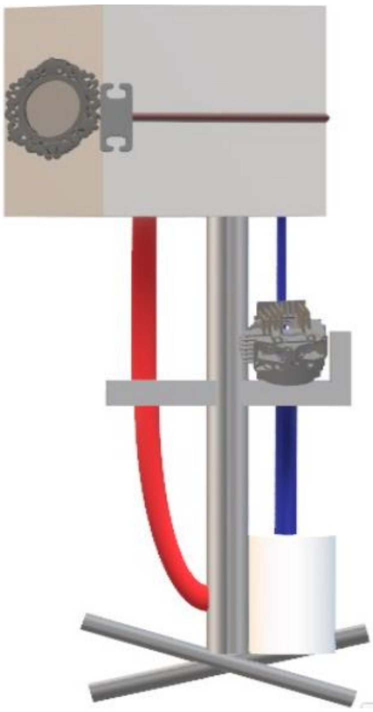

Figure 19: Concept 4 – WashingBox

4.3.4 Six thinking hats

Six thinking hats resulted in the selection of the winning concept based on the sums received from all participants, Appendix 4. The ranking of the different concepts was as follows: concept 4 with a ranking of 7 points, concept 3 with 5 points and concepts 1 and 2 with -2 points. This meant that the winning concept according to six thinking hats became concept 4 where the total positive total sum including all activity participants was 14 points while the negative sum was -7 points.

4.4 Prototyping

After the collaboration between the workers and the researcher to select the best concept, a virtual model could be constructed with a subsequent physical alpha prototype.

4.4.1 Solidworks – Virtual prototype

The final simulation of the WashingBox is seen in Figure 20 below. The result was a removable washing machine consisting of most components, see Appendix 5 for a more detailed description of the components included. The machine comprises 12 nozzles and a filter that returns the solvent used, see figure 21 and consists mainly of stainless steel.

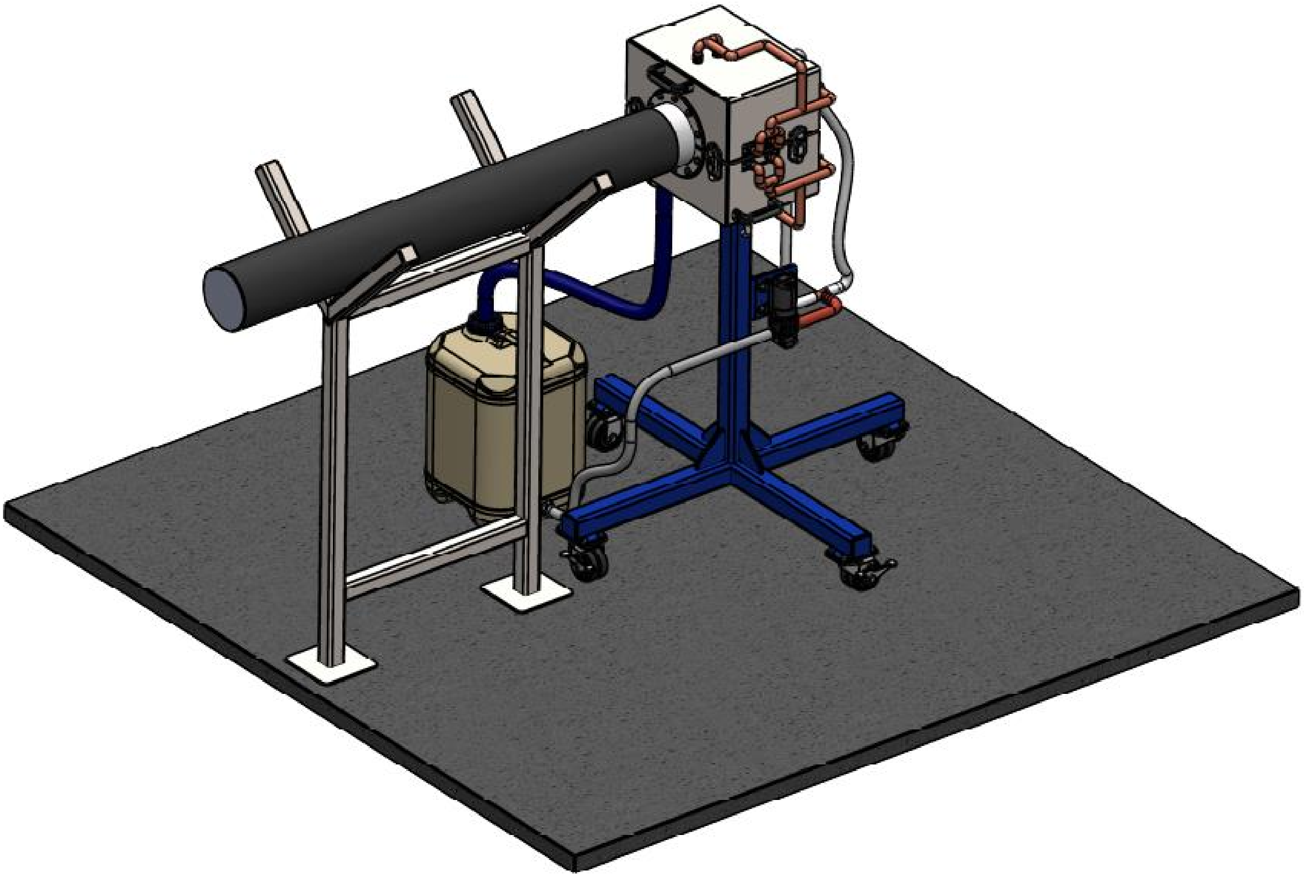

Figure 20: The final virtual simulation of the Washing Box.

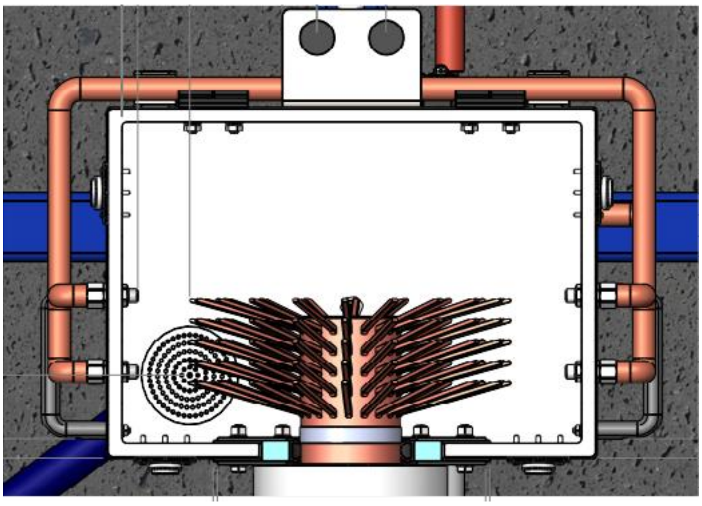

Figure 21: The washing box viewed from above.

4.4.2 Alpha Prototype – Design and Functionality

The result for the appearance of the alpha prototype can be seen in Figure 22 and 23. However, the functional properties of the prototype were deficient because it could not contribute to optimal cleaning. It gave a certain effect on the cleaning which could be noticed on some areas of the conductor. The main areas that were partially cleaned from the compound were the upper surfaces of the threads, about 60% of each thread.

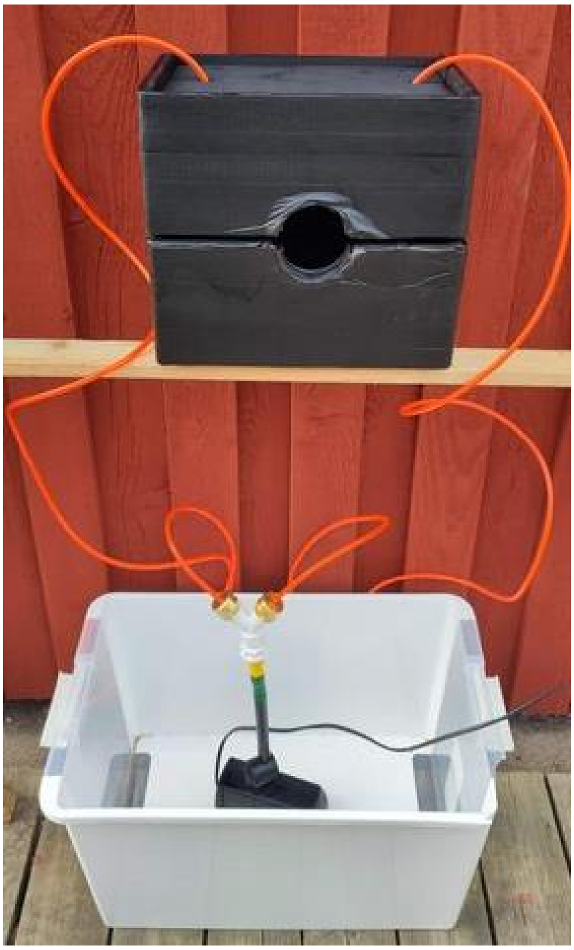

Figure 22: Alpha-prototype - Design

Figure 23: The interior and exterior design of the alfa-prototype.

4.4.3 Planning of the Beta-Prototype

Based on the answers obtained from the two companies that were contacted for information about nozzles and pumps, a pump made of stainless steel was chosen to be the most appropriate where the pressure of this pump was up to 16 bar and the flow was a maximum of 345 L/h [49]. As for the nozzles, a full consonant variant consisting of the material stainless steel was chosen with a capacity of about 4.5 l /m at a pressure value of 7 bar, see figure 24.

NOZZLE TYPE				CODE	D mm	D1 mm	Capacity at different pressure values (l/min) (bar)						
DAM	DBM	DCM	DDM				0.7	1.0	2.0	3.0	5.0	7.0	10
•				0740 xx	1.0	0.5	0.36	0.43	0.60	0.74	0.96	1.13	1.35
•	•			1118 xx	1.1	1.0	0.57	0.68	0.96	1.18	1.52	1.80	2.15
•	•			1147 xx	1.2	1.1	0.71	0.85	1.20	1.47	1.90	2.25	2.68
•	•			1188 xx	1.3	1.2	0.91	1.09	1.54	1.88	2.43	2.87	3.43
•	•			1212 xx	1.4	1.2	1.02	1.22	1.73	2.12	2.74	3.24	3.87
•	•	•		1235 xx	1.5	1.3	1.14	1.36	1.92	2.35	3.03	3.59	4.29
•	•	•		1294 xx	1.7	1.5	1.42	1.70	2.40	2.94	3.80	4.49	5.37
•	•	•		1370 xx	2.0	1.8	1.79	2.14	3.02	3.70	4.78	5.65	6.76
•	•	•	•	1470 xx	2.1	2.0	2.27	2.71	3.84	4.70	6.07	7.18	8.58
•	•	•	•	1588 xx	2.3	2.0	2.84	3.39	4.80	5.88	7.59	8.98	10.7
	•	•	•	1659 xx	2.5	2.2	3.18	3.80	5.38	6.59	8.51	10.1	12.0
		•	•	1740 xx	2.7	2.3	3.57	4.27	6.04	7.40	9.55	11.3	13.5
		•	•	1835 xx	2.8	2.6	4.03	4.82	6.82	8.35	10.8	12.8	15.2
		•	•	1940 xx	3.0	3.0	4.54	5.43	7.68	9.40	12.1	14.4	17.2
		•	•	2105 xx	3.2	3.2	5.07	6.06	8.57	10.5	13.6	16.0	19.2
		•	•	2117 xx	3.4	3.3	5.65	6.75	9.55	11.7	15.1	17.9	21.4
		•	•	2147 xx	3.8	3.7	7.10	8.49	12.0	14.7	19.0	22.5	26.8
			•	2188 xx	4.3	4.3	9.08	10.9	15.4	18.8	24.3	28.7	34.3
			•	2235 xx	5.0	4.5	11.4	13.6	19.2	23.5	30.3	35.9	42.9

Figure 24: Information about the nozzle with a 45-degree angle.

4.5 Laboratory tests for the chemicals

4.5.1 Solubility of the compound in the various solvents

Table 4 below shows the results from the laboratory tests of the selected solvents. PF-Solvent dissolved the compound in its entirety in 7 minutes compared to Strovel's which dissolved the entire compound in 9 minutes. The other chemicals only partially dissolved the compound after 60 minutes during both attempts, except from Ecosolv A which didn't solve the compound at all.

Table 4: The results of the tests performed.

Solvent	Amount of compound (g)	Amount of solvent (ml)	Time for dissolution of the compound (min)	Number of attempts
PF-Solvent	2	20	7 (fully)	2
Strovels	2	20	7 (fully)	2
Ethanol	2	20	60 (partly)	2
Ecosolv A	2	20	60 (no dissolution)	2
Paraffin oil	2	20	60 (partly)	2

4.5.2 Conductivity measurement

The result obtained from the measurement of conductivity was that “Strovel's Smådelstvätt 100” affects the conductivity to a greater degree than PF-Solvent does, as can be seen in Figures 25-28 below. Figure 26 shows that the conductivity peak, ie the maximum for the effect of the solvent on the conductivity of XPLE for Strovels Smådelstvätt 100, is 842.5. For PF-Solvent, the peak is instead 40.36, which is seen in Figure 28.

	Positive polarity		
		Conductivity, fS/m	
	Peak P	16 h 70 °C	24 h RT
XLPE/Strovels smådelstvätt 100	842.5	**4.268**	1.513
XLPE/PF Solvent	40.36	**0.2129**	0.3466

Figure 25: The conductivity measurements for PF-Solvent and Strovels Smådelstvätt 100

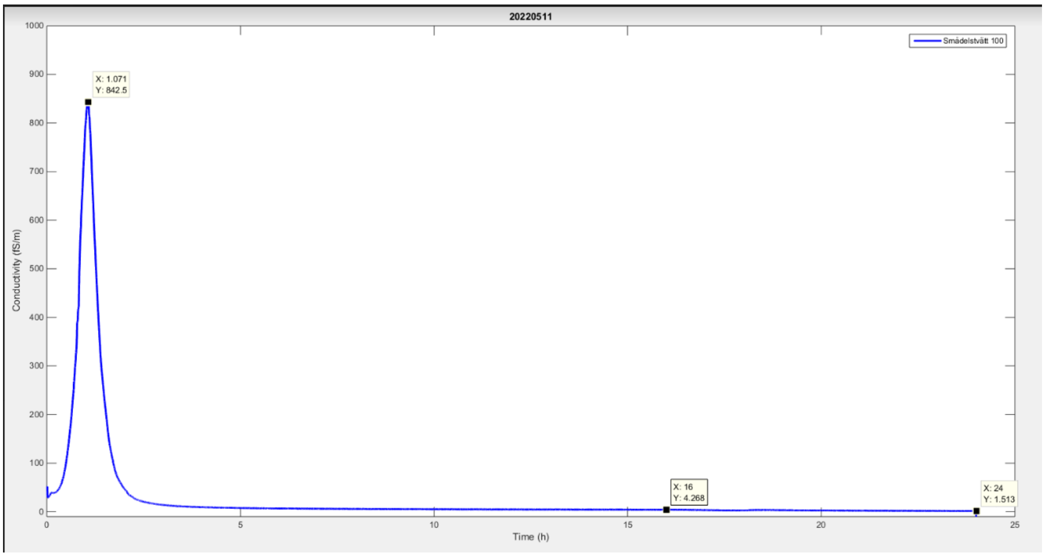

Figure 26: Conductivity measurement of Strovels Smådelstvätt 100

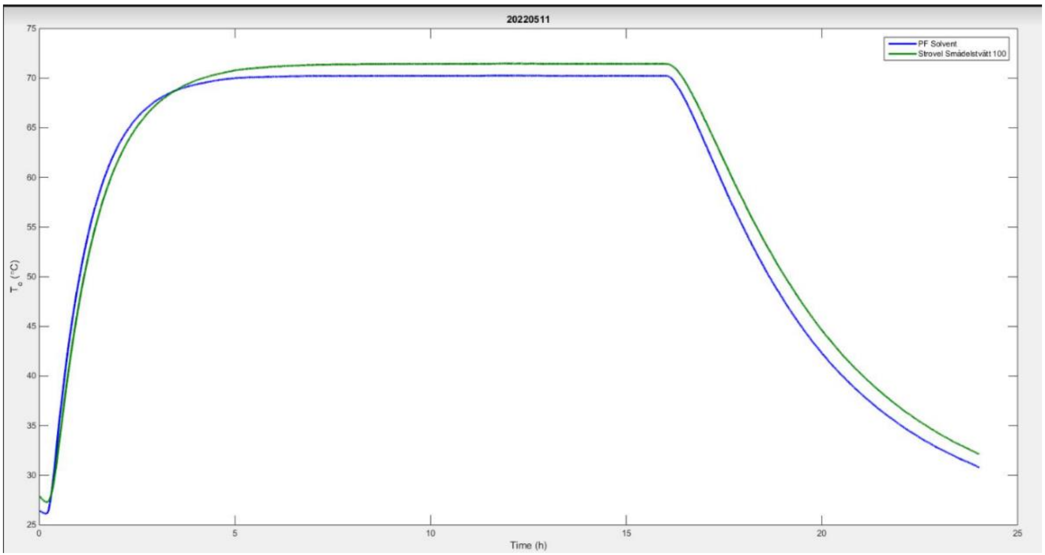

Figure 27: The conductivity measurements for PF-Solvent and Strovels Smådelstvätt 100.

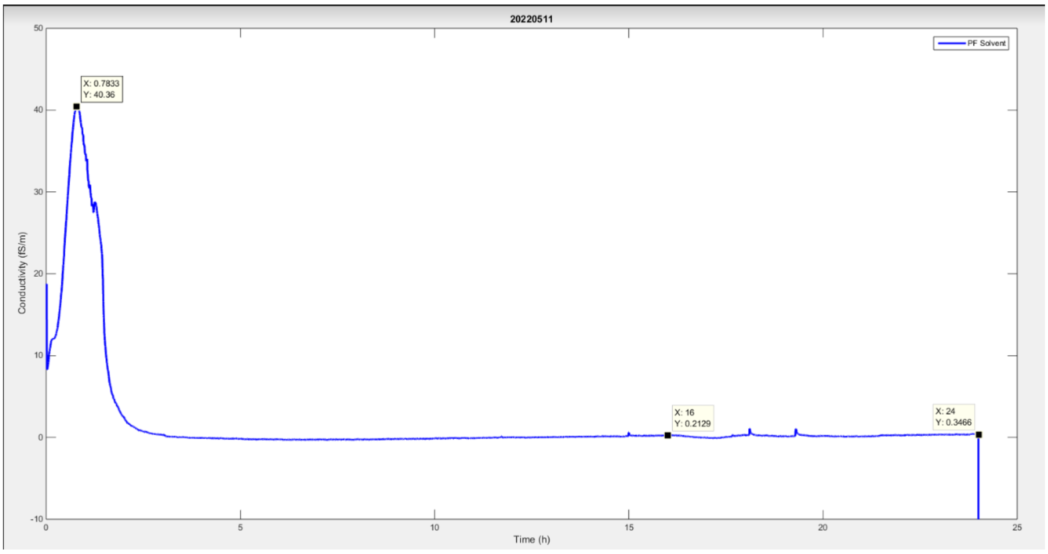

Figure 28: The conductivity measurements of the PF-Solvents.

4.6 Sustainability Aspect

The sustainable template specified six LSCs that the product must fulfill in order to be considered sustainable. Appendix 6 show how the LSC was determined based on the product's attributes and the product's lifespan. Table 6 lists the LSCs that were discovered.

Table 5: The results from the sustainable template

Leading Sustainable Criteria (LSC)	Comment
End-of-life recyclability	Easy to disassemble, few different kinds of materials
Robust ("hands off" usage)	Can sustain at least 120 days of function without needing maintenance.
Toxicity of metal treatment	There are no hazardous water-resistant chemical therapies.
When producing and repairing, use local suppliers and contractors.	Only use suppliers/contractors in Blekinge.
Important information, such as public access rights and recycling facilities.	Teach workers how to use the product safely
Repairs do not degrade the product's quality.	When repairs are done, the product should retain its durability and appearance.

A deeper rating of weight and maturity was developed based on these LSC as well as the needs from the needfinding. The grading results demonstrate that the needs and LSC: s interact in some manner, as shown in Appendix 6.

5 DISCUSSION

The relevant results obtained from the methods are discussed below.

5.1 Research approach

The approach adopted for this project was a mixture of participatory action research and the design thinking strategy. In this case, the combination worked out well since the focus, among all, was including the requirements and needs of the workers at the splice department as well as exchanging ideas with the supervisor at NKT. The various phases of the project were also effectively coordinated and did not clash with one another at any point over the course of the project. As a result, all phases have directed the work in the manner anticipated, making it easier to go on with the project. When the several strategies are examined individually, it can be shown that one was slightly more difficult to adapt than the others.

The individuals who are impacted by the problem should be given an opportunity to contribute to the process of determining which aspects of the problem should be addressed, for example via interviews with the workers as was made in this case. Organizations must engage in the decision-making process when it comes to implementing new policies and procedures. As a result, the researcher set out to meet these criteria throughout the course, which was somewhat successful. Because NKT was included in the initial scope of the work, which contributed to the project moving the right direction. Most of the results for the splice department at NKT have been examined by key stakeholders to provide information and give them an opportunity to remark and make suggestions before moving forward with any of the proposed solutions. Throughout the study, there have also been updates on the results obtained of the various research questions.

However, because some of the activities has not engaged the partner on a deeper level, it is possible that the stakeholders could have been incorporated to a greater extent. Due to the large number of employees from various departments who were engaged in various aspects of the project, it is understandable that communicating, per mail, could be more time consuming than expected. This is since some of the employees were having difficulty finding acceptable times in their schedules. Another argument may be that the researcher is inexperienced with working with such a framework, as such research was carried out by the researcher for the first time. As a result, there has been a lack of prior experience with the technique, making it difficult to comprehend how and when to involve the stakeholders to complete a productive project involving the Participatory Action Research.

A higher level of familiarity with the design thinking strategy made it simpler for the researcher to pursue. Stakeholder demands have been considered designing a solution that is in accordance with the company's desires as well as sustainable. It was necessary to test some different prototypes to determine which concepts were working seen from both the design- and the functionality aspect.

5.2 Data collection

A lot of data and information have been gathered for this thesis. Interviewing, for example, was one way of collecting information. To some extent, the first research question has been partially answered by using the interview questions and methodology that were evaluated favorably. There is, however, the possibility that the project may have gone in an entirely different route if additional needs had been identified. A more positive conclusion may have been achieved with different questions and methods, therefore it's difficult to say whether the interview questions were the perfect ones or not.

After a good collaboration with the workers in the splice department as well as engineers and analysts from different departments, we agreed that a controlled, mechanical process can be a major contributing factor to the amount of solvent leakage being reduced or totally inhibited. This was because the current technique used includes sources of error related to human factors. The process cannot be carried out optimally and differs from worker to worker, which also means different amounts of solvent leakage, among other things. A machine, on the other hand, encloses the solvent, can possibly reuse it, and store it in a well-defined place. This in combination with the cleaning procedure being streamlined in terms of time and cost makes the machine approach the clearly superior alternative.

5.2.1 Needfinding

Based on the results obtained from the interviews, it can be said that in principle all workers in the splice department today have a negative attitude to the existing cleaning process. The main reason for this attitude is that it is a time and energy consuming process that they have been struggling with for several years. In the past, workers have tried to develop new ways of working but have failed. Another important point that they raised was that they thought that a lot of material was wasted, which is negative from an environmental point of view. Through this information, needs and wishes could thus be highlighted and further initiate the concept generation to satisfy these needs. It is therefore very important to involve the workers in the process because they are in the field of work and have a lot of information about the work procedure compared to, for example, the boss or other employees who are not on site to the same extent. By involving the workers, trust and security are also created because they get the chance to have their voices heard and they can contribute to an improvement of the procedure if necessary. Another important point that most workers highlighted was to transform the procedure from being manual to becoming mechanical. This has been previously tested by them, but they have not succeeded in developing a functional and robust prototype to test whether it is possible and reasonable to implement such a change. In summary, the interviews with the workers gave a broader view of the problems with the procedure from their perspective, which was that the procedure today is manual which requires a lot of time, energy, and costs seen from the environmental and social perspective.

5.3 The alternative Chemicals

The results showed that PF solvent was the most effective cleaning agent in comparison with other tested solutions. However, Strovels smådelstvätt 100 was also effective as it dissolved the entire compound already after 9 minutes, which is 2 minutes later than PF solvent. Despite this time difference, it may be possible to replace the current solvent with Strovels as it has been shown to have lower health risks compared to PF solvent. In terms of cost, this solvent is cheaper to buy compared to PF solvent. If it is used simultaneously with mechanical cleaning, you can get large savings on the solvent because the process is controlled compared to if it is a worker who sprays the agent and spills unknowingly. This will also mean that the two extra minutes that differ will possibly be negligible in the mechanical procedure when other parameters come into play, such as the pressure from the nozzles. As for the remaining solvents and why the tests were interrupted after 60 minutes, it was because they only showed partial dissolution of the compound and that it was ineffective in terms of time. The cleaning procedure was intended to be streamlined and a time span of 60 minutes for a partial dissolution is ineffective if you look at it as it will delay the whole procedure instead of streamlining it. In addition, it would have been necessary to use large amounts of the solvents to be able to dissolve all the compound on all copper wires because it both acts slowly and requires larger amounts to be applied in both manual and mechanical procedures. This is because the compound will not actually be dipped in the solvent as in the tests.

5.3.1 Conductivity measurement – PF-Solvent vs Strovels Smådelstvätt 100

At the first opportunity as a conductivity measurement was performed the results could not be obtained due to system failure which caused the procedure to stop after 2h instead of 24h. Thus, another experiment was performed, and results could then be obtained. The results showed that there were large differences in terms of impact on conductivity as Strovels Smådelstvätt 100 had a significantly higher impact on conductivity. This may be due to how the chemical composition of Strovels differs from PF-Solvent which had more stable chemical bonds. Based on these results, this means that Strovels Smådelstvätt 100 cannot replace the currently used solvent PF-Solvent. Differences on the peak between these two solvents 802.14 and that the conductivity after 16 hours in 70 degrees differed by 4.0551, which is also a relatively large difference, see Figure 25. This means that when using a solvent that has a high impact on the conductivity when cleaning the conductor, this can have negative effects on the splicing itself as the properties of the high voltage cable may be adversely affected, especially the bearing consisting of XLPE. Furthermore, this can cause defects on the cable, which means that the defective piece must be cut off and splicing must be carried out again, which is both time and cost inefficient in the long run. Based on the experiment, PF-Solvent's good conductivity properties could also be confirmed and thus it is still recommended to use this particular solvent as it showed significantly lower values with regard to the conductivity effect.

5.4 Ideation

When generating the various ideas, the main method was brainstorming both individually but also in groups with both the workers and the supervisors at NKT. The individual ideation procedure could be perceived as challenging because there was no other person to brainstorm with and thus stimulated to come up with further ideas. However, a round of brainstorming was also carried out with the workers, which gave rise to further ideas that could then be used to be further analyzed with the help of the various tools.

5.4.1 Pugh Matrix

The Pugh matrix helped to rank the 20 different concepts based on predetermined criteria that were considered relevant. The criteria included the three important aspects: worker safety, the environment, and sustainability. As for the criterion “cost”, the starting point was not only the cost that will be required to produce, but this criterion also included long-term costs for both the concept but also for any waste that it may contribute to, hence the figure -1 for some of the concepts.

The concepts that showed a total score of -3 or more were excluded because these were considered unsuitable to proceed with. This was since the disadvantages of these concepts outweighed the advantages and some of them were also unsuitable for development into an alpha prototype as this would have been time and resource consuming.

5.5 The prototypes – functionalities and design

In general, the prototype could be designed like the one created in Solidworks but with fewer components. However, there were some shortcomings with it, which contributed to the cleaning not being precise in comparison with what had been expected. There are several different reasons for this and one of the reasons is that only two nozzles were used which were placed in the upper part of the box compared to the virtual model which instead had 12 nozzles. Unfortunately, the physical prototype could not consist of as many nozzles. The reason was the costs that would have been added when purchasing these. Furthermore, because it would be a more complex prototype that would then have required more time to implement.

Another factor that may have contributed to the lack of cleaning was the actual spray angle on the nozzles. The spray angle was relatively large and scattered compared to the angle of the nozzles planned to be used for the beta prototype, where these had an angle of 45 degrees. This resulted in some rays falling outside the focus area, i.e., the compound-coated copper wires, which in turn contributed to only the upper surfaces of each individual copper wire being cleaned while the lower surfaces remained compound coated, because of the lack of accuracy in cleaning.

As for the pump used, it may also have contributed to the lack of accuracy of the cleaning. The pump used was a diaphragm pump with a low pressure, about 3 bar in comparison with the pump that was intended to be used in the beta prototype, which instead had 7-8 bar. This then contributed to the compound not being able to be completely removed in places.

As for the visual modelling of the machine, most of the components were constructed with the so-called sheet metal that has been thinned and flattened by an industrial process. Sheet metal is a basic metalworking material that can be cut and bent into several shapes. Sheet metal is used to make many daily items. This material is unique in that it is very lightweight, which contributes to the construction becoming cheaper to manufacture as not as much material needs to be used, and that it becomes easy to choose the right thickness based on the principles of strength theory while it is easy to handle. The design enables the workers to carry out the whole process mechanically without having to put on heavy protective equipment as it is constructed in a safe manner. The machine consists, among other things, of a rubber part that encloses the conductor, which separates the inside of the box from the external environment while the solvent used is preserved inside the machine, which is environmentally and health friendly. The design also involves a reuse of the solvent because there is a built-in filter that partly filters down the used solvent at the same time as it returns to the beaker and is then pumped up again for reuse. An advantage of this is precisely that you save on resources as you do not have to use as much of the solvent, which is environmentally friendly and economical. However, a disadvantage may be that it takes longer for the conductor to be cleaned as the solvent weakens after it has been used once, given that reactions occur with the compound, which means that it does not return to its cup in its original condition.

5.5.1 The beta-prototype

The initial idea for prototyping was that only an alpha prototype would be developed to test the concept's functionality roughly. However, it was quickly realized that further development had been an advantage in that the simulated model was much more developed compared to the alpha prototype and had thus needed a slightly more advanced prototype to really investigate the functionality. Since this work was carried out for a limited time, it was thus decided that only planning of a beta prototype could be relevant and that future work could then be to implement the plan as established. With the help of the components chosen for the beta prototypes, a more efficient prototype had hopefully been obtained because the pressure from, for example, the pump had been significantly higher, and the nozzles had been more numerous and spread the intended solvent to an extent that contributes to more efficient cleaning of copper wires.

5.6 Sustainability Aspect

The results gained from the template provided the project with useful guidelines for refining the concept into a long-term solution. Many of the components of the physical product will be built from stainless steel, which will make it simpler to recycle at the end of its useful lifespan. Stainless steel should be environmentally friendly treated to make it resistant to chemicals injected into the product and other types of destruction. The same holds true for the paint, which must also be ecologically friendly to prevent dangerous compounds from leaking out. The pump and nozzles are the only parts of the solution that can't be improved for the environment. These devices rely on heavy metals, which are difficult to remove from the product, for their functionality. Using materials from local vendors will further reduce the environmental effect of the solution. You may reduce the number of supplies that must be sent across the globe by doing this.

6 CONCLUSIONS

In this thesis, it was investigated whether it is possible to streamline the existing cleaning procedure based on the health, environment, and sustainability aspects. To investigate this, three questions were formulated that concern these aspects, where the questions would then be answered with the help of different research approaches, tools, and processes.

Regarding the first research question, the design thinking strategy, in combination with literature research, was implemented to be able to begin the investigation of the issue. The first stage was to visit the department, observe and conduct interviews to gather information about the current process, how the process is carried out, how much material is used and how much is wasted during the procedure. When enough information was gathered, the supervisor at NKT was involved where the collected information was presented to proceed with an idea generation related to the identified problem. This idea generation was therefore based on the information collected. The result obtained after the idea generation was that it requires above all a development of a device that cleans the copper wires. This device can then keep the solvent in a special place and at the same time, the worker has more control over how much solvent is used. If the work is done manually, there are always human sources of error involved in the process. The reason is because the work is done differently in terms of how much force is used when manually cleaning the conductor in relation to the amount of solvent used during the process. If a worker applies a little less force during the manual cleaning or works more slowly, it will contribute to the conductor not being cleaned as quickly. This will further contribute to more solvents being used in order to dissolve the compound from the copper wires, which is based on the observations made when visiting the department. An apparatus, on the other hand, works with the same force or pressure without, for example, getting tired in the arms at the same time as solvents are applied to the extent that the worker himself decides.

For the second research question, a combination of literature search and laboratory tests was performed to investigate whether any of the selected solvents seen in Table 4 can replace PF-Solvent. According to the tests, it turned out that Strovels Smådelstvätt 100 had an equivalent effect on the compound during the same time interval as PF-Solvent. In addition, it turned out that Strovels was milder from the environmental and health aspects, which answered the question that this solvent can replace today's used solvents in terms of environmental friendliness, time efficiency and health. However, it should be noted that the laboratory tests that were issued were of a static nature, i.e., that the solvent was allowed to react with the compound without additional compressive forces equal to those of the manual cleaning. However, since the comparison between Strovels Smådelstvätt 100 and PF-Solvent gave a positive result, the assumption may be that the effect will be similar when implementing the result in the manual or mechanical procedure. The prerequisite for implementing this result is, however, that a conductivity measurement is carried out for both PF solvent and Strovels smådelstvätt100 in order to investigate whether the solvents have a negative impact on the copper wires themselves. The results from the conductivity measurement showed that Strovels Smådelstvätt 100 had a significantly higher impact on conductivity. Based on these results, Strovels Smådelstvätt 100 cannot replace the currently used solvent, PF-Solvent. Based on the experiment, PF-Solvent's good conductivity properties could also be confirmed and thus it is still recommended to use this solvent as it showed significantly lower values regarding the conductivity effect.

Regarding the third research question, the development of a mechanical device can contribute to reduced waste of various materials during the procedure. Disposable materials such as brushes, bottles, gloves, and rags are discarded in large quantities today because they are contaminated or destroyed during cleaning of the conductor. By investing in a machine, that type of waste will be eliminated as they will not be needed at all for the process as the machine performs the work. In addition, the speed of cleaning will be increased because high pressure will be used with the pump that the machine consists of and the nozzles that distribute the solvent in a controlled and focused way. The solvent used in the cleaning will also be able to be reused during the same procedure because it is filtered back to a beaker which is then pumped up again for cleaning, which also means less waste. On the other hand, the risk with this circulation of solvents may contribute to the mechanical procedure taking longer than expected but still shorter than the manual work. The reason for this is that the solvent that is pumped back to the conductor has lost some of its chemical properties. However, it can still be effective due to the pressure used to pump out the agent.

Finally, investing in such a machine can be expensive, but in the long run this investment leads to savings in materials used today, where most are also disposable materials that contribute to a negative impact on the environment as these cannot be recycled. However, a machine procedure involves a large transition that requires a lot of time, resources and planning as it is a machine that must be developed through collaborations with different industries. As this transition is time consuming, the solution in the short term, based on the results obtained, may be that the existing solvent PF-Solvent is replaced with Strovels Smådelstvätt 100 as it has been shown to have the same good effect when cleaning but with the advantage that it has less negative impact on health and the environment.

6.1 Future work

The purpose of the project was to streamline the cleaning of the substance compound on conductors in some high voltage cables before splicing. The next step in the process will be to try to implement the results obtained from the work. For example, a virtual model of a machine was performed with a subsequent physical prototype of this machine. The next step will thus be to develop another prototype to test the concept by using a more reasonable pressure and suitable nozzles to really be able to estimate the efficiency of a mechanical cleaning process. The reason for this is that if the virtual machine is to be developed into a physical one, the costs will be very high due to its complexity and therefore it is desirable to first do further research using iterated prototypes so as not to invest in a machine that may not be directly applicable to this particular cleaning procedure. Thus, a start to this large concept could have been to make a simple form of the virtual model where you only include properties such as pressure and flow and then be able to get feedback from the workers and at the same time be able to estimate how much waste has been reduced by using this mechanical device.

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Appendix 1

1. ***How long does it take for you to clean the compound on each cable end?***
   - ☐ 1-3 hours
   - ☐ 3-6 hours
   - ☐ 6-8 hours
   - ☐ > 8 hours

2. ***What tools and chemicals do you use when cleaning the cable ends?***
   - ☐ Cleaning brush, cleaning cloths, spraybottles
   - ☐ PF-Solvent
   - ☐ Others
     - ☐ Specify_______________________________

3. ***How much chemicals and other materials are utilized during the cleaning process?***

   Chemicals:
   - ☐ 1-2 bottles of chemicals
   - ☐ > 2 bottles of chemicals

   Other materials:
   - ☐ Big amount of disposable materials is thrown away
   - ☐ Others
     - ☐ Specify____________________________

4. ***Which part of the process is perceived to be the most demanding?***
   - ☐ The removal of the compound
   - ☐ Folding up the copper wires.
   - ☐ Both of the parts are the most demanding
   - ☐ Others
     - ☐ Specify:__________________

5. ***Instead of the conventional method, have you used other methods to remove the compound?***
   - ☐ No
   - ☐ Yes

   5a. If yes, What other methods have you used?
   - ☐ Mechanically
   - ☐ Another solvent
   - ☐ Manually but with another tool
   - ☐ Other:______________________-

   5b. How did you experience it?
   - ☐ Good
   - ☐ Bad
   - ☐ Neutral
   - ☐ Others:_________________

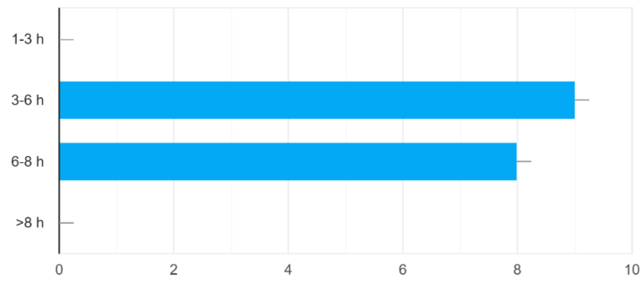
6. ***Do you actively wear full protective equipment?***
   - ☐ Yes
   - ☐ No

   6.a. If no, why?
   - ☐ Uncomfortable
   - ☐ No need for so much equipment
   - ☐ Time-consuming
   - ☐ Harder to work with it
   - ☐ Too hot wearing all of it
   - ☐ Others:___________________-

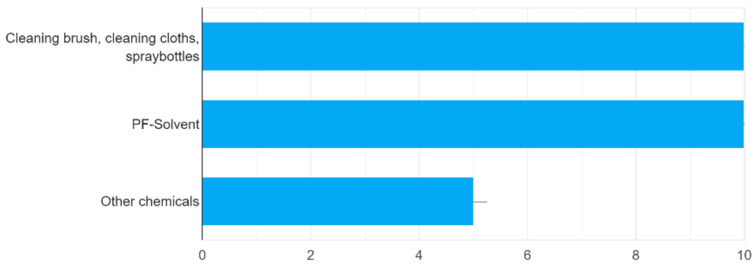
7. ***What is your attitude to the existing procedure that you work according to?***
   - ☐ Positive____
   - ☐ Neutral____
   - ☐ Negative____

Appendix 2

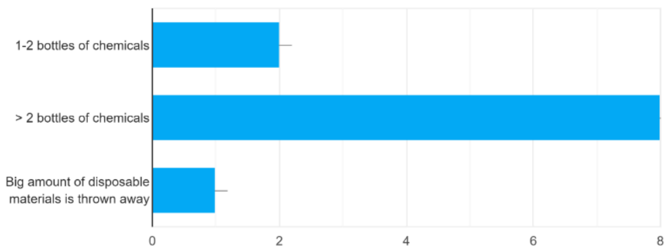
1. How long does it take for you to clean the compound on each cable end (conductor)?
10 svar



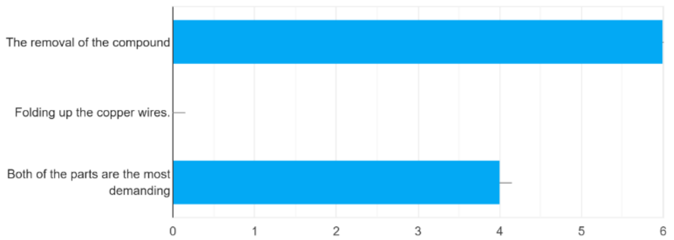
2. What tools and chemicals do you use when cleaning the cable ends?
10 svar



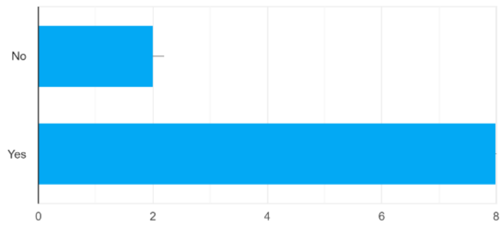
3. How much chemicals and other materials are utilized during the cleaning process?
10 svar



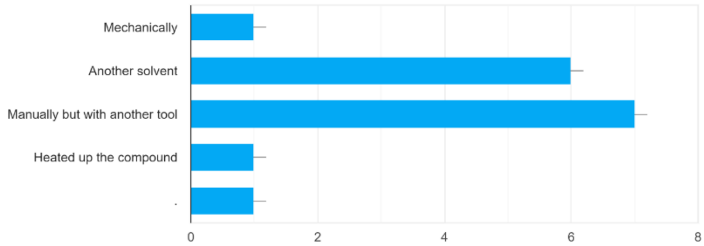
4. Which part of the process is perceived to be the most demanding?
10 svar



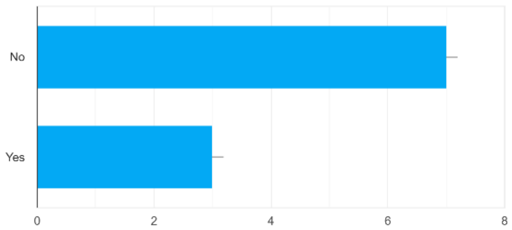
5. Instead of the conventional method, have you used other methods to remove the compound?
10 svar



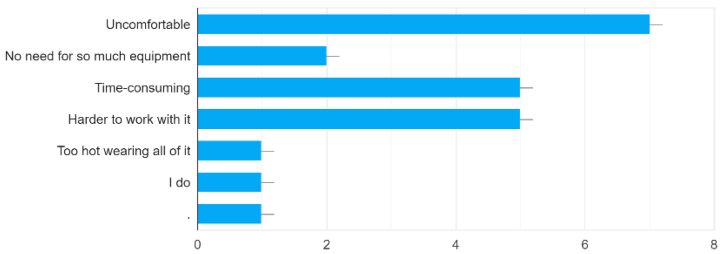
5a. If yes, what other methods have you used?
9 svar



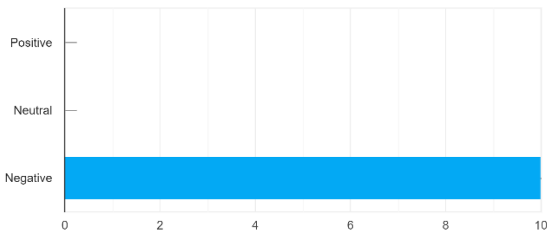
6. Do you actively wear full protective equipment?
10 svar



6a. If no, why?
9 svar



7. What is your attitude to the existing procedure that you work according to?
10 svar



Appendix 3

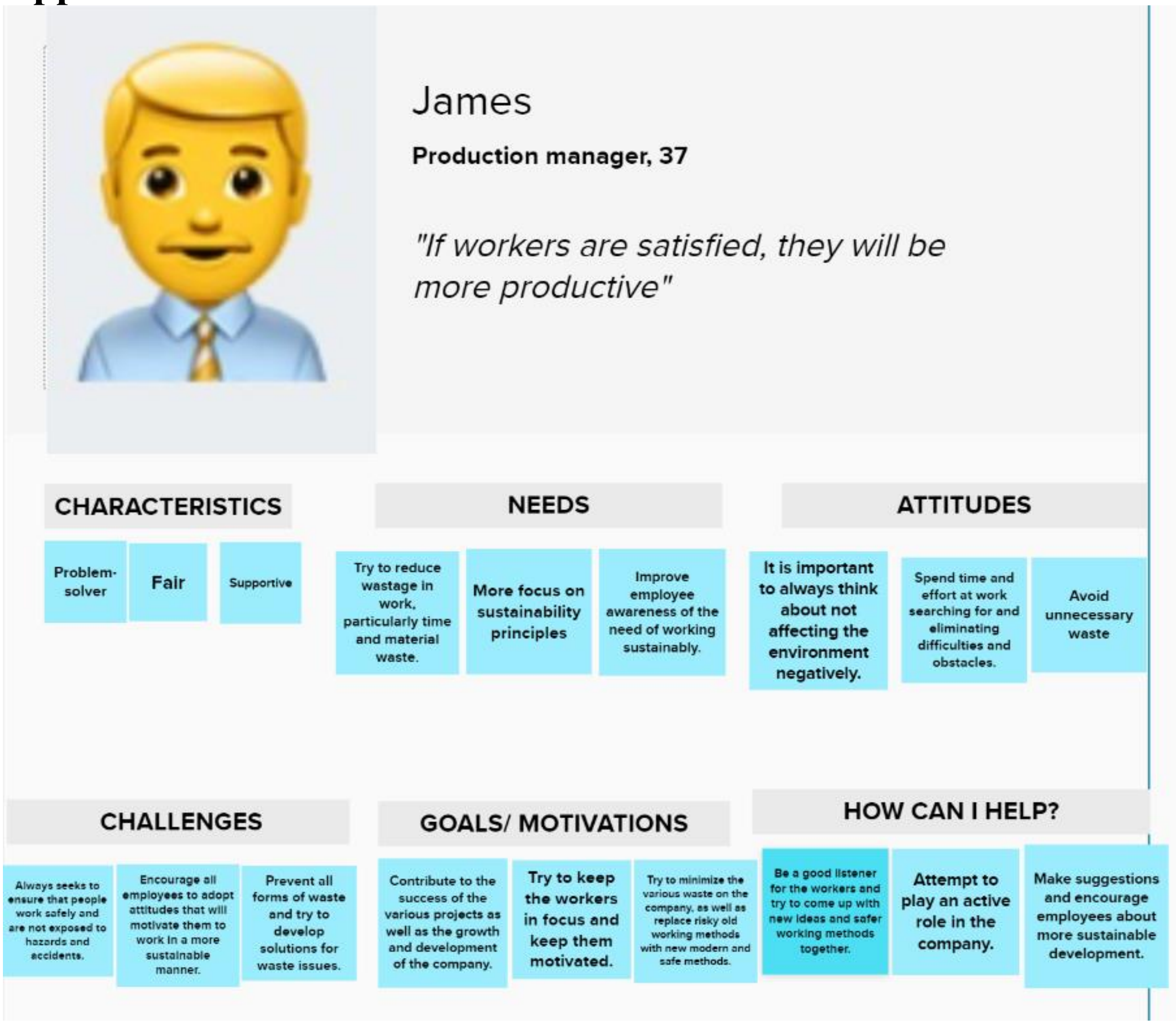


Figure A1: Persona - The Production Manager.

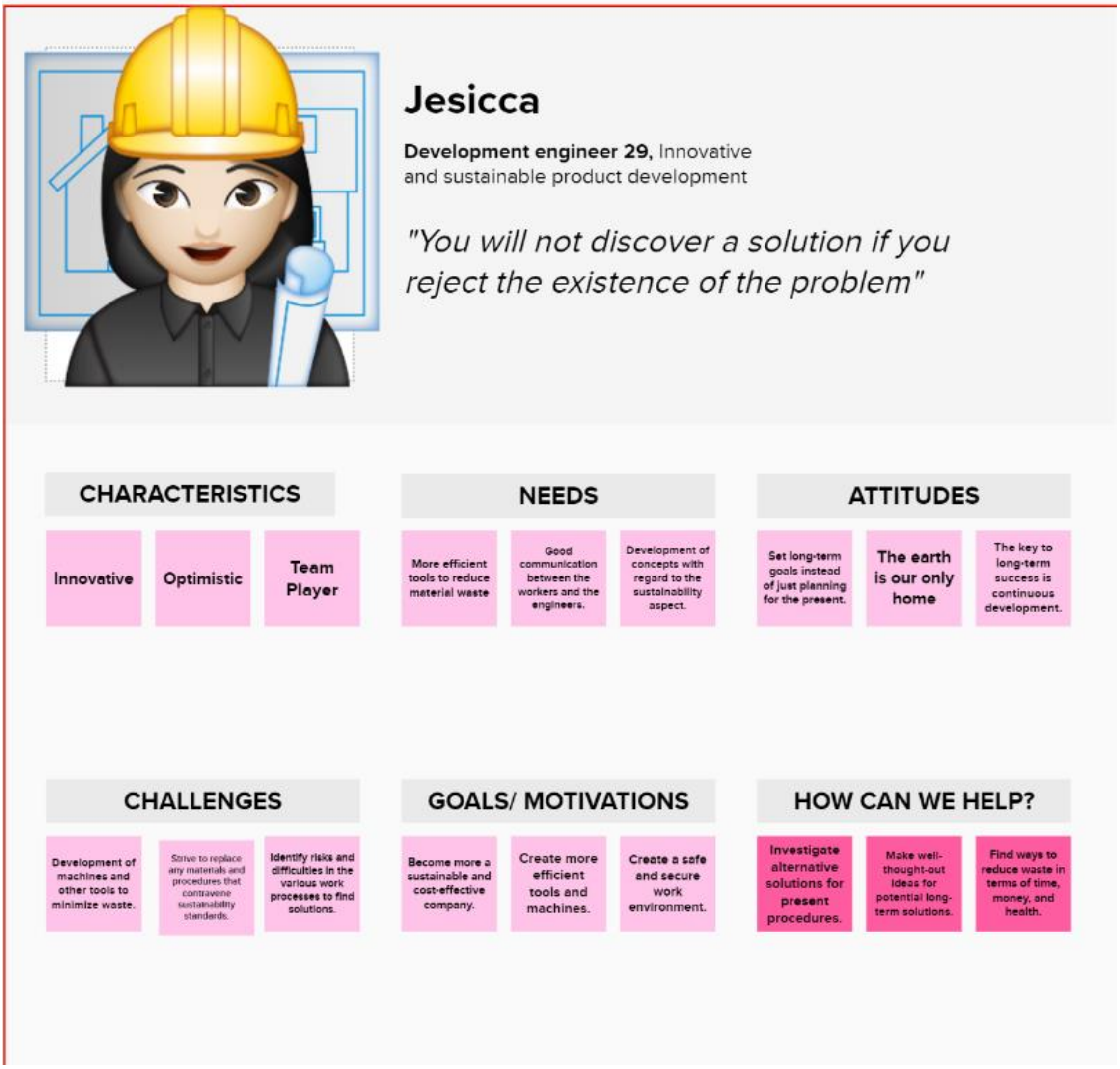


Figure A2: Persona - Development Engineer.

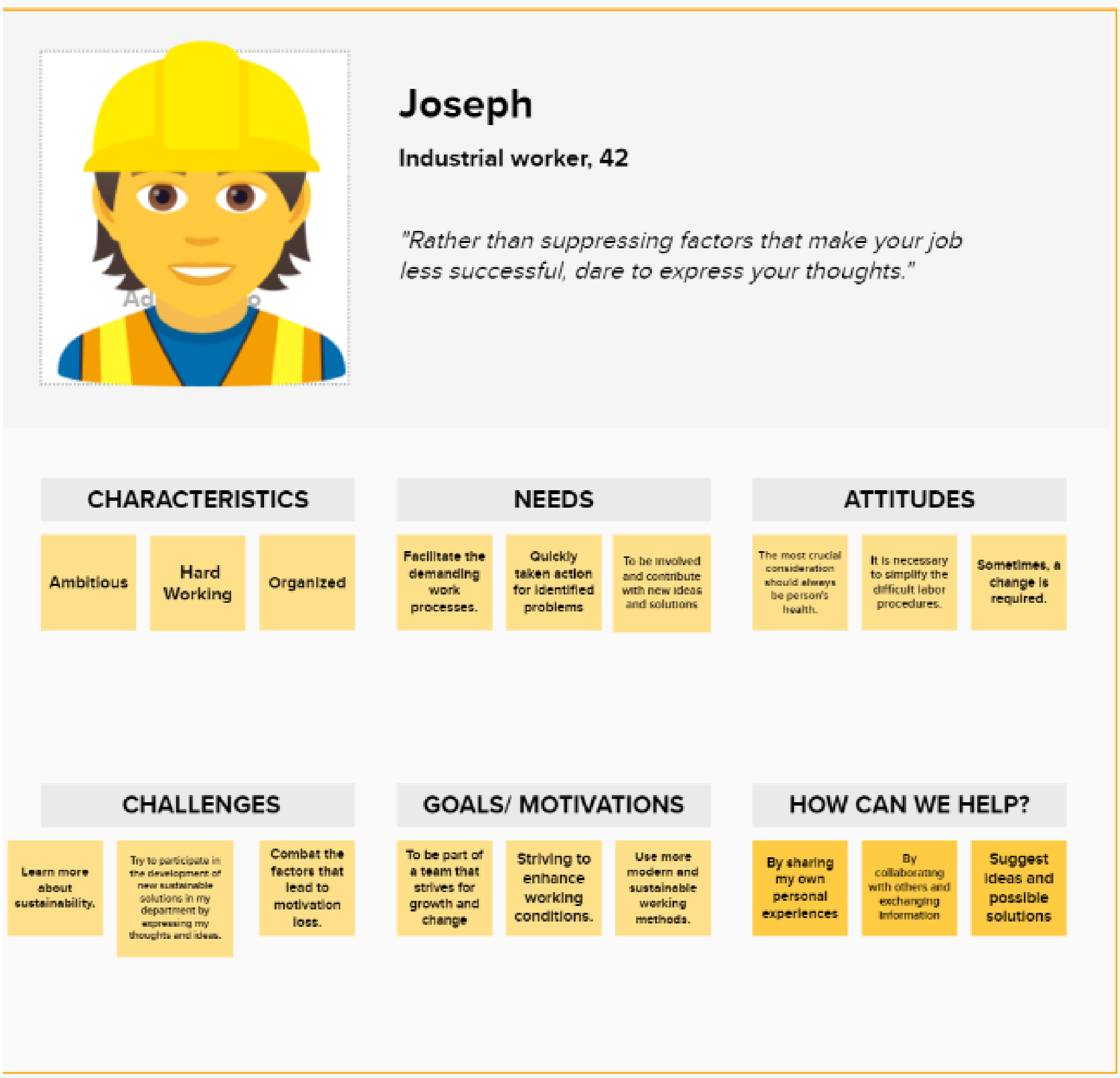


Figure A3: Persona - Industrial Worker

Appendix 4

Concept	Description	White - Facts	Red - Feelings	Yellow - Strenghts	Sum	Black - Weaknesses	Sum	Ranking	Green - New ideas
1 - Rotating brush part	A cleaning tool consisting of a rotating brush part and a small container containing the solvent. There is a button on the container that causes liquid to leak to the brush part in a timely manner, which causes the brush part to rotate.	That tool will streamline the work process to some extent, is easy to manufacture and test. The tool makes the process go a little faster compared to the time required when using the manual methods used today. It requires wearing protective equipment and	It feels good that using such a tool can reduce the effort for the workers. It feels less good that you still need to wear protective equipment and that you can not control the spread of chemicals.	Small and flexible tool. Lightweight and easy to use. Cheap to construct. Does not require much material for manufacturing. Manageable.	10	Spill of solvent. Takes quite a long time to clean each copper wire. Still requires manual labor when using and refilling solvents. Limitation in the dimensions of the liquid container → waste of time when you need to refill several times during the process.	−12	−2	Replace the brush with steel wool and ensure that the device's operation is not affected as a result of the modification.
2 - A battery-powered cleaning tool with a rotating brush head.	A battery-powered cleaning tool with a rotating brush head. The solvent is pumped upwards towards the brush head by means of a pumping effect.	Efficient cleaning due to built-in mechanical rotating properties of the brush head. Flexible tool that is manageable. You do not need to have an electrical outlet because it is battery-powered, but it requires that you constantly charge the batteries.	It feels good that you can perform the cleaning process faster while you can control the amount of solvent to be used. It feels bad that you need to fill the container several times because it is not that big. And that there will be spillage of the solvent, which means that arebtane may have to wear protective equipment.	Efficient cleaning due to built-in mechanical rotating properties of the brush head. Easy to handle and easy to use, "on" button allows the head to rotate automatically independently of the worker. The worker can control the amount of solvent that is pumped out by actively pressing a button to get the amount required. This function can also be set so that it happens automatically. Relatively cheap and easy to construct. Battery-powered → no stationary device that requires an electrical outlet	8	More complex device compared to idea 1, which requires more components during construction. Relative leakage of solvent → workers must wear protective equipment at work. Limited dimensions of containers which require filling as in idea 1. Requires manual work.	−10	**−2**	Using a box to surround the head of the machine to reduce the possibility of solvent leakage and waste.
3 - Mechanical device with a rotating brush head	A mechanical cleaning tool consisting of the following components: 1) removable, rotating brush head, 2) Adjustable rubber components that close the cavity during the cleaning process, 3) solvent containers, 4) motor and pump, 5) spray nozzle.	Efficient and smooth cleaning process with the help of such a machine that is easy to handle, while reducing spills and no heavy protection equipment is required when using it. It should be a special brush with a certain size and thickness to cope with the sharp strands.	It feels good to have a machine that performs the entire cleaning process by just starting it. It feels less good that you need to change the head away often because the copper wires are sharp, the brush is destroyed quickly.	Time-efficient mechanical device, electrically powered and starts with an "On" button. Negligible with spillage of solvent. Relieves the workers when they only need to start the machine. Contributes to good durability as it replaces disposable materials used in today's manual process. Safe handling and collection of used solvent.	13	Expensive investment (but cost-effective in the long run). The brush head will need to be changed frequently due to wear caused by the sharp raised copper wires. Finishing work is required as the machine will not clean the threads 100 percent. Requires a specifically designed brush where the straws have increased hardness, a certain length and elastic to be able to clean well.	−8	**5**	Instead of utilizing a brush component, try with increasing the pressure in the nozzles and other cleaning methods that do not require the use of a brush.
4 - High pressure washing machine	A mechanical cleaning device that consists of a number of components and has the function of cleaning the entire conductor at one and the same time. The device is designed in such a way that the raised wires all fit in the square cavity of the machine. The entrance to the cavity is made by folding up the upper half of the square. The circle on one side of the square, shown in the figure to the right, is also divided into two so that it too can open and close with the square.	An efficient and smooth cleaning procedure is achieved by the use of a machine that is simple to use and maintain, while also eliminating spills and requiring no heavy protective equipment when in use. Due to the fact that the machine is equipped with a number of spray nozzles, there is no requirement for a brush component. The cleaning technique is based on the use of high pressure.	It feels good to have a machine that performs the entire cleaning process by just placing it correctly then starting it. It feels smart to be able to reuse solvent. It is positive that the workers do not have to wear protective equipment when using the machine.	Quick and efficient cleaning of the cable ends due to the high pressure that the spray nozzles spray out the solvent, as well as the heating effect in the container. Cost-effective due to material savings of, among other things, disposable materials and solvents. Increased durability due to the reuse of solvents and reduced health risks for workers. Environmentally friendly. Negligible spillage of the solvent. Easy to use, the process does not need to be monitored. Adjustable upper and body. Detachable cup. Electric	14	Complex in construction, includes most components compared to other ideas. Expensive investment compared to other ideas, however, cheaper than other machines that exist today in general.	−7	**7**	Try to include some form of heat treatment by heating the solvent or some form of internal heat in the machine that heats the compound on the conductor.

Appendix 5

No. ARTICLE	DESCRIPTION	REFERENCE	QTY
1	WB-22-03	/	1
2	WB-22-02	/	1
3	Cable	/	1
4	WB-22-05	/	2
5	WB-22-05	/	2
6	WB-22-01	/	1
7	WB-22-09	/	2
8	337_1-50-50-6-a-2-sw_02	/	3
9	337_1-50-50-6-a-2-sw_01	/	3
10	mdp-000-000.stp	NOT SPECIFIED	1
11	3234K21	High-Pressure Spray Nozzle	12
12	1766A3_Draw Latch	Draw Latch	4
13	Tuyau-01	/	1
14	TuyauN02-02	/	1
15	6432T113	Supported 45 Degree Flared Fitting	14
16	WB-22-04	/	1
17	51875K48	Nut for 3/8" OD Tight-Seal Brass Compression Tube Fitting for Air and Water	12
18	Tuyau-03	/	1
19	T	/	1
20	Tuyau-04	/	1
21	Tuyau-05	/	1
22	ec_2515_d_m6x18-145	/	2
23	Lubrification	/	1
24	9908T33	Cart-King Caster	4
25	Sole	/	1
26	MirrorConduite de liquide	/	1
27	gn_27171	/	3
28	ISO 4762 M4 x 30 - 20N	/	6
29	ISO 2009 - M6 x 25 - 25N	/	8
30	Washer ISO 7091 - 5	/	6
31	Washer ISO 7091 - 6	/	44
32	ISO - 4032 - M6 - W - N	/	8
33	ISO - 4032 - M4 - W - N	/	6
34	ISO - 4032 - M3 - W - N	/	6
35	ISO 7380 - M5 x 20 - 20N	/	4
36	ISO - 4161 - M5 - N	/	20
37	hex screw gradeab_iso	/	16
38	WB-22-07	/	4
39	WB-22-10	/	4
40	WB-22-06	/	1
42	ISO 4018 - M6 x 30-WN	/	10
43	ISO - 4034 - M6 - N	/	10
44	countersunk raised head cross recess screw_iso	/	24
45	Washer ISO 7092 - 3	/	6
46	WB-22-11	/	1
47	PLASTIC JEERY CAN	/	1
48	Support	/	1

Figure A1: Description of the components involved in the WashingBox

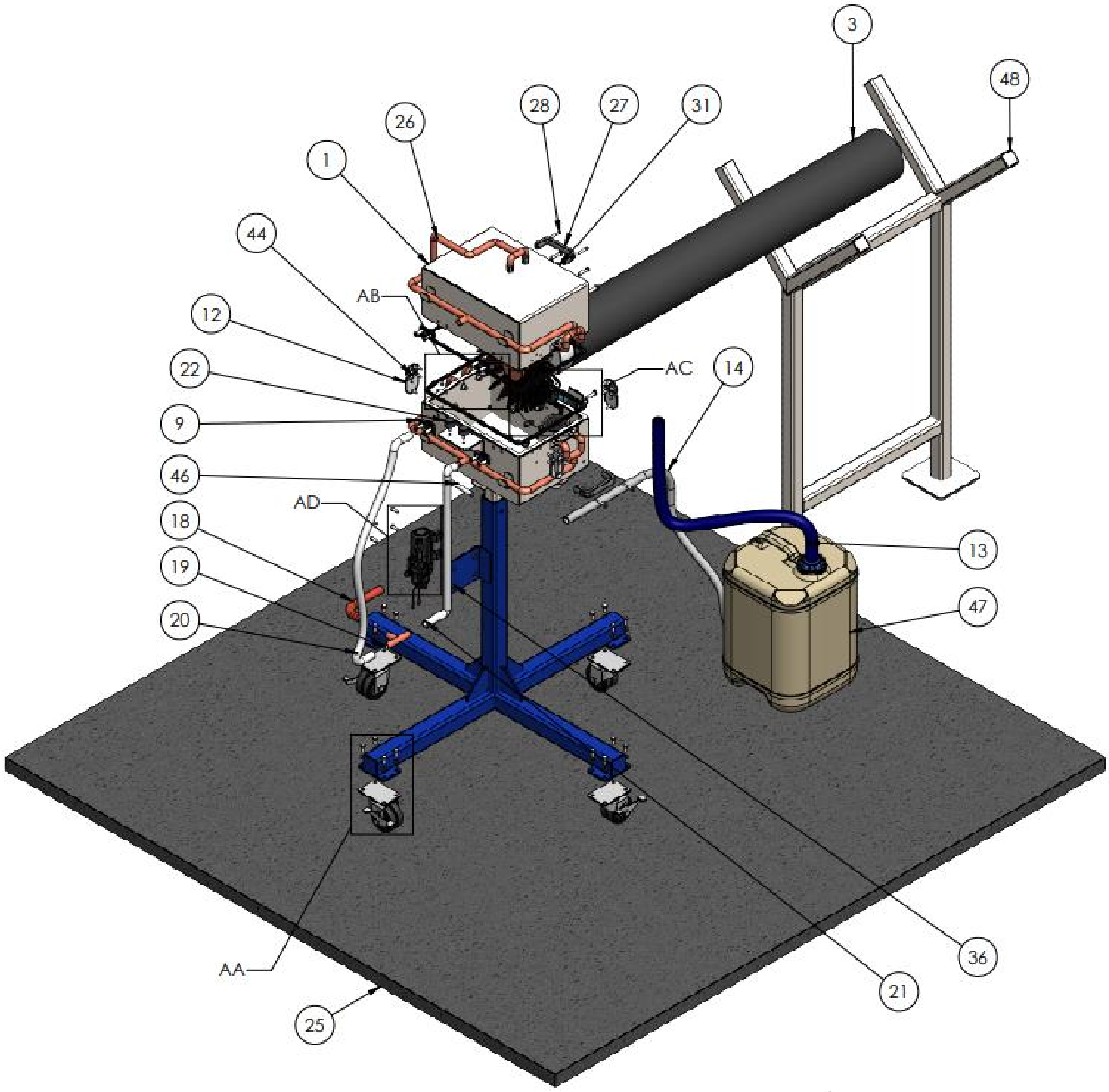


Figure A2: The final simulation of the WashingBox.

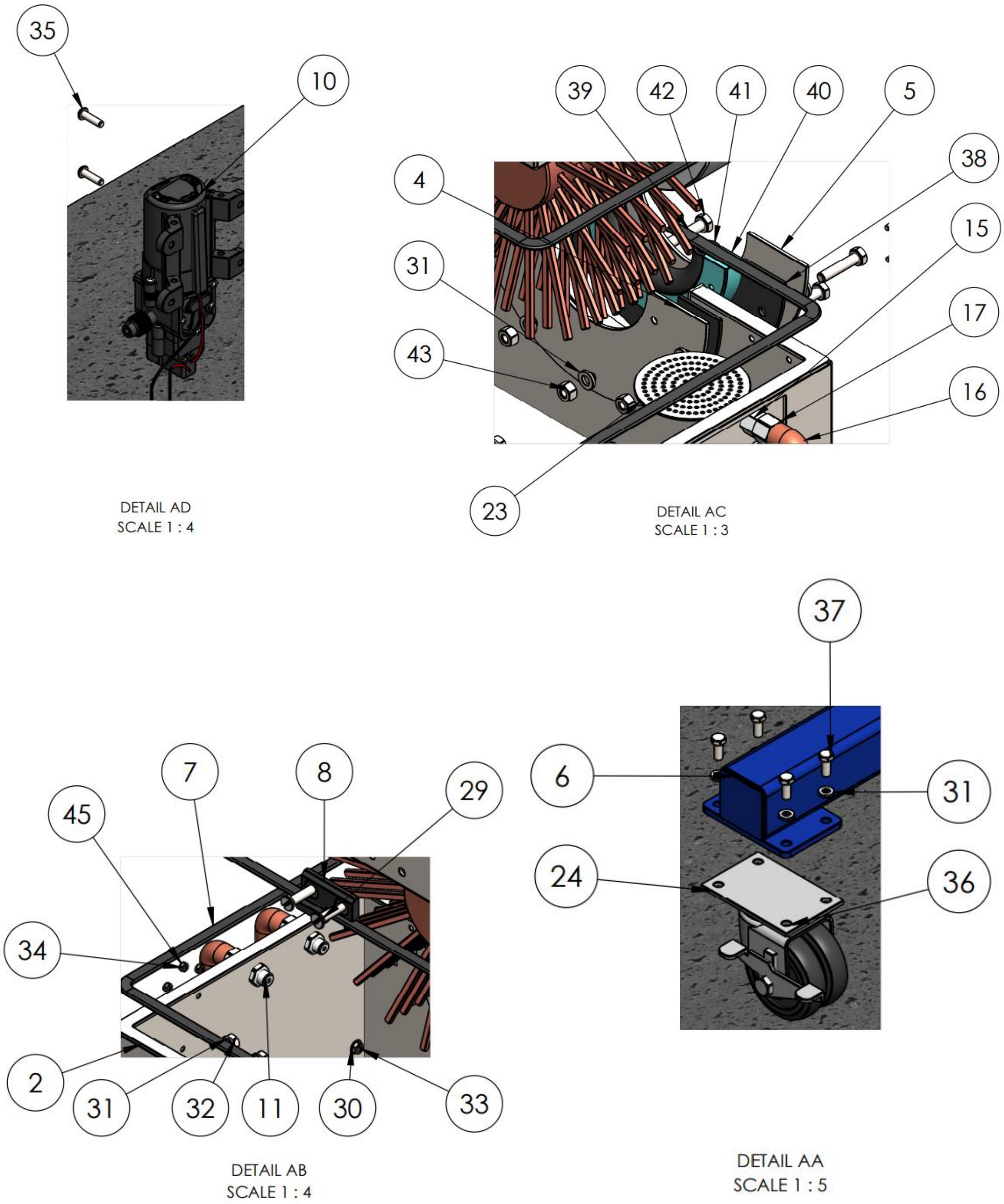


Figure A3: A more detailed view of the WashingBox.

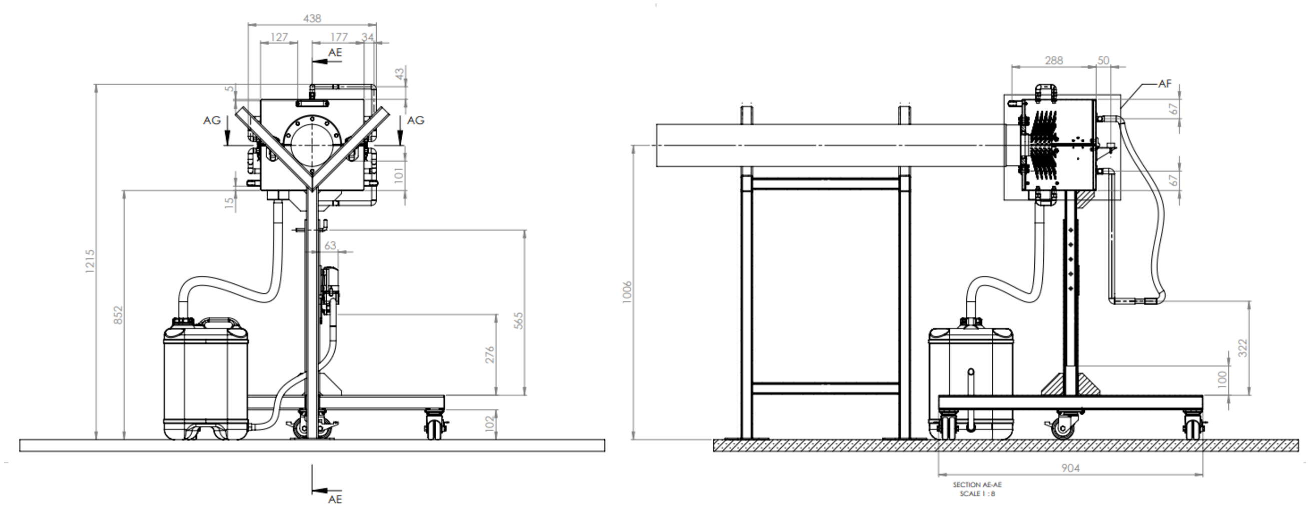


Figure A4: Drawings of the WashingBox

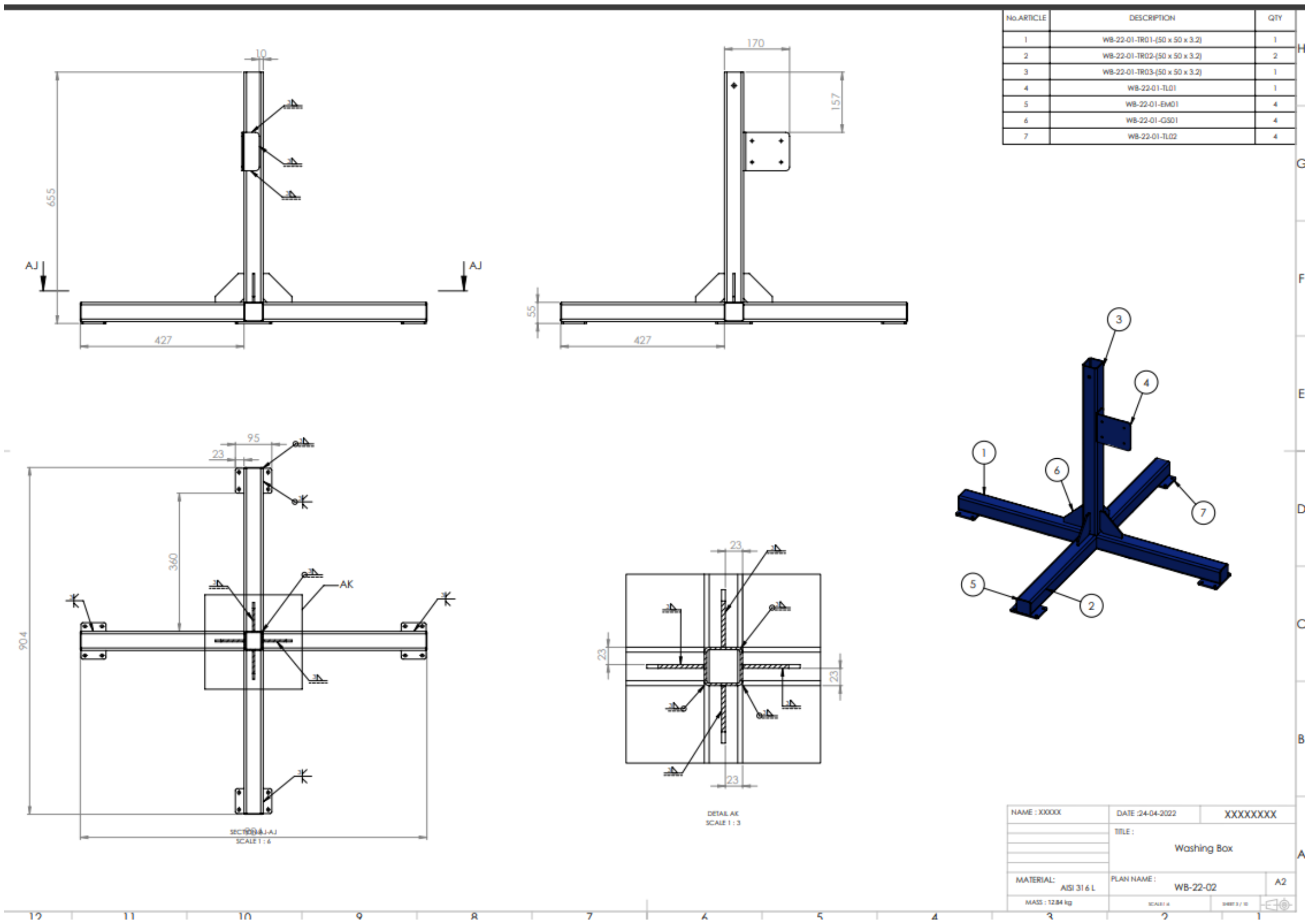


Figure A5: Drawings of the WashingBox.

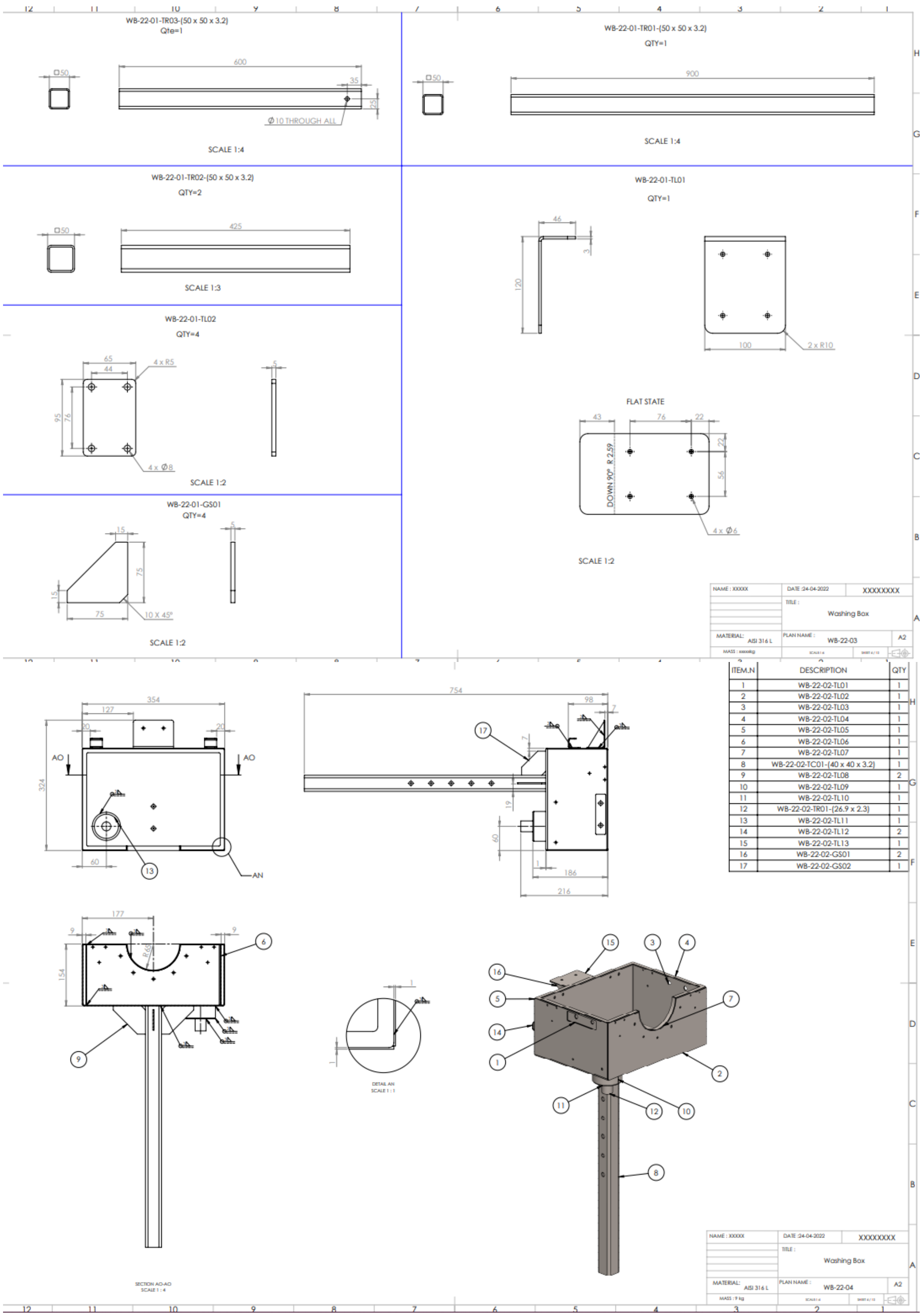


Figure A6: Drawings of the WashingBox.

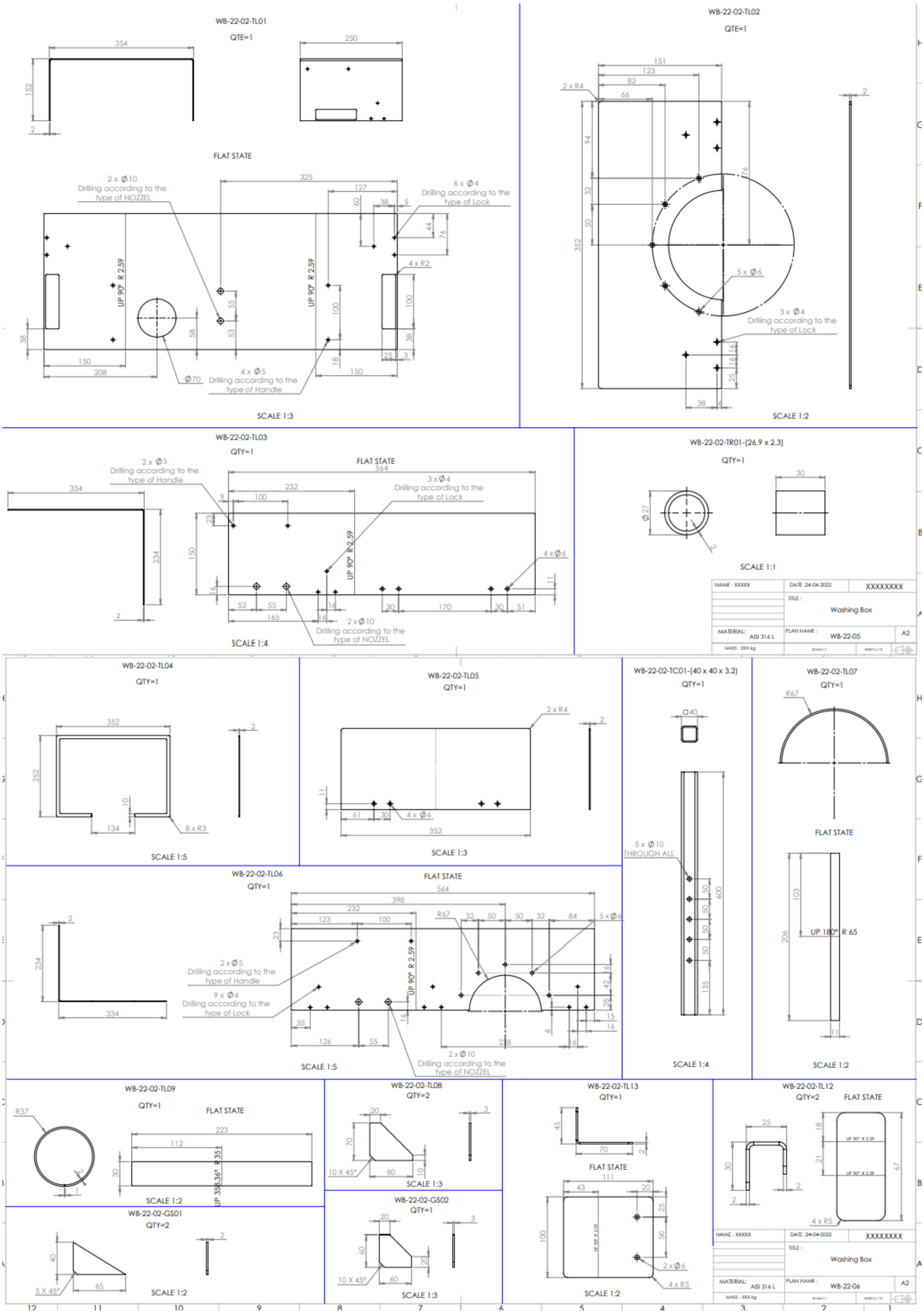


Figure A7: Drawings of the WashingBox

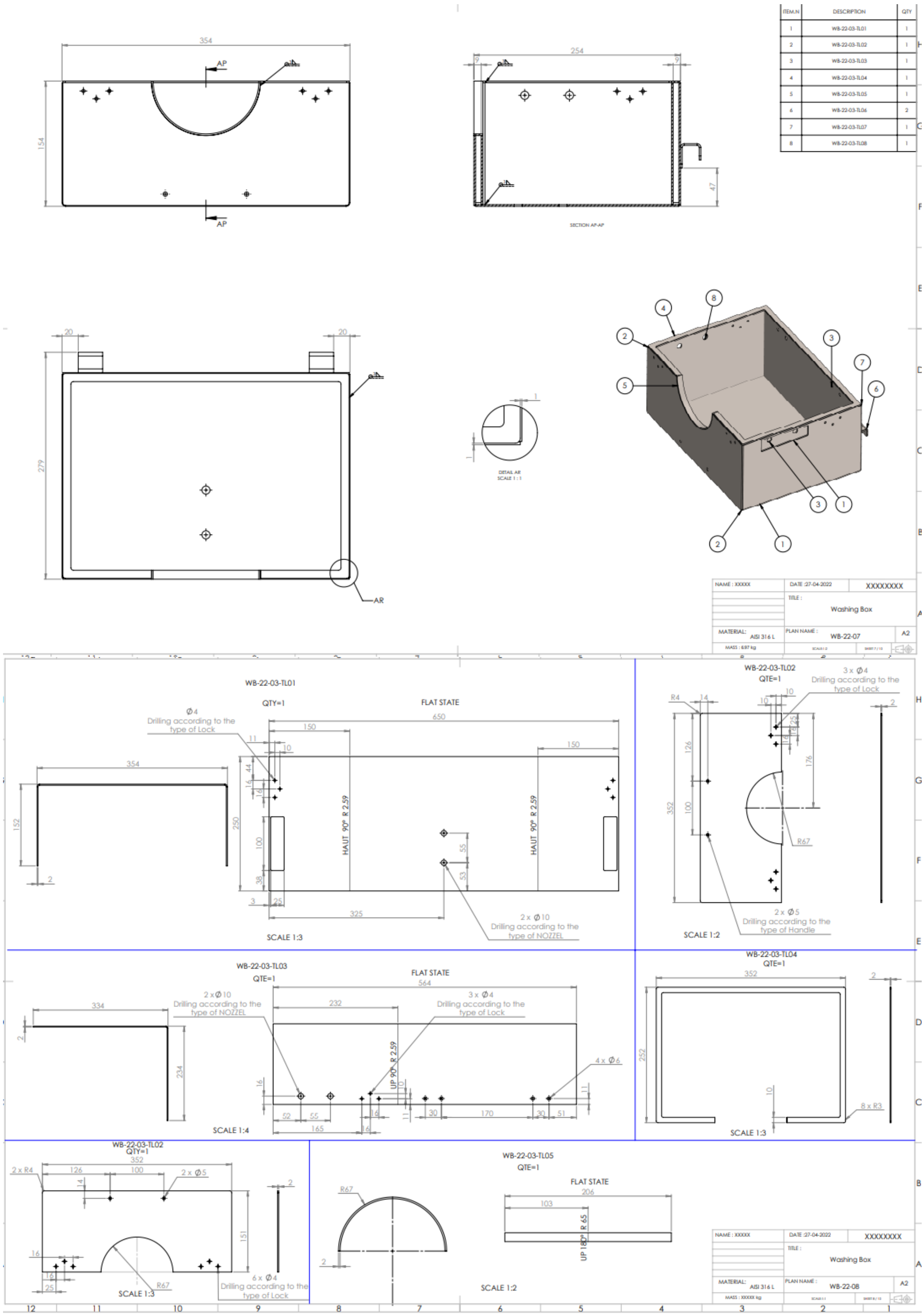


Figure A8: Drawings of the WashingBox.

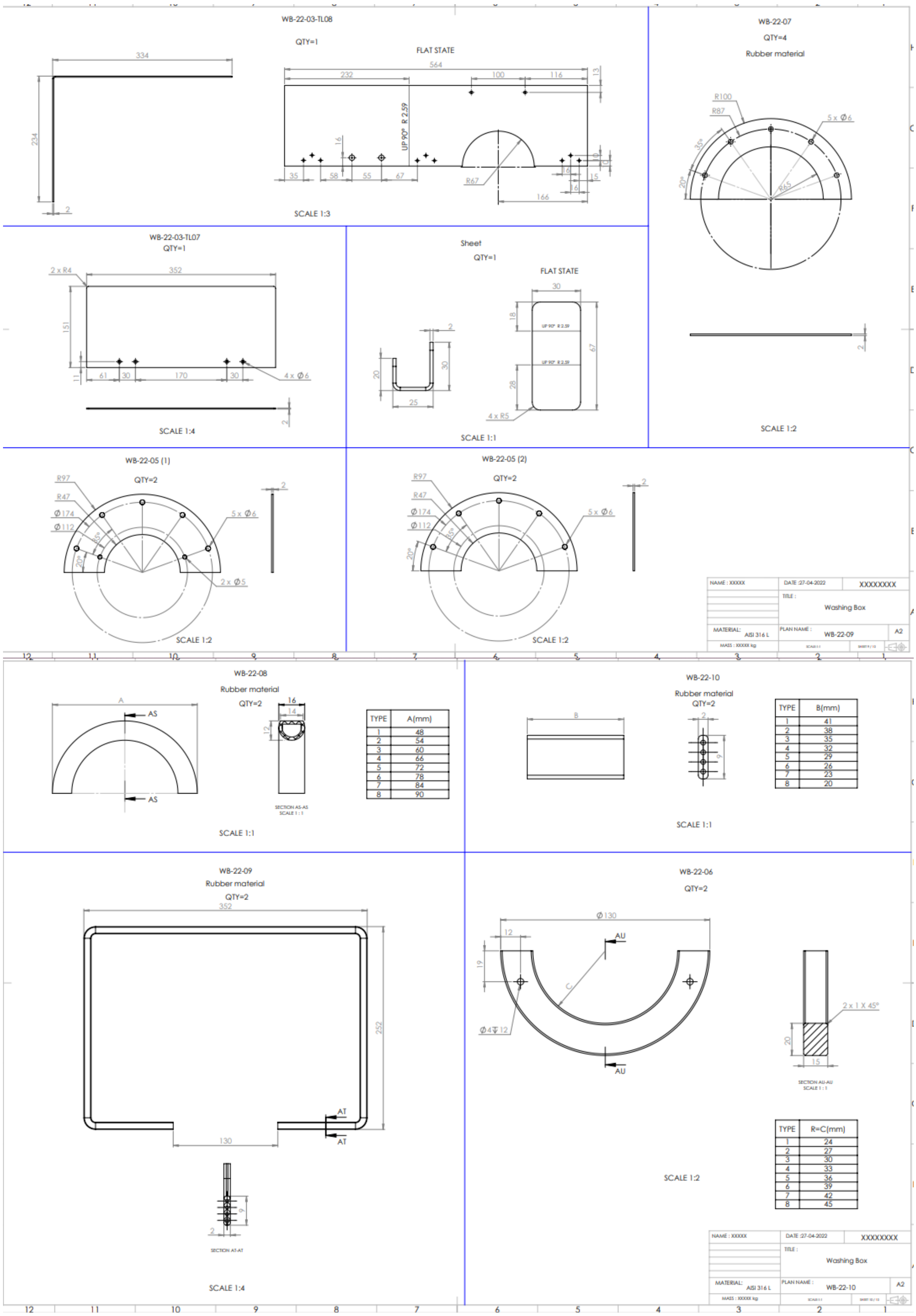
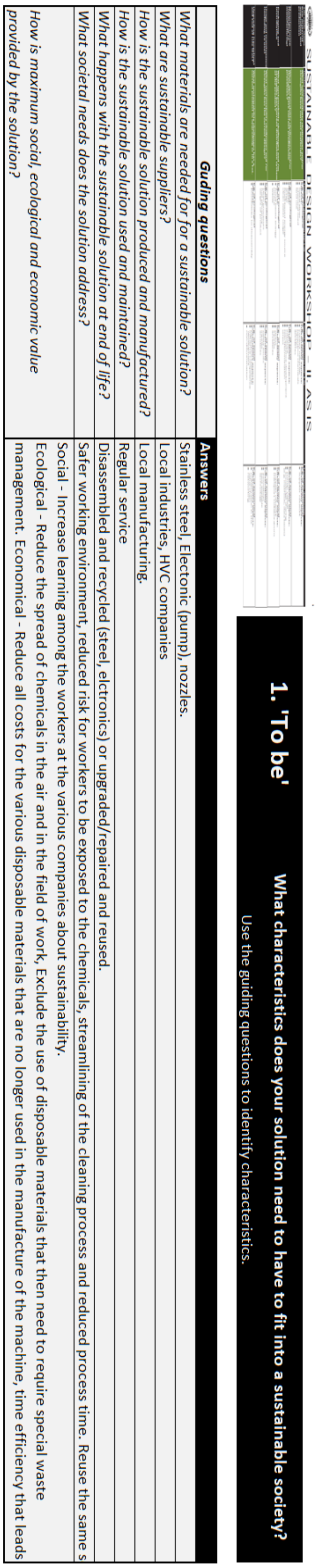


Figure A9: Drawings of the WashingBox.

Appendix 6

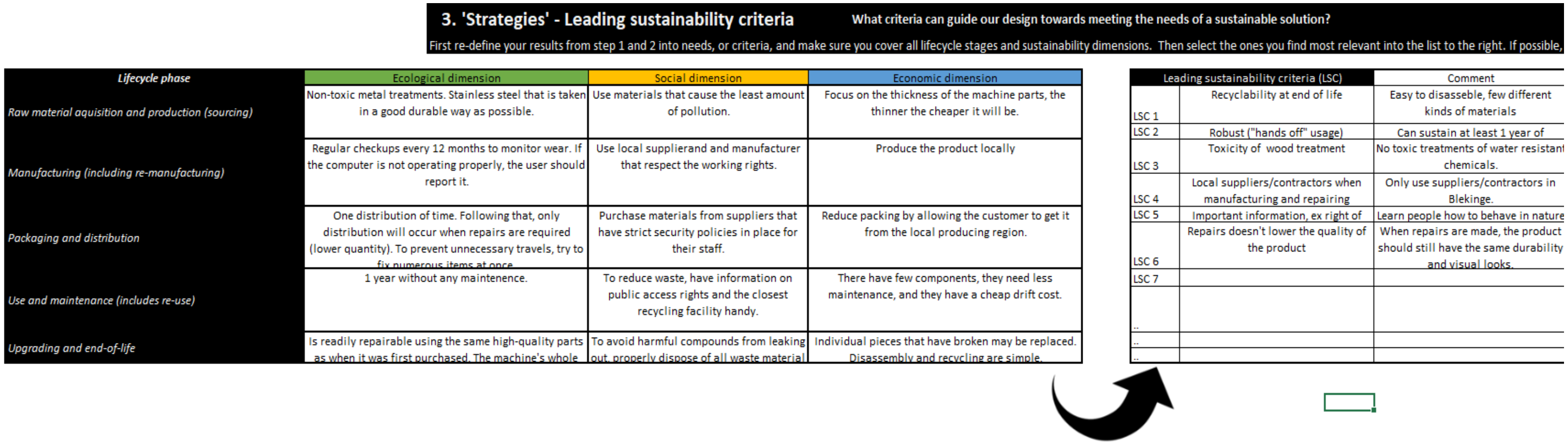


Guding questions	Answers
What materials are needed for for a sustainable solution?	Stainless steel, Electonic (pump), nozzles.
What are sustainable suppliers?	Local industries, HVC companies
How is the sustainable solution produced and manufactured?	Local manufacturing.
How is the sustainable solution used and maintained?	Regular service
What happens with the sustainable solution at end of life?	Disassembled and recycled (steel, elctronics) or upgraded/repaired and reused.
What societal needs does the solution address?	Safer working environment, reduced risk for workers to be exposed to the chemicals, streamlining of the cleaning process and reduced process time. Reuse the same s
How is maximum social, ecological and economic value provided by the solution?	Social - Increase learning among the workers at the various companies about sustainability. Ecological - Reduce the spread of chemicals in the air and in the field of work, Exclude the use of disposable materials that then need to require special waste management. Economical - Reduce all costs for the various disposable materials that are no longer used in the manufacture of the machine, time efficiency that leads

Figure A1: Sustainability template

Lifecycle phase	Guiding questions	Ecological dimension	Social dimension	Economic dimension
Raw material aquisition and production (sourcing)	What are current strenghts and/weaknesses with current materials?	e.g. metal alloys, chemical processing, land use	e.g. conflict material, hazardous substances, pollution, corruption	e.g. resilience of supplier network
		must be made of the same material The weakness is that there are certain components that contain mixtures of chemicals, which makes the	manufactured locally, which means that industries can begin to take sustainability into account when manufacturing.	pros: Cheap parts and cheap to manufacture compared to what it contributes to. Con: A risky investment if no one will invest in it
Manufacturing (including re-manufacturing)	What are current strenghts and weaknesses with intended manufacturing processes?	material efficiency, chemical processing, water consumption, energy source	e.g. influence, competence development, stress	e.g., human capital, knowledge sharing
		Making electronics requires chemicals and materials that are very bad for the environment. When stainless steel is made, it gives off a lot of	Benefits: Local production (Swedish working condition) Working conditions may be dangerous	Pros: Electronics production is well-developed, inexpensive, and simple. Stainless steel is also a low-cost material to work with.
Packaging and distribution	What are current strenghts and weaknesses with the intended means of distribution?	e.g. waste, energy source	e.g., injuries, stress, accidents	e.g., human capital, knowledge sharing
		Weakness: Some components, such as the nozzles and the pump, need transportation. Strengths -A local producer would provide the product	Due to the country's geographical location, Sweden enjoys a wide range of working rights. Cons: Poor working conditions in nations	Pro: There is just one installation fee. Cons: Maintenance may be required.
Use and maintenance (includes re-use)	What challenges or opprtunities may occur related to the intended use?	e.g. remanufacturability, user behaviour, energy and water use	e.g. safety, integrity, accidents	e.g. legal compliance of partner companies
		Vandalism, unplanned repairs, and electrical fires are among the challenges.	Advantages: The workers do not have to do the demanding work processes, it leads to more efficient work. Disadvantages: There is a risk that you know how to act if something goes wrong in the machine	Challenges: That the transformation from the manual method to the mechanical one will be successful according to expectations and goals.
Upgrading and end-of-life	What are strenghts and weaknesses related to waste minimization and material upgradeability?	e.g. ease of disassembly, number of materials, toxic substances	e.g. hazardous chemicals, working conditions	e.g., costs or benefits of waste management solutions or partnerships
		Reduced use of disposable materials, robust parts in the machine that can have a long service life which leads to a reduction in emissions and waste management	Pros: It is simple to add new features to the solution. All of the materials are recyclable and may be utilized after it is recycled.	Pros: The machine should be capable of disassembling and replacing defective parts with new ones.

Figure A2: Sustainability template



3. 'Strategies' - Leading sustainability criteria **What criteria can guide our design towards meeting the needs of a sustainable solution?**

First re-define your results from step 1 and 2 into needs, or criteria, and make sure you cover all lifecycle stages and sustainability dimensions. Then select the ones you find most relevant into the list to the right. If possible,

Lifecycle phase	Ecological dimension	Social dimension	Economic dimension
Raw material aquisition and production (sourcing)	Non-toxic metal treatments. Stainless steel that is taken in a good durable way as possible.	Use materials that cause the least amount of pollution.	Focus on the thickness of the machine parts, the thinner the cheaper it will be.
Manufacturing (including re-manufacturing)	Regular checkups every 12 months to monitor wear. If the computer is not operating properly, the user should report it.	Use local supplierand and manufacturer that respect the working rights.	Produce the product locally
Packaging and distribution	One distribution of time. Following that, only distribution will occur when repairs are required (lower quantity). To prevent unnecessary travels, try to fix numerous items at once	Purchase materials from suppliers that have strict security policies in place for their staff.	Reduce packing by allowing the customer to get it from the local producing region.
Use and maintenance (includes re-use)	1 year without any maintenence.	To reduce waste, have information on public access rights and the closest recycling facility handy.	There have few components, they need less maintenance, and they have a cheap drift cost.
Upgrading and end-of-life	Is readily repairable using the same high-quality parts as when it was first purchased. The machine's whole	To avoid harmful compounds from leaking out, properly dispose of all waste material	Individual pieces that have broken may be replaced. Disassembly and recycling are simple.

	Leading sustainability criteria (LSC)	Comment
LSC 1	Recyclability at end of life	Easy to disasseble, few different kinds of materials
LSC 2	Robust ("hands off" usage)	Can sustain at least 1 year of
LSC 3	Toxicity of wood treatment	No toxic treatments of water resistant chemicals.
LSC 4	Local suppliers/contractors when manufacturing and repairing	Only use suppliers/contractors in Blekinge.
LSC 5	Important information, ex right of	Learn people how to behave in nature
LSC 6	Repairs doesn't lower the quality of the product	When repairs are made, the product should still have the same durability and visual looks.
LSC 7		
..		
..		
..		

Figure A3: Sustainability template