industriDESIGN

Extension – Operator Environment for Forest Harvesters
Extension – Operatörsmiljö för Skogsskördare

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Abstract

A forest harvester operator is today facing a stressful work environment with a high demand on coordination skills and effectiveness to run the operation with positive economical outcome. The learning phase is very long compared to similar work.

The vision for this project was to transform the machine, through intuitive and innovative interface design, into an extension of the operator’s body. In this way it provides higher productivity as well as user friendliness, shorter learning phase and a healthier work situation.

This was realized through the use of prior but yet not market available related research. Through market studies, applicable technology already available in other industries was found. The result is a complete seat with controls for a conceptual Gremo harvester realizable in the year 2023.
Sammanfattning

Dagens operatörer av skogsskördare ställs inför en stressande arbetsmiljö med höga krav på effektivitet och koordinationsförmåga för att bedriva sin verksamhet med positivt ekonomiskt resultat. Inlämningsfasen är relativt lång jämfört med liknande arbetsuppgifter.

Visionen för detta projektet var att med hjälp av intuitiv och innovativ gränssnittsdesign skapa en maskin som upplevs mer som en förlängning av operatörens egen kropp. Detta ska syfta till att korta ner inlämningsfasen, öka produktiviteten och skapa en hälsosammare arbetsmiljö.

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1 Introduction

A forest harvester operator is today facing a stressful work environment with a high demand on coordination skills and effectiveness to run the operation with positive economical outcome. The learning phase is long.

The vision and inspiration for this project was to transform the machine, through intuitive and innovative interface design, into an extension of the operator’s body. With this mindset the goal was to propose a concept which provides higher productivity as well as user friendliness, shorter learning phase and a healthier work situation.

This project was done as a part of the Industrial Design Master program at JTH and in collaboration with the company Gremo AB. Gremo is a Swedish manufacturer of forest machinery and has its roots in Denmark. A longer description of the company can be found under the theory section of this report.

1.1 Background

The forest industry has experienced both big golden years and economic hardship during the last 30 years. In the 1970’s the industry went through a decade of innovative thinking and was revolutionized in the early 1980’s by the introduction of the “single grip harvesting head” used in “cut-to-length logging”. In the wake of this innovation followed several years with big economic margins in the whole production chain before the prices of timber adjusted itself.

There are two principles of logging, “full tree” and “cut-to-length”. The later means that the harvester is responsible for felling, removing the branches, cutting up to different lengths and sorting the timber in different price groups as well as planning the infrastructure with timber piles and road planning for the forwarder. This task involves several operations and therefore puts a higher demand on the harvester operator.

Since the 1980’s the industry have been experiencing decreasing margins as the prices have been held fairly low while costs have increased. Since the product is very static and hard to influence the economic margins can be highly influenced by innovations among the production methods. Yet, no manufacturer has since 1981 been able to present a concept with as big impact as the “single grip harvesting head”. This project tries to attack this problem by taking the operator himself as a starting point. This is done by analysing and explorative, innovative thinking around the Man/Machine Interface in a single grip harvester.
1.2 Objectives

The aim of this project is to study the work situation for operators of forest harvesters and to set this against a preconceived conceptual idea which promises possibilities to enhance this environment. The focus of this enhancement is ergonomics, user friendliness and productivity. The result of the project aims to provide a concept that:

1. Shortens the total learning curve for new operators and therefore increases the total production quantity per machine.
2. Creates a faster and more intuitive way of operating the machine and therefore also increases the productivity.
3. Enables the introduction of new radical ideas that further increases productivity.
4. Reduces overload injuries to operators as an effect of a very static and stressful work situation.

1.3 Delimitations

This report describes the work carried out during the development of an interface concept for forest harvesters. Because the interface of a forest harvester is a complex system where many different tasks is carried out this project was focused on the primary function of the machine. The primary function was identified as the control input for the harvester crane and therefore the work was limited to this function. Some further aspects also closely related to the operator work environment were brought up because of their influence on the interface design. Such was sitting ergonomics and therefore a new seat design along with the control system was made as a part of this project.

The work carried out was based on design thinking and design knowledge but these philosophies will not be described in any large extent in this report. This report will have the design process, its methods and the actual work performed in this project as the central point.
1.4 Disposition
Section 1 describes the background, objectives and delimitations of this project.

Section 2 describes theories which this project is based on. It contains an overview of the design thinking, what industrial design is and design knowledge. It also contains reviews of project related research connected to the work environment for forest harvester operators as well as a description of the company Gremo.

Section 3 describes some of the various industrial design methods used in this project, such as design brief, functional analysis, mind map, sketching and modeling, combinations, analogies, and several others.

Section 4 describes in chronological order how these methods were used during the project. It also describes the information these methods generated and how this information was used.

Section 5 describes the result – a complete harvester operator’s seat with control units and all aspects of this concept. The section also answers the question why the result is what it is.

Section 6 analyses the scope of this project and methods used to cope with this. It contains a reflection over the ramifications of the resulting concept and recommendations for future work.
Theoretical Background

This section describes the theoretical aspects which this project is based on. It starts with a brief description of Industrial Design, design thinking and the design process. After this comes a review of the research and literature directly related to the product system in question. The final part of this section describes the company Gremo which this project was done in collaboration with.

2.1 Industrial Design and design knowledge

According to Jerker Lundeqvist the borders for the terms design and product development has been and still is rather undefined. As an example design and designing has in Sweden often been associated and restricted to what can be described in English as “styling”. While in English speaking countries design is a wider term which overlaps into the term product development. Lundeqvist also says “design is a way of dealing with problems associated with the shape, manufacturing and usage of artefacts.”[1, p. 59] He also says that the term design should incorporate both the object itself and the objects entire lifecycle. Design is a way of setting artefacts attributes and its relations to the surroundings. [1]

Warell says about design: “One could say that designing in its widest sense is the creation of a solution to a problem, for certain purposes, with a given set of requirements, and within certain constraints. It can also be stated that anything which is designed is made for a purpose; it has a function.”[2, p. 8]

2.1.1 Industrial Design

Warell describes Industrial Design as the areas normally treated by industrial designers or their likes. These areas are aesthetics, semantics, appeal, graphics, product and corporate identity, ergonomics, and visual form conceptualization. [2]

Warell says about industrial design: “design with particular emphasis on the relation between product and man, e.g., semiotic, ergonomic and aesthetic aspects of the product” [2, p. 10]
2.1.2 Design Knowledge

Bryan Lawson says to explain design one must first look at what certain type of knowledge designers share. He implies that this knowledge sets design work apart from other fields of scientific work. One can easily point out who is more and who is less successful among designers. The problem occurs when we try to explain why one is more successful than the other. Lawson says that tacit knowledge is an important clue to explaining design knowledge. With tacit knowledge one means the kind of knowledge that is learned through the experience of doing and trying. This knowledge is hard to transfer to another person through writing or verbal communication. Perhaps this can explain why design knowledge is a hard concept to pin down and explain in writing. [3]

In the book “Designerly ways of knowing” Nigel Cross has identified five aspects of design knowledge:

- Designers tackle “ill-defined” problems.
- Their mode of problem-solving is “solution focused”.
- Their mode of thinking is “constructive”.
- They use “codes” that translate abstract requirements into concrete objects.
- They use these codes to both “read” and “write” in “object language”.

Cross also talks about tacit knowledge and that “design knowledge” is as much a skill as it is traditional scientific knowledge. [4]

2.2 The Design Process

There have been many attempts to visualizing the design process with systematic models and structured approaches. The goal of this has been to make the designers process towards a good solution more effective. These systematic procedures have not yet proven their value in design practice so design work still proceeds in a rather ad-hoc and unsystematic way. [4]

With that being said there is models to describe this process with the purpose to explain it to outsiders. In the following text one of these models will be described.
2.2.1 The Double Diamond Design Process Model

The British organisation Design Council have studied the design process in 11 leading companies and from this put together a model that describes the similarities in these companies way of working. This model was chosen for this report to describe the process of the project.

Here follows short descriptions of the different steps of the process. These steps are managed with a range of tools described under the section “Methods” in this report.

Discover
The first quarter of the double diamond model marks the start of the project. This begins with an initial idea or inspiration, often sourced from a discovery phase in which user needs are identified. These include: Market research, User research, Managing information, Design research groups.

Define
The second quarter of the double diamond model represents the definition stage, in which interpretation and alignment of these needs to business objectives is achieved. Key activities during the Define stage are: Project development, Project management, Project sign-off.
Theoretical Background

Develop
The third quarter marks a period of development where design-led solutions are developed, iterated and tested within the company. Key activities and objectives during the Develop stage are: Multi-disciplinary working, Visual management, Development methods, Testing.

Deliver
The final quarter of the double diamond model represents the delivery stage, where the resulting product or service is finalised and launched in the relevant market. The key activities and objectives during this stage are: Final testing - approval and launch, Targets - evaluation and feedback loops.

[5]

2.2.2 Design Thinking
Design thinking is another way of describing the process, methodology and how designers work. Design thinking is described as a way to help designers stay innovative. It involves a toolkit of methods with the main focus on people – the stakeholders. As described above, design thinking is an iterative process to address poorly defined problems and this is done through a balance of analytical and creative thinking. These problems are addressed through the methods in the toolkit with a positive approach: problems are seen as possibilities.

This approach is seen as collaboration between a designer and a multidisciplinary team instead of the image of the lone designer artist working alone in the studio. Design thinking as a term was first used by Professor Peter Rowe at Harvard Graduate School 1987. Some of the methods themselves date back to before the 1950’s. [6]
2.3 Study of project related research

Below follows a description of earlier made research which is closely related to this project and/or the forest industry.

2.3.1 Dynamic Sitting, Seated work position and related subjects

2.3.1.1 Problems with traditionally designed sitting

Low back injury and pain is the main cause of workers compensation claims and has an indirect cost on individual productivity. It is one of the most common reasons worldwide for missed work and decreased efficiency. Low back pain is one of the most debilitating disorders of the human musculoskeletal system. [7] [8]

It is also a widely accepted notion among ergonomists that the standard office chair can contribute to the development of low back pain, as it results in an increase in intradiscal pressure, increased reliance on the muscles of the back and an unstable work position. This is a result of that a conventional office chair encourages in general an angle of 90 degrees between trunk an thigh and by doing this can also promote the problems mentioned above. [9][10]

The notion that all seats becomes uncomfortable over a period of time is widely accepted. Further sitting comfort is depending on the properties of the user and the task performed as well as the seat itself.

According to Bohgard comfort is a complex concept based on subjective assessments. Discomfort is defined as perceived improper physical load. Discomfort is not necessarily the antithesis to comfort since according to Bohgard the lack of discomfort doesn’t have to mean the presence of comfort. A perceived short term comfort could result in severe physical problems over a longer period of time. [11]
Theoretical Background

“One of the prime causes of back problems for forest harvester operators is sitting in the same position for long periods of time. It is therefore important that the operator is able to shift his position during work. In the basic sitting posture, the body should be positioned such that the angle between trunk and thighs is 105-120°. The operator should then be able to vary his posture: A relaxed position for the hips is when the trunk-thigh angle is 135°. The best posture for the lower back and pelvis is when the trunk-thigh angle is 120° and the back is in the same position as when the individual is standing upright. This can be achieved with a slightly higher seat whose leading edge is angled slightly downward (see Figure 5 and Figure 6). The larger angle between trunk and thigh also reduces the strain on the lower back. It is vital that good lumbar support is achieved.” [12, p. 27]

2.3.1.2 Saddle seat
Chair design in a saddle configuration has been developed in an attempt to address earlier mentioned problems. In a study of the Bambach™ saddle seat compared to a standard office chair it was shown that subjects reported more lower-back discomfort when using the standard office chair compared to the saddle seat. On the other hand it was also reported more discomfort in other parts of the body when using the saddle seat although these reports decreased when subjects became more used to the new chair design. Analysis from photographs revealed small, but evident differences in trunk-to-thigh angles between a standard office chair and a saddle seat. Statistically it was indicated that the saddle seat can be associated with greater trunk-to-thigh angles compared to a standard office chair. There was a clear relationship between trunk-to-thigh angles and comfort. Specifically, greater trunk-to-thigh angles were associated with reduced levels of overall body discomfort, particularly lower back discomfort. [13]

2.3.2 Boom Tip Control
A conventional forest machine crane is controlled by a number of joystick movements which each controls a specific hydraulic cylinder in the crane. This means that the operator needs to coordinate several of these movements simultaneously in order to produce the desired boom tip movement. [14]

A given freedom of movement in the joystick controls a certain cylinders movements. As Parker writes, in this manner smooth movement of the end effector frame requires a lot of training. “…motion (and force feedback if used) will not be intuitive.” [15, p. 11]
Boom tip control is a different control method for hydraulic cranes. It has been and still is a research topic at IFOR (Intelligenta Fordon Off-road). IFOR is a research network and competence centre started by Umeå University, Local manufacturers, the Swedish research institute Skogforsk and the Swedish University of Agriculture.

The development of this control method is an attempt to improve the work environment of the machine operator by putting less workload on the driver. This is done by letting the operator only set the desired motion for the boom tip. A computer system then calculates how the different linkages of the crane should move in order to result in this desired motion. This is believed to allow simpler crane design, higher productivity, longer life expectancy of the crane and an easier system to learn for the beginner. [14]

“This resolved control method gives intuitive control over the end effector, as in/out motion of the master corresponds to an in/out motion of the end effector(similarly for other degrees of freedom)” [15, p. 12]

![Diagram showing the difference between Joint Mode (traditional) and Resolved Mode (Boom Tip Control)](image)
2.3.3 Exoskeletal Master Arm

A telemanipulator is a device which allows a person to remotely manipulate objects. It comes in many different forms with different levels of sophistication. These devices have been used in the subsea and nuclear industries for many years. It consists of a master controller connected to a manipulator such as robot arm. To create an intuitive system the master and the slave is often kinematically equivalent. Heavy duty hydraulic machines can also be seen as telemanipulators. [15]

The word exoskeleton comes from biology and the study of insects. It refers to the loadbearing structure that is also the outermost protection against the elements for certain animals. Similar structures have also been artificially attached to human bodies throughout history mainly for protection. In recent years, industrial interest of the concept has increased. Powered exoskeletons that boost the wearer’s body have been developed for several purposes. Similarly an exoskeletal master arm is a telemanipulator master externally attached to a human arm in order to teleoperate a robotic arm for complex tasks. The robot arm is in this setup mimicking the operators arm motions. [16]

Picture 2.2. Manit Telemanipulator operating at CERN 1977 [http://cds.cern.ch/record/917749]
2.3.4 Haptic Technology

The sense of touch is used whenever someone physically interacts with the environment. This automatic force feedback sense helps us to handle objects without damaging them and to determine a lot of their attributes without our visual sense. As tools and machinery are used to expand the abilities of the human body the tool itself acts as a barrier for the haptic sense. For this reason force feedback is often incorporated into advanced telemanipulator devices. If heavy duty hydraulic machinery is seen as telemanipulators they could also benefit from force feedback. [15]

Force feedback has been used for many years in the computer gaming industry to create more realistic gaming interfaces. Here often with motors imbedded in the control devices to create vibrations of different kind to correspond to the events in the game. Other ways of creating haptic feedback include electro active polymers, piezoelectric, electrostatic and subsonic audio wave surface actuation. Teleoperators, mobile devices, personal computers and virtual reality are other examples of where haptic technology is used.

The use of force feedback in manipulation robots has been shown to reduce reaction forces and to improve assembly tasks. The potential gains for providing force feedback in forest machinery are many. These include better control when manipulating large trees, greater awareness of machine tip over but also help to reduce the damage on logs and the wear on the machines hydraulic system. Excessively applied forces could be minimized and it would be easier for the operator to damp out payload swing. [15]

“While it is possible to provide visual or audio feedback, these routes typically have greater processing delay than the more intuitive feedback channel through the operator’s hand” [15, p. 20]

2.4 Ergonomics

Ergonomic issues have been addressed in some of the previous parts of this chapter but an addition of related ergonomic areas here follows.
2.4.1 Control Movement Stereotypes

People have from previous experiences expectations on how controls will work in the system. For example to raise something vertically one would expect to move the control upwards. Because of the one-to-one correspondence this stereotype is very clear. This differs from the stereotype to raise an airplane where the pilot pulls the lever backwards. Another example is the light switch which is generally moved upwards to turn on in U.S. while the exact opposite is the norm in Europe. Helander says that operators under stress are likely to revert to the behaviour first learned. For this reason it is important to analyse the compatibility between control movements and the controlled element. [17]

2.4.2 Shoulder Muscle Fatigue

A muscle that is exposed to continuous physical load is developing fatigue. This results in decreasing performance until the muscle no longer is reacting to the stimulus. Over time fatigue can lead to overload injuries. It has been shown that operators of off-road machines are experiencing higher load on the shoulder muscle apparatus when the seat is elevated compared to the hand controls. The reason for this can be assumed to be loss of proper armrest support. For an application where the operator has to move around his arm in three dimensions it is therefore important to provide equal constant arm support through the whole range of movements. [18][19]

2.4.3 Hand Ergonomics

“There are two basic grips: the power grip and the precision grip. In the power grip, the hand makes a fist with the forefingers on one side and the thumb reaching around. There are three different categories of power grip that are differentiated by the direction of the force: force parallel to the forearm, e.g., a saw; force at an angle to the forearm, e.g., a hammer; and torque about the forearm, e.g., a screwdriver.” [17, p. 216]

As Chaffin, Andersson and Martin write: “The grip strength varies with grip span which is measured at the center of the hand.” Generally the maximum grip is achieved at 8cm. However if the object is round, the maximum strength is achieved when the diameter is about 4cm. [20]

“For precision grips there are two subcategories: the internal precision grip where the tool is held inside the hand, e.g., a table knife; and the external precision grip where the tool is pinched by the thumb against
the index finger and middle finger, e.g., a pen. A hand tool can often be designed in different ways, since there are different ways of exerting power on the tool and the task." The option chosen, in which way the tool is used, should depend on how the task is organized and what is convenient for the operator. Therefore one can design special purpose hand tools to fit specific tasks. Sometimes it is also possible to combine several hand tools into one multipurpose tool. [17, p. 216]

When producing a hand tool, a major concern is whether the user is left- or right-handed. "Right-handed tools for left-handed users create awkward situations." The left-handed person can try to use the tool with the right hand but their skill and power is better with the left hand so consequently the productivity will decrease. Therefore, a hand tool should be, whenever possible, designed so that it can fit both left-handed and right-handed user. [17, p. 217]

"There are two major concerns in hand-tool design: injuries due to musculoskeletal disorders and vibration-induced injuries. One common recommendation for preventing CTD is that the movement of the hand should be minimized. Ideally, the hand should be in its neutral straight position, and sometimes handles can be modified to better fit a task." [17, p. 219]

![Picture 2.3. On top; good design since the wrist remains straight. Bottom; bad design](image)

[17, p. 220]
2.4.4  Cognitive Ergonomics

Cognitive ergonomics is the interaction between humans and different elements of a system as these interactions are affected by the human mental processes such as perception, memory, reasoning and motor response. [21]

2.4.4.1  Displays and Virtual Environments

Design can either facilitate interaction or increase the task difficulty in a display or controls of a machine. The capacity of the human perception system is limited therefore using figure-ground differentiation (identifying a figure from the background) can reduce the incoming data to more manageable proportions. This is because figure information receives preferential processing over ground information.

2.4.4.2  Figure-ground Differentiation

Contours can influence the differentiation of figure and ground information. By using different colors or changes in light the contours could be enhanced and a useful method to differentiate parts of a display or recognize a symbol.

2.4.4.3  Grouping

Grouping occurs when there are several separate elements to form a complete percept. If grouping is done correctly the efficiency of visual scanning could be improved.

2.4.4.4  Color

Colors could be used to mediate a situation connected to a system, for example traffic lights, red means stop, green means go. Generally red is used to express danger or stop and green or blue to express go or everything is normal.

2.4.4.5  Controls

Select manual controls so they are appropriate to the task and intuitive to use. Over the years many of the controls has become standardized and a user would be confused and annoyed to find other type of controls that they are accustomed with. [17]
2.5 Gremo

This project was done in collaboration with the company Gremo AB which is a Swedish manufacturer of forest machinery.

Gremo was started in Denmark in the early 1960’s and in the beginning the company was focusing on the manufacturing of timber trolleys for farming tractors. 1968 the Swedish manufacturer Timmerville was bought. Timmerville was by that time manufacturing an articulated forest forwarder. This meant an important step for Gremo towards manufacturing of advanced forest machines.

Gremo bought 1988 by Swedish investors and 1993 Gremo 950 was introduced. This forwarder was a result of customer focused development and its good sales figures increased the company’s share of the market.

Gremo has a history strongly influenced by innovative thinking. This has been shown in several occasions and an example of this is the remote controlled harvester “besten”. “Besten” has been a research project at Gremo for the years 2010 – 2013. It has currently been going through 1000 hours of field testing. Although there are many advantages with the system the operators have still not managed to reach the speed of a traditional system. The reason for this is believed to be loss of perception as a result of the fact that the operator is not situated on the harvester physically.

Gremo has market shares internationally but their most important markets are Sweden, Denmark, Germany, Ireland, Scotland, Switzerland and Austria. [22]
3 Method

As described in the theory section of this report the design process can be seen as a toolkit of methods. Some of the skill lies in picking the right method for a given problem out of this toolbox. The goal of these methods is to keep a balance between analytical and creative thinking. In other words, to explore the project in an expanding way and then narrow it back down through several iterations. It has been said that there is as many design methods as it is designers but below follows a description of the methods used in this project. The methods are described in roughly the order they were used in the project but many methods was used continuously, revised or used in different stages.

3.1 Mind Map

A mind map is a diagram that shows the connections and relations between ideas or other things related to the project. It is vital to understand these connections in the start of a design project. In the centre of the mind map diagram is a keyword. It can for example be an idea or the project name. Around this keyword nodes are placed that consists of images, symbols or words. Lines or arrows are then used to show connections between the nodes. [6]

3.2 Market research

Market research is used to identify gaps in the market and areas for improvement. It can also gather information about the companies status against it competitors. When conducting the market research a key task for the designer is also to identify future user needs and trends. To manage this, the analysis performed is often focused on trends and in what directions the trends are headed. The span of impact this analysis can have is everything from complete product innovation to styling details such as colour or surface texture. [5]

3.3 User Research

User research is often an important part of the design process and this goes along with the design thinking which is as described earlier very people oriented. There is a wide range of user research methods and many of them are based on traditional marketing methods. An example of these methods is the unstructured interview, where questions can be modified by the researcher during the interview. Another method is behavioural mapping where the researcher studies and records the behaviour of the user.
Designers often take part in conducting this research. It has been found that their creative skills can help identify problems and solutions from the data. Also this multidisciplinary work can give more insight and help set the project objectives early in the design process. [5][6]

3.4 Function Analysis

Function analysis is a way to identify all the functions of a product and to set their importance in relation to each other. The main reason for conducting this analysis is to go to the roots of why the product exists, what its main purpose is and to find all different ways this can be achieved. When doing a function analysis it is very important express the functions as primitive as possible in order not to limit creative thinking. All functions are labelled with one of four levels of importance: Primary, Necessary, Desired and Unnecessary. Functions can also be ordered into a hierarchy of sub functions to show their dependence of each other. The functions are expressed with one verb and one noun each, ex. “shorten grass” for the primary function of a lawn mower. Restrictions are also assigned to the functions if necessary to further explain or set a limit to a function. [23]

3.5 Design Brief

The design brief is a short text written to describe the feel of the resulting product and user one should aim for. This is done by following a set of rules or questions the brief shall give an answer to. The design brief made for this project can be found in among the attachments of this report.

3.6 Analogy, Mutation and Combination

Analogical thinking is suggested as a basis for creative design and is a way to use existing things, natural or manmade, and find the analogy between these and other things. This can be used to identify a new use for an existing product or to visualize how a product might work. Similarly, mutations involve modifying features of an existing thing to a product that meets the desired functions. Useful qualities of the existing are identified in the same time as the inadequate features. The inadequate features are then modified.

Further combinatory thinking is also a common way for designers to solve problems. Combinations are this regard means to combine features of different things to something that solves the problem better than the existing would singularly. [4]
3.7 **Gantt Schedule**

Proper planning of a design project is important to be able to manage the sometimes chaotic creative process in relation to deadlines and other people involved in the project. One way to do this is by splitting the work up in relevant sections and then place these sections on a timeline from project start to delivery date. The resulting chart is called a Gant Schedule. [23]

3.8 **Pugh Matrix**

This method involves making a matrix chart where important criteria is used to evaluate different design proposals. This is done in a group where first the different design criteria’s are identified and then the design proposals are evaluated against a norm such as an existing product. The evaluation scale consists of + (substantially better), - (clearly worse) or S (more or less the same). [6]

3.9 **Sketching**

Sketching is an important tool for the designer especially during the ideation process but also later when presenting ideas for evaluation. Ideas that would take a very long time to explain in words can be communicated in an instead through images.

During the ideation process sketching act as a testing ground for the ideas previously formulated as lose thoughts. Rather quickly one can determine what could work and where the problem areas lie. In this stage the images produced by the designer is also a communication tool for all people involved in the project – be they marketing people, engineers, manufacturers or other designers.

The images that is the result of ideation sketching or concept sketching is somewhat “fuzzy” compared to for example more precise images generated by 3D cad programs. This fuzziness can be intentional, a result of very quick sketches or it can be intentional mistakes made by the designer. These can be misinterpreted or understood correctly but regardless of which it often results in inspiration for more sketches, an innovative idea or sometimes a complete new direction for the project. [23][24]

Alan Pipes defines concept sketches as “a collection of visual cues sufficient to suggest a design to an informed observer”. [24, p. 19]

This implies that concept sketching and ideation sketches are mainly for internal use.
Method

Presentation drawings are something completely different. These are intended to show the decision makers or customers a realistic representation of the product so that a decision about whether to go ahead with the project or not. These can be 2D renderings, 3D renderings or animations. They can be used throughout the entire process as material for evaluation. [23][24]

3.10 Mock-Ups and Sketch models
Mock-Ups and sketch models is a way of testing design solutions in reality. It is an effective tool to identify problems or possibilities which would have been hard to see on two dimensional images or on virtual models. Sketch models should be made fast and simple to quickly be able to test a range of ideas. Mock-ups on the other hand can be made with a variety of sophistication according to need. These models can be made in any material but the focus should quick and rough modelling.

3.11 Post It Exercise and Concept Selection
This method can be used to evaluate a number of different concepts with the use of a set of predetermined attributes. The concept sketches are pinned to a large wall or spread out on a big table. The participants should be a small group of stakeholders. Each stakeholder is given a package of unused Post-It notes or equivalent. The task for the participants is to write down one of the attributes, which is all placed clearly beside the sketches, on a note and then place the note on the sketch that he or she thinks best represent that word. This is done by all participants and for all attribute words on the list. The designer then choses the top voted concept for further development. [6]

3.12 C-box
The C-box is a way to evaluate and map concept ideas. It is very effective to handle a large number of concepts. The C-box consists of a two-axis cross chart where for example conventional – innovative is on the horizontal axis and basic – luxury is on the other. On this chart a group of stakeholders places the concepts with regard to the two axes. After this the group can for example place the company on the chart according to earlier done strategic market analysis. The method shows in what direction the area of opportunity lies for a given project. [6]
3.13 CAD-modelling

CAD-modelling is done with the help of computer programs for building 3D virtual models of the product. There are many different types of this software and the reason for using them varies. The models can be used to test concept ideas, generate photorealistic images for final presentation, create material for rapid prototyping or create underlays for further sketching.
4 Approach and Implementation

The shape of the double diamond model described under the theory section above is meant to visualize the iterative nature of the design process. First comes a phase of expanding the project through explorative methods. After this comes a phase of reducing and decision making to zoom in towards the project goal. The third phase is then again an expanding one where the defined project directions are further explored. Finally comes a second phase of decision making to narrow down the project towards a presentable result. Since this is dealing with so called wicked problems these iterations can go on forever to constantly improve different aspects of the project. It is therefore important to keep this in mind and have the insight to decide when it is good enough.

This double diamond model of the design process does not completely correspond to the process in this project and although this is true the iterative nature and the phases of expanding and reducing was the same. Since the process is very personal and sometimes introvert with intuition as the basis for the decisions taken, I have chosen to write the rest of this report from a personal viewpoint.

My design process, as many others, is a mix of analytical and creative thinking. This mix of two often antagonistic ways of thinking can be at times chaotic and intuition plays a vital role in the decisions that is taken. Because of this it is hard and not completely correct to describe the process in an ordered, structured and linear fashion. On the other hand one must try to do exactly that in order to make this way of working understandable. To accomplish this I have chosen to split this part of the report up into sections corresponding to the different process phases. Sometimes there is a fine line between what can be defined as the use of a method and the result of this use since the result often are used as parts of method-use in other stages of the process.

4.1 A Preconceived Idea

Before this project began I had a preconceived idea on how to improve the way an operator controls complex heavy machinery like forest harvesters. So in the beginning this was treated as a hypothesis to be tested.

In the core of this idea was the will to transform the machine to something that feels like a continuation of the operator’s body. This I think is the ultimate goal for interface design in general - to be one with the machine so to speak. The inspiration for these thoughts came from advanced robotics and the exciting world of science fiction.
The powered exoskeleton is a concept that has been explored in science fiction for a long time and in recent years technology has made these applications economically appealing for many different industry branches. I think it is the result of humanity’s everlasting will to augment and improve itself and it is a natural part of evolution. It is in the truest sense a physical mechanical continuation of a user’s body.

I saw a gain in introducing this thinking in the industry of forest machinery. This is today complex machinery where a lot of effort has to be placed into learning a not so intuitive system which then must be operated under high demands of efficiency.

Here follows a description of the steps taken to test this idea and to reach a goal that, even though different, still have the initial philosophy in its core – the machine as a continuation of the operator’s body.

### 4.2 Initial research and project development

This part can be seen as corresponding to the “Discover” phase in the “Double Diamond” model. Similar work was conducted several times throughout the project.

#### 4.2.1 Mind Map & Market Research

The project was started with a kick-off meeting at Gremo AB where I met the local manager. In this meeting my idea was discussed and in what way it could have value for the company. After this meeting I conducted a study of all existing technology and research related to this project and my hypothesis. A list of competitors to Gremo was also collected and reviewed. From this material I created a few “Mind maps” (see Picture 4.1) to map out the boundaries of the project and to get an overview of what work was needed to be done and in which areas. Relations between different aspects of the project could also be identified.

The history of the forest industry was also studied to get a feel for the trends and innovations that have had large impacts.

The scientific research made in the related fields of advanced robotics and exoskeleton applications is extensive and expanding. High tech industries like military, medical and engineering are a driving force behind this research. In order to structure my work I used these “Mind Maps” to decide what held sufficient relevance and importance.
### 4.2.2 User Research

In my design work I see this part as a very important tool and this is true especially in this project which has a very close relation to the user of the product. On three occasions during the project unstructured interviews was carried out with active harvester operators. In the first interview the theme was very free and I let the operator give his viewpoint on the work situation. The later interviews were directed to revolve more around the findings I had made during the project.

To just ask a person about how he or she is using a product and what they like and not like is according to me not sufficient. Often one must study the user in action and make up opinions that are not contaminated by a long user experience of the existing product. Subjects often, especially professional users, seem to develop a sense of personal connection and pride when it comes to the products they use in their occupation. This can cloud their thinking of what is good, bad and what could be made differently. With this knowledge in mind I did a field study of a harvester operator’s workday. I later wrote my thoughts during this day down on a paper and created another “Mind Map” around the work situation of today *(see pic. 4.2).*
One interesting opinion of some operators was regarding making the control system more intuitive and user friendly. It was according to the operators important not to make the system too easy to use or else the “fun” of driving a forest harvester will be lost. These operators enjoyed the challenge and took pride in overcoming it. This opinion is something that I choose to work with in my design.

4.3 Defining the Project

At this time in the project it was expanding rapidly and it became necessary to set up some limitations and directions for the project. A second meeting with the company Gremo was done to discuss my findings and to set the project direction and what should be done and what not. At this meeting I presented three different possible directions with different level of innovation and technology. The directions were presented with a number of sketches. These sketches were made before the meeting in a loose undetailed manner to show the mood for every direction instead of solutions. The idea with this was not to limit creative thinking in the discussions at this meeting.
**Direction 1** (see pic. 4.3) is based on technology in a way that it could theoretically be launched as a new control interface today. It uses the concept of "Boom Tip Control" with controls in a traditional arrangement.

Picture 4.3. Direction 1, "Boom Tip Control"

**Direction 2**, "Exoskeleton"
Direction 2 (see pic. 4.4 and 4.5) also takes advantage of “Boom Tip Control” but here with an exoskeletal master arm setup. This was meant to go more in line with the original philosophy – the machine as a continuation of the operator’s body. To produce this feeling an analogy was important: the arm of the operator represents the crane boom and the harvester head at the boom tip represents the operator’s hand. Because this setup would mean controlling a complete crane with a single arm the idea of putting two cranes on the machine was implemented - one crane for each arm. The gain with doing this would be a raise in productivity per machine hour.
Direction 3 (see pic. 4.6) takes advantage of more advanced interface technology similar to the ones used for motion capture for example in the movie industry.

On the background of these sketches it was decided during the meeting to continue with direction 2.

Direction 1 was seen as to up to date to be viable as an innovative product in 10 years. The industry has already started to develop similar system components that will be available in the near future. It is in other words to close on the timescale for big implementations to be made. Further in discussion with active operators and other stakeholders in the forest industry it became evident that the industry is in doubt that a system with traditional joysticks will be able to fully take advantage of “Boom Tip Control” and “Shared Control”.

And opposite from that direction 3 was considered to advanced to be realizable in 10 years.
4.3.1 Function Analysis and Design Brief

A function analysis (see attachment 1-4) was made after the second company meeting to structure the rather complex product and task into manageable parts. This function analysis was updated and changed several times during the project. It was split up into 4 parts: Cabin, Seat, Control Units and Arm Support. This was done since a forest harvester is a very complex machine system and this project was only meant to deal with some parts of this system. For example a useful primary function for the whole cabin could not be found since it consists of many systems with rather different purposes. This also resulted in a better overview of the entire project and on what work should be carried out for different aspects of the project. Blank rows were left in the function analysis to be filled in during for example ideation sketching.

I also wrote a Design Brief (see attachment 5) to keep my thoughts and ideas focused on the initial philosophy and idea. Without this it is very easy to lose track and focus on what is important. The Design Brief was reviewed on some occasions during the project.

4.3.2 Gantt Schedule

To be able to plan and manage this project with regards to other people involved and the deadlines a Gantt Schedule (see attachment 6) was created in the software Microsoft Project. I also found this to be very useful to further split up the work in parts to make it easier to grasp.

4.4 Developing the Concept through Ideation

A clearer direction was at this point starting to emerge but it needed further developing to test out all possibilities. Therefore a second expansive phase was undertaken. In this phase many side tracks was investigated and each side track meant another iteration of exploring and defining. Many of these side tracks proved to be dead ends and back tracking were needed. Because of the complexity of the product the first ideation sketches were very simple line drawings (see pic. 4.7) to figure out the “anatomy” of the control system and how it should work. In the beginning my thoughts was still towards a true exoskeleton setup made up from rigid “limbs” connected with rotating joints.
4.4.1 Ideation Sketching

Even though sketching as a tool was used during the entire project this was perhaps the phase were it was used most frequently. The sketching was helping my mind to develop and test my ideas. In this phase the sketching is very introvert and internal and it is made mostly for myself and not with the purpose to be presented. I tried to keep my sketching on a good balance between super quick and very defined - refined enough to clearly show the idea and quick enough to be able to test as many ideas as possible and to “turn the problem inside out”. Sketches of scenarios were also made to visualize how the product was thought to be used. (see pic. 4.8 to 4.10)
Approach and Implementation

Picture 4.9. Ideation Sketches

Picture 4.10. Usage scenario
To come to terms with what was important and to keep the focus on the original task I did a simple cartoon like sketch of a usage scenario (pic. 4.10). This displays how the system with double cranes was meant to work. The basic idea was that one crane is running a set pattern of tasks while the operator is setting the task pattern for the other crane. When the task is set and the first crane is done with its program the operator is switching attention from the second crane to the first to set a new pattern.

The sketches in this phase were often limited to describing parts instead of the complete concepts. Here I used similar divisions as for the function analysis: Cabin, Arm Support, Hand unit, Seat. The part formerly seen as control unit was now partly the Hand unit and partly the Arm support. This was done to keep focus on the functions instead of the solutions and to keep to the human arm/crane analogy.

Picture 4.11 shows an early sketch of the operator seat. It was decided quite early in the process to use some sort of saddle seat. The idea of using a saddle seat in off-road vehicles has been suggested before. It is also commonly used on extreme speed boats for the superior stability it provides for the occupant. When sitting on a saddle seat it becomes natural to use your legs to counter act the vehicles movements. Also the saddle seat has been proven to reduce some of the common overuse injuries related to sitting.
Later the idea of a rotating seat as part of the machine controlling functions was explored. I wanted to go as far as I could with the idea to activate more parts of the body for controlling the machine and this was a way to also give the operators legs a vital role.

Picture 4.12 shows a sketch that was made to describe the idea of a rotating chair as part of the control system. The rotation of the chair controls which of the two cranes is active as well as the rotating motion of each crane. This was thought as a cheaper, more activating and more intuitive way of letting the operator rotate along with the cranes. Today three different systems exist. The most basic is a fixed cabin and chair where the operator needs to twist his neck when operating the crane out to the sides of the machine. The slightly more sophisticated is the rotating chair where the operator himself rotates the chair with his feet to follow the crane rotation. The last one is a rotating cabin which automatically follows the crane. The advantage with the last one over the second is that the operator sits in a more secure position with a seat fixed to the cabin.

Picture 4.13 shows a few of the ideation sketches made later in the process focused on the design and function of the seat.
4.4.2 Analogy, Mutation and Combination

Along with the sketching tool I used analogies, mutations and combinations to find new ways of thinking but also to make my ideas more credible. The analogy of the crane as a human arm with the harvester head as the human hand is according to me very strong. Later it was found difficult to justify this in a literal way but I managed through mutations and combinations to keep the philosophy of this analogy. Combinations and mutations were very important when dealing with a company such as Gremo. Gremo has limited funds when it comes to developing these rather expensive systems completely on their own. Therefore finding, combining and mutating existing technology and products were necessary. Three different products with technology that could be used were found (pic. 4.14 to 4.16).
The predator control arm (*pic. 4.14*) is the controlling device for a cinematically equivalent robotic arm. The fact that it was cinematically equivalent was very appealing to use in this project since that would probably mean a very intuitive connection between the control unit and the controlled robotic arm. It also has a built in force feedback system.

Equipois (*pic. 4.15*) is a movable arm-support designed to give equal support regardless of the arm position. It is mainly developed for industrial assembly task. The idea was to use the support technology of this product but add electronic sensors so the system could read the operators arm position. To get force feedback, motors or some other means of haptic feedback would also have to be added.

The Novint Falcon (*pic. 4.16*) gaming controller is developed as a control device for computer games. It offers one-hand 3 dimensional control along with high resolution force feedback. The same company that developed the Falcon has also done similar products for use in the medical field as controlling devices for surgical robots. Many successful trials have been made on academic level to use the Falcon as controlling device for different telemanipulators.

As mentioned above I used the philosophy of the machine as an extension of the user’s body. That the whole crane of the harvester is represented by the operator’s entire arm and hand (*pic. 4.17*). This I believe should be at the core of an intuitive and user friendly control system.
4.4.3 Mock-Ups ad Sketch Models

A very simple model of the arm-support and hand-unit was done to test how it corresponded to the anatomy of the human arm. As an example the overall size needed to be verified but also the distances between the individual parts. Besides from this there were mainly two aspects that needed to be tested. First the position of the point where the whole arm-unit was connected to the rest of the control unit was tried in order to give the arm as relaxed a position as possible. As described in the theory section under “Fatigue” it is important to keep the arm and shoulder in an unstrained position in order to avoid overuse injuries. The testing was carried out by simply moving the imagined attach position around until the subjects arm was as relaxed as possible (see pic. 4.18 to 4.20).

![Picture 4.18. Optimum attach position](image)
![Picture 4.19. Attach position to far back](image)
![Picture 4.20. Attach position to far ahead](image)

The other aspect of the arm-unit was the position of the hand-joystick. This control device was meant to control some motions of the harvester head and in these trials it is represented by cylindrical shape similar to the ones found on 3D CAD mice such as the “Space ball”. This cylinder was also moved around until the most natural and relaxed hand position was found (see pic. 4.21 and 4.22).

Picture 4.18 shows the best position that was tested, where the wrist is in a relaxed and natural position.

![Picture 4.21. Best position tested](image)
![Picture 4.22. Strained position](image)
4.5 Defining the Final Concept

Another phase of reducing the questions was needed and here several different methods were used. Since I was getting closer to a final concept and needed to take some important decisions I involved Gremo as much as possible during this phase.

4.5.1 Pugh Matrix

A “Cross Matrix” was created using a similar template as the Pugh Matrix. Because this was performed by myself, the subjective nature of the evaluations made in a Pugh Matrix seemed inappropriate. Instead the matrix was simplified and the different concepts could either fulfil (marked with an X) or not fulfil (marked with a -) the different criteria (see pic. 4.23). For an explanation of the 4 first concepts in the matrix see picture 4.8.

<table>
<thead>
<tr>
<th></th>
<th>&quot;Exoskeleton master arm&quot;</th>
<th>&quot;Arm support with motion capture + joystick&quot;</th>
<th>&quot;Motion capture glove + arm support&quot;</th>
<th>&quot;Crane anatomy&quot;</th>
<th>&quot;Motion capture glove&quot;</th>
<th>&quot;Traditional joystick with arm support&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offer crane control</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Offer high speed crane control without correction</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Allow visibility of machine and crane</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>Offer user friendliness</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Cooperate with seat for crane movements</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Be intuitive</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Promote movement of operators body</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Enough degrees of freedom for master/slave setup</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Offer arm support</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>Minimize size</td>
<td>-</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

The “Cross Matrix” clearly shows the two winners as “Arm support with motion capture + joystick” and “Motion capture glove + arm support”. This meant that the true exoskeleton idea was not any longer valid to continue working with. Also, based on discussions with Gremo described earlier any system with motion capture gloves or their likes would be to advance to be realizable for the company in 10 years. So from this point “Arm support with motion capture + joystick” was chosen as the concept to work further with.
After this was done a third meeting with Gremo was arranged. At this meeting 5 people was present. The Local manager, a mechanical engineer, a software and electronics engineer, a sales person and myself. I first presented all my work through my sketches and they were all was spread out over the tables and the walls in the conference room. To get the all participants of the meeting to truly think through my ideas from different viewpoints we conducted two evaluation exercises.

### 4.5.2 Post It Exercise and Concept Selection

Before the meeting a set of attributes was prepared. Each member of the group was handed a package of Post-It notes and the attributes was placed visibly on the wall. The assignment was to write a freely chosen attribute on a note and place that note on the concept sketch that you saw best corresponded to this word. This was done until all participants of the group had gone through the complete list of attributes. The attributes was as following:

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Attribute</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unitary</td>
<td>Aesthetic</td>
<td>Activating</td>
</tr>
<tr>
<td>Intuitive</td>
<td>Robust</td>
<td>Simple</td>
</tr>
<tr>
<td>User friendly</td>
<td>Precision</td>
<td>Safe</td>
</tr>
<tr>
<td>Ergonomic</td>
<td>Fast</td>
<td>Evident</td>
</tr>
<tr>
<td>Production friendly</td>
<td>Logistic</td>
<td></td>
</tr>
</tbody>
</table>

Picture 4.24. Post-It exercise and Concept Selection at Gremo
Naturally after this followed discussion about the evaluations and selections made. After the exercise everything was photographed so it could be analysed also in retrospect.

### 4.5.3 C-box

To further clarify what concept should be chosen for further work another exercise was made. The C-box proved very valuable since the results could also be compared directly against the strategic market analysis that Gremo had done earlier. A C-box with Conventional – Innovative on the horizontal axis and Basic – Luxury on the vertical axis was drawn up on a whiteboard. The task for the group this time was to write down the names of the different concepts and then place them on the C-box chart.

The results of this meeting was brought back to the design studio and analysed. From this several decisions was made about the final concept.
For example the group was in strong favour of the Novint Falcon technology because it seemed to be possible to implement with the least amount of effort and financial means and at the same time hold everything that was needed for the concept.
Further the question over what type of seat to use was also quite clear after the meeting. The arguments fell in favour of the slightly raised saddle seat because of its good ergonomic values and raised stability the operator would experience in rough terrain with the possibility to counteract vehicle movements with his/her legs. It could also result in better blood circulation as a result of a more activating way of sitting.

### 4.6 Exploring the Final Concept and Finalizing

This was a phase of the project were exploration and defining was mixed on a daily basis so I have therefore chosen to write this as one part in this report. This phase of the project could be seen as another stage of expanding and reducing. During this stage two surface modellers were involved daily in the project. They were helping out with the 3D modelling of some parts so in some regards this part of the project was a group work. The modellers were present in the design studio for 4 weeks and during that time mostly were modelling for this project. Most of the important decisions were at this time already taken but still some remained.

For example the question of the rotating seat was still an open one. Through some sketching with quick 3D cad mock-ups as underlays I soon found the rotating chair would cause some problems not earlier identified. For the operator to be able to rotate inside the cabin with sufficient clearing space the cabin would have to be made substantially larger. This on the other hand would cause further problems with stability of the entire machine since it would mean raising the centre of gravity. Also it was thought to create stability issues for the operator himself. On the basis of this a fixed seat with instead a rotating cabin was selected.

The rest of the work was turning more and more into styling work as the concept was getting more and more defined. In the beginning of this period the modellers was doing quick mock-ups in 3D for me to sketch on to define all the detail. The most effort though was put into the hand/arm unit and how it should work together with the Novint Falcon technology (see pic. 4.27 and 4.28).
Picture 4.27. Ideation sketches of the hand unit

Picture 4.28. Sketches to explore the meeting between the Falcon, the arm/hand unit and the seat
4.6.1 Cad modelling and Rapid Prototyping

To finalize the model high detail 3D cad models needed to be built to use for presentation image rendering, rapid prototyping and animations. As described earlier CAD models was used to test and verify sizes and proportions in the first few weeks.

Once the concept was almost completely defined both modellers and I was working constantly for 1.5 weeks with 3D modelling of the final concept. We divided the work in parts so that each member of the group could focus on just one part. One modeller did the Falcon control unit with the arm support part, the other modeller focused on an interior shell for the cabin to use as a frame in images and I did the rest of the seat and a quick cabin exterior to test and verify proportions.

Since it was my responsibility to ensure that the parts would fit together and visualize my idea properly this period meant that I often sat down with the modellers to explain my design in words and sketches. According to me it is very easy that details gets missed or wrongly interpreted when trying to transfer rather abstract ideas between people and therefore I tried to as often as I could to do check-ups and discuss details with the modellers. In my opinion this is very crucial when working in a team with this type of projects.

In order to produce a detailed physical scale model of the seat and controls I decided to 3D print the model. The 3D model was therefore split up into parts that corresponded to the different materials they should visualize. The different parts was sent to a prototyping company and printed (see pic. 4.29). After this it was approximately 100 hours of model work to get the right colour and surface texture for the model. The part were fitted, sanded and spray-painted to get an illusion of the different materials in a real product.
The complete design process in this project took 15 weeks from the start-up meeting to the final presentation. It was an iterative process with several phases of expanding and reducing the problem. At the final presentation a physical model along with computer renderings was presented.

Some of this material can be seen under the “Result” section of this report, where also the final design with its functions is described.

### 4.7 Holistic viewpoint

The design of a complex system like a complete forest harvester control system demanded a very holistic approach. Every aspect of how the machine was operated needed to be studied and all these aspects could possibly effect how the controls were designed. Therefore all other functions of the machine interior were subject for analysis and development. Even though the seat and the controls was the only parts truly designed into a final concept a sort of mental design work was done for the rest.

In a forest harvester there are many other functions besides just controlling the crane even though this is the main task. Here follows a few examples of other important functions:

- The hydraulic system of the machine needs to be supervised and adjusted as well as the engine.
- When cutting timber to length and setting the price this information needs to be reviewed somehow and stored.
- The cabin climate needs to be controlled.

These functions all demands some sort of operator input and also some way of supervising these systems. To picture a scenario and a context that would fit a future harvester some thought was put also into the design of these functions. One solution that could work is a sort of heads-up display with mixed reality and voice control. This would go well along with the idea of using more senses for the interface and could also make the system more intuitive and easy to learn.

Another scenario that was pictured was the cabin and how the design of this could develop in the future with perhaps a focus on increasing the visual field for the operator or putting more effort into styling.

For a designer it is according to me an important thing to try and go outside of the boundaries of the task at hand and see how things relate to each other in a bigger picture. It is sometimes a difficult thing to do but can on the other hand be very rewarding.
5 Result

The final concept that this project resulted in is a complete suspension seat with control units for a conceptual machine realizable in 10 years. Picture 5.1 shows an overview of the main feature on the new design. Each part of this chapter individually describes these features and all aspects about them. Results from holistic analysis, related to this concept, around the usage of harvesters will also be described in the last parts of this section. This end of this section also describes the group work result and the physical model work performed during the last part of the project.

5.1 The Control Units

A lot of emphasis was put into creating a very intuitive way of controlling the machine and in doing so also drastically reducing the time it takes to learn the necessary skills for efficient operation. This would mean higher total production quantity per machine and that was one of the main goals with this project.
The control units consist of two identical units (one for each arm) and are based on the Novint Falcon game controller described in the previous chapter. The future machine also has two identical cranes – one for each controller.

Together with “Boom Tip Control” the system will provide an intuitive way of directly controlling the boom tip movements. Between the crane and operator arm there will be a sort of analogy. The operators arm represents the bigger movements of the crane while the operators hand represents the movements and functions of the harvester head at the tip of the boom (see pics. 5.2 to 5.7).

![Image](image1)

**Picture 5.2. Arm movements in three degrees of freedom**

![Image](image2)

**Picture 5.3. Arm Motion Represents Crane Movements in Three Dimensions**
5.1.1Boom Tip Control

Picture 5.2 and 5.3 shows how the tip of the boom will be controlled through the operators arm movements. The powerful motors of the Falcon controller will provide direct force feedback from the crane and at the same time provide an even level of arm support no matter in what position the arm is in. To accomplish this, the control unit will at the beginning of each workday calibrate to the relaxed operators arm weight.

Further the amplitude of the operator's motions controls the crane speed. Since the Falcon allows 10 cm of movement the resolution between slow precision and very fast movements is high and it can also be adjusted according to the operators wish.

5.1.2Harvester Head Control

Similarly the harvester head will be controlled by the operators hand in a way that the harvester head can be seen as the hand of the crane.
The picture above shows how the operator's wrist movements control the harvester head rotation. Also here the amplitude of motion sets the speed of the machine. This wrist motion will also control the steering of the entire machine as a secondary function.

The inclination of the harvester head will be controlled by the rotating knob at the tip of the hand unit. *(see pic. 5.4)* This knob will also control forward and backward terrain driving of the entire machine as a secondary function.

The Picture below shows the pressure sensitive knob which is the control not only for the harvester head inclination but also for the grapple. The knob is operated with thumb and index finger in a traditional pinch grip and it has three levels of sensitivity: close, hold and release. This is also an analogy as described above. The grapple corresponds to the pinching function of the operators fingers *(see also pic 5.8).*
For felling and processing trees, all these control functions together is designed to give the impression similarly to picking fruit or reaching for an object and picking it up. This is believed to be a motion that is very intuitive and something humans learn during early childhood. The controls are set up to be as kinematically equivalent as possible – arm/boom, hand/harvester-head and pinch-motion/grapple.

### 5.1.3 Force Feedback

An important part of this project was to activate more senses in the control system to further create a deeper connection between operator and machine. It has also been shown that it can raise productivity and reduce tree damage when used on forest machinery (see the theory section about force feedback). This was partly why the Novint Falcon (described under the implementation part above) was used as base for the control system. The Falcon gaming controller already incorporates an advanced and powerful haptic feedback system.

For the hand unit enough room has been given for motorised position sensors both for wrist rotation and the turning knob.

### 5.1.4 Why the Novint Falcon?

As described further in the implementation section Gremo has limited funds to spend on developing and manufacturing their own electronic parts. Further, since the number of sold harvesters is only 50 units/year, it was decided to work with an already developed and market available control system. The Falcon gaming controller included all the necessary functions for this concept at a very low price. With design some changes this device was therefore incorporated in the control system.
5.2 Ergonomic Aspects

5.2.1 Sitting

The saddle seat idea was inspired by the speedboat industry where the high need for passenger stability is similar to that of a forest harvester operating in rough terrain. This higher stability is a result of the fact that the occupant of a saddle seat has more freedom to use his legs to counteract the vehicle movements (pic. 5.9).

![Picture 5.9. Saddle seat for higher stability](image)

Another positive feature of a saddle seat design is the effects it has on decreasing lower back pain related to sitting. This is due to that the saddle seat is promoting a larger leg-to-torso angle compared to a traditional seat (pic. 5.10).

![Picture 5.10. High leg-to-torso angle](image)
The type of saddle seat commonly used in boats has a very narrow profile with a thin upper surface. The total time an occupant sits on these seats is relatively short. In a forest harvester on the other hand the time spent sitting is often full workdays so the demand for comfort is higher. Because of this the seat was given a triangular shape with a large sitting surface but still narrow enough in the front to let the legs have room for movement.

With this design it will also be possible in a larger degree to vary the sitting height and still keep proper foot contact with the cabin floor. A lower sitting height will result in a more traditional sitting position with the pressure distributed towards the wider rear of the seat. While a raised sitting height will utilize the narrower front section of the seat and distribute the pressure also partly on the inside of the occupant's thighs.

As seen in picture 5.9, on the previous page, the backrest is of a semi high design and it ends just below the shoulders. It also has a tapered design which is becoming narrower up towards the arms and shoulders of the occupant. The widest section is sharply curved around the lumbar region. This was done to allow the operator to more freely move his arms with the new control system but still offer necessary stability.
5.2.2 Hand and Arm Issues

As described in the theory section: for a task where the worker has to move his arms during long periods a constant support is needed. This support is provided by the same motors that creates the force feedback in the Novint Falcon unit. If the system is calibrated after the operators arm weight in a relaxed state the system can determine if and in what direction the operator wants to move his arms. As a result of this the motors in the Falcon’s force feedback system can always provide an equal amount of support regardless if the operator is moving his arms or not. The arm support consists of a flexible part allowing a range of arm sizes. The part’s shape which is partly wrapping around the operator’s arm comes from the need that the control unit must be able to follow the arm motion in three dimensions, including upward motion. The pressure of these wrapping parts only need to be very slight since the operator is also fixing his arm to the unit with his grip around the hand unit (See picture 5.12 below).

Picture 5.12. Arm Support and Falcon Unit

The shape of the arm support also comes from the need to easy get in and out of this enclosing part. See explanatory picture below.

Picture 5.13. Getting Into the Arm/Hand Unit
As seen in the pictures above the index finger and thumb is in a precision pinch grip on the turning knob. This was done since this knob is partly the control for the grapple and a more precise grip would be preferable to reduce damage on tree stems when gripping trees. The rest of the fingers hold the hand unit in a power grip and the operator has because of this the possibility to use one finger on any of the buttons situated on the lower front without losing his hold of the unit. The hand unit was given a slight angled position to provide a relaxed hand-to-upper angle of the operator’s wrist (see pic 5.14). This is important to reduce the risk of overuse injuries in the elbow and lower arm.

5.3 Form Language

Gremo AB does not have any design manual or clear design directions for their products. The cabin interior is to a substantial degree a combination of standard components. This could be a reason for the bulkiness and cramped feeling found during the study of the harvester work environment. Because of this cramped environment necessary systems must be placed in a circumferential way around the operator seat. This in turn limits the operator’s view of the environment outside the cabin. To solve this issue it was decided to give the seat an as slim as possible design. This philosophy of lightness was then kept throughout the entire concept.

On the other hand a feeling of robustness must also be kept since this machine is a working tool which the operator must be able to rely on. Since the cabin is rotating with the cranes and the view of the area surrounding machine is very important the main lines was given directions forward-outwards to give the impression that the seat and controls are opening up the view for the operator (see picture 5.15 below).
As described above to give the product a light presence but still robust looking design was a priority through the whole project. To accomplish this, the parts are designed as “naked” as possible. This also means that the design is showing a lot of function which in turn also was considered as a positive effect since it can make the product easier to understand and rely on.

Some parts though could not be completely naked for various reasons. For example the electronic components of the arm/hand control unit needs protection and showing them would make the design look to complex and fragile. Another example of covered function is the chair suspension system. For safety reasons and to protect the components a gaiter is covering them. Even though this is a cover the gaiter is designed to visualize how the suspension function works underneath (see pic. 5.16).
5.4 Colour and Trim

Gremo has been using green as colour for their products for a long time. They also use black and sometimes white or light grey as complements. Green is mostly used for covering hoods and parts in plastic or sheet metal and black is used for functional parts as the crane and under carriage. It is not any connection between the exterior and interior when it comes to colour and trim. The interiors are mostly grey and black plastic or sheet metal. The green was in this project considered a bit “old” looking and not so fitting for a conceptual future design. It is also a colour quite close to some of Gremo’s competitors, such as John Deere and Logman (see pic. 5.17).

![Picture 5.17. Colour Comparison: Logman, Gremo and John Deere](image)

This project was seen from the beginning as a kick start for more design thinking in the development of Gremo’s products. One part of this work would be to analyse the brand colours. Therefore the colour combination chosen for this conceptual design is a proposition for a direction Gremo could take when it comes to brand colours.

![Picture 5.18. Percentage Equivalent Colour Charts for Logman, Gremo and John Deere](image)

The picture above displays the product colours and their approximate percentage of use for the three brands. Green and black is used in a similar fashion for all three. Logman and John Deere both uses slight variations of yellow as an accent colour to highlight for example their logo or lines in their products. Gremo doesn’t use any accent colour but small amounts of white and light grey mostly for their logo which is often placed on the green parts. Gremo’s use of black is far less than the competitors and it makes the black a bit weak in its expression as a complement or supportive colour. Instead Gremo is using their green in a far larger extent, sometimes also for the undercarriage as can be seen in picture 5.17. These two aspects make their products feel static in
their expression. Another issue is that the light grey logo colour doesn’t produce enough contrast against the green to really stand out.

To address some of these issues this concept is proposing a new set of brand colours for Gremo (see picture 5.19). Since the interior normally don’t have any connection with the exterior (colour and shape wise) it can be used as a smooth transit to another colour scheme.

Picture 5.19. Colour and Material for the Final Design

The black supportive colour is used in a far larger extent to create a stronger and more balanced expression. The green is chosen to clearly differentiate the colour scheme from Gremo’s competitors (see picture below).

Picture 5.20. Colour Comparison Charts for Logman, New Proposition for Gremo, John Deere
5.5 Radical Possibilities

There are many ways to picture how best to take advantage of this new control system. This section describes some of these possibilities.

With the less coordination demanding controls it is possible to control a harvester crane with one arm. Therefore it would be possible to operate two cranes in tandem and at the same time control the terrain driving of the entire machine. This would mean a substantial raise in productivity. This is possible because of a shared control system where some functions are run automatically by the on-board computer. The operator fells a chosen tree and drags it to the right place for bucking. With cameras mounted on the both the cranes it is possible for the operator to do easier movements with the two cranes simultaneously. The automatic bucking is then started and the operator can focus entirely on the second crane.
Another possibility is to let the operator mark out a number of trees with the one crane. The automatic system is then using this as a path for harvesting the marked tree while the operator is marking trees with the other crane.

A third possibility involves mixed or augmented reality. Two virtual cranes can be visible through the operator’s headset. With these two virtual cranes the operator is virtually harvesting the trees while the two real cranes is one step behind again using the operators input as paths for automatic robotic control.

An aspect that these have in common is that they will put a demand for high coordination skill back on the operator. In a traditional harvester these skills are needed to control one crane in a smooth and fast enough manner to be economical. But in this future machine they are used for assignments that a human is better at compared to a computer - planning, assessment and supervising. These human skills are in this way also indirectly used to raise productivity.

### 5.6 Result of the Group Work

As described earlier some parts of the 3D models were done by surface modelling students from the Surface modelling education at I12, Eksjö. These students were helping with the modelling and preparation for rapid prototyping of some parts. The parts worked on by the surface modellers are marked with red on the picture below.

![Picture 5.23. Parts modelled by external surface modellers](image)
5.7 Physical model

As described in the implementation section above a physical model was made from 3D printed plaster parts. The parts were printed 3 weeks before the project was finished and some changes and additions to the design was made after the model was finished and therefore the model is not a perfect representation of the final design. The picture below shows the finished model.

Picture 5.24. Physical Model
6 Conclusion and discussion

In this section I will talk about scope and the difficulty in on beforehand seeing the extent of work a project will result in. And by doing this I will also touch the subject of which methods to use and how to use them.

Radical ideas have a certain capacity of generating a lot of new problems. I will discuss the problems that my ideas generated.

I will also go thru the work that must and should be done before this concept can be realizable.

6.1 Scope and Methods

As I have mentioned earlier in this report explaining design and design knowledge seems to be very difficult and the experts in the field themselves admit to having trouble with this. That is the reason this report has the design process, its methods and the actual work performed in this project as the central point. Since every design project is different and every designer works differently it can be dangerous to try to form a model for how to do design the best way.

One thing it is agreed on though is that the most people working with design have in common a very holistic viewpoint. It is a will to include as many aspects as possible and work from the outside inwards to more detailed work as the project progresses. This can be compared to traditional engineering work which often processes in the opposite direction. Engineers tend to start by focusing on the details of their expertise and then figure out a way for all those details to work together.

A project such as this one might not be seen as the typical industrial design project. I think though, that the development of a complex system such as forest harvesters has a lot to gain from taking this holistic viewpoint. This projects starting point was a very loose vision of how to improve this work environment. Visions like these are very helpful when it comes to keeping a whole team with various individual expertises focusing towards the same goal. The danger here though is that the designer forming this vision doesn´t see all the ramifications it could lead in to and because of this the project could get out of control. Another danger is that the designer doesn´t manage to communicate this vision clear enough for others to understand.
In this project both of these dangers was clearly noticeable. In the beginning the ramifications of the project expanded rapidly and were getting very hard to keep an overview on. This was solved by limiting down the project and this in turn goes a bit against the holistic idea. If there had been more time and people constantly involved these limits would not have needed to be set and the result would probably hold more value. As it is now it should be seen as a spark which shows a possibly rewarding direction for Gremo as a company to work against.

The other danger of having trouble communicating the vision was also noticeable and this could have been made differently. Here it is my opinion the sketching and sketching technique plays a vital role. Although a lot of sketching was done during this project a lot of it was done for internal use and not with intent to be viewed and understood. While these types of sketches are very helpful and important more focus should have been placed on making presentable sketches. As an example: to save time a lot of the sketches was divided into part sketches and not showing the concept as a whole. For me as a designer with a clear vision on my mind it is easy to see how all these would fit and work together. In the same time it proved hard to communicate my vision to the stakeholders through these sketches.

More and longer meetings with the company in the beginning could also be a solution to this. More meetings in the beginning would also make project definition work easier. The later evaluation meetings proved very useful and similar session could possibly be done earlier and in that way cut the time it took to set the project direction and limitations.

All of these problems boils down to the difficulty in clearly seeing the entire scope and as mentioned above all the ramifications of a project like this.

**6.2 Ramifications of the Result**

I personally still believe very strongly, as I did from the start of the project, that taking the viewpoints taken in this project would result in a machine where the operator interface is far superior to anything else on the market.

There are though a number of aspects to consider when it comes to the resulting design of this project.
First of all the saddle seat has a lot of different positive aspects as described earlier in this report. A potential problem area though is the fact that its use raises the sitting height of the operator and in turn demands a higher cabin to allow the same view field. The higher sitting height could also mean a better viewing angle of the area close to the machine. This is also according to me a very clear proof that any conceptual design projects of this magnitude would benefit from the holistic viewpoint mentioned above. The cabin, controls, seat and entire interface should be seen as one product.

Further the motorised arm supports are strictly hypothetical and whether this could be a functioning alternative is unclear. Also the wrapping nature of the arm supports needs some flexibility to allow different individuals. This flexibility is thought to be given by the material but what this would mean when it comes to ergonomics and comfort is also unclear.

Another problem could be unintentional movements of the boom controls since the arm support is no longer stationary to the operator seat. This is believed to be solved by the larger magnitude of the falcon control unit’s motions but could still prove to be an area for concern.

When it comes to the more radical idea with double craned harvesters it is easy to see the direct productivity gains this would mean. What is harder to picture is the control problems it generates. Some examples are how to avoid the cranes crashing, how to minimize “empty crane driving” and how the temporary secondary crane should be controlled and supervised.

### 6.3 Future Work

As mentioned above taking a more holistic viewpoint of this project would be necessary. To analyse the cabin design and how it will be affected by the ideas in this concept should be seen as priority when developing this concept further.

Extensive testing with mock-ups and prototypes must be done for all aspects of the concept since some of the functions are very hypothetical and others have yet to prove their full potential.

As mentioned in this report this work was never meant to arrive in a production ready design but more to show a possible direction for harvester interfaces by the use of recent research and recently developed products. Because of this a lot of work in many different areas remains before these ideas can prove their full potential and gain. It is believed that this work could be managed in a period less than 10 years.


7 References


[18] Grandjean, Etienne (1988) Fitting the task to the man


8 Attachments

Attachment 1  Function Analysis of Harvester Cabins
Attachment 2  Function Analysis of Harvester Control Units
Attachment 3  Function Analysis of Harvester Operator Seat
Attachment 4  Function Analysis of Harvester Arm Supports
Attachment 5  Design Brief
Attachment 6  Gantt Chart
## Function analysis

By: Anders Mellberg

**Product:** Harvester Cabin for Gremo AB

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<td>Meet Engineering demands</td>
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<tr>
<td></td>
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<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
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## Function analysis

*By: Anders Mellberg*

**Product:** Harvester Control Units for Gremo AB

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## Function analysis

**By:** Anders Mellberg

**Product:** Harvester Seat for Grema AB

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</tr>
<tr>
<td>Cooperate with</td>
<td>Controls</td>
<td>N</td>
</tr>
<tr>
<td>Allow</td>
<td>Freedom of movement</td>
<td>N</td>
</tr>
<tr>
<td>Offer</td>
<td>Suspension</td>
<td>N</td>
</tr>
<tr>
<td>Meet</td>
<td>Ergonomic guidelines</td>
<td>N</td>
</tr>
<tr>
<td>Be</td>
<td>Durable</td>
<td>N</td>
</tr>
<tr>
<td>Allow</td>
<td>Winter clothing</td>
<td>D</td>
</tr>
<tr>
<td>Offer</td>
<td>Flexibility</td>
<td>D</td>
</tr>
<tr>
<td>Secure</td>
<td>Operator</td>
<td>N</td>
</tr>
<tr>
<td>Be</td>
<td>Intuitive</td>
<td>D</td>
</tr>
</tbody>
</table>

*D* indicates a strong requirement, *N* indicates a normal requirement.
## Function analysis

**Product:** Harvester Arm Support for Gremo AB  

<table>
<thead>
<tr>
<th>Function</th>
<th>Class</th>
<th>Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offer Support</td>
<td>P</td>
<td>For arms and shoulders</td>
</tr>
<tr>
<td>Allow Visibility</td>
<td>N</td>
<td>Of machine and crane</td>
</tr>
<tr>
<td>Display Unity</td>
<td>N</td>
<td>With the rest of the machine interior</td>
</tr>
<tr>
<td>Offer User friendliness</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Meet Ergonomic guidelines</td>
<td>N</td>
<td>For men and women, 95 %</td>
</tr>
<tr>
<td>Be Durable</td>
<td>N</td>
<td>Nordic climate, hot conditions, wear and tear</td>
</tr>
<tr>
<td>Allow Winter clothing</td>
<td>D</td>
<td>Enough room for driver in thick clothes?</td>
</tr>
<tr>
<td>Cooperate with Seat</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td></td>
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<td>N</td>
<td></td>
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<tr>
<td></td>
<td>D</td>
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<td>D</td>
<td></td>
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<td>D</td>
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<td></td>
<td>D</td>
<td></td>
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<tr>
<td>Be Intuitive</td>
<td>N</td>
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</tbody>
</table>

**By:** Anders Mellberg
Design Brief – Forest Harvester Cabin and Interface for Gremo AB

The Gremo Harvester Interface should be seen as something wanting to make life easier for the operator. The whole machine should through the interface transform into an extension of the operators body. It provides higher productivity as well as user friendliness, shorter learning phase and a healthier working situation.

The Cabin is the protection against the elements, a warm and welcoming atmosphere but also refined and sophisticated.

The system lets the operator control 2 separated cranes with high speed and efficiency.

The operator is a professional forest worker with a high understanding of and interest in the forest industry. He also has a big interest in the technology that is connected to his work. He works hard in a demanding, hard pressed situation. Time must always be used to the fullest.

By inviting the operator to move his whole body to control the machine, overuse injuries is reduced. This more dynamic work situation is creating the feeling that the operator is more deeply connected to his machine. The adjustments and user-friendliness makes it feel that it is custom made just for him.

The new interface shows Gremos image as innovative and user focused. The Cabin and Interface should both reflect every aspect described in this brief and at the same time fit together with the rest of the machine both when it comes to design and philosophy.

The range of adjustments makes the product comfortable for most individuals(men and women). The compact and sturdy design shows quality and reliability. The system makes it possible to provide a larger space inside the cabin and a better view of the machine and working area outside the cabin. It also creates a faster and more effective working pattern.

Highly intuitive, user-friendly and effective: The new Gremo Harvester Control system is experienced as the perfect real time link between man and machine!

By: Anders Mellberg