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Development of environmentally friendly chair concept

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Submission date: June 2012
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NORGES TEKNISK-
NATURVITENSKAPELIGE UNIVERSITET
INSTITUTT FOR PRODUKTUTVIKLING
OG MATERIALER

MASTEROPPGAVE VÅR 2012
FOR
STUD.TECHN. LISE ABRAHAMSEN KRATTER

UTVIKLING AV NYTT MILJØVENNLIG STOLKONSEPT
Development of environmentally friendly chair concept

I forbindelse med forskningsprosjektet LPD ble det utviklet og patentert en stolmekanisme (VAPAC) som er patentert i Europa og USA. VAPAC har alt bevisst store funksjonelle, miljømessige og produksjonsmessige fordeler men det har enda ikke vært utviklet en stol som har utnyttet potensialet.

Masteroppgaven har derfor som hovedmål å designe ett konsept som gir best mulig kundeverdi og samtidig størst mulig verdiskapning for potensiell produsent. Viktige deloppgaver blir derfor:

1. Utarbeid forretningsideer basert på alternative kundegrupper og markedssegmenter

2. Utarbeid en kravspesifikasjon basert på valgt forretningside

3. Skissere alternative stolkonsepter basert på kravspesifikasjon

4. Evaluere, velge og designe i 3D den valgte konseptløsningen

I den grad tiden tillater det:

5. Bygge en enkel testrigg for optimalisering av sittekomfort

6. Analysere og optimalisere valgt konseptløsning mht kravspesifikasjonen (design, materiale, stivhet, funksjon, produksjon, resirkulering og transport)

Før kandidaten går i gang med forsøkene, skal han/hun sette opp en oversiktlig forsøksplan som inneholder alle opplysninger om forsøksmetodikk og forsøksbetingelser. Planen skal foreligge til godkjenning innen tre uker etter utlevering av oppgaven.

Besvarelsen redigeres mest mulig som en forskningsrapport med et sammendrag på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse, etc. Ved utarbeidelse av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Med henblikk på lesning av besvarelsen er det viktig at de nødvendige henvisninger for korresponderende steder i tekst, tabeller og figurer anføres på begge steder. Ved bedømmelse legges det stor vekt på at resultater er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte og diskuteres utførlig.

Senest 3 uker etter oppgavestart skal et A3 ark som illustrerer arbeidet leveres inn. En mal for dette arket finnes på instituttets hjemmeside under menyen undervisning. Arket skal også oppdateres ved innlevering av masteroppgaven.

Besvarelsen skal leveres i papirformat i to eksemplarer. Lever også en elektronisk versjon av oppgaven på CD eller DVD i pdf-format.

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Institutt for produktutvikling og materialer

PREFACE

This report is as a master thesis written for the Institute of Product Development and Materials at NTNU the spring of 2012.

I would like to thank my Supervisor Terje Rølvåg. His assets, advice and dedication to the project have been great resources during the whole project.

PURPOSE OF THE THESIS

The purpose of this thesis is to develop a new chair concept based on a unique tilting mechanism called VAPAC (Virtual Adjustable Pivot Axis Chair). This chair consists of a tilting mechanism that offers a new and exciting sitting experience which gives a feeling of sitting in a cradle or a swing.

The chair concept will focus on low environmental impact and ergonomic seating. Concerning the ergonomics, the tilting mechanism will be the most important feature. With regards to the environmental impact, there will be a focus on simple production, few parts, low weight, simple assembly, environmental friendly materials and transportation in the form of a flat packed unit. Functional and simple design will also play an important role when developing the chair concept.

The concept development will be taken to a level that describes the main functions and design of the chair. Results from this thesis shall contribute to the realization of the VAPAC concept as an exclusive product made available on the chair market.

ABSTRACT

The governing purpose of the thesis is to develop a chair concept based on a tilting mechanism called VAPAC. This chair concept has many potential ergonomic and environmental benefits that should be included and developed in the design.

The report starts with an analysis of different segments within the chair market. Based on an evaluation, office chairs was chosen as the segment for the VAPA-Chair. Due to an interesting tilting idea suggested by the Supervisor/Concept originator, a test rig was built in order to try out a chair concept using straps for the tilting mechanism. This assignment was not originally one of the main tasks in the problem definition of this thesis[1]. Due to curiosity and expectations for the idea, it was chosen to include this assignment in the thesis. A user survey reviled that this tilting idea offered an exciting and comfortable sitting experience. The concept using straps as tilting stringers was therefore developed further and important lengths and angles regarding the tilting mechanisms were settled. A problem occurred due to the risk of the chair tilting completely around if the user leans too much forwards or backwards in the chair. Making the stringers stiff so that they can withstand pressure when introduced to a load solved this problem. The tilting function was still the same as with the regular straps because the stringers were attached in joints, allowing the stiff straps to rotate freely. An Idea using turnbuckles as stringer was developed. This solution ensured the required stiffness as well as possibilities for height adjustment and a stop mechanism for the tilting.

The terms "Ergonomic" and "Environmental friendly" is introduced, and important elements from these was set as requirements for the chair concept. Design sketches, doodling and brainstorming generated ideas for different concepts. Different functional concepts was introduced and evaluated as sub-parts of the chair. One concept was chosen for each part resulting in a holistic concept for the chair.

The preliminary work results in a final concept, which is presented in the form of hand sketches and a 3D model using the program NX 7.5 Mechatronics[2]. A lot of time was spent on modeling a simple and functional design with ergonomic and environmental friendly solutions.

A material analysis was conducted regarding the bearing structure of the chair using the Life cycle analysis tool Eco-indicator 99. The analysis compared aluminum and steel. Due to low environmental impact using recycled aluminum, this material was chosen for the VAPA-Chair. A life cycle analysis was also conducted on the chair using the program CES Edupack. The analysis showed that the part of the chair's lifecycle that impacts the environment the most, is the production of materials. Based on these results, it is recommended that the

[1] Formerly found under assignment 5 in the problem definition "If time allows it"
[2] The 3D model of the VAPA-Chair is available in an electronic attachment

VAPA-Chair should focus on weight optimization of the chair and use as much recycled aluminum as possible in the production.

Based on results from the report, a list of recommendations for further work is presented.

SAMMENDRAG

Hensikten med oppgaven var å utvikle et stolkonsept basert på en vippemekanisme kalt VAPAC. Dette stolkonseptet har mange potensielle ergonomiske og miljøvennlige fordeler som burde bli inkludert og utviklet i designet.

Rapporten starter med en segmentanalyse av stol markedet. Basert på evaluering av analysen ble kontorstol valgt som segment for VAPAC stolen. På bakgrunn av en interessant ide fra veileder, ble en testrigg bygget for å prøve ut et konsept der stropper ble brukt i vippemekanismen. Denne oppgaven var opprinnelig ikke en del av hovedoppgaven for denne rapporten[3]. På grunn av nysgjerrighet og forventninger til ideen, ble det valgt å inkludere denne oppgaven i rapporten. En brukerundersøkelse viste at denne løsningen ga en spennende og behagelig sitteopplevelse. Konseptet med stropper som vippende vanger (stringers) ble derfor tatt videre og viktige størrelser og vinkler med tanke på vippemekanismen ble fastsatt. Et problem oppstod fordi det ville det være fare for at stolen skulle vippe helt rundt når brukeren lente seg langt fremover eller bakover i stolen. Dette problemet ble løst ved å avstive vangene slik at de kunne motstå trykk ved påkjent belasting. Vippe funksjonen var fremdeles den samme som med vanlige stropper fordi vangene ble festet i ledd som de avstivede stroppene kan rotere fritt rundt. Det ble utviklet en ide der strekkfisker blir brukt som vanger. Denne løsningen oppfyller kravene til stivhet i tillegg til mulighet for høydejustering og en stoppemekanisme for vippingen.

Utrykkene “Ergonomi“ og “Miljøvennlig“ blir introdusert og viktige elementer fra disse blir fastsatt som krav til stolkonseptet. Design skisser, drodling og brainstorminger genererte ideer til forskjellige konsepter. Forskjellige funksjonelle konsepter ble utviklet og evaluert for ulike deler av stolen. Ett konsept ble valgt for hver del som til sammen gir et helhetlig konsept for stolen.

Forarbeidet resulterer i et endelig konsept som ble skissert med håndskisser og modellert i 3D i programmet NX 7.5 Mechatronics[4]. Mye tid ble brukt på å modellere et enkelt og funksjonelt design med ergonomiske og miljøvennlige løsninger.

En materialanalyse ble utført på bærestrukturen til stolen ved hjelp av livs løps analyse verktøyet Eco-indikator 99. Analysen sammenlignet aluminium og stål. På grunn av de lave miljøpåvirkningene for resirkulert aluminium, blir dette materialet valgt for VAPAC stolen. Det ble utført en livs løps analyse på stolen ved å bruke verktøyet CES Edupack. Analysen viser at det er produksjonen av materialer som er den delen av stolens livsløp som har mest negativ effekt på miljøet. Basert på disse resultatene, blir det anbefalt at VAPAC stolen burde fokusere på optimalisering av vekt og benytte så mye resirkulert aluminium som mulig i produksjonen.

[3] Denne oppgaven stod opprinnelig som punkt nummer 5 “Hvis tiden tillater det“ i oppgaveteksten
[4] 3D modellen av VAPAC stolen er tilgjengelig i et elektronisk vedlegg

Basert på resultatene i rapporten er det laget en liste over anbefalinger for videre arbeid.

CONTENTS

CHAPTER 1: INTRODUCTION

This chapter introduces the background, the basic function of the VAPAC mechanism and the vision of the thesis.

1.1 VIRTUAL ADJUSABLE PIVOT AXIS CHAIR (VAPAC) MECHANISM

This mechanism is invented and developed by Professor Terje Rølvåg and its main purpose is to offer a new and very comfortable sitting experience in a chair. *Figure 1* shows the basic flexible 2D structure where rotation is allowed about a virtual pivot axis. The rotation point is defined by the angle of the structure, and the systems rotation and tilting experience is dependent on the dimensioning of the structure.

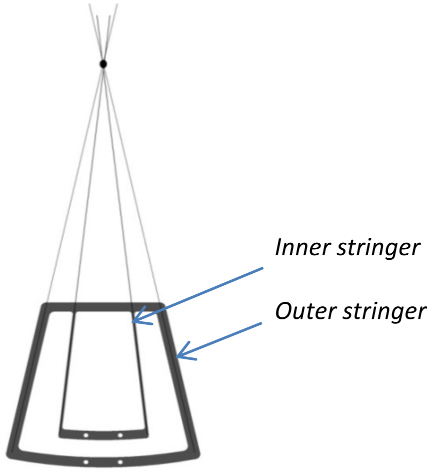


Figure 1: 2D structure of VAPAC

The VAPA-Chair contains two sets of stringers where the inner stringers are attached to the seat of the chair while the outer stringers are attached to chair legs or they work as chair legs themselves. The general idea of the concept is to give a new and unique sitting experience, which gives a feeling of sitting in a swing. By moving the center of gravity backwards in the chair the seat will tilt forward. When moving forward, the seat will then tilt backwards.

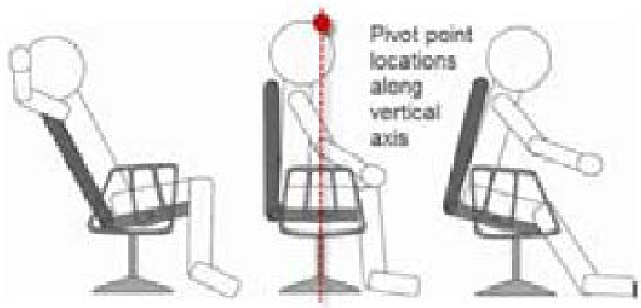


Figure 2: Movement of center of gravity (1)

1.1.1 VAPAC BENEFITS

The VAPAC has many benefits that can give the product an advantage on the chair market.

Ergonomic Benefits

- **Dynamic and pleasant seating**: The tilting mechanism offers a pleasant and dynamic sitting experience, which allows the user to easily switch positions by leaning backwards or forwards in the chair.

Environmental benefits

- **Major reduction in components and assembly operations:** Similar traditional chairs often have heavy and complex adjustment mechanisms that require a comprehensive assembly operation. The VAPAC have an easy assembly and can be flat packed and shipped to a reseller or directly to the user.

- **Simple production:** The production requires less energy than traditional designs. The parts can be easily recycled and no toxic materials are used (1).

1.2 PRIVIOUS WORK WITH VAPAC

The VAPAC mechanism was patented by Professor Terje Rølvåg in June 2010. Since then, there have been several projects evolving the VAPA-Chair. The design company Eker Design AS made design sketches of the VAPA-Chair in 2010, while a master- and project thesis were written the same year at the Institute of Product Development and Materials at NTNU.

Figure 3: Design by Eker Design AS

Figure 4: Model from earlier thesis

In a master thesis written by Patrick Schneider, a functional prototype was developed using a Polyamide Plastic as inner and outer stringers for the VAPAC mechanism. Calculations and analyses were conducted on the stringers before a prototype was developed, but they turned out not to be conformed to the final result. Nevertheless, the prototype still offers the VAPAC tilting (2).

A project thesis written by Martin Kleppe Asphjell, builds on some of the results and recommendations from the master thesis written by Patrick Schneider. Material analyses and simulations resulted in production of three different stringers made of Polyoksymetylene (POM). A functional prototype was also build from an existing chair from Håg, which was modified with the VAPAC stringers. The VAPAC tilting in the prototype turned out to have a fairly satisfying effect (3).

Results, recommendations and experiences from previous work will be used in this thesis to develop the VAPA-Chair even further.

Appendix A shows the details of the patented VAPAC mechanism.

1.3 VISION

The vision and main goal for this master thesis is to:

- Develop an environmental friendly and ergonomic chair concept based on the VAPAC (Virtual Adjustable Pivot Axis Chair) mechanism.

CHAPTER 2: MARKET SEGMENTS FOR CHAIRS

In this chapter, different segments within the chair market will be investigated and evaluated. The segment that seems most fitting for the VAPAC concept will be used in the further development of the VAPA-Chair.

2.1 APPROACH, BRAINSTORMING

A Brainstorming session was held on the 6^{th}. of February 2012. The focus for this brainstorming was to identify different segments in the chair market and the most important requirements in each segment. Results from this session were then used to determine the segments and develop ideas for concepts within each segment.

Brainstorming partisipants:

- Professor Terje Rølvåg, concept originator and supervisor
- Professor Knut Åsland, professor and teacher at IPM
- Bjørg Ganly, PHD at IPM concerning LCA- analysis
- Morten Christophersen, student at the School of Entrepreneurship
- Mats Herding Solberg, student at Industrial Design
- Johanne Eskerud Hovi, student at IPM working with a VAPA-Cradle

2.2 SEGMENTS FOR CHAIRS

Chairs can be categorized in many ways depending on what properties that are emphasized. Some examples are color, price, properties, quality, weight, chairs for different ages or chairs for different kinds of use. For this report, chairs are developed into segments after different kinds of use. These categories can also be divided in many ways but there are some common names for chairs for the same kinds of use. The segments chosen to be investigated in this report are office chairs, lounge chairs, conference chairs and transport chairs. These decisions are based on recommendations from the brainstorming session.

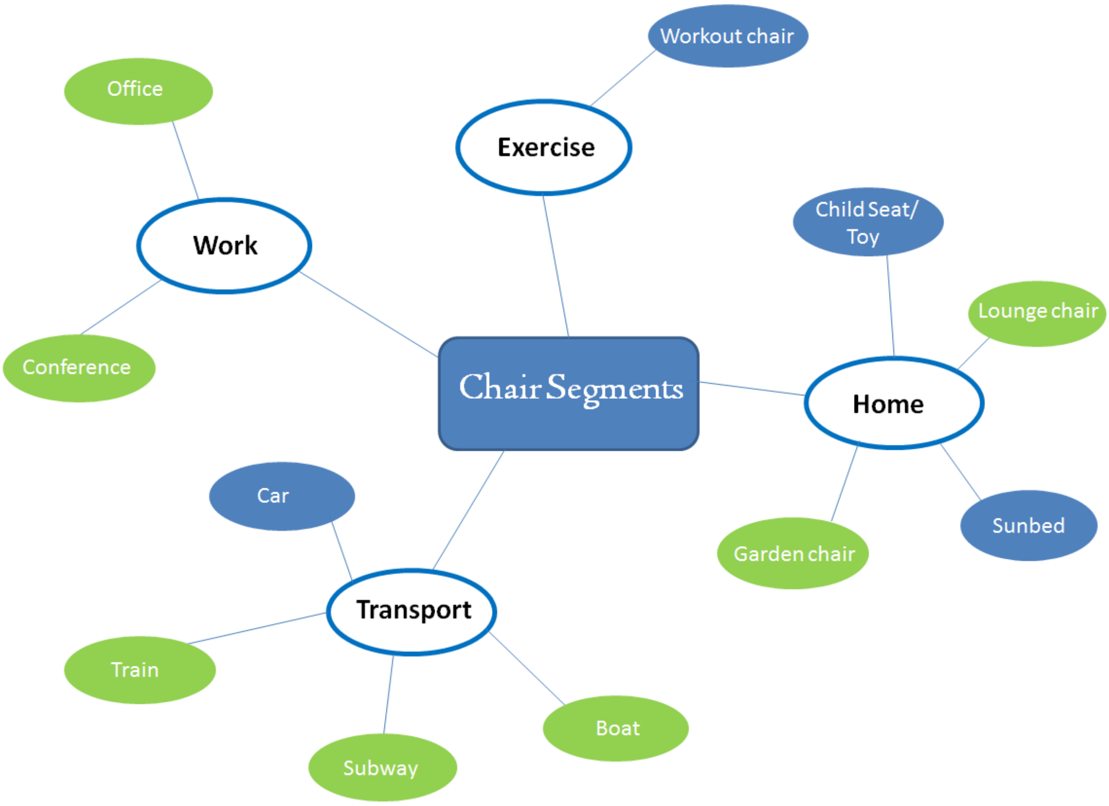


Figure 5: Chair segments. The green dots are the segments investigated in this thesis

2.2.1 WORK

Under the category work, the segment has been divided into office chairs and conference chairs. These two types of chairs are common and important in a working place for a typical company and they have certain requirements concerning use.

Office chairs

Office chairs can be described as chairs that are meant to be used in front of a table where the user is working, often in front of a computer. Sitting in front of a computer or reading and writing on paper often require that the user's back is in an upright position and that the arms rest on the table in front with an angle of approximately 90° (4). For an office chair it is important that the user can be able to do some adjustments on the chair. This is due to the fact that many people have jobs that require sitting for many hours each day. It is therefore important with a comfortable chair that is able to switch positions, height and angle of the back.

Example:

Figure 6: HÅG H09 Inspiration (5)

Figure 7: Klemens work chair from IKEA (6)

The Inspiration office chair from Håg is a modern high-end product which offers a number of different adjustments. Tilting can be adjusted or locked and the height of seat, armrests and headrest can be regulated. The weight is 21.5 kg. The Klemens work chair from IKEA is in a lower price range than the Inspiration and only have the most basic adjustment properties. Seat height and backrest can be regulated. The weight is approximately 9 kg.

How to use the VAPAC mechanism

The mechanism could be used to easily tilt the seat back and forth so that the user can experience a comfortable and varied sitting position throughout a whole working day. This active seating also stimulates the use of muscles in the back and stomach.

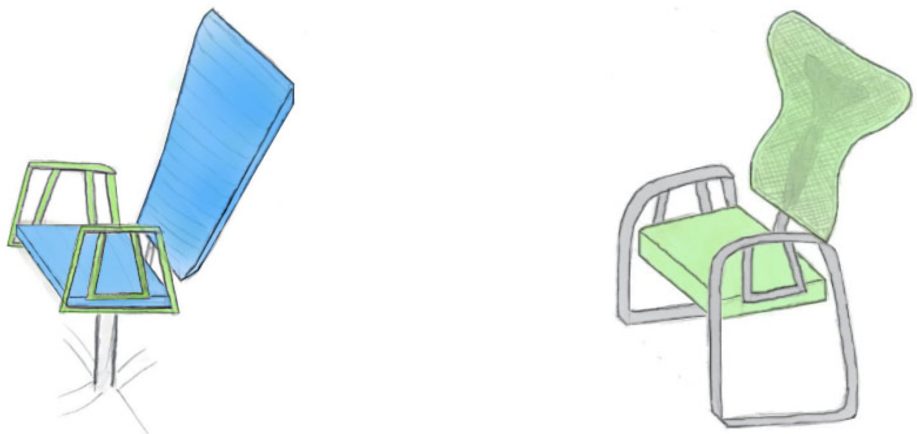


Figure 8: Example designs of VAPAC office chair

Environmental benefits

The VAPAC mechanism may result in an office chair that has a low weight compared to most chairs today in this segment. Because of its simple structure it would also offer less components than similar products, which often contains large and complex adjustment tools for tilting. Due to this, the production of the chair will be simpler and less energy consuming without the need for casting and welding. The structure also makes it possible to deliver the chair as a flat packed unit so that a reseller or the user can assemble it. This saves the costs for industrial assembly and transport, and also makes the product more environmental friendly.

Negative aspects

To be able to develop a lightweight product with few components that can be flat packed, it may not be possible to offer as many adjustment possibilities as the most complex high-end products offered today.

Conference chairs

Conference chairs are typically used in conference rooms at a working place. They are meant to be used for meetings or conferences, which can vary much in time. The requirements concerning comfort and options for adjustments are not as high as for office chairs because the time the user spend sitting in a conference chair is considered much less than for an office chair. Nevertheless, business meetings may last for many hours and it is important that the user can sit comfortable and is able to relax while sitting.

Example:

Figure 9: Hȧg Conventio Wing (5)

Figure 10: Meda Conference Chair (7)

The Håg Conventio Wing is a considerably basic conference chair with the possibility to tilt 12° forwards and 11° backwards (5). The Meda conference chair from Vitra is a high-end product within this segment, with modern leather design details and with a special designed spring underneath the seat, which gives the chair a unique sitting and tilting experience (7).

How to use the VAPAC mechanism

The VAPAC mechanism can offer a simple, dynamic tilting back and forth so that the user can sit comfortable and varied trough short or longer meetings or conferences.

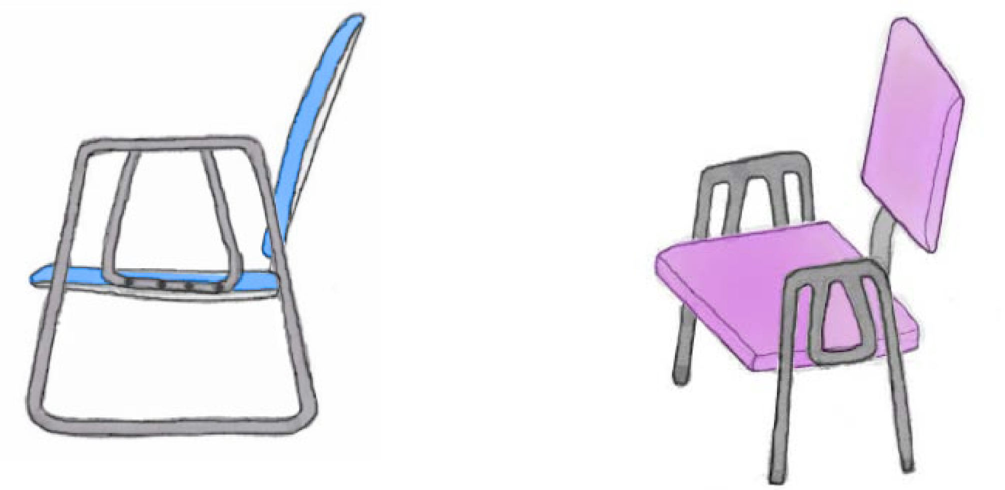


Figure 11: Example designs of VAPAC conference chair

Environmental benefits

The environmental benefits are basically the same as for the office chairs, but since conference chairs often are less complex and lower weight, there will be room for even more simpler solutions. Flat packing however may be less convenient for this segment in order to offer a light and simple chair compared to competing products. Since conference chairs often are ordered in large quantities, it would be time-consuming and inconvenient for the costumer/user to assemble all the chairs themselves.

Negative aspects

Conference chairs is often used on different events where there is a need for more chairs than usual and some of them may get stored away when they are not in use. Chairs that are based on the VAPAC mechanism will probably not be able to stack on top of each other for storage due to the structure. This may cause problems if the area for storage is small.

2.2.2 TRANSPORT

This category can be divided into many sub-segments depending on how many transport methods there is. In the case of public transport, trains and subway chair solutions have been investigated. For private transport, boat chairs are the focus. The segments were chosen due to exiting benefits of the VAPAC mechanisms within these transport methods.

Public transport

In public transport it is important to be able to transport as many people as possible in the most convenient way. The chairs or the seats are often very basic without too many adjustments or padding and with materials that can be easily cleaned.

Example:

Figure 12: First class seats on the Shanghai Maglev train

Figure 13: New York City subway

As shown in the pictures above, train seats are often designed to give a more comfortable transport experience than subway seats. This is probably due to the fact than train rides often last longer than subway rides, and train tickets are more expensive. Simple and space-saving seat solutions are important within both segments.

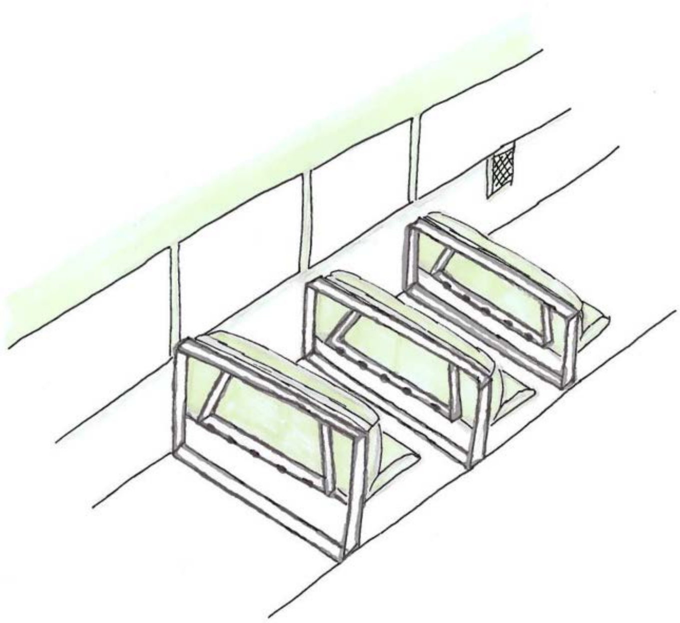


Figure 14: VAPAC Train

How to use the VAPAC mechanism

Trains and subways run on tracks and therefore the passengers experience a different movement than in transport using wheels. When a train moves forward, the passengers at times feel a sideways movement due to turning and irregularities on the tracks. Using the VAPAC mechanism in this direction could even out this movement and give the passenger a more comfortable sitting experience.

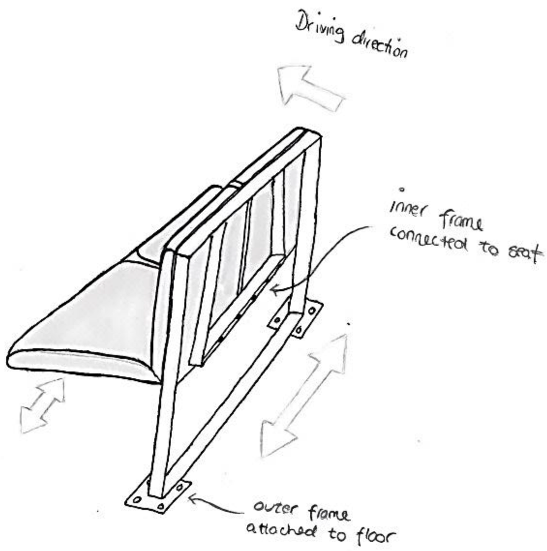


Figure 15: Tilting concept for VAPAC train seat

Environmental benefits

By replacing existing chairs with VAPA chairs it is possible to use more environmental friendly materials.

Negative aspects

The segment for public transport may be a difficult market to infiltrate because of existing contracts with other suppliers and because there are high public demands and standards regarding structure and materials (e.g. crash testing). The VAPA-Chair may be more expensive than existing products, and there is a large uncertainty how this innovative mechanism will be received in this marked.

Boats

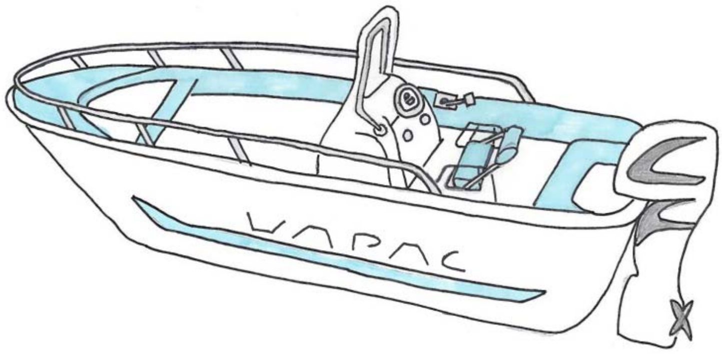


Figure 16: The VAPAC boat

Especially for speedboats, it is important with comfortable seating due to waves and rough seas. It is also important to consider the surroundings due to wear and corrosion. Saltwater affects all metal components that are exposed, and shortens the lifetime of the product.

There are many types of boat chairs on the market today and the price range varies a lot depending on what quality, comfort and amenities the costumer wants. The products within the high-end market are expensive and often heavy.

Example:

The BLUE SEA Maia Pendel Single is a Boat chair that fits most leisure boats in medium size. Chair stand is bought separate and it is possible to choose different kinds depending on which boat or conditions the seat is supposed to be used in and what kind of adjustments the costumer is interested in. The chair stands comes as standards and adapters are used to fit to and mount to different kinds of chairs (8).

Figure 17: BLUE SEA Maia Pendel Seat with three optional accessories (8)

How to use the VAPAC mechanism

By designing a Boat chair based on the VAPAC mechanism, there will be no need for heavy metal components or complicated shock absorbers. The typical movement for a boat follows the waves and the sea. The VAPAC mechanism could reduce the movement from the sea and offer the user a more calm and dynamic sitting experience. By implementing springs to the VAPAC structure, the movement from the sea would be even further reduced.

Because there are many different types of boats and because the sea differs from place to place, there is a need for multiple levels of liability. The VAPAC structure could be offered for different levels of duty. Low duty for boats where stresses from sea and speed are not too extreme, and heavy duty for advanced speedboats used in heavy sea. This way, the VAPA-Chair could offer the right sitting experience for each type of use.

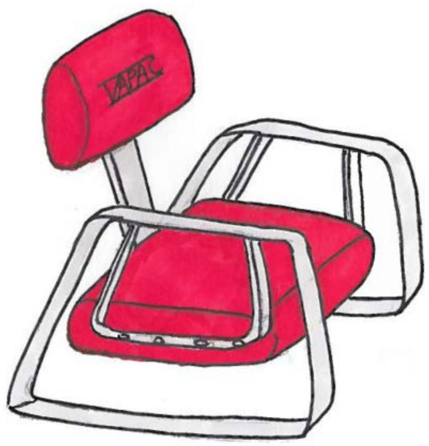


Figure 18: VAPAC boat chair

Environmental benefits

The VAPA-Chair for boats could reduce the need for heavy and advanced metal parts for shock absorbers and adjustments. This way it offers a more environmental friendly solution by using fewer, lighter parts mostly made of plastic. The new solution would also be cheaper to produce and less energy consuming because of the simple structure. It would have longer lifetime due to resistance to wear and corrosion. Other benefits by decreasing the use of metal components are that there is no need to anodize the material in acid and hazarders solutions.

Negative aspects

Because of the harsh environment at sea there are high demands for materials and structure of the chair. Robust materials may not be as environmental friendly as materials that can be used on chairs within other segments. The chair needs to fulfill extensive requirements regarding crash testing.

2.2.3 HOME

Chairs for use in private homes can vary a lot depending on what the user prefer. Some people think that design is the most important criteria for a chair and that it matches the rest for the interior, while other people are more concerned about comfort and function. Many people prefer a combination of these features for their home.

Lounge chairs

Lounge chairs are often used for relaxation whether that means sitting in the chair watching TV, reading a book, taking a nap or surfing on the internet. A requirement to fulfill this means of use is that the user can change position easily from an upright sitting position to a backwards-lying position depending on the user's wishes. For this segment, comfort and design may be more important than for the other segments.

Example:

There are many different kinds of lounge chairs to fulfill different kinds of needs for the costumers.

Figure 19: Optima from Møbel Galleriet (9)

Figure 20: Stressless Eagle from Ekornes (10)

Figure 19 shows a product where trendy design and comfort is combined. It is possible to regulate the back so it can be used to sit or lie in. *Figure 20* shows the popular Stressless chair. This chair was first launched in 1971 and the design hasn't changed much since then. The main focus is comfort, and with the adjustable back it is possible to go from a sitting to a lying position.

Figure21: Reflex. Design by Peter Opsvik (11)

The Reflex chair follows the movements of the human body for an optimal, comfortable and ergonomic sitting experience. The design is urban and exciting.

How to use the VAPAC mechanism

Lounge chairs are a wide segment and allow a lot of creativity and design freedom due to costumer's different preferences and requirements. The VAPAC mechanism could in this segment be used as a design feature as well as offer a comfortable feeling of sitting in a swing. As previously mentioned, the tilting will stimulate the use of muscles in the back and the stomach.

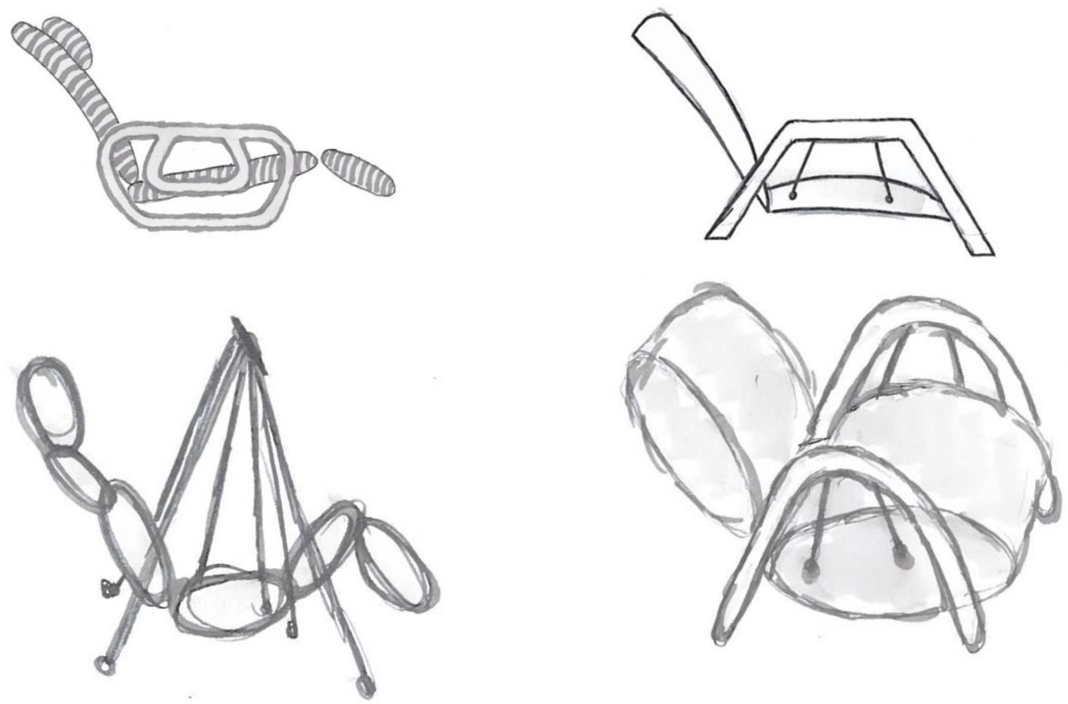


Figure 22: Sketches, VAPAC Lounge chair

Environmental benefits

Because of the simple structure of the VAPAC mechanism it is possible to flat pack the product for self-assembly by the costumer. As mentioned before, this saves the costs for industrial assembly and transport and also makes the product more environmental friendly. Many private costumers wish to choose environmental friendly products and it is possible to design a chair that fulfills this requirement based on the VAPAC mechanism.

Negative aspects

There are no major disadvantages for VAPAC in this segment.

2.2.4 EVALUATION OF SEGMENTS

When choosing a segment for further development, there are many criteria that need to be considered. It is important to figure out which segment the VAPAC mechanism has a sufficient potential. Potential for environmental friendly, ergonomic and innovative design are the most important arguments. The investigation of the segments and the chair market makes it possible to find the best way to realize the VAPA-Chair as a product that can compete with existing solutions on the market.

Segment / Consider-ation	Work		Transport		Home
	Office	Conference	Train/Subway	Private boats	Lounge chairs
Environmental impact	+ Low weight + Few components + "Green" materials + Flat packing + Self-assembly by user + Simple production	+ Low weight + Few components + "Green" materials + Simple production	+ "Green" materials + Simple production	+ Low weight + Few components + "Green" materials + Flat packing + Longer lifetime than existing products ÷ Need robust materials that may have an negative impact + Simple production	+ Few components + "Green" materials + Flat packing + Self-assembly by user + Simple production
Innovative potential	+ New solution for tilting + Interesting design	+ New solution for tilting + Interesting design	+ Offer a new and interesting seating ÷ The public market may not be interested in new solutions	+ Offer a new and interesting seating that can follow the movement of the sea + Interesting design	+ New solution for tilting + Interesting design + The market is open for radical products
Cost	+ Possibility for low production costs		÷ May be more expensive than existing products	+ Less expensive than existing high-end products	
Other	÷ Less adjustment properties than existing high-end products + Prototypes and knowledge from earlier research	÷ Not possible to stack chairs on top of each other for storage ÷ Inconvenient for the user to assemble large quantities of chairs	÷ May be a difficult market due to existing contracts with other suppliers and public demands and standards	+ Corrosion resistant materials ÷ Large demands for materials and structure due to harsh environment ÷ Must fulfill requirements regarding crash testing	+ Market with high focus on design and comfort
Sitting experience	+ Comfortable and ergonomic sitting experience	+ Comfortable and ergonomic sitting experience	+ Comfortable and ergonomic sitting experience	+ Comfortable and ergonomic sitting experience	+ Comfortable and ergonomic sitting experience

Table 1: Evaluation of segments

Based on the evaluation above and by consulting with Supervisor/concept originator, the report will concentrate on the office segment. The VAPA-Chair was originally intended for office chairs, and previous reports written on the VAPA-Chair has been within this segment. This may contribute to develop a well functional, ergonomic, and environmental friendly chair.

CHAPTER 3: REQUIREMENT SPESIFICATION

A Requirement Specification was formulated at an early stage in the project in order to determine goals, requirements and limitation for the development of the VAPA-Chair. The requirements are based on earlier experience and work with the VAPA-Chair, requests from the concept originator of VAPAC, ergonomic research and a user survey. The User Requirements Specification and the Product Requirement Specification will form the basis for the decisions made in the development of the VAPA-Chair in the following chapters in this report.

3.1 USER REQUIREMENT SPECIFICATION

Section	Description	Shall	Should
1	**Use**		
1.1	Easy and intuitive to use	√	
1.2	Offer a comfortable sitting experience	√	
1.3	Offer an ergonomic seating		√
2	**Design**		
2.1	Differ from other products available on the chair market.		√
3	**Assembly**		
3.1	Easy to assemble		√

Table 2: User Requirement Specification

3.1.1 COMMENTS

Requirements regarding use

1.1 The chair should not have too many or complex adjustment mechanisms. It should be easy for the user to understand how to adjust the chair and this should not be a comprehensive action.

1.2 Since the VAPAC is an office chair, it will often be used for many hours each day. It is therefore a requirement that the user sits comfortably.

1.3 The design of the chair should cause no harm to the body and be designed as ergonomic as possible.

Design requirements

2.1 In order to be a successful product on the chair market, the chair should have an interesting and different design from other existing products.

Assembly requirements

3.1 The assembly of the chair should be easy to do with the help of a user manual.

3.2 PRODUCT REQUIREMENT SPECIFICATION

Section	Description	Shall	Should
1	**Functional requirements**		
1.1	The chair tilts easily when the user move its center of gravity		√
1.2	A tilting effect of 22° total	√	
1.3	Adjustable seat height from 400 to 530 mm		√
1.4	Support and function with users in the weight 45-120 kg		√
1.5	Support and function with users in the height 160-190 cm		√
2	**Production requirements**		
2.1	Be able to mass produce		√
2.2	Produce the main components out of one piece of material		√
3	**Environmental requirements**		
3.1	Transport the product as a flat packed unit	√	
3.2	Consist of materials with low environmental impact		√
3.3	Not more than 15 parts		√
3.4	Weigh less than 10 kg		√
3.5	Weigh less than 15 kg	√	

Table 3: Product Requirement Specification

3.2.1 COMMENTS

Functional requirements

1.1 In order to develop an ergonomic solution, the chair should easily tilt without too much physical exertion performed by the user.
1.2 For the requirements of tilting degree, the value from an earlier master thesis regarding VAPAC has been used. This value is based on results from an analysis of existing office chairs (2).
1.3 The chair should have height adjustment in order to let people of different height sit comfortably and ergonomic. The values are taken from the spine medical portal Spine-health.com, developed by a multi-specialty group of medical professionals (12).

1.4-1.5 It is important that the chair is functional for people of different height and weight.

Production requirements

2.1-2.2 The main components of the chair should be produced out of one piece of material in order to get a simple, environmental friendly and economic production. An extruded aluminum profile could be used by cutting it into proper lengths and bending it into the proper shapes. This method will also be suitable for mass production.

Environmental requirements

3.1-3-5:

If the assembly is easy and the chair consists of few parts, the user would be able to do it themselves. The chair could then be delivered as a flat packed product. This will result in large economic savings.

Flat packing the product will result in great space savings during transport. This means that many products could be transported together each time, lowering the negative impact on the environment. This would also result in less costly logistics.

Material selection will have a large impact on the environment and it is therefore important to have this in mind when developing the chair. The materials used for the chair should be nontoxic, and as many materials as possible should be recyclable.

Weight savings will reduce the environmental impact in all parts of the products life cycle. It is also cost efficient. Fewer parts will have the same positive impact. Different weight of office chairs were investigated using a competitor analysis from an earlier VAPAC thesis (2). The average weight is approximately 20 kg. Half of this weight is set as a requirement for the VAPAC in order to stand out on the office chair market.

3.3 PREVAILING STANDARDS

In order to produce and sell the VAPA-Chair, it needs to be designed according to the EN 1335 standard for office chairs. This is a common European standard, which is valid for most European countries including Norway. This standard consists of three parts:

- Part 1: Measurements. Definition of dimensions.
- Part 2: Safety requirements.
- Part 3. Safety test methods.

ANSI/BIFMA X5.1-2002 is a U.S structural standard. The chair company Håg uses this for approval of their chairs combined with the European EN 1335.

Other standards of relevance:

- ANSI/HFES 100-2007 (U.S ergonomic standard)
- BS 5459.2: 2000 (European structural standard)
- AS/NZS 4438: 1997 (Australia, New Zealand ergonomic standard)

These standards are not included in the Requirements Specification for this thesis. This is due to the early stage of the concept development of the VAPAC in this report and due to the limited availability on the standards. In order to develop a reasonable concept with regards to design, the VAPAC has been compared with other office chairs which follow the prevailing standards. In the recommendations for further work section (Section 9) in this report, the standards will be mentioned as a matter for investigation.

CHAPTER 4: TEST RIG FOR VAPAC STRAPS

The previous work done on the VAPAC mechanism concerning dimensioning, calculations and prototyping, has been conducted with stringers made of plastic that has some degree of stiffness. The inner and outer stingers have both been made in the same material, with the same properties, produced as one part. Based on previous experience with the VAPA-Chair, the supervisor/concept originator suggested trying out a more flexible material for the VAPAC mechanism like a belt or strap solution. The possibility for using straps as inner stringers has been investigated in this chapter by building a test rig. This solution could result in a very comfortable sitting experience.

The biggest concern of the strap solution is that the seat and the backrest could flip around causing the person sitting to drop on the floor. This can happen due to the lack of stiffness in the material. If the person sitting in the chair leans too much forwards or backwards, the whole chair can tilt around. If this is an issue, it may be possible to prevent this with some kind of safety strap or lock.

If this concept seems feasible, the test rig is also used to find the proper angels and positions for the inner stringers in order to get the preferred tilting experience.

4.1 APPROACH

Mounting 12 Aluminum beams together made the supportive frame of the test rig. These beams have slots so that casters can be regulated back and forth on the frame. The casters are attached to the stringers and this way it is possible to adjust the angle of the inner stringers. The height of the inner stringers can by adjusted using clamps on the straps. Smaller beams are attached to the stringers and a chair seat, allowing even more adjustment possibilities. The height of the chair can also be adjusted. The seat used for the test rig is taken from an earlier VAPAC prototype. (Octan office chair from Skeidar)

Figure 23: Beam with slots and caster

Figure 24: Test rig

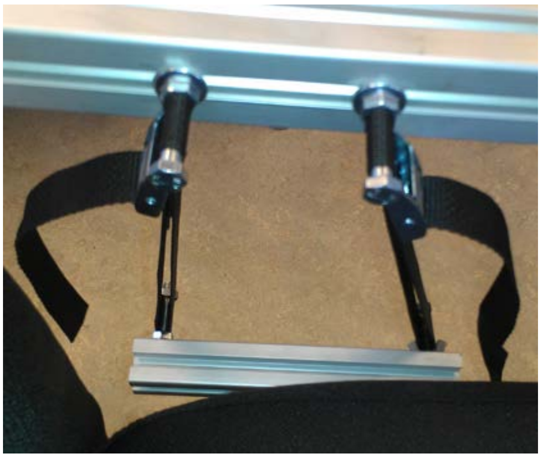


Figure 25: Inner stringers made of straps and beams

Figure 26: Adjustment possibilities on the test rig

4.2 FINDING THE RIGHT ADJUSTMENTS, USER SURVEY

In order to find a comfortable and safe tilting mechanism for most people, it was important to get opinions from users with different weight, height and gender because the tilting may feel somewhat different for each person. 16 people participated in a user survey where they were asked about the sitting comfort and how they would like to have the stringers adjusted. Each participant had the chair height adjusted to a height they personally prefered. It was a focus on finding test participants with different heights and bodyshapes.

In order to conduct the user survey, some of the adjustment possibilities had to be determined in advance. This is due to the complexity of the user survey if the all the parameters were adjustable for each participant. First, the stringers and the beams attached to the seat were adjusted and attached so that the seat and the backrest were balanced and stood steady.

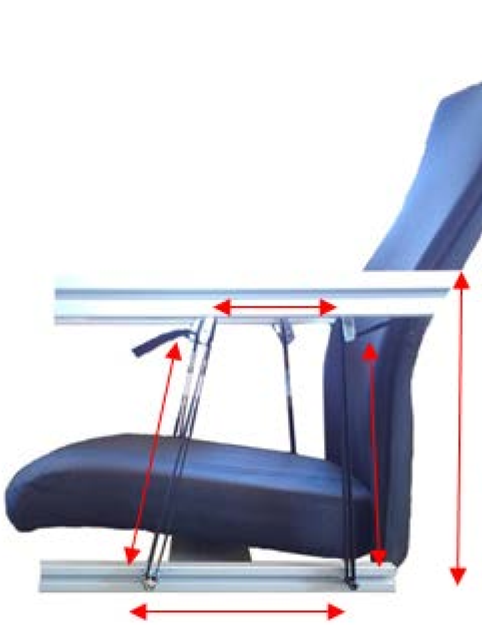


Figure 27: Adjustment parameters

- A fixed height from the seat to the armrest was decided, this by adjusting the length of the straps until a person with a height of 180 cm sat with the albows and the lower parts of the arms resting with an elbow angle of 90° (4). The height was set to 200 mm and compared with the height of earlier VAPAC prototypes and two regular Håg office chairs in order to know that it was reasonable.
- Since it is a desire to spend as little force as possible in order to tilt back and forth in the chair, the virtual pivot axis of the VAPAC mechanism was placed approximately above the center of gravity for a person sitting straight up in the chair with the seat flat.

- The tilting effect was set to approximatly 11° forward and 11° backwards in accordance with the Product Requirements Specification. If the tilting exeeds this value, the stringer will collaps due to the lack of stiffness in the straps.

Three test persons participated in determine the values from the requirements above. *Figure 28* shows the values set prior to the user survey.

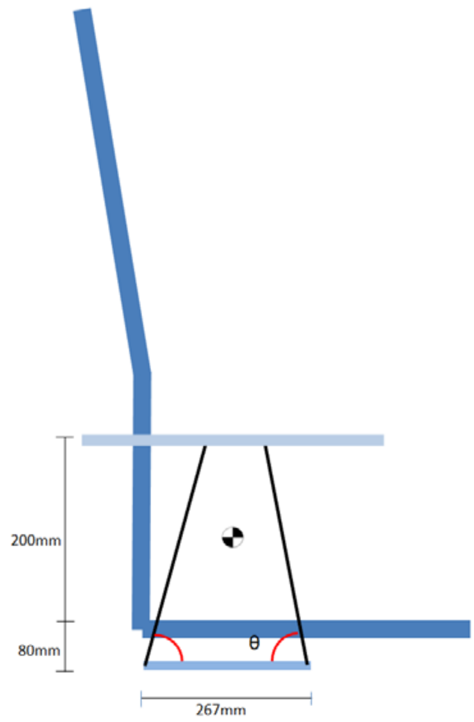
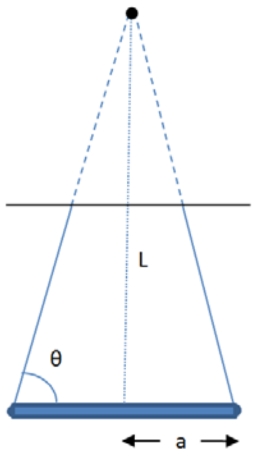


Figure 28: Predetermined parameters

Three different tilting angles (*ϑ in figure 27*) were prepared to be tested in the user survey. They were decided by the three test participants who contributed to the preset settings. By moving the casters on the armrests back and forth, they tried out multiple effects and iterated their way to determine the three angles.

The 16 test participants were asked which of the three settings they liked the most and rated the sitting comfort from 1 to 6. The results were then analyzed with regards to gender, height and weight in order to understand if these factors would have an impact with respect to the tilting. During the test, the participants were also asked about the general sitting experience and the comfort.



Figur 29: Inner stringer

The three tilting angles are A: 70°, B: 75 ° and C: 78°. The virtual pivot point will differ for each angle and the tilting frequency will therefore also differ.

$$\tan\theta = \frac{L}{a} \rightarrow L = a * \tan\theta$$

$$L_A = 366{,}8mm$$
$$L_B = 498{,}2mm$$
$$L_C = 628{,}1mm$$

The frequency decides the tilting effect of the mechanism. It was not possible to obtain any relevant data concerning tilting frequency with regards to sitting comfort. Due to this, the tilting frequencies were not calculated. Nevertheless, the equations relevant for this tilting effect were derived and they are available in Appendix B.

4.3 RESULTS

Gender [M/F]	Height [cm]	Weight [kg]	Alternative A: 70° (1-6)*	Alternative B: 75° (1-6)*	Alternative C: 78° (1-6)*
F	166	53	6	3	1
M	185	85	6	3	4
M	199	108	4	6	5
M	185	78	5	4	6
F	170	62	3	6	5
F	175	56	5	6	3
M	186	105	2	5	4
M	179	78	3	4	5
M	189	87	5	3	2
F	165	65	4	6	1
M	179	77	3	4	5
M	180	74	2	5	2
F	178	70	4	6	5
M	180	75	4	6	3
M	180	70	5	6	4
M	182	73	5	4	3
	Average: 180	Average: 76	Sum: 66	Sum: 77	Sum: 58

Table 4: Results from user survey

******The numbers 1-6 is a rating of how comfortable the sitting experience is. 1 is bad, 3 is “ok”, while 6 is very good. The participants were asked to compare and rate the comfort with regards to other office chairs they had used or tried before.*

Votes: A: 32.8 %, B: 38,3%, C: 28,9%

Table 4 shows that alternative B was rated as the most comfortable alternative. It won by 5.5% so the result did not distinguish very much. When looking at the general comfort, alternative B got 80,2%, alternative A got 68,8% and alternative C got 60,4%. B is therefore considered a pretty comfortable sitting experience while C is considered as slightly better than “ok”.

It was not possible to find any specific pattern between height, weight or gender with regards to the sitting experience. Only 5 out of the 16 participants were females. 50, 9% of the female rating was for alternative B so this is slightly higher than the total percentage for this alternative. A reason for the lack of opposing opinions may be that the high flexibility of the straps makes it easy for everyone to tilt back and forth.

The test reveals that some kind of mechanism has to be implemented in order to avoid the chair to tilt around when leaning far back or forth in the chair.

4.3.1 GENERAL FEEDBACK

- “The chair is fun to sit in.”
- “When using Alternative A, the chair feels a bit unsafe to sit in.”
- “It feels very relaxing when leaning back in the chair.”

The general feedback from the test participants was positive and actually everyone said that the chair was comfortable to sit in. Several people pointed out the fact that the back follows the body when leaning forwards and backwards in the chair and they thought this gave a good support in many positions. Some people said that when trying alternative B the tilting felt natural and that it was effortless to tilt. The same persons pointed out that when sitting in alternative A, they wanted to reduce the tilting while they tried to force the tilting when sitting in alternative C.

4.3.2 SOURCES OF ERROR

- When adjusting for the three different angle selections in the user survey, the prefixed parameters may have changed a bit.
- The seat and backrest used in the test rig is not identical with the final product the user survey is intended for. Structure and weight difference may cause the tilting experience for the final concept to differ a bit from the test rig.
- Since the prefixed parameters are settled only using three test persons, they may not be optimal for all people since weigh, body structure and comfort preferences may differ from person to person.
- A test group of 16 persons will not give a fully impression of the whole user group for the VAPA-Chair. The survey is intended to give an indication of how the tilting comfort is perceived.

4.3.3 EVALUATION OF USER SURVEY

Based on feedback from test participants, a VAPAC mechanism using straps as stringers is considered as a promising solution and it will therefore be used further in the report developing the VAPA-Chair.

When evaluating the results from the User survey it is important to consider the many sources of errors. With these considerations in mind there is still a fairly favor of alternative B with a tilting angle of 75°. This value will therefore be used further in the report.

CHAPTER 5: AN ENVIRONMENTAL FRIENDLY AND ERGONOMIC VAPA-CHAIR

This chapter explains the terms Environmental friendly and Ergonomic, and which features from each category that will be implemented in the design of the VAPAC.

5.1 ENVIRONMENTAL FRIENDLY, WHAT DOES IT MEAN?

The word "Environmental friendly" is often associated with products or services that cause minimal or no harm to the environment. The terms "Eco-friendly" or Green" is also used to describe the same. Environmental friendly is a widely used word and it can be defined in different ways, and therefore there is no standard international definition for this term. Sometimes it is used in wrong and scheming ways to "Green wash" a product; that means to give a false impression of a product or service that may be harmful to the environment.

5.1.1 ENVIRONMENTAL FRIENDLY POTENTIALS

In this thesis, it is a focus on environmental friendly solutions when developing the VAPA-Chair. Nevertheless, the report will not cover all possible environmental benefits for the product. As mentioned in the introduction, the VAPAC have some potential benefits that can result in environmental friendly solutions.

Based on the Requirement Specification, the following environmental initiatives will be the main focus for this report:

- Recyclable materials
- Nontoxic materials
- Assembly by reseller or user
- Disassembly by user in order to recycle
- Low weight
- Few parts
- Transport the product as a flat packed unit
- Simple production with low energy consumption

5.1.2 LIFE CYCLE ASSESSMENT (LCA)

A Life Cycle Assessment (LCA) can contribute to develop an environmental friendly product. *"LCA addresses the environmental aspects and potential environmental impacts throughout a products life cycle from raw material acquisition through production, use, end-of-life-treatment, recycling, and final disposal (i.e. Cradle-to-grave)"* (13).

By investigating the different stages for a product through the whole life cycle, it is possible to determine which stages that are the most critical concerning the environmental impact and what part of the cycle that need further improvements or new solutions. *Figure 30* shows a typical life cycle for a product.

Figure 30: Life cycle phases for a product (14)

A Simple LCA analysis will be conducted in chapter 7.8, investigating potentials for improvement for the developed concept.

5.1.3 ECO-INDICATOR 99

The Eco-Indicator 99 is a tool intended to give designers an indication of how a product will impact the environment. It is a simplified LCA which purpose is to help designers making clever decisions regarding environmental impact during product development.

A simple eco analysis will be conducted in chapter 7.6.1, comparing different materials based on environmental considerations.

5.2 ERGONOMICS, WHAT DOES IT MEAN?

"Ergonomics, also known as human factors, is the scientific discipline that seeks to understand and improve human interactions with products, equipment, environments and systems. Drawing upon human biology, psychology, engineering and design, ergonomics aims to develop and apply knowledge and techniques to optimize system performance, while protecting the health, safety and well-being of individuals involved" (15).

When developing products that interact with humans, ergonomics is a crucial requirement for the design. For a chair, the interaction lies in the seating, and it is this interaction of ergonomics that is of interest for this report.

5.2.1 SITTING WHILE WORKING

More and more people spend most of their working day sitting in front of a desk. Depending on what type of work a person is doing or on a person's energy level, the sitting positions are different. A usual way to sit is with a straight back with the arms resting on a desk with an elbow angle of approximately 90° and with the legs straight down from the seat. If a person is working energetic on a computer or is reading or writing something on the desk it is normal to lean forward over the desk and this way move the center of gravity forward. In this position the feet will often automatically move backwards underneath the chair for a comfortable posture. When a person want to sit more relaxed and leans backwards in the chair, the center of gravity also moves backwards and the feet are often positioned stretched out under the desk (16).

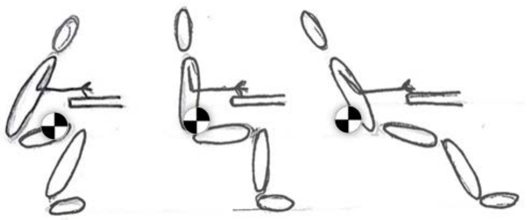


Figure 31: Sitting positions and center of gravity

When people are sitting they always try to find the best position depending on what they are doing and what they are sitting on. Former standards and guidelines on chair design tell how to sit in a "correct" way. Even though these standards exists, more and more experts realize that these few positions are not well fitted to all people and that it is important to switch between many positions (17).

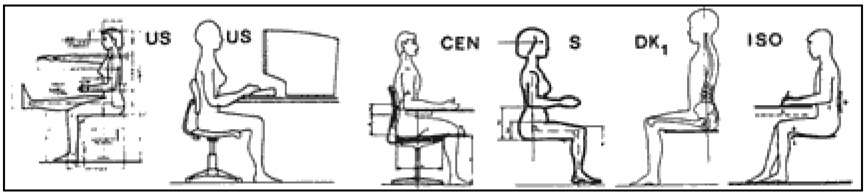


Figure 32: Former international standardizations for proper sitting positions (18)

Even though a person sits in a comfortable and in a "correct" way, it is not natural for a human to sit still in the same position for a long time. Even the "best" position becomes uncomfortable after a while. The Norwegian Industrial designer Peter Opsvik is a well-known chair designer. His quote: "*The best posture is always the next one*", is a suitable description of the mindset for a person sitting in a chair. It is important that a chair offers the opportunity to switch positions and offer comfort and support in multiple postures.

Tim Springer, president and founder of HERO (Human Environmental Research Organization, Inc.), is considered as one of the top two or three experts in the world on issues of work behavior and the work environment. His research on ergonomic office seating points out 6 criteria on what an office chair should do (17):

- **Support a person's body**
  No humans are alike and a chair should be able to fit all body types and individuals of different sizes.

- **Support activity**
  Throughout a working day, people do different tasks for different time periods. It is important to endorse all these types of activities.

- **Promote movement**
  The natural movement of the body should be promoted and encouraged by the chair. A chair should also support these natural movements. Movement should be easy and effortless and not be constrained.

- **Enable performance**
  An ergonomic office chair should contribute to improved performance and enable people to be more effective while working.

- **Be easy to use**
  Most office chairs have multiple adjustment possibilities in order to fit individuals of different sizes. Research shows that chairs which require activating a control in order to change positions, those controls are seldom used (19). People do not want to think about their chair while they work and therefore it is important that it is easy to use.

- **Do no harm**
  A chair should not cause pain, stress, injury or any discomfort to the body. The chair design should also minimize negative impact on the environment with regards to production, transport, use and disposal.

These 6 requirements will be used as goals when developing an ergonomic solution for the VAPA-Chair.

CHAPTER 6: DEVELOPMENT OF COMPONENTS

This chapter will focus on developing different sub-parts for the final design of the chair. Different concepts for each sub-part will be presented and evaluated based on predetermined requirements or considerations based on research.

6.1 ERGONOMIC DESIGN OF COMPONENTS

The backrest and the chair seat of the VAPA-Chair will be developed considering the requirements described in chapter 5.2.1.

6.1.1 DESIGN OF THE BACKREST

When sitting in a chair for a longer period of time, it is important that the body get sufficient support. If not, there is a high risk of developing back, neck, shoulder or head pains. The most important concern regarding this is the lower back. It is vital to support the luminary spine so that it will keep its natural and correct curve. If a person sits “slumped” forwards for a long time there is a risk of overstretching the spinal ligaments and strain the spinal discs causing back pain (20).

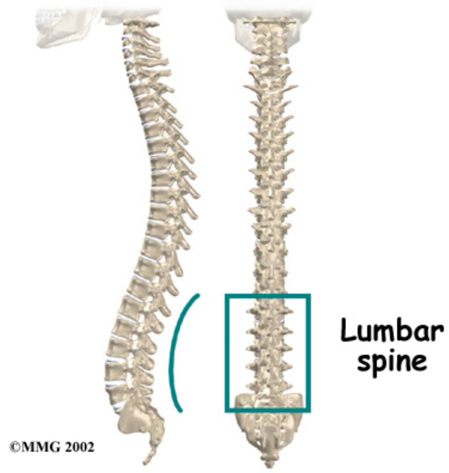


Figure 33: The spine and its natural curvature (21)

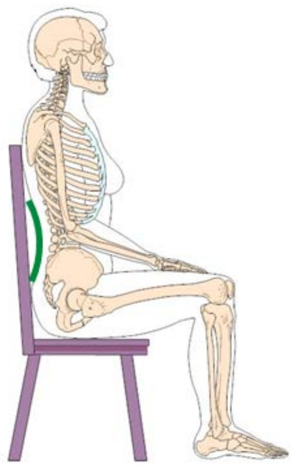


Figure 34: A sitting person

For the chair backrest it is therefore important that the shape supports the back and lets the spine rest in a natural curvature. The VAPA-Chair will focus on ensuring a shape that supports the lower back in a way that fits most users. Based on a research on lumbar disc pressures and myoelectric back muscle activity during sitting, a lumbar support should fall somewhere between 15-25 cm from the chair seat (22). The backrest should also support the neck, shoulders and the upper parts of the back in a way that allows the user to relax in a natural curvature.

With regards to tilting, the backrest should support the lower parts of the back in all positions. *Figure 35* shows some working positions and how the VAPAC mechansim follows the movement of a person sitting in the chair in front of a working desk.

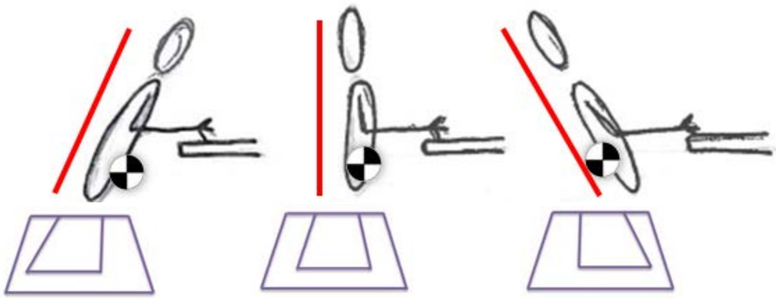


Figure 35: Sitting positions

Additional support

Due to the fact that people have different height, weight and shape, it is challenging to develop a chair backrest that fits all body types without adding too many adjustment features. An alternative is to introduce different pillows for additional support. One pillow should give support to the neck area, while one pillow should be for lumbar support. They could be attached with elastic bands that fit around the VAPA-Chair backrest, and can be adjusted up and down on the backrest in order to support all people. These pillows could be offered to the VAPAC users as optional accessories.

Figure 36: Support pillow (23)

The pillows should be designed using memory foam to be able to adapt and support the natural curvature of each unique human.

6.1.2 DESIGN OF CHAIR SEAT

The seat of the VAPA Chair must be short enough to ensure contact for the lower back and the backrest without feeling pressure behind the knees, but still be long enough to support the legs and not cause pressure on the mid-thigh area (24).

6.2 APPROACH, DEVELOPING CONCEPTS

6.2.1 BRAINSTORMING

On the 22th. of April 2012, a brainstorming session was held concerning design and function. The following people were participating:

- Terje Rølvåg, supervisor and inventor of VAPAC
- Johanne Eskerud Hovi, student writing a master thesis on a VAPA-Cradle
- Mats Solberg, master student in Industrial Design
- Trond Are Øritsland, professor in Industrial design
- Hege Berg Bache, master student at IPM

During the session, the participants were asked to come up with ideas for esthetic, yet functional designs. They were also asked to keep environmental aspects in mind. Interesting and creative solutions came up during the meeting they were discussed further by the whole group.

Professor Trond Are Øritsland suggested that the esthetic design of the chair should evolve around the VAPAC function and that this feature should be clearly visible and prominent in the design. This was well received by the rest of the group because the design would focus on an innovative feature and this way differ from existing office chairs. Due to positive feedback this idea was recommended to be an esthetic requirement for the VAPA-Chair.

Figure 37: Brainstorming session

Figure 38: Sketches from Brainstorming

6.2.2 SKETCHING

Throughout the whole duration of the project, a lot of time has been spent on sketching different ideas for design. This has been an iterative process with a lot of editing and rejection of concepts. Friends and fellow students have contributed with ideas and comments along the way.

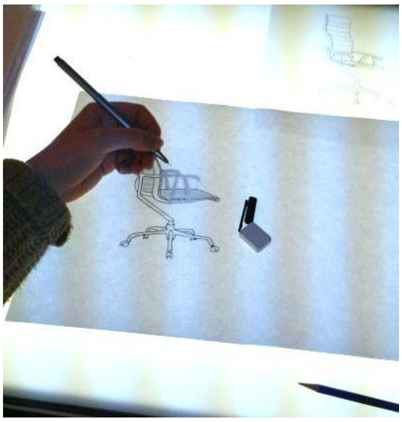


Figure39: Sketching

6.2.3 INDUSTRIAL DESIGNER

The supervisor/concept originator hired the industrial designer Atle Stubberud from the company Soon Design AS to look at some design solutions for the VAPA-Chair. The concepts he came up with were used as inspiration when developing creative ideas for the chair.

Figure 40: VAPAC sketches by Soon Design AS

6.3 SURROUNDING ENVIRONMENT

When introducing a new product to a market, it is important to offer an appealing design concerning the segment the product is introduced to. As mentioned in chapter 2.2.1, office chairs are mostly used in the office environments in public and private companies. They are also used in personal offices in private homes. For this segment the functions and properties are important and the design therefore needs to consider this. The chair also needs to fit into the surrounding environment, in this case an office.

Companies and offices often try to keep a minimalistic and lean design without too many different colors and designs to give a clean and orderly overlook in the office environment. The VAPAC need to match the surrounding interior and facilities.

Figure 41: Office environments (1-6)

6.3.1 ESTHETIC DESIGN, TRENDS 2012

With regards to appealing design, these are trends that vary from place to place, from person to person and it changes with time. It is hard to determine specific Interior design trends and they can change often while some stays for many years. For the recent years, a new segment within interior design has become popular. Interior inspired by industrial design has become a new urban expression. Inspired by old large warehouses, the furniture are made of natural materials like metal and wood used in their raw form combined with basic and worn materials like leather or linen. Colors are carefully used without taking the focus from the natural materials (25). For an office chair like the VAPAC, this could have several benefits. One benefit is that the chair would be environmental friendly because of the use of raw materials instead of processed ones. In additions, the clean and simple industrial design makes it easy to draw the esthetic focus to the function of the chair; the VAPAC mechanism. Hopefully, with a design like this, the VAPA-Chair design will stay relevant and have an appealing appearance for many years.

6.4 IDEAS FOR DESIGN

The approach described in this chapter resulted in multiple ideas for design. *Figure 42* represents some of the different designs developed at this stage in the process.

Figure 42: Different ideas for chair design[5]

[5] The VAPAC mechanism has not been included in all the pictures.

6.5 CONCEPTS FOR COMPONENTS

Before developing the final chair concept, the design of different parts on the chair has been investigated. This is to ensure the best solutions for each component before combining them to a holistic product. The chair is divided into four parts; stringers, chair legs and backrest and seat.

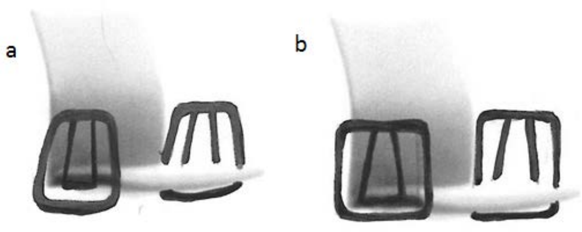
6.5.1 STRINGERS

The stringers are responsible for the main function for the chair; the tilting. It is an important design feature for the chair and it have additional functions like armrests and can also be used as chair legs.

Different shapes were investigated and evaluated with respect to function and tilting. It is important that the structure allows proper tilting so that the VAPAC mechanism is functional.

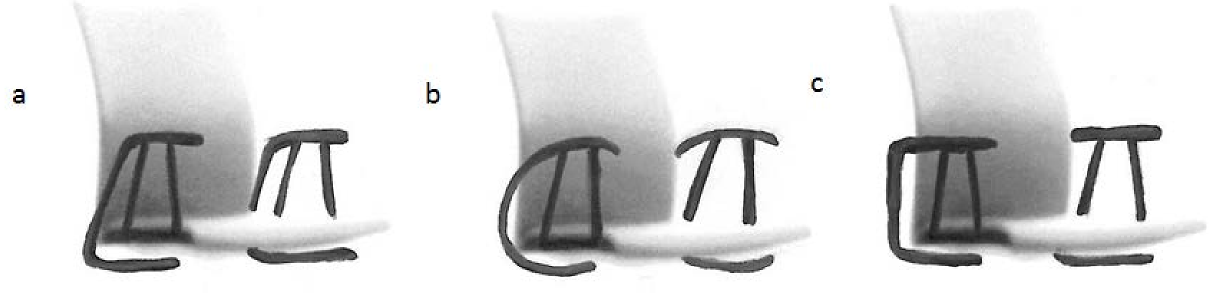
Outer stringers

Concepts for the outer stingers will be evaluated. The outer stringers are the bearing structure of the chair that attaches the inner stingers to the chair legs. The criteria for the evaluation are function, esthetic design and strength of the structure.



Concept 1:
A square structure around the inner stringers

+ Strong structure
+ Experience with structure from earlier VAPAC projects
÷ Slightly massive structure
÷Does not distinguish much from other office chairs compared to the other concepts
÷ Does not show the function of the VAPAC mechanism very well

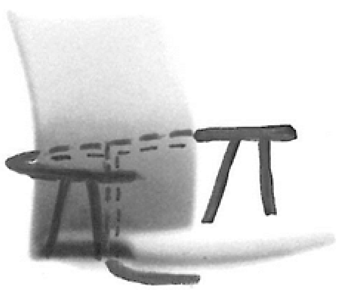


Concept 2: The same as concept 1 without the front part of the structure

+ Lean and discrete structure
+ Innovative design
+ Small amount of materials needed
÷Not as structurally strong as concept 1

Concept 3: The same as concept 1 without the front part of the structure

+ Innovative design
+ Lean and discrete structure but maybe not as discrete as concept 2
+ Small amount of materials needed
÷ Not as structurally strong as concept 1



Concept 4:
Framework behind and underneath the chair backrest and seat

+ Innovative design that distinguish a lot from other office chairs
+ No need for outer stringer structure, lean and discrete design
+ Allows a high degree of tilting
+ Shows the function of the VAPAC mechanism very well
÷ No experience with regards to structure from earlier work with VAPAC

Evaluation

Based on the pros and cons for the different concepts, concept 4 will be used for further work in this report. This is mostly due to the interesting and innovating design and the good tilting possibilities. The concept is based on an idea that occurred during a brainstorming session.

Inner stringers

In chapter 4, a test rig was developed in order to test the possibility of using straps as inner stringers. A user survey was conducted and the responses were positive. The angles of the stringers were set to 75°. During the testing it occurred that there is a risk that the seat of the chair may tilt all the way around backwards or forwards due to the lack of stiffness in the material of the inner stringers. To prevent this, some kind of safety strap could be attached underneath the seat and to the chair legs. With respect to the esthetic design and the complexity of this mechanism, this may not the best solution.

Another way out of this problem is to apply some stiffness to the stringers. In order to offer the same type of tilting as with regular straps, the stringers need to be attached to the seat and to the armrests with joints. It will than allow rotation in the x and z direction. If a solid beam were placed inside a thin leather strap, the stringers would still look like regular straps but it would also offer the required stiffness.

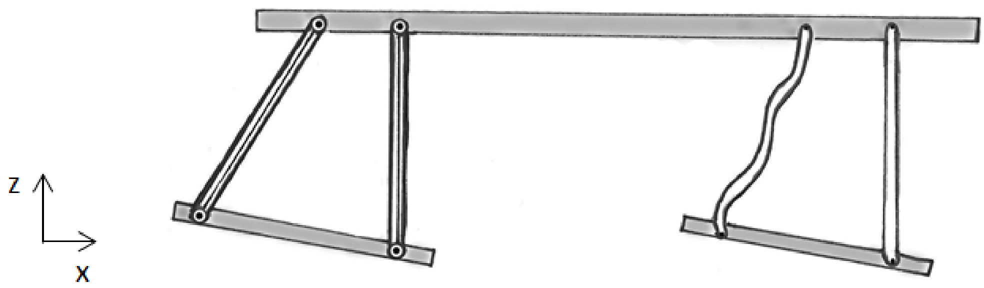


Figure 43: Tilting results for the new (left) and old (right) stringers

Stringer support, turnbuckle

A turnbuckle could be placed inside the leather straps in order to offer the required stiffness. It would also be a simple way to attach the stingers to the rest of the chair by using bolts trough the holes in the mounting head of the turnbuckle and into threaded holes in the chair. The bolts should be threaded in each end. Prior to the attachment, the height of the armrest could be adjusted to fit the user by turning the turnbuckle to a proper length. Another benefit with this solution is that the tilting could be stopped by applying a wing nut to the bolts connected to the chair seat. This way the user could turn the wing nuts until the stingers are stuck in the wanted position. With regards to safety, it is important that it is not possible to remove the wing nut from the bolts and disassembly the stringers from the chair. *Figure 44* explains and shows the function of the turnbuckle.

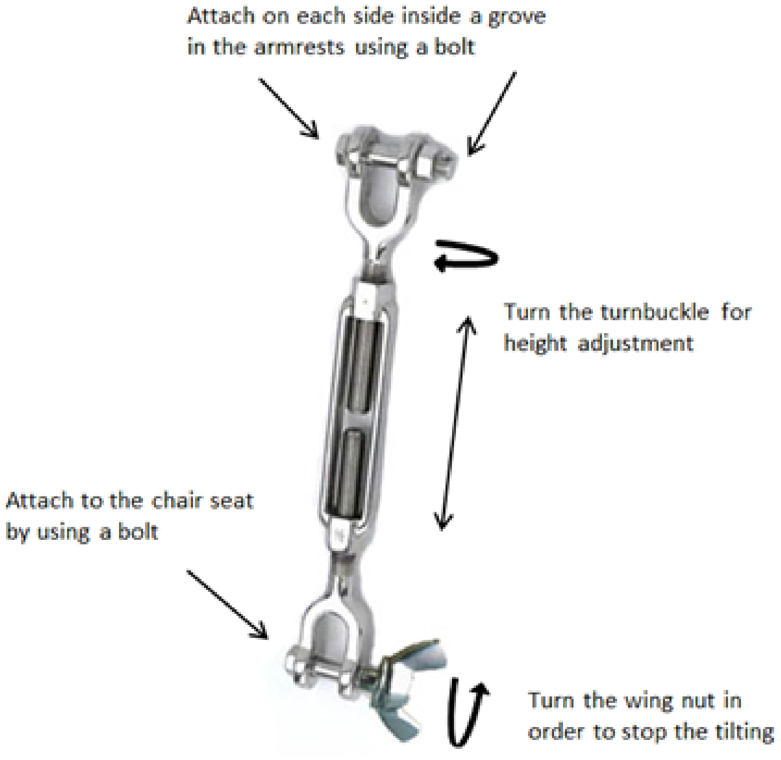


Figure 44: Function of the turnbuckle

Due to the simplicity and function of this type of inner stinger, this solution will be used as stringers for the VAPAC concept.

6.5.2 BACKREST AND SEAT

The backrest and the seat of the chair are supposed to be comfortable to sit in and lean on. Many people like a soft seat and backrest, but what people prefer varies a lot. The fact that people are different in height and shape makes it challenging to find the right chair shape for everyone.

Figure 45: Multiple chair designs

Three developed concepts for seat and backrest will be evaluated as alternatives for the VAPA-Chair with respect to innovative design and environmental considerations.

Concept 1:
A cushion soft top supported by a plastic bottom

This solution is used on many office chairs like the Klemens work chair from IKEA shown in chapter 2.2.1

+ It is possible to make the seat and backrest very soft
÷ It may be challenging to make the structure environmental friendly due to the use of a large amount of material
÷ The innovation level is not very high since this is a common way to make chairs

	**Concept 2:** **A supportive solid frame covered by a thin fabric or net** This fabric can be inelastic or it can be elastic to better follow the curves of the person sitting in the chair + Environmental advantages because the structure do not require many different-, or large quantities of materials ÷ It may be as soft and comfortable to sit on as a cushion

	**Concept 3:** **A hammock or elastic web attached to a solid backbone or a frame.** + Innovative and creative design + Comfort of a structure that follows the curves and the movements of the body. + The same environmental benefits as concept 2. ÷ It may not be as soft to sit on as a cushion.

All of the concepts above can have pillows for neck and lumbar support attached to the backrest.

Evaluation

The three different concepts for the backrest and seat were evaluated further with respect to the stringers, the sitting comfort and the simplicity of the structures. A combination of concept 1 and 3 resulted in the final structure; two solid profiles supporting a leather cushion. The seat and backrest will be one part because this results in less components and a simpler structure.

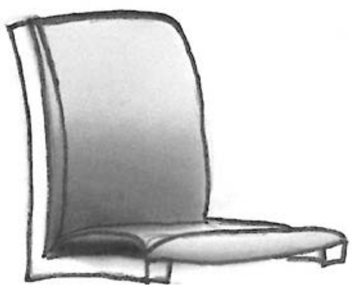


Figure 46: Seat and backrest concept

6.5.3 CHAIR LEGS

There are many kinds of design and structures of chair legs. Common for many office chairs are that they have wheels. This makes it easyer for the user to move around on the floor in the office. Another common feature is the 360° rotation in the horisontatial direction in order to turn in the chair. Many people like to have som kind of support for their feet on the chair for a more comfortable seating. Height adjustment for the chair may be dependent on some parts of the structure in the chair legs, this needs to be considered when choosing the type of chair legs for the VAPAC.

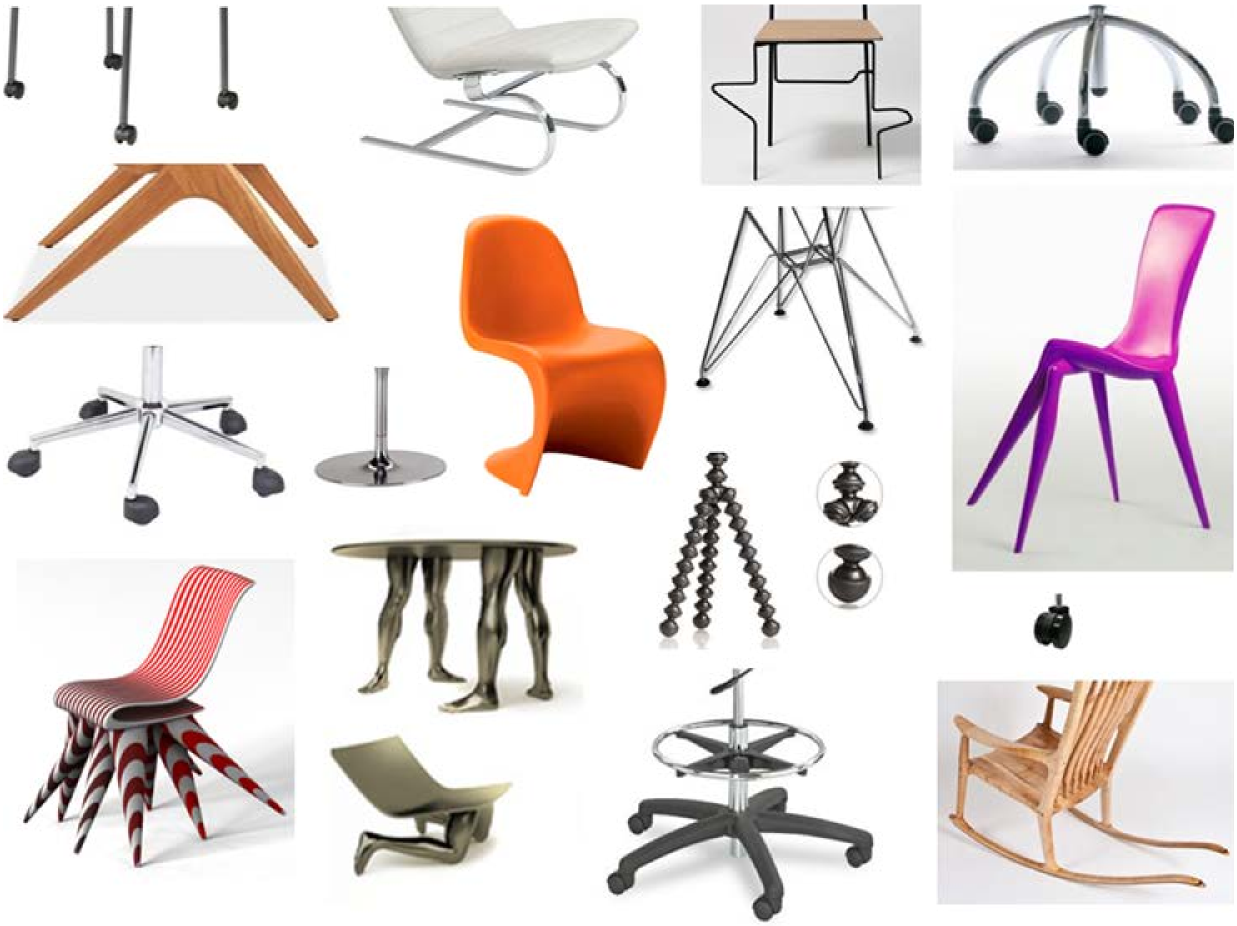
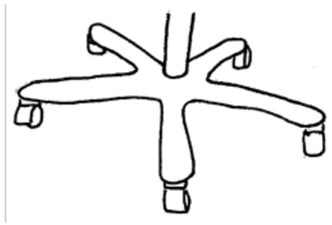


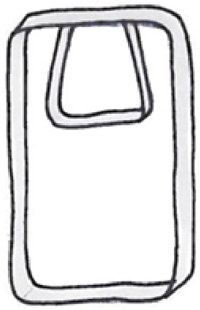
Figure 47: Multiple designs of chair legs

Three developed concepts for chair legs will be evaluated as alternatives for the VAPA-Chair with respect to function and environmental impact.



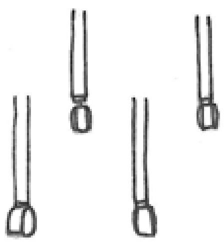
Concept 1:
A cylinder attached to five legs in a star shape. This is may be the most common type of legs in the office segment

+ The user can use the star shaped legs to rest the feet
+ Since there is only one cylinder coming down from the seat, adjustments like height and horizontal rotation can easily be implemented in the structure
+ Stable and solid structure
÷ The structure may be heavier and more complex compared to the other concepts



Concept 2:
Structure with outer stringers as chair legs

+ Easy to flat pack and few parts
+ Simple and cheap to produce
+ Material and weight savings by using the stringers as legs
÷ Complicated to implement a rotating mechanism on the chair and the height adjustment may be more complex than common methods
÷ Hard to implement regarding the chosen stringer solution (See chapter 6.5.1, concept 4)



Concept 3:
Regular chair legs typically used on basic dining or conference chairs.

+ Simple and cheap to produce
+ Easy to flat pack and few parts
÷ Adjustment solutions may be hard to implement

All of the structures can be combined with wheels so the chair can easily move around on the floor.

Evaluation

Due to the functional requirements regading adjustment and rotation, concept 1 will be used further in the report. This concept allows the features to be implemented in the chair legs. Since this is the most usual concept in the office segment, it is possible to order the chair legs for the VAPAC from an external supplier.

6.5.4 SUMMARY

Table 5 shows the different solutions chosen for each part of the chair.

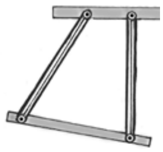
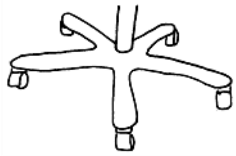
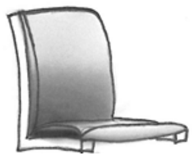
Part	Bearing structure	Inner stingers	Chair legs	Backrest and Seat
Solution				

Table 5: Summary of the different parts and their solution

These sub-parts form the basis for the development of the final VAPAC concept.

6.6 FUNCTIONS AND ADJUSTMENTS

There are many possible adjustment properties that can be implemented in the VAPA-Chair. Nevertheless, to be able to develop a chair that is light, made of few components and is able to be flat packed, it will not be favorable to have too many adjustment mechanisms. The following mechanisms have been chosen for the VAPAC due to ergonomic- set against environmental requirements settled earlier in the report:

- Seat height adjustment
- Armrest height adjustment
- Horizontal rotation
- Tilting
- Chair movement

The tilting and the armrest height adjustment is a result of the VAPAC mechanism in the stringers while height adjustment and rotation will be implemented in the chair legs. In addition to this, wheels will be attached to the legs in order to move the chair around on the floor. *Table 6* shows the adjustment properties and which component they are implemented in.

Component / Adjustment property	Stringers	Chair legs	Wheels
Sitting height		×	
Horizontal rotation		×	
Chair movement			×
Tilting	×		
Armrest height	×		

Table 6: Adjustment mechanisms

6.7 ASSEMBLY

The assembly of the VAPAC should be easy and it is therefore important to find smart solutions for mounting the chair together.

6.7.1 ASSEMBLY OF SEAT

The largest challenge concerning the assembly is the attachment of the seat leather cushion to the two solid seat beams. It is important that the seat is attached tightly so that the cushion is stretched in order to sit comfortably. Three different solutions have been considered:

1. Attach the leather cushion by entering a male groove on the leather seat into a female groove in the solid seat beams along the length of the beams.
2. Mount the leather cushion to the solid beams by using several quick couplings.
3. Place two thin plates within the leather cushion and attach to the solid beams with screws.

After investigating chairs already on the market with the same type of leather seat, solutions number 3 was considered as the best with regards to the required stretching of the leather cushion. This method is therefore chosen for the assembly of the VAPAC.

6.7.2 GENERAL ASSEMBLY

The remaining assembly of the VAPAC should be done by using screws and/or quick couplings in order to make the assembly as easy as possible.

CHAPTER 7: FINAL CONCEPT

This chapter presents and analyzes the final concept for the VAPA-Chair. Hand sketches and a 3D model show the final design.

The final concept is a result based on the requirements settled the previous chapters and the design will be evaluated with respect to this.

7.1 DESIGN, SKETCHES

A lot of time was spent throughout the project doodling and sketching different designs. *Figure 48* shows the final sketches.

Figure 48: Hand sketches

These sketches were presented to the concept originator. The feedbacks were positive and the industrial designer from Soon Design was commissioned to make design sketches based on the ones shown in *figure 48*. The results from this are available in Appendix E.

7.2 DESIGN, CAD

When the final concept was chosen, the 2D sketches were used to develop a 3D CAD model with more accurate dimensions and structures. A lot of time was spent on modeling the concept using the CAD program NX 7.5 Mechatronics. These NX files are available in an electronic appendix. The basic supporting structure was modeled first before a more detailed design was developed. The figures below show the final design.

Figure 49: CAD design of VAPAC

Figure 50: VAPAC available in multiple colors

Figure 51: VAPAC with additional support pillows

Figure 52: VAPAC in office environment

As shown in *figure 50,51 and 52*, the VAPAC can be made available in multiple colors and with additional pillows for back and neck support. This way the VAPAC can match each user and office environment.

7.3 STRINGERS

Figure 53: Stringers

The pictures above show the 3D design of the inner stringers. They have a 75° angle and are attached to the seat and to the armrests with bolts which allows the stringers to rotate freely. The tilting mechanism should feel similar to the mechanism created by the test rig in chapter 4. Due to the stiffness in the stringers, the tilting effect will be even better with a higher degree of forward and backward tilting. The stringer solution using turnbuckles has not been included in the 3D model due to lack of time when this idea arose. Nevertheless, *figure 53* shows the attachment of the stringers. See chapter 6.5.1 for details regarding the turnbuckle solution.

7.4 ASSEMBLY

Figure 54: Exploded view

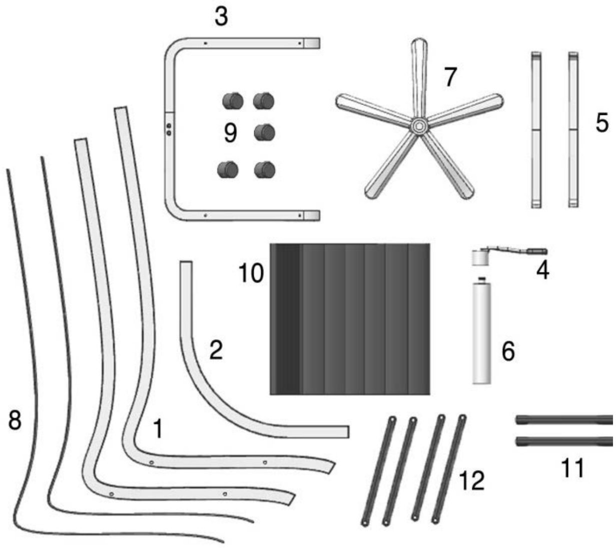


Figure 55: Numbered parts

The chair consists of 23 parts. It might not be correct to consider this as few parts when considering that the user or reseller is responsible for the assembly. Ikea is a typical company that delivers their products as flat packed units. They usually contain less than 20 parts and a few screws, but these parts often consist of many sub-parts which are assembled prior to the packing. Many office chairs have complex adjustments mechanisms containing of up to 50 parts (2). The VAPA-Chair has therefore few parts compared to other office chairs. 23 parts is much more than the settled requirement in the Product Requirement Specification in chapter 3.2. 15 parts turned out to be too optimistic for the VAPA-Chair.

To assembly the chair there is a need for approximately 20 screws, and the chair will be delivered to the user as a flat packed unit. The assembly may be more challenging for the user than some other office chairs that are delivered as flat packed units. This is yet again because some of the parts delivered consist of many sub parts that are assembled prior to the flat packing. This is not the case for the VAPAC, but the assembly is still considered simple enough to be done by the user.

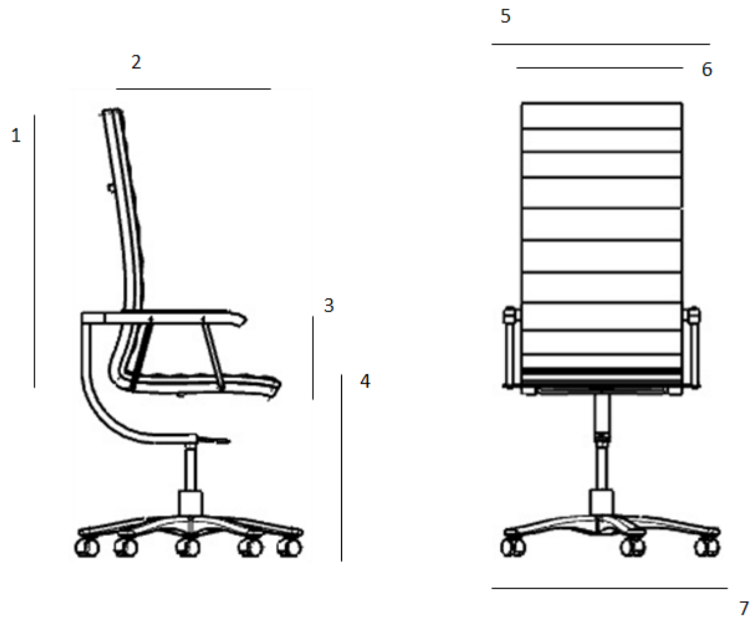
Disassembly is possible so that the user can recycle the different parts after ended use. An Allen key can be included in the chair package for assembly/disassembly or quick couplings could be used instead of screws for easy assembly/disassembly. If the costumer prefers additional back and neck support pillows, this can also be included in the flat packed unit.

Figure 56: Allen keys

Figure 57: Paper box for flat packing

7.5 DIMENSIONS

The dimesions are based on ergonomic requirements settled earlier in the report and some of them are taken from or compared to the Skeidar Octan office chair used to build the test rig in chapter 4. The measurements are collected from the 3D model in NX.



1. Height of back : 800mm
2. Depth of seat: 460mm
3. Distance from seat to armrest and distance from seat to lumbar support: 200mm
4. Seat height: 395-530mm
5. Chair width: 575mm
6. Seat and back width: 472mm
7. Chair legs diameter: 695mm

Figure 58: Chair dimensions

7.6 MATERIAL SELECTION

In order for the chair concept to be environmental friendly, it is important to choose materials that give the low environmental impact but still serve its purpose. The bearing structures of the VAPA-Chair have been evaluated based on this by using the LCA tool Eco-indicator 99 (26).
Figure 59 shows the bearing structure of the chair. For this it is important with a material that has a high strength and stiffness. A metal will be suitable for this purpose. According to the CES Edupack material library, low carbon steel and aluminum 6061 wrought T6 are common materials used in furniture design and these two materials will be compared with respect to strength, cost and environmental impact.

Figure 59: Bearing structure

Material	Density (kg/m3)	Young's modulus (GPa)	Yield strength (MPa)	Tensile strength (MPa)	Price (NOK/kg)
Low carbon steel	7800-7900	200-215	250-395	345-580	4-4,4
Aluminum 6061, wrought T6	2670	68-74	193-290	241-320	14.3-15.7

Table 7: Material properties obtained from the CES Edupack material library

As shown in *table 7*, steel has a higher Young's modulus than the chosen aluminum. This means that to get the same strength from Aluminum as the steel, there is a need for a larger volume of material. Since the density for Aluminum is much lower than for steel, the weight would still be lower with increased volume. The price for Aluminum is significantly higher than for Steel.

7.6.1 ECO-INDICATOR 99, LCA

In order to choose the material with the lowest environmental impact, the production, processing and waste management of the two materials has been compared. An indicator is used in Eco-indicator 99 which represents a value of environmental impact. This indicator includes several environmental damage potentials; human health, ecosystem quality and resources. In Appendix C, these factors are elaborated further.

The values are taken from the indicator forms available in Eco-indicator 99. One kg of steel has been compared with one kg of aluminum. The unit for the indicator is in millpoints per kg. Processes chosen for the bearing structure are based on requirements from the Requirement Specification in chapter 3. These are extrusion for the aluminum and bending for both steel and aluminum.

Phase / Material	Production of metals	Indic-ator	Processing of metals 1	Indicat-or	Processing of metals 2	Indicator	Recycling of waste	Indic-ator	Tot
Steel	Block material	86	Bending	0,00008			Recycling Ferro metals	-70	16
Aluminum 0 % Rec.	Block material	780	Extrusion	72	Bending	0,000047	Recycling Aluminum	-720	132
Aluminum 100 % Rec.	Block material	60	Extrusion	72	Bending	0,000047	Recycling Aluminum	-720	-588

Table 8: Eco-indicator 99 results

Comments

It is important to note that the three processes is a simplified version of the reality and that not all of the sub-processes are considered**.** The Eco-indicator 99 has limited options and level of accuracy resulting in an outcome with multiple sources of error. It also is important to note that the analysis is only intended to give an indication of which material that impacts the environment the least, it cannot be published as evidence.

The results are based on 1 kg steel vs. 1 kg aluminum. Since aluminum is lighter than steel, the weight required would be higher for steel than aluminum even though steel has a higher strength. The results from the analysis should consider this when evaluating the values of the indicator.

Evaluation

The results from *table 8* shows that the 100% recycled aluminum have sufficiently less environmental impact than the 0% recycled aluminum and the steel. The reason for this is that the energy required to recycle aluminum is only 5% of the energy required to produce it (27). Based on this, it would be natural to choose the 100% rec. aluminum. Unfortunately, the present situation on the aluminum market makes it hard to obtain recycled aluminum and it is costly. Nevertheless, as much recycled material as possible should be used to lower the environmental impact. In the future, more recycled aluminum will be available. Within the next 10 years, the amount of recycled aluminum available is expected to increase with

75% (28). The new aluminum extracted to make the VAPA-Chair will contribute to increase the availability of recycled material after the end of life. Based on these arguments, aluminum will be used to produce the bearing structure of the VAPA-Chair.

7.7 WEIGHT ANALYSIS

In order to conduct an LCA analysis of the final chair concept, the weight of all the components needs to be determined.

The volume was calculated using a measure body feature in NX. Then, the volume was multiplied with the density of the aluminum and other used materials to find the weight of each component. The largest aluminum parts were set to have a hollow structure with a thickness of 4mm.

Material	Part no.*	Part Name	No. of Parts	Density [kg/m^3]	Volume [m^3]	Weight [kg]
Aluminum, 6061-T6				2730		
	1	Seat bearing structure	2	2730	0,000 624 960	1,71
	2	Bearing beam	1	2730	0,000 295 372	0,81
	3	Armrest structure	1	2730	0,000 623 740	1,70
	4	Adjustment pin	1	2730	0,000 049 111	0,12
	5	Seat support beam	2	2730	0,000 241 533	0,66
	6	Cylinder	1	2730	0,000 092 362	0,25
	7	Chair legs	1	2730		1,0**
	8	Attachement plates	2	2730	0,000 225 765	0,62
Sum						6.87
Plastic, POM	9	Wheels	5	1430	0,000 314 865	0,45
Polymer foam	10	Seat and back batting	1	38	0,000 136 177	0,01
	11	Armrest batting	1	38	0,000 096 448	0,00
Sum						0,46
Leather				810		
	10	Seat and back surface	1	810	0,001 584 133	1,28
	11	Armrest surface	1	810	0,000 042 408	0,03
	12	Inner stringers[6]	4	810	0,000 245 099	0,20
Sum						1,51
Tot			24			8,84

Table 9: Weight calculations

**Figure 55 shows a picture of the numbered parts.*

***The chair legs used in the NX model is obtained from an earlier VAPAC model intended for a different material than aluminum and will therefore not be appropriate for a volume measure. The weight of the chair legs is therefore set to an approximately value of 1 kg.*

[6] The stiff material in the inner stingers has not been included in the weight analysis because this structure was not included the 3D model. Since these are small parts, the lack of data will not affect the result significantly.

The total weight of the chair is approximately 9 kg. This is within the weight requirements settled in the Product Requirement Specification. Since there have been no strength calculations conducted on the final design, the weight is not optimized and the value should be looked at more as an indication. For further work on this VAPA-Chair, it is recommended to optimize the design with regards to strength and weight.

7.8 LCA ANALYSIS

A simple LCA analysis was conducted using the program CES Edupack 2011. This was done in order to see which part of the product's lifecycle that have the largest environmental impact. The indicators for this program are CO_2 footprint (kg) and Energy consumption (MJ). Several simplifications and assumptions were done regarding transport and manufacture. The program itself has limited options and levels of accuracy resulting in a LCA report with multiple sources of error. It is important to note that the LCA analysis is only intended to give <u>an indication</u> of how much the product may impact the environment, it cannot be published as evidence as an environmental friendly product or be used to compare the product to competitors.

7.8.1 TRANSPORT

Transport of materials is a part of the product's life cycle that plays a role for the CO_2 footprint and energy usage. Some simplifications and assumptions have been made in the transport input due to lack of accurate data. When calculating the distance for transport, Trondheim is set as the location for the packing. To reduce the environmental impact, it is a focus on short distance transport. The materials are transported with 32 or 14 tonne trucks.

Chair legs: The VAPA-Chair will consist of chair legs that are produced by an external supplier. The supplier is assumed to be located in Sweden, Stockholm. (802km) (Based on information from the head of production in Håg.)

Aluminum: The aluminum is assumed to be transported from Sunndalsøra in Norway. (188km)

Leather and foam: This is assumed to be transported from Denmark, Copenhagen (1097km)

7.8.2 INPUT DATA

Data regarding material, weight, process and end of life treatment were plotted into the LCA program. There was a focus on recycling as many parts of the chair as possible. The percentage of recycled aluminum used was as an assumption set to 40%.

1. Material, manufacture and end of life

Qty.	Component name	Material	Recycled content	Mass (kg)	Primary process	End of life
1	Seat bearing structures	Aluminum alloys	40,0%	1,71	Extrusion, foil rolling	Recycle
1	Seat support beams	Aluminum alloys	40,0%	0,66	Extrusion, foil rolling	Recycle
1	Armrest structure	Aluminum alloys	40,0%	1,7	Extrusion, foil rolling	Recycle
1	Adjustment pin	Aluminum alloys	40,0%	0,12	Extrusion, foil rolling	Recycle
1	Bearing beam	Aluminum alloys	40,0%	0,81	Extrusion, foil rolling	Recycle
1	Cylinder	Aluminum alloys	40,0%	0,25	Extrusion, foil rolling	Recycle
1	Chair legs	Aluminum alloys	40,0%	1	Extrusion, foil rolling	Recycle
1	Attachment plates	Aluminum alloys	40,0%	0,62	Extrusion, foil rolling	Recycle
1	Wheel	Polyoxymethylene (Acet	Virgin (0%)	0,45	Polymer molding	Recycle
1	Polymer foam	Flexible Polymer Foam (	Virgin (0%)	0,01	Polymer extrusion	Combust
1	Seat and back surface	Leather	Virgin (0%)	1,28	Incl. in material value	None
1	Stringers	Leather	Virgin (0%)	0,2	Incl. in material value	None
1	Armrests	Leather	Virgin (0%)	0,03	Incl. in material value	None

2. Transport

Name	Transport type	Distance (km)
Aluminum	32 tonne truck	200
Leather and foam	14 tonne truck	1000
Chair legs	14 tonne truck	800

Table 10: CES Edupack input data

7.8.3 RESULTS, ECO AUDIT REPORT

Energy consumption and CO2 Footprint Summary:

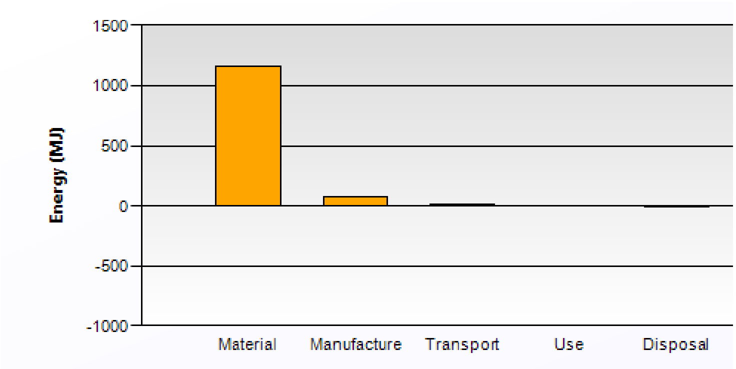


Figure 60: Energy consumption

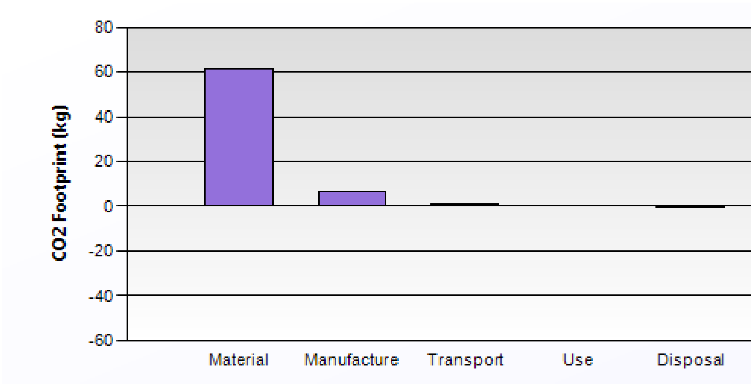


Figure 61: CO2 footprint

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.16e+03	92.0	61.3	89.1
Manufacture	81.8	6.5	6.12	8.9
Transport	14.3	1.1	1.02	1.5
Use	0	0.0	0	0.0
Disposal	5.13	0.4	0.359	0.5
Total (for first life)	**1.26e+03**	**100**	**68.8**	**100**

Table 11: LCA summary for final design

As shown in the graphs, the largest environmental impact is due to the materials. Manufacture is second, but significantly lower. It is therefore the material phase of the life cycle that should have the main focus for improving.

The parts that had the highest percentage of environmental impact was the bearing structure of the chair. One initiative that can lower the impact is to use a more environmental friendly material than aluminum alloys but due to strength requirements, this can be challenging. Another solution can be to use a higher degree of recycled aluminum. In order to check the environmental effect of this, the analysis was run again using 80 percent recycled aluminum. This resulted in almost half of the CO_2 footprint and energy consumption. This proves the importance of using recycled aluminum. Even though the resource of this is limited and costly, the VAPAC should focus on utilizing as much recycled aluminum as possible.

% Recycled aluminum used	Energy (MJ)	CO2 (kg)
0	1810	99
40	1260	68,8
80	719	38,5

Table 12: Environmental impact from different amounts of recycled aluminum

Weight reduction is another alternative which should be looked further into. Reducing the material production will naturally reduce the environmental impact. In order to do this, the structure of the final concept of the VAPAC should be optimized with regards to weight. Due to limitations in time, and to the concept development level settled for this report, this has not been included.

The LCA analysis also revealed that the production of leather for the seat had a high percentage of negative environmental impact compared to other parts of the chair. This is due to the tanning processing of skin in order to produce the leather. The tanning uses several chemicals which has a negative environmental impact. As a recommendation for further work, other more environmental friendly materials should be considered for the chair seat.

CHAPTER 8: EVALUATION OF FINAL DESIGN

The final design for the VAPAC fulfills several of the requirements settled earlier in the report.

8.1 VISUAL DESIGN

The design offers a new and innovative esthetic expression where the function of the tilting draws the attention in the design.

8.2 PRODUCTION

Based on the material selections and the final design, it should be possible to manufacture the bearing structure out of one aluminum profile by cutting it into different lengths and bending it into different shapes.

8.3 ENVIRONMENTAL CONSIDERATIONS

The final VAPAC concept covers the following environmental initiatives:

Requirement	Solution/Result
Recyclable materials	Aluminum is used for the bearing structure of the chair due to the low environmental impact when using recycled aluminum.
Nontoxic materials	No toxic materials have been used for the VAPAC. However, the processing of leather may contain toxic chemicals. The use of leather should be reconsidered and replaced with more environmental friendly materials.
Transport as a flat packed unit	All the parts of the chair can be stacked together and flat packed prior to the transport to the costumer.
Low weight	The weight of the chair is approximately 9 kg. This is low compared to other office chairs. The structure should be optimized with regards to weight and strength in order to find the exact weight of the chair.
Assembly/Disassembly by reseller or user	The assembly may be more challenging for the user than some other chairs that are delivered as flat packed units. Still, it is considered simple enough for the user to manage with the help of a user manual.
Few parts	Considering that there is no need for a comprehensive industrial assembly before the product reaches the user as a flat packed unit, the chair is considered to consist of few parts compared to other office chairs.
Simple production	The simple production of the chair allows low energy consumptions

Table 13: Summary of the environmental requirements and their solutions

8.4 ERGONOMICS AND COMFORT

The tilting mechanism and the general design of VAPAC contribute to an ergonomic and dynamic seating:

Requirement	Solution/Result
Support a person's body	The chair can be adjusted in order to fit people of different height. By using turnbuckles as inner stringers, the height of the armrests can be regulated during the assembly of the chair. Support pillows can be attached to the chair for additional lumbar and neck support.
Support activity	The tilting makes it easy for the user to switch positions often and stimulates the use of muscles in the back and stomach.
Promote movement	Because the chair is not fixed in any tilting angle, the natural movement of the body is promoted and encouraged by the chair with a total tilting effect of more than 22°. Due to the new stringer solution using turnbuckles that rotate freely, movement is easy and effortless and not constrained.
Enables performance	As an ergonomic office chair, the VAPAC could contribute to improved performance and enables people to be more effective while working.
Easy to use	The Chair consists of no complex adjustment components and don't need any instructions regarding use.
Do no harm	The chair will not cause pain, stress, injury or any discomfort to the body. The tilting ensures that the critical lower parts of the back are supported by the backrest in all forwards or backwards positions. The shape of the backrest is to some extent designed to support the spine in order to prevent back pains. For people who prefer to sit in a fixed position, the tilting can be stopped by turning a wing nut located on each stringer.

Table 14: Summary of the ergonomic requirements and their solutions

Figure 62: Ergonomic seating

9 CONCLUSION

The final concept for the VAPA-Chair is developed to a level that describes the main function and design. There are still consideration to be taken with regards to optimization of production, simulation and design, but the concept still fulfills the purpose of the thesis; To develop a new chair concept based on the VAPAC mechanism with focus on low environmental impact , ergonomic seating and simple and functional design.

Below is a short summary of the final concept and some user experiences regarding the ergonomics of the tilting. The assertions to the user experiences are based on feedback during a user survey conducted on a VAPAC test rig in chapter 4.

Final design

Figur 63: CAD design

<u>In general</u>:
The inner stringers responsible for the tilting consist of four stiff straps. They are attached to the seat and the armrests by bolts allowing the stingers to rotate freely.
The main structure of the chair consists of simple extruded and bent Aluminum profiles.

<u>User experience</u>:
The tilting mechanism offers a comfortable and exiting sitting experience for an office chair.
It is fun to sit in but still relaxing.

10 RECOMMENDATIONS FOR FURTHER WORK

This thesis presents a new concept for the VAPA-Chair. In order to realize the VAPAC concept as an exclusive product made available on the chair market, there are several features that need further development:

- Find suiting chair legs from a supplier or develop a new custom made for the VAPAC.
- Test and optimize the chair with respect to weight and strength according to the prevailing standards mentioned in chapter 3.3. Safety requirements should also be investigated.
- Find an environmental friendly material for the chair seat cushion.
- Conduct a complete and accurate LCA analysis calculating exact CO_2 footprint and energy usage so it can be used for official comparison to other products and as a sales argument to compete with other environmental friendly furniture on the market.

SOURCES

1. Rølvåg T. Virtual Adjustable Pivot Axis Chair (VAPAC) mechanism. [Information sheet] Trondheim; 2010.

2. Schneider P. Evaluering og optimalisering av nytt konsept for stolmekanismer [Master thesis]. Trondheim: NTNU; 2010.
3. Asphjell MK. Design og optimalisering av ny kontorstol. [Master Thesis]. Trondheim: NTNU; 2010.
4. Fraser K. Computer Workstations: Design & Adjustment. [Online]. The University of Queensland; 2009. [Cited February 2012]. Available from http://www.uq.edu.au/ohs/pdfs/computerworkstations.pdf
5. HÅG. HÅG Norway. [Online]. [Cited February 2012]. Available from http://www.hag.no
6. Ikea. Products. [Online]. [Cited February 2012]. Avalible from http://www.ikea.com/no/no/catalog/products/S69866952/
7. Vitra. Meda conference chair. [Online]. [Cited February 2012]. Available from http://www.vitra.com/en-lp/office/products/meda-conference-chair-2/overview/
8. Marineshop. BLUE SEA Maia Pendel Single. [Online]. [Cited February 2012]. Available from http://www.marineshop.no/PartDetail.aspx?q=p:10527680
9. Møbel Galleriet. Optima. [Online]. [Cited February 2012]. Available from http://www.mobelgalleriet.no/nyheter.php
10. Ekornes. Stressless. [Online]. [Cited February 2012]. Available from http://www.ekornes.no/stressless-hvilestoler/stressless-wing-stressless-eagle/eagle
11. Okolo. Reflex. [Online]. [Cited February 2012]. Available from http://okoloweb.cz/projects/reflex
12. Spine-Health. Coosing the right office chair. [Online]. [Cited May 2012]. Availible from http://www.spine-health.com/wellness/ergonomics/office-chair-choosing-right-ergonomic-office-chair
13. International standard. NS EN ISO 14044. Environmental management - Life cycle assessment - Requirements and guidelines; 2006. p. 5.
14. Cycle Assessment Procedure for Eco-Materials. The CAP'EM Eco Material Tool. [Online]. [Cited May 2012]. Available from http://www.capem.eu/capem/en/6935-newsletters.html
15. Taylor and Francis. Ergonomics. [Online]. The official Journal of the Instutute for Ergonomics and Human Factors. 2010; Vol 54. ISSN 1366-5847. [Cited April 2012]. Available from http://www.tandf.co.uk/journals/terg
16. Opsvik P. Rethinking Sitting. Oslo: Gaidaros Forlag AS; 2008. p. 47.
17. Springer T. The Future of Ergonomic Office Seating. [Online]. Knoll Workplace Reasearch; 2010; p. 3 [Cited May 2012]. Available from http://www.knoll.com/research/downloads/wp_future_ergonomic_seating.pdf
18. Mandal AC. Det siddende menneske, Homo sedens. København: GEC Gads Forlag; 1983. ISBN 87-12-56150-9.
19. Vink P, editor. Office chairs are often not adjusted by end users. The Human factors And Ergonomics Society 51st Annual Meeting 2007; Santa Monica, California. p. 1015-1019

20. Spine-Health. How to reduce back pain. [Online]. [Cited May 2012]. Available from http://www.spine-health.com/wellness/ergonomics/office-chair-how-reduce-back-pain
21. Steamboat Spine & Sports Physical Therapy. Lumbar Degenerative Disc Disease. [Online]. [Cited April 2012]. Available from http://www.steamboatspineandsports.com/Injuries-Conditions/Lower-Back/Lower-Back-Issues/Lumbar-Degenerative-Disc-Disease/a~48/article.html
22. Andersson G. Lumbar Disc Pressure and Myoelectric Back Muscle Activity During Sitting. John Wiley & Sons; 1991. p. 302-313.
23. Amazon. Safco Lumbar Support Memory Foam Backrest. [Online]. [Cited June 2012]. Available from http://www.amazon.com/Safco-Lumbar-Support-Memory-Backrest/dp/B001MS6X4G
24. Kokot D, Allie P. Choosing a Chair Based on Fit, Comfort and Adjustable Fatures. [Online]. Steelcase Inc; 2005. [Cited May 2012]. Available from http://www.oneworkplace.com/pdfs/whitepapers/ChoosingAChair.pdf
25. Design Shuffle. Design Trends for 2012. [Online]. [Cited March 2012]. Available from http://www.designshuffle.com/blog/design-trends-for-2012/
26. Baayen H. Eco-indicator 99, Manuals for Designers. [Course literature from TMM3 Miljøvurdering av produkter]. Ministry of Housing, Spatial Planning and the Environment; 2000.
27. Tønseth S. Matematikk skal øke gjenbruk av aluminium. [Online]. Sintef; 2011 [Cited June 2012]. Available from http://www.sintef.no/Presserom/Forskningsaktuelt/Matematikk-skal-oke-gjenbruk-av-aluminium/
28. Knutzen T. Sterk vekst ventet i global resirkulering av aluminium. [Online]. Hydro; 2010. [Cited June 2012]. Available from http://www.hydro.com/no/Pressesenter/Nyheter/Arkiv/2010/Sterk-vekst-ventet-i-global-resirkulering-av-aluminium/

APPENDIX

APPENDIX A: VAPAC INFORMATION SHEET

Title: Virtual Adjustable Pivot Axis Chair (VAPAC) mechanism.

Dato: 18/06-2010

Keywords: *DESIGNPRISEN 2010, VAPAC office chairs*

Written by: Terje Rølvåg

Reference: DESIGNPRISEN 2010

Current situation:

Office chair mechanisms are complex and difficult to design, optimize, produce and maintain. Here are some typical solutions:

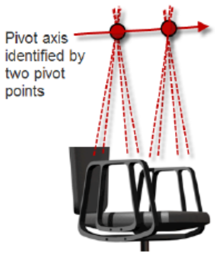
The office chairs also has to be assembled before shipping due to a high number of pre-stressed components. This is a logistics problem.

A comprehensive Swizz survey (1992) of the correlation between chair designs versus human back and fatigue problems concluded that: "it's recommended to design chairs that support the body in a wide range of positions related to the tasks to be completed sitting in the chair. The user should be offered the best option possible to reduce physical strain by varying the position"

However, all existing mechanisms are limited to a one degree of freedom rotation which doesn't support the human body need for dynamic sitting positions (variations).

Solution:

The VAPAC concept eliminates the need for traditional mechanism components in a tilting office chair. The invention is based on one or two flexible 2D structures. The flexible structure allows two translational and a flexible tilting rotation about a virtual pivot axis (3 degrees of freedom / DOF's).

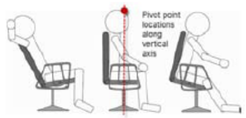


The tilting stiffness is given by the geometry and thickness of the flexible 2D structure.

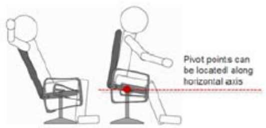
The direction of the pivot axis is defined by the two pivot points or the surface normal of the flexible structures. The centre of rotation is given by the geometry and can be outside the volume of the flexible structure itself. The centre of rotation can also be controlled by varying the contact points between the seat and the flexible structure.

VAPAC Benefits:

• ***Dynamic and pleasant sitting positions (coupled and continous 3 DOF motion).*** *The flexible structures can be tilted to locate the pivot points along any axis. The tilting characteristics (center, knee or cradle tilting) are optional . The VAPAC concept can therefore be used as a platform solution for any office chair. The tilting characteristics is simply altered by selecting different flexible structures. The structures also have linear tilting characteristics until self contact occur (the traditional locking position). Then it still allow flexible motion but the stiffness increase*



An exciting type of seating comfort is obtained when the pivot axis is located above the shoulder height!



Center and knee tilting is the most common choice

• ***Easy production.*** *The flexible structures can be casted or extruded in large volumes due to the inherent 2D design. The structures can be extruded and cut to give the optimal thickness and stiffness. Injection molding is an alternative production method allowing a nicer design.*

The flexible 2D structure can be extruded in aluminum, stacked and located under the chair.

Injection molding allows a very flexible design of the arm support.

• ***Major reduction in components and assembly operations.*** *Traditional complex chair mechanisms require dedicated assembly lines including welding operations. VAPAC can be flat packed before shipping and assembled by the reseller for maximum customer comfort. The reseller can also optimize the seating comfort by offering different flexible structures to the customer.*

• ***No maintenance required.*** *No joints, friction, pre-stressed components or tolerance problems due to a complete absence of sliding surfaces or hinges.*

• ***Environmental friendly design.*** *The production (casting or extrusion) demands much less energy compared to traditional designs. All materials can easily be recycled. No lubricants or chemicals are needed!*

•***Very lean and flexible design.*** *VAPA replaces the traditional heavy and hidden chair mechanism with a flexible structure that blends design and function with no compromise in seating comfort.*

APPENDIX B: EQUATIONS FOR TILTING FREQENCY

In order to find an approximately value for the frequence (cycles/second) for the adjusted angles and widths for the stringers, some calculations need to be conducted. The equations are based on the case of an ideal simple pendulum consisting of a point mass m suspended from a support by a massless string with the length L. For small oscillations the frequency of a simple pendulum is given by;

$f = \frac{1}{2\pi}\sqrt{\frac{g}{L}}$. In the case of the stringers, the expression for the frequency will be a bit more complicated. This is due to the length of the beam (*see figure 64*) and the angle of the two straps. It will therefore be rotation in three directions. *Figure 64* illustrates how the stringers can be looked at mathematically.

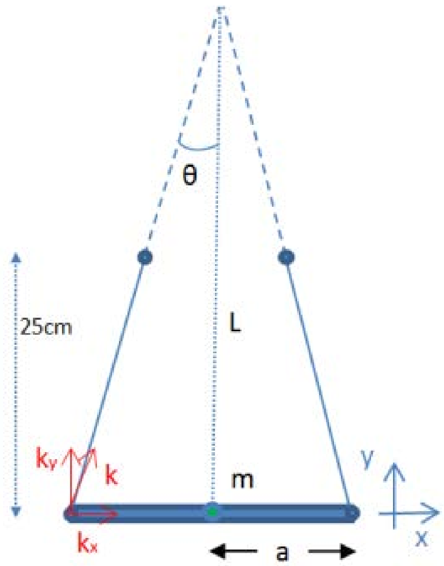


Figure 64: Mathematical case

The frequency can be found by using the following equations:

x-direction: $$f_1 = \frac{1}{2\pi}\sqrt{\frac{2k_x}{m}} = \frac{1}{2\pi}\sqrt{\frac{2k\sin\theta}{m}}$$

y- direction: $$f_2 = \frac{1}{2\pi}\sqrt{\frac{2k_y}{m}} = \frac{1}{2\pi}\sqrt{\frac{2k\cos\theta}{m}}$$

θ-direction: $$f_3 = f_\theta = \frac{1}{2\pi}\sqrt{\frac{g}{L}} = \frac{1}{2\pi}\sqrt{\frac{g\tan\theta}{a}}$$

$\tan\theta = \frac{a}{L} \rightarrow L = \frac{a}{\tan\theta}$

K is the spring constant of the system [kg/s^2].

The frequency that is interesting is the lowest one of the three effects, and this will change as the angle θ changes. It was not possible to obtain any relevant data concerning tilting frequency with regards to sitting comfort. Due to this, the tilting frequencies were not calculated.

APPENDIX C: ECO-INDICATOR 99, ENVIRONMENTAL DAMAGE POTENTIAL

The Eco-indicator project has resolved these problems as follows:

1 The LCA method has been expanded to include a weighting method. This has enabled one single score to be calculated for the total environmental impact based on the calculated effects. We call this figure the Eco-indicator.
2 Data have been collected in advance for the most common materials and processes. The Eco-indicator has been calculated from this. The materials and processes have been defined in such a way that they fit together like building blocks. Thus there is an indicator for the production of a kilo of polyethylene, one for the injection moulding of a kilo of polyethylene and one for the incineration of polyethylene.

The Eco-indicator of a material or process is thus a number that indicates the environmental impact of a material or process, based on data from a life cycle assessment. The higher the indicator, the greater the environmental impact.

1.3 The "Eco" we indicate

Discussions on the environment are frequently confused. An important reason for this is the usually unclear definition of the term environment. In the Eco-indicator 99 we have defined the term "environment" with three types of damage:

1 Human Health; Under this category we include the number and duration of diseases, and life years lost due to premature death from environmental causes. The effects we include are: climate change, ozone layer depletion, carcinogenic effects, respiratory effects and ionising (nuclear) radiation.
2 Ecosystem Quality; Under this category we include the effect on species diversity, especially for vascular plants and lower organisms. The effects we include are: ecotoxicity, acidification, eutrophication and land-use.
3 Resources; Under this category we include the surplus energy needed in future to extract lower quality mineral and fossil resources. The depletion of agricultural and bulk resources as sand and gravel is considered under land use.

Next to the effects mentioned here there are some additional effects that could contribute to these three damage categories. We believe we have captured the most relevant effects, but unfortunately a method as this can never be absolutely complete[2].

Another limitation is in the selection of the damage categories themselves. For instance we could have included damage categories like the damage to material welfare or the damage to cultural heritage, but we did not choose to do so.

1.4 Differences with the Eco-indicator 95

The concept of working with standard Eco-indicators is not new. In the Eco-indicator 95 project this principle was introduced[3]. The most important difference with the 95 version of the method is the much improved methodolo-

2 The following effects that may be relevant are not included:
- *Human Health: Noise, endocrine disrupters and non carcinogenic or non respiratory effects of some substances like heavy metals.*
- *Ecosystem Quality: Greenhouse effect and ozone layer depletion (both are included in Human Health) and the effect of phosphates.*

In general these shortcomings will not have a very big effect, but in specific cases, for instance when systems that produce high noise levels, or emit large amounts of heavy metals or phosphates, the Eco-indicator value may misrepresent the environmental load.

3 The Eco-indicator 95 final report, NOH report 9514, July 1995; ISBN 90-72130-77-4

APPENDIX D: ECO AUDIT REPORT

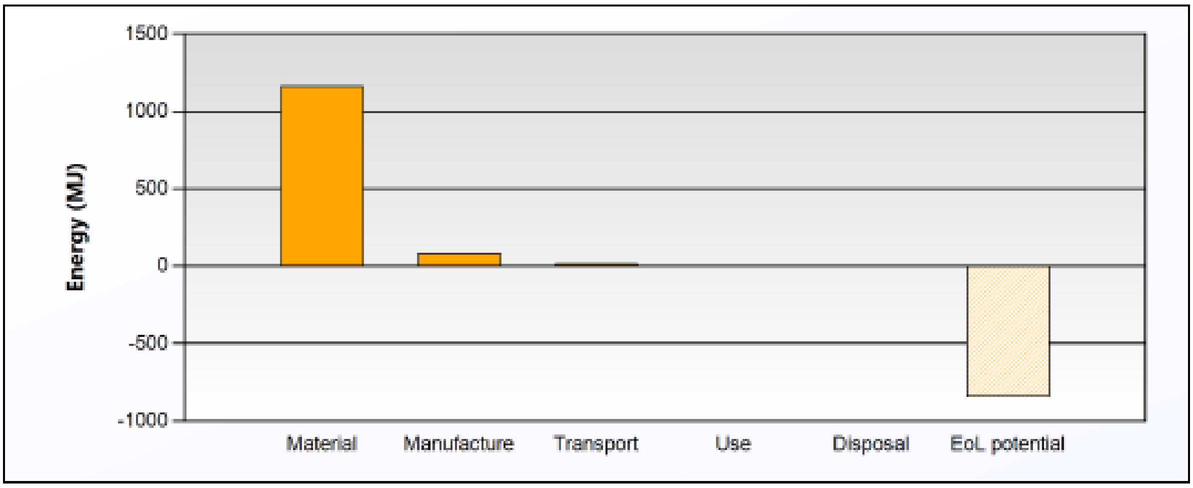
CES 2011 EDUPACK

Eco Audit Report

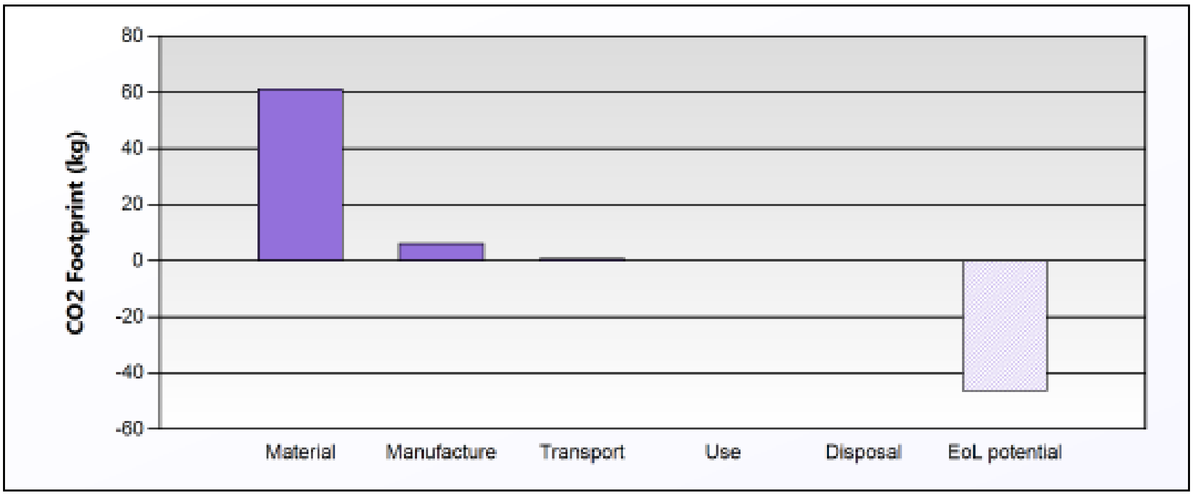
Product Name

Product Life (years) 15

Energy and CO2 Footprint Summary:



Energy Details...



CO2 Details...

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.16e+03	92.0	61.3	89.1
Manufacture	81.8	6.5	6.12	8.9
Transport	14.3	1.1	1.02	1.5
Use	0	0.0	0	0.0
Disposal	5.13	0.4	0.359	0.5
Total (for first life)	**1.26e+03**	**100**	**68.8**	**100**
End of life potential	-846		-46.4	

CES 2011 EDUPACK

Eco Audit Report

Energy Analysis

Energy and CO2 Summary

	Energy (MJ)/year
Equivalent annual environmental burden (averaged over 15 year product life):	84

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass	Energy (MJ)	%
Seat bearing structures	Aluminum alloys	40,0%	1.7	1	1.7	2.4e+02	20.4
Seat support beams	Aluminum alloys	40,0%	0.66	1	0.66	92	7.9
Armrest structure	Aluminum alloys	40,0%	1.7	1	1.7	2.4e+02	20.3
Adjustment pin	Aluminum alloys	40,0%	0.12	1	0.12	17	1.4
Bearing beam	Aluminum alloys	40,0%	0.81	1	0.81	1.1e+02	9.7
Cylinder	Aluminum alloys	40,0%	0.25	1	0.25	35	3.0
Chair legs	Aluminum alloys	40,0%	1	1	1	1.4e+02	11.9
Attachment plates	Aluminum alloys	40,0%	0.62	1	0.62	86	7.4
Wheel	Polyoxymethylene (Acetal, POM)	Virgin (0%)	0.45	1	0.45	47	4.0
Polymer foam	Flexible Polymer Foam (LD)	Virgin (0%)	0.01	1	0.01	1.1	0.1
Seat and back surface	Leather	Virgin (0%)	1.3	1	1.3	1.4e+02	11.8
Stringers	Leather	Virgin (0%)	0.2	1	0.2	21	1.8
Armrests	Leather	Virgin (0%)	0.03	1	0.03	3.2	0.3
Total				13	8.8	1.2e+03	100

*Typic: Includes 'recycle fraction in current supply'

Manufacture:

Energy and CO2 Summary

Component	Process	Amount processed	Energy (MJ)	%
Seat bearing structures	Extrusion, foil rolling	1.7 kg	18	22.4
Seat support beams	Extrusion, foil rolling	0.66 kg	7.1	8.7
Armrest structure	Extrusion, foil rolling	1.7 kg	18	22.3
Adjustment pin	Extrusion, foil rolling	0.12 kg	1.3	1.6
Bearing beam	Extrusion, foil rolling	0.81 kg	8.7	10.6
Cylinder	Extrusion, foil rolling	0.25 kg	2.7	3.3
Chair legs	Extrusion, foil rolling	1 kg	11	13.1
Attachment plates	Extrusion, foil rolling	0.62 kg	6.7	8.1
Wheel	Polymer molding	0.45 kg	8	9.8
Polymer foam	Polymer extrusion	0.01 kg	0.057	0.1
Total			82	100

Transport:

Energy and CO2 Summary

Breakdown by transport stage Total product mass = 8.8 kg

Stage name	Transport type	Distance (km)	Energy (MJ)	%
Aluminum	32 tonne truck	2e+02	0.81	5.7
Leather and foam	14 tonne truck	1e+03	7.5	52.4
Chair legs	14 tonne truck	8e+02	6	41.9
Total		2e+03	14	100

Breakdown by components

Component	Component mass (kg)	Energy (MJ)	%
Seat bearing structures	1.7	2.8	19.3
Seat support beams	0.66	1.1	7.5
Armrest structure	1.7	2.8	19.2
Adjustment pin	0.12	0.19	1.4
Bearing beam	0.81	1.3	9.2
Cylinder	0.25	0.41	2.8
Chair legs	1	1.6	11.3
Attachment plates	0.62	1	7.0
Wheel	0.45	0.73	5.1
Polymer foam	0.01	0.016	0.1
Seat and back surface	1.3	2.1	14.5
Stringers	0.2	0.32	2.3
Armrests	0.03	0.049	0.3
Total	8.8	14	100

Use:

Energy and CO2 Summary

Relative contribution of static and mobile modes

Mode	Energy (MJ)	%
Static	0	
Mobile	0	
Total	0	100

Disposal:

Energy and CO2 Summary

Component	End of life option	Energy (MJ)	%
Seat bearing structures	Recycle	1.2	23.3
Seat support beams	Recycle	0.46	9.0
Armrest structure	Recycle	1.2	23.2
Adjustment pin	Recycle	0.084	1.6
Bearing beam	Recycle	0.57	11.1
Cylinder	Recycle	0.18	3.4
Chair legs	Recycle	0.7	13.6
Attachment plates	Recycle	0.43	8.5
Wheel	Recycle	0.32	6.1
Polymer foam	Combust	0.005	0.1
Seat and back surface	None	0	0.0
Stringers	None	0	0.0
Armrests	None	0	0.0
Total		5.1	100

EoL potential:

Component	End of life option	Energy (MJ)	%
Seat bearing structures	Recycle	-2e+02	24.1
Seat support beams	Recycle	-79	9.3
Armrest structure	Recycle	-2e+02	23.9
Adjustment pin	Recycle	-14	1.7
Bearing beam	Recycle	-96	11.4
Cylinder	Recycle	-30	3.5
Chair legs	Recycle	-1.2e+02	14.1
Attachment plates	Recycle	-74	8.7
Wheel	Recycle	-27	3.2
Polymer foam	Combust	-0.11	0.0
Seat and back surface	None	0	0.0
Stringers	None	0	0.0
Armrests	None	0	0.0
Total		-8.5e+02	100

Notes:

Energy and CO2 Summary

CES 2011 EDUPACK

Eco Audit Report

CO2 Footprint Analysis

Energy and CO2 Summary

	CO2 (kg)/year
Equivalent annual environmental burden (averaged over 15 year product life):	4.58

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass	CO2 footprint (kg)	%
Seat bearing structures	Aluminum alloys	40,0%	1.7	1	1.7	13	21.5
Seat support beams	Aluminum alloys	40,0%	0.66	1	0.66	5.1	8.3
Armrest structure	Aluminum alloys	40,0%	1.7	1	1.7	13	21.4
Adjustment pin	Aluminum alloys	40,0%	0.12	1	0.12	0.92	1.5
Bearing beam	Aluminum alloys	40,0%	0.81	1	0.81	6.2	10.2
Cylinder	Aluminum alloys	40,0%	0.25	1	0.25	1.9	3.1
Chair legs	Aluminum alloys	40,0%	1	1	1	7.7	12.6
Attachment plates	Aluminum alloys	40,0%	0.62	1	0.62	4.8	7.8
Wheel	Polyoxymethylene (Acetal, POM)	Virgin (0%)	0.45	1	0.45	1.8	2.9
Polymer foam	Flexible Polymer Foam (LD)	Virgin (0%)	0.01	1	0.01	0.044	0.1
Seat and back surface	Leather	Virgin (0%)	1.3	1	1.3	5.5	9.0
Stringers	Leather	Virgin (0%)	0.2	1	0.2	0.86	1.4
Armrests	Leather	Virgin (0%)	0.03	1	0.03	0.13	0.2
Total				13	8.8	61	100

*Typic: Includes 'recycle fraction in current supply'

Manufacture:

Energy and CO2 Summary

Component	Process	Amount processed	CO2 footprint (kg)	%
Seat bearing structures	Extrusion, foil rolling	1.7 kg	1.4	22.4
Seat support beams	Extrusion, foil rolling	0.66 kg	0.53	8.7
Armrest structure	Extrusion, foil rolling	1.7 kg	1.4	22.3
Adjustment pin	Extrusion, foil rolling	0.12 kg	0.096	1.6
Bearing beam	Extrusion, foil rolling	0.81 kg	0.65	10.6
Cylinder	Extrusion, foil rolling	0.25 kg	0.2	3.3
Chair legs	Extrusion, foil rolling	1 kg	0.8	13.1
Attachment plates	Extrusion, foil rolling	0.62 kg	0.5	8.1
Wheel	Polymer molding	0.45 kg	0.6	9.8
Polymer foam	Polymer extrusion	0.01 kg	0.0045	0.1
Total			6.1	100

Transport:

Energy and CO2 Summary

Breakdown by transport stage Total product mass = 8.8 kg

Stage name	Transport type	Distance (km)	CO2 footprint (kg)	%
Aluminum	32 tonne truck	2e+02	0.058	5.7
Leather and foam	14 tonne truck	1e+03	0.53	52.4
Chair legs	14 tonne truck	8e+02	0.43	41.9
Total		2e+03	1	100

Breakdown by components

Component	Component mass (kg)	CO2 footprint (kg)	%
Seat bearing structures	1.7	0.2	19.3
Seat support beams	0.66	0.076	7.5
Armrest structure	1.7	0.2	19.2
Adjustment pin	0.12	0.014	1.4
Bearing beam	0.81	0.093	9.2
Cylinder	0.25	0.029	2.8
Chair legs	1	0.12	11.3
Attachment plates	0.62	0.071	7.0
Wheel	0.45	0.052	5.1
Polymer foam	0.01	0.0012	0.1
Seat and back surface	1.3	0.15	14.5
Stringers	0.2	0.023	2.3
Armrests	0.03	0.0035	0.3
Total	8.8	1	100

Use:

Energy and CO2 Summary

Relative contribution of static and mobile modes

Mode	CO2 footprint (kg)	%
Static	0	
Mobile	0	
Total	0	100

Disposal:

Energy and CO2 Summary

Component	End of life option	CO2 footprint (kg)	%
Seat bearing structures	Recycle	0.084	23.3
Seat support beams	Recycle	0.032	9.0
Armrest structure	Recycle	0.083	23.2
Adjustment pin	Recycle	0.0059	1.6
Bearing beam	Recycle	0.04	11.1
Cylinder	Recycle	0.012	3.4
Chair legs	Recycle	0.049	13.6
Attachment plates	Recycle	0.03	8.5
Wheel	Recycle	0.022	6.1
Polymer foam	Combust	0.00035	0.1
Seat and back surface	None	0	0.0
Stringers	None	0	0.0
Armrests	None	0	0.0
Total		**0.36**	**100**

EoL potential:

Component	End of life option	CO2 footprint (kg)	%
Seat bearing structures	Recycle	-11	24.3
Seat support beams	Recycle	-4.4	9.4
Armrest structure	Recycle	-11	24.2
Adjustment pin	Recycle	-0.79	1.7
Bearing beam	Recycle	-5.4	11.5
Cylinder	Recycle	-1.7	3.6
Chair legs	Recycle	-6.6	14.2
Attachment plates	Recycle	-4.1	8.8
Wheel	Recycle	-1	2.2
Polymer foam	Combust	0.024	-0.1
Seat and back surface	None	0	0.0
Stringers	None	0	0.0
Armrests	None	0	0.0
Total		**-46**	**100**

Notes:

Energy and CO2 Summary

APPENDIX E: DESIGN SKETCHES FROM SOON DESIGN AS

APPENDIX F: ELECTRONIC APPENDIX

The zip file contains the 3D model of the VAPAC concept as part files.

Open the part file named “konsept1 (2)” in NX. This file contains the assembly of the chair.