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TALLINN UNIVERSITY OF TECHNOLOGY

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DEPARTMENT OF MACHINERY

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ENDER ÖZGÜN

SHOWER SEAT DESIGN and OPTIMIZATION

Tallinn 2015

MASTER'S THESIS TASK

2014 /2015 Academic Year 2nd Semester

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Field Of Study: Design & Engineering

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MASTER'S THESIS TOPIC

SHOWER SEAT DESIGN

Nr	Task Description	Completion Date
1	Market Research Of The Existing Shower Seats	February 2015
2	Evaluation Of The Existing Shower Seat Features	February 2015
3	Determining The Possible Novel Features Of The New Shower Seat	March 2015
4	Designing The New Shower Seat	April-May 2015

Design and Engineering problems to be solved:

The main objective of the Master's Thesis is to understand what is already existing on the market of shower seats and designing a new product which brings novelty and fresh value.

Defense application submitted to deanery not later than

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ABBREVARATIONS

3D: Three Dimensional

AS: Aktsiaselts

CAB: Cellulose Acetate Butyrate

Caltech: California Institute of Technology

DC: Direct Current

EU: European Union

EU-28: Abbrevaration for 28 State Members of European Union

FEA: Finite Element Analysis

FR: Feed Rate

GMA: General Morphological Analysis

HDPE: High Density Polyethylene

LDPE: Low Density Polyethylene

LLDPE: Linear Low Density Polyethylene

MIG: Metal Inert Gas

OÜ: Osaühing

PVC: Polyvinyl Chloride

PVF: Polyvinylidene Fluoride

RIM: Reaction Injection Molding

RRIM: Reinforced Reaction Injection Molding

SPH: Seconds Per Hole

SRIM: Structural Reaction Injection Molding

UHMWPE: Ultra High Molecular Weight Polyethylene

VOC: Volatile Organic Compounds

RAL: Reichs - Ausschuss für Lieferbedingungen

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1.Introduction

Motio is a unique shower seat design which fulfills the customer's need with easy functioning and most convenient design. Motio is the personal Master Thesis topic of M.Sc Design and Engineering Student Ender Özgün. However the Thesis Topic had been set by one of the leading bathroom furniture and technologies producer company called Balteco AS in Estonia. And the design process went through strong colloboration and consultation with Balteco Staff.

The Thesis mainly divided into three phase;

1. Product Market Research & Company Meetings.
2. Desing Process & Company Meetings.
3. Strength and Cost Analyses.

Starting phase was conducted to highlight the problems, available opportunities, features which can be developed further in order to set the goals for product design. Student and the Balteco AS had various meetings to determine both the problems and the goals.

Following phase was the designing of the product and evaluating concepts by the help of design tools and scoring charts. The strength calculations and cost analyzes were made to validate the design from engineering approach and show the price for the end product to compare it with other products or re-evaluate the product itself. Summary finishes the thesis to brief explanation of the process as well as suggesting what might be done as further development.

1.1 Balteco AS

Balteco, as a leader in hydro massage bath development and manufacturing in Northern Europe, was established by a group of talented and ambitious engineers in 1990. Over the past twenty years the company has gained a lot of experience and extremely valuable know-how, which is realized into the most current Balteco product range to represent probably the best hydro massage bath range on the market. Wide range of designer series of baths include an extensive line produced from sanitary cast acrylics and a new line of freestanding baths branded as Xonyx massive stone baths and other products from Solid Surface.

Unique aspect of Balteco is a talented and experienced product development team including designers and engineers: we design and engineer every aspect of the new hydro massage bath – from outer design to custom designed electronic controls. As a recognized leader of hydro massage bath development, we have over the years introduced numerous valuable functional innovations and technical solutions that have been become an industry standard and have been adopted by other quality manufacturers.

As proof of continuous innovative product development, award-winning product design and high quality – Balteco is proud to claim vastly more than 100.000 satisfied hydro massage bath customers all over Europe. (1)

1.1.1 Organizational Chart of Balteco AS

The organization chart is a diagram showing graphically the relation of one official to another, or others, of a company. It is also used to show the relation of one department to another, or others, or of one function of an organization to another, or others.

Chairman of the Board: The chairman or chairperson, or simply the chair, sometimes known as chairwoman, is the highest officer of an organized group such as a board, a committee, or a deliberative assembly. (2)

General Manager: A general manager is any executive who has overall responsibility for managing both the revenue and cost elements of a company's income statement, known as profit & loss (P&L) responsibility. A general manager usually oversees most or all of the firm's marketing and sales functions as well as the day-to-day operations of the business. (3)

Financial Director: The role of the finance director varies according to the size of the company involved. However, in general, he or she oversees all financial aspects of company strategy and is responsible for the flow of financial information to the chief executive, the board and, where necessary, external parties such as investors or financial institutions. (4)

Chief Accountant: Responsible for the coordination of the division wide annual audit and preparation of the Comprehensive Annual Financial Report and other mandated reports. Advises senior staff on accounting and other financial matters; implements new accounting standards and formulates financial policies; plans, manages, and coordinates monthly and financial year-end closing activities; and performs related duties as required or assigned. (5)

Marketing: The process of planning and executing the conception, pricing, promotion, and distribution of ideas, goods, and services to create exchanges that satisfy individual and organizational goals. (6)

Sales: Responsible of selling the products of Balteco in and outside of Estonia.

Development: Department of design and product innovation. Responsible of improving the aesthetics, usability of existing products or come up with brand new solutions.

Production: Responsible of manufacturing the planned, designed and developed products; overcoming the production problems and assuring to fit in the quality standards.

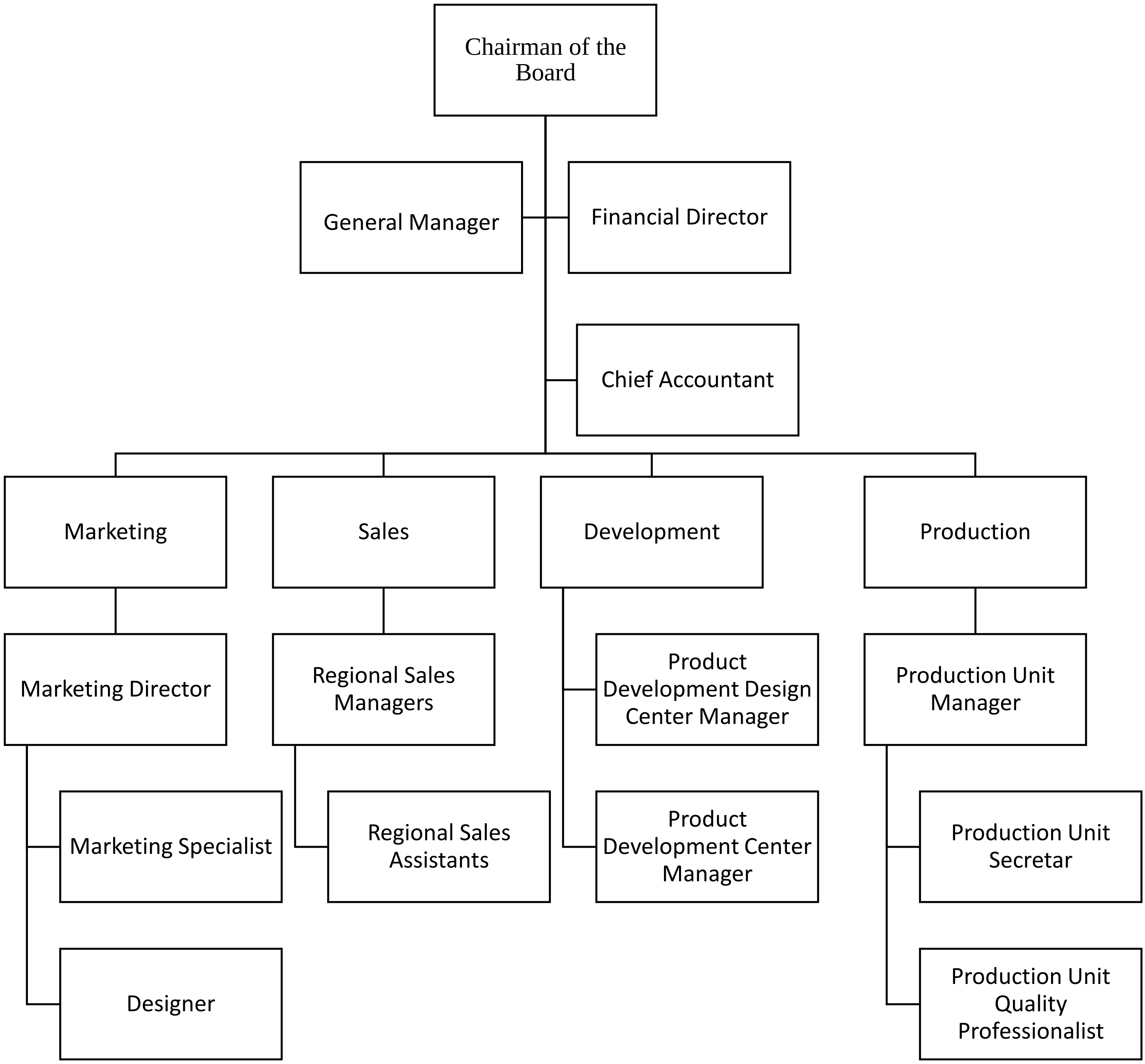


Figure 1 Balteco AS Organizational Chart

1.1.2 Product Range of Balteco AS

The company’s product range is listed as below.

- Baths & Whirlpools

Figure 2 Examples for Baths & Whirlpools

- Shower Cabins

Figure 3 Examples for Shower Cabins

- Massage Panels

Figure 4 Massage Panels

- Steam Cabins

Figure 5 Examples for Steam Cabins

- Mini pools

Figure 6 Examples for Mini Pools

- Shower Walls

Figure 7 Examples for Shower Walls

- Furniture

Figure 8 Examples for Furniture

- Basins

Figure 9 Examples for Basins

- Wellness Capsules

Figure 10 Wellness Capsules

1.2 Shower Seats

Shower seat is a product which provides comfortable shower experience with different design options and one purpose. The need for the shower seat may be based on personal preference or health and physical conditions of the individual. The function of the shower seat is simply letting you have a sit while taking the shower.

<u>Foldable Wall Mounted Shower Seat</u>

Figure 11 Foldable Wall Mounted Shower Seat (7)

<u>Non - Foldable Wall Mounted Shower Seat</u>

Figure 12 Non Foldable Wall Mounted Shower Seat (8)

Shower Stools

Figure 13 Shower Stools (9)

Description of the Components

Seat: The Part which user sits while having a shower.

Wall Mount: The structure which attaches the seat to the wall with fastners. Most of the time, the fastners are wall plugs and suitable bolts.

Stopper: For the foldable seats, it is the part which blocks the rotational movement of the seat and provides a steady position to the seat.

Rotator: For the foldable seats, it is the structure which enables the seat has the folding option. They can be pins, bearings, hinges, etc.

Ribs: They are the supports and mount structures to the wall on the non foldable wall mounted shower seats.

Legs: Legs are the parts which stools stand on the ground.

1.3 Benefits of Shower Seats to Balteco AS

Balteco AS currently does not have any shower seat in their product range. Being one of the biggest bathroom technologies producer in Northern Europe, shower seat addition would add crucial values to the company. However with multiple benefits, the most important one would be enlarging the target group.

The recent studies show that aging population in Europe is increasing and the design for elderlies in various industries and areas is becoming a popular topic to focus on. Particularly for bathroom products, it is clearly understandable that a shower seat would attract the elderlies as well as disabled people from the point of providing;

- Comfort (Such as preventing fatigue, reaching the feet easier by sitting, etc.)
- Safety (Preventing slipping, hitting body parts when moving, etc.).

These aspects surely can broaden the user target group both in the perspective of the buyer type and as well as the quantity of the buyers. Moreover it can be simply seen as a bathroom furniture which can be purchased based on pure will on luxury or aesthetics. In addition to broaden the target group, shower seat can add more importance to the other related new products of Balteco AS.

By saying that it has to be mentioned that Balteco AS recently came up with new shower cabinets with larger dimensions, and provided wider space to the user. Also lower height basins which are easier to go in and out makes the user more maneuverable with the combination of larger cabinets. With all those new products and dimensions it can be said that shower seat would fit in to bathroom better.

Another value could be a new marketing strategy to bundle the seats with cabinets, basins, massage panels, etc.

2. Shower Seat Market Research

From the market research which had been done by visiting the producers, retailers and doing an online research; it had been clearly understood that there was humongous production facilities, product portfolios and competitors all around the world. In this section initially importance of shower seat was examined, shower seat types had been evaluated by their various aspects which could have affected the user experience. Also types of the seats were taken into consideration and evaluated by using The Weighting and Scoring Method.

2.1 Importance of the Shower Seat

During the researches the relation of medical purposes of the shower seats, from the point of view of disabled people's comfort, had been observed. Furthermore information showed that not only disabled people but elderlies might need to have sitting assistant during the bathing. Therefore examination of the trends of aging population of EU had been thought as a helpful path to show that shower seats might have not been considered only as niche product but a need for individuals and families in the future.

2.1.1 Population Structure and Ageing

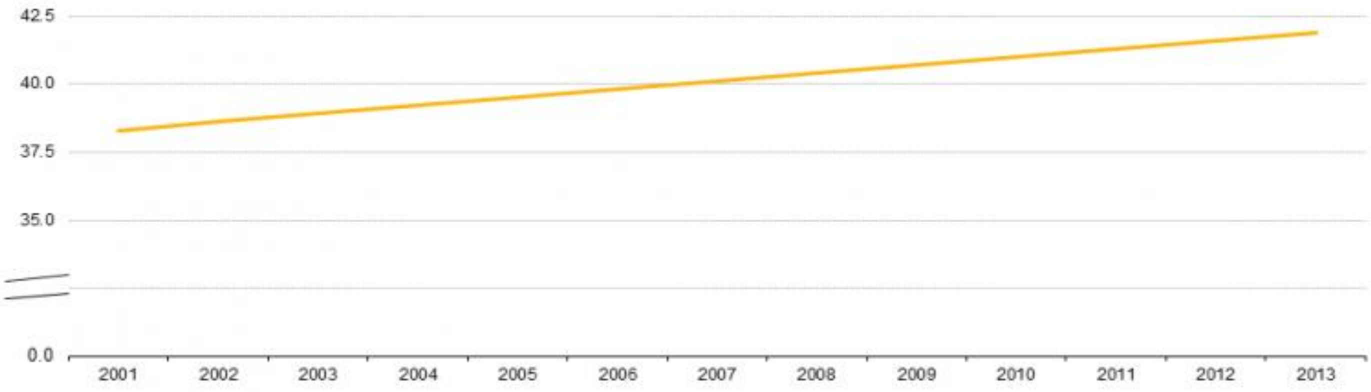
Consistently low birth rates and higher life expectancy will transform the shape of the EU-28's age pyramid; probably the most important change will be the marked transition towards a much older population structure and this development is already becoming apparent in several EU Member States. As a result, the proportion of people of working age in the EU-28 is shrinking while the relative number of those retired is expanding. The share of older persons in the total population will increase significantly in the coming decades, as a greater proportion of the post-war baby-boom generation reaches retirement. This will, in turn, lead to an increased burden on those of working age to provide for the social expenditure required by the ageing population for a range of related services. and higher consistently low birth rates and higher life expectancy will transform the shape of the EU-28's age pyramid; probably the most important change will be the marked transition towards a much older population structure and this development is already becoming apparent in several EU Member States.(10)

2.1.2 Tables and Figures of Population Structure

Table 1 Population Age Structure by Major Age Groups, 2002 and 2012 (11)

	0–14 years old		15–64 years old		65 years old or over	
	2002	2012	2002	2012	2002	2012
EU-28 (1)	16.8	15.6	67.2	66.5	16.0	17.9
Belgium (1)	17.5	17.0	65.6	65.7	16.9	17.3
Bulgaria (1)	15.0	13.4	68.1	67.8	16.9	18.8
Czech Republic	15.9	14.7	70.3	69.1	13.9	16.2
Denmark	18.7	17.7	66.5	65.0	14.8	17.3
Germany	15.3	13.2	67.6	66.1	17.1	20.6
Estonia (2)	16.9	15.5	67.6	66.8	15.4	17.7
Ireland	21.2	21.6	67.6	66.5	11.1	11.9
Greece	15.2	14.7	67.4	65.6	17.4	19.7
Spain	14.5	15.1	68.5	67.5	17.0	17.4
France	19.0	18.6	65.0	64.3	16.0	17.1
Croatia (2)	16.6	15.1	66.9	67.0	16.5	17.9
Italy	14.2	14.0	67.1	65.2	18.7	20.8
Cyprus	21.5	16.5	66.8	70.7	11.7	12.8
Latvia	16.7	14.3	67.9	67.2	15.4	18.6
Lithuania	19.0	14.8	66.5	67.1	14.5	18.1
Luxembourg (1)	18.9	17.1	67.1	68.9	13.9	14.0
Hungary (1)	16.3	14.5	68.4	68.6	15.3	16.9
Malta	19.2	14.8	68.2	68.8	12.6	16.4
Netherlands	18.6	17.3	67.7	66.5	13.7	16.2
Austria	16.7	14.6	67.8	67.6	15.5	17.8
Poland (1)	18.4	15.1	69.0	71.1	12.6	13.8
Portugal	16.2	14.9	67.3	66.0	16.6	19.0
Romania	17.7	15.2	68.4	68.5	13.9	16.3
Slovenia (1)	15.4	14.3	70.1	68.9	14.5	16.8
Slovakia	18.7	15.4	69.9	71.8	11.4	12.8
Finland	17.9	16.5	66.9	65.4	15.2	18.1
Sweden	18.2	16.7	64.6	64.5	17.2	18.8
United Kingdom	18.7	17.6	65.4	65.6	15.9	16.8
Iceland	23.1	20.7	65.3	66.6	11.6	12.6
Liechtenstein	18.4	15.8	71.1	69.8	10.5	14.4
Norway	20.0	18.5	65.0	66.1	14.9	15.4
Switzerland (1)	16.9	15.0	67.5	67.8	15.6	17.2
Montenegro (1)(2)	:	18.9	:	68.1	:	13.0
FYR of Macedonia (2)	21.6	17.2	68.0	71.0	10.4	11.8
Serbia (1)	16.1	14.4	67.3	68.3	16.6	17.3
Turkey	29.6	25.3	64.9	67.4	5.5	7.3

(1) Break in time series.
(2) The population of unknown age is redistributed for calculating the age structure.
Source: Eurostat (online data code: demo_pjanind)



X axis: Median Age
Y axis: Year

Figure 14 Median age of population, EU-28, 2001–13 (12)

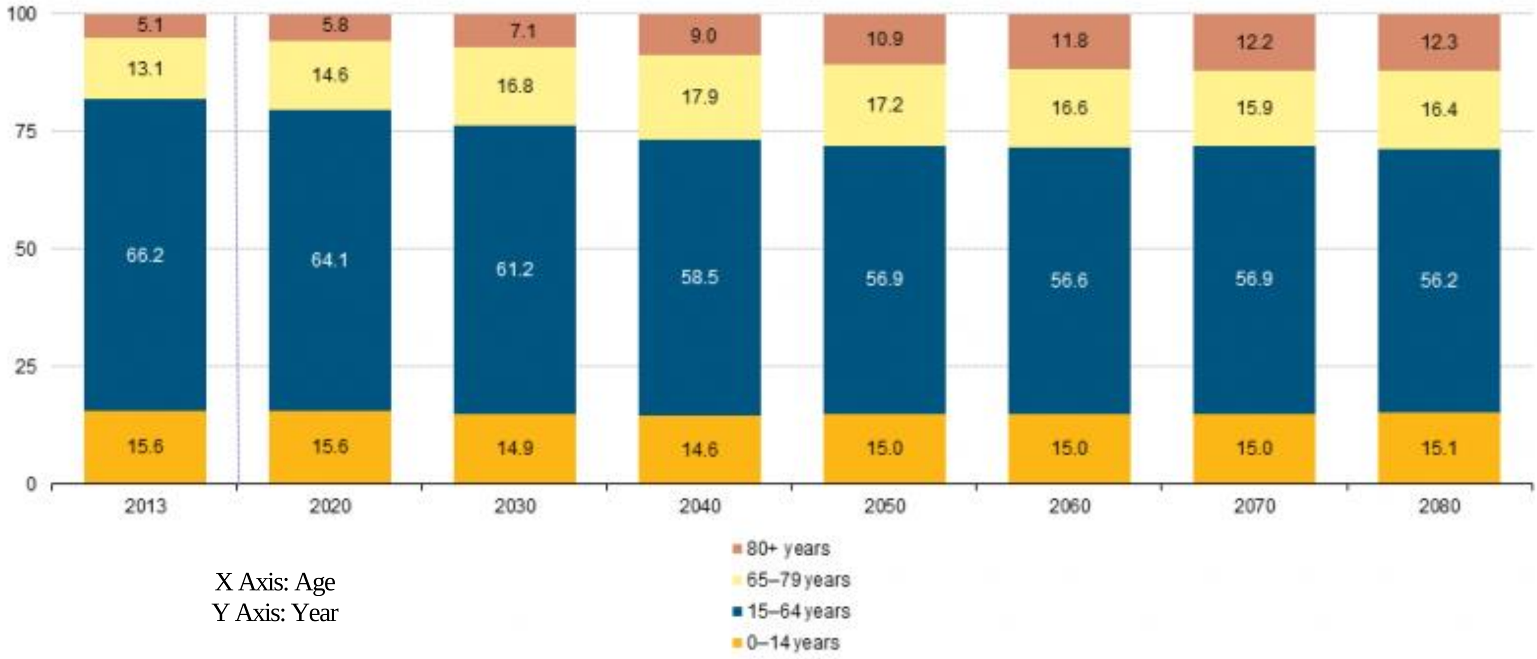


Figure 15 Population structure by major age groups, EU-28, 2013–80 (% of total population) (13)

2.1.3 Bathroom Safety for Elderly

The investigation of the aging population had been conducted focusing in mainly EU Member States, and also the study had been backed up about the necessity and safety protection of shower seats for elderly with the following AGE UK organization factsheet topics.

“Simple aids to daily living support people to maintain their independence in mobility, toileting, bathing, cooking, dressing, reaching, eating etc. Many of these items cost less than £30 and include items such as: kettle tippers, shower stools, reachers, adapted cutlery and raised toilet seats.”(14)

“People aged 60 or over can get mobility aids for their home at a reduced rate of 5% VAT. This covers the supply and installation of grab rails, ramps, stair lifts, bath lifts, built-in shower seats or showers containing built-in shower seats and walk-in baths with sealable doors. The reduced rate will not apply where the goods are supplied without installation (but will apply to installation services alone) or for any repairs or maintenance of the items once they are installed.” (14)

2.2 The Weighting and Scoring Method

The weighted scoring method, also known as 'weighting and scoring', is a form of multi-attribute or multi-criterion analysis. It involves identification of all the non-monetary factors (or "attributes") that are relevant to the project; the allocation of weights to each of them to reflect their relative importance; and the allocation of scores to each option to reflect how it performs in relation to each attribute. The result is a single weighted score for each option, which may be used to indicate and compare the overall performance of the options in non-monetary terms. (15)

The method had been formed based on 1-5 scoring scale where the properties of the existing products assigned between 1 and 5. The ratings of the numbers were set below;

- 1 = Poor
- 2 = Fair
- 3 = Average
- 4 = Good
- 5 = Very Good

Each property type of the selected product ranges had been assigned a number between 1 and 5. At the end, the points had been summed up for every product range category. And the bigger result indicates, the product range has a better value to offer for the user experience. This evaluation directed the process to follow the optimum product range to focus on and to generate the concepts according to the decision.

2.3 Evaluation of the Existing Products

In this section a scale method was used which had been described briefly at the previous headline to determine the positive and negative aspects of the products and which specific product range to follow in the concept generating phase. Method was generated according to the;

- Dimensions.
- Functionality
- Material.
- Maximum Load Capacity.
- Aesthetics.
- Installation Ease.
- Usability of the products.

Table 2 Shower Seat Types to Evaluate

Wall Mounted Fixed	Wall Mounted Foldable	Separate Stools
		

Table 3 Shower Seats and Properties

	Dimensions (Width &Depth)	Cost	Maximum Load Capacity	Functionality	Usability	Installation Ease
Wall Mounted Fixed (8)	-	-	-	Sitting while Showering	Covers Space in Small Showers	Needs Hard Wall and Extra Reinforcement
Wall Mounted Foldable (16)	360x360 mm	95 €	150 Kg	Sitting While Showering	Getting Space by Folding	Needs Hard Wall and Extra Reinforcement
Separate Stools (17)	432x368 mm	27 € (18)	112,5Kg	Sitting While Showering	Mobility by Changing the Position of the Seat	Does Not Require Any Extra Structure and Tool.

Table 4 Rating Chart

	Dimensions	Cost	Max. Load	Functionality	Usability	Aesthetics	Installation Ease	SUM
Wall Mounted Fixed	-	-	-	-	2	4	2	8
Wall Mounted Foldable	3	2	4	-	5	3	2	**19**
Seperate Stools	2	4	2	-	3	1	4	16

With the gathered information available about the product range types; Rating Chart had been conducted as can be seen above at the Table 4.

As it is seen from the chart, Wall Mounted Foldable Shower Seats had been evaluated as the best product range to follow for the concept generation.

- Dimensions were evaluated due to their compactness, how much space they cover or provide to the user.
- Functionality was evaluated based on the please which was provided to the user and also the space which was created for the user at the end of the shower process.
- Cost was considered as the last purchasing cost for the customer. Maximum load is the weight that product can withstand at the worst scenario.
- Aesthetics was the topic of the design approach to the product and how appealing was the product to the end user.
- Finally installation ease was rated according to the easiness of the assembly of the product itself and how easy to install the product to the desired area (bathroom, shower, etc.).

From the scoring chart the product range had been decided, the measure which had to be decided after the chart was initial inputs to take into consideration in order to start the concept generating process:

- Easy Folding Mechanism.
- Strong Structure. (Which could serve wide range of users due to their weights.)
- Production Ease.
- Aesthetical Appeal.
- Market Requirements.
- Fresh Value.

These inputs which had been stressed out above were discussed in the meetings and came out of market research and online researches for the existing products. In addition to being initial values to the concept, inputs can be considered as the goal for the product. Meaning not only concept but the end product must had fulfilled the requirements which mentioned. Although the entry of the product to the market and the interest of the users to the product, and sales numbers, or the feedback of the users to the product may change some end features as further development to optimize the product.

3. Product Design Phase

3.1 Concept Generation

Product range and the inputs for the concept were taken into consideration to follow for the early concept and 3D concepts had been started to generate by using Solidworks 3D modelling software having mostly rough instincts about the concept and not too deep inspiration and consultation. The purpose was creating an argument over a solid initial concept rather than having theoretical or hypothetical discussions. This approach had been followed to have certain criticism and feedback.

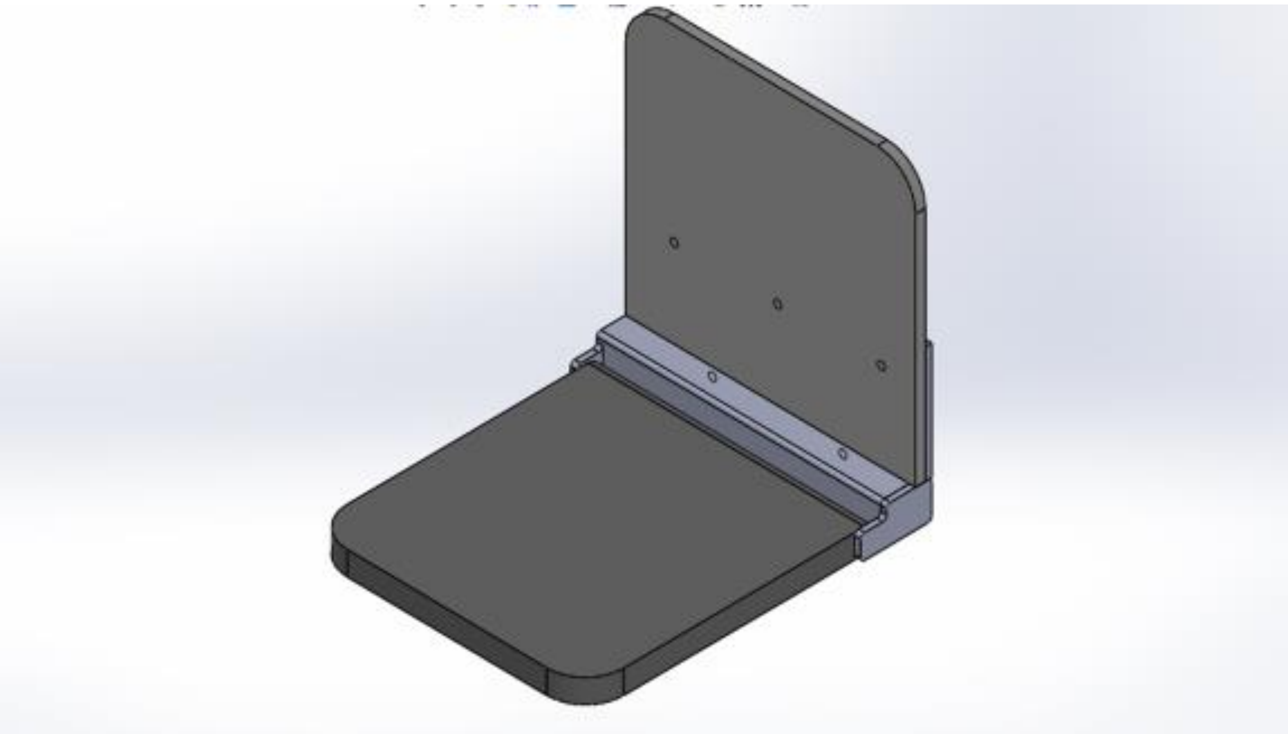


Figure 16 First Concept

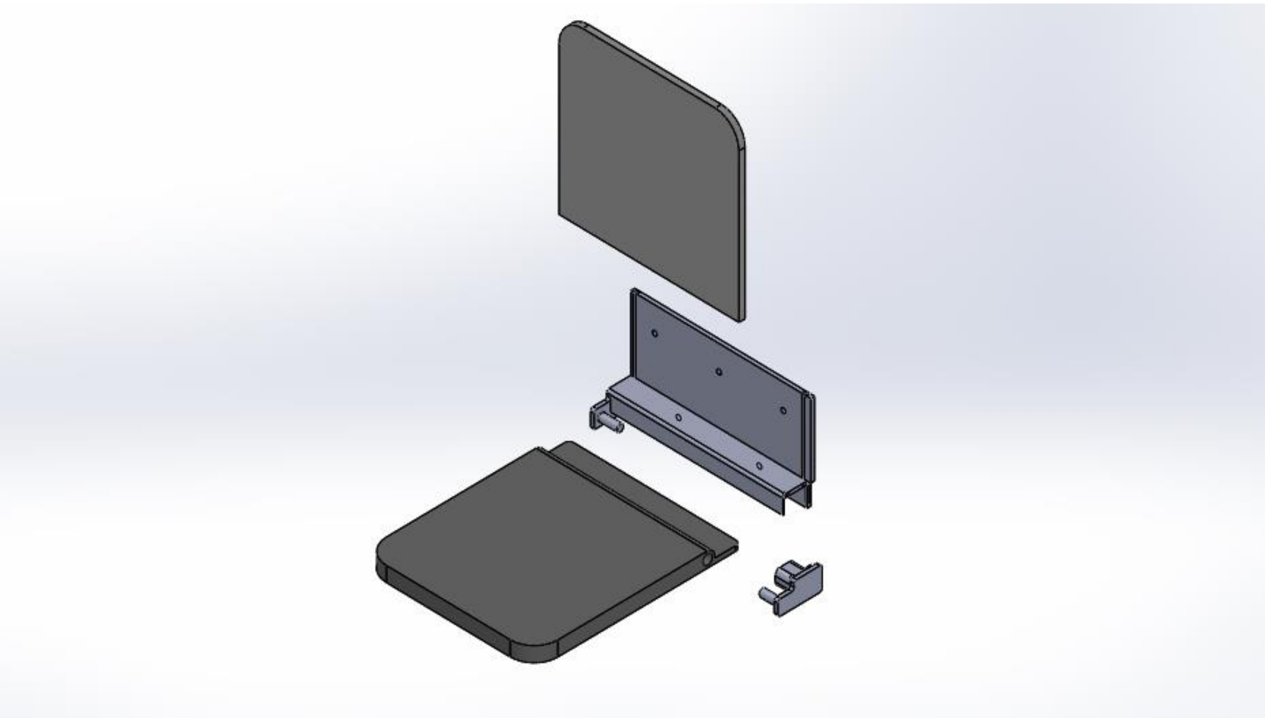


Figure 17 Exploded View of the First Concept

Figure 16 & 17 shows that the general idea for the first concept was having a rigid product with a comfortable feature of backseat. Yet this initial idea arose too many criticism from Balteco AS staff. Couple of the feedbacks had been listed as following;

- Aesthetically not appealing.
- Not ergonomic.
- Mounting structure is hard to produce.
- Costly to produce.

After the discussion the feedback was to prioritize the essential and needed features for the concept, drawing sketches by hand to be able to have generic, fast ideas and not to dwell around the 3D softwares at the beginning, looking for the products which were not only existing for a bathroom (thinking outside of the box.) to have ideas and inspirations about the further process.

Due to the feedback a restart of the process with choosing the most suitable elements for the product considered as a logical step, thus morphological matrix study (which had been taught during the Design & Engineering curriculum.) had been essential step to conclude. Down below the definition and the history of the Morphological Analysis and the Matrix had been presented.

3.2 General Morphological Analysis

General Morphological Analysis (GMA) was developed by Fritz Zwicky - the Swiss astrophysicist and aerospace scientist based at the California Institute of Technology (Caltech) - as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes (Zwicky 1966, 1969).(19)

Zwicky applied this method to such diverse fields as the classification of astrophysical objects, the development of jet and rocket propulsion systems, and the legal aspects of space travel and colonization. (Greenstein & Wilson, 1974). (20)

Fritz Zwicky offered a broader approach for morphological research:

Fritz Zwicky proposed a generalized form of morphological research:

"Attention has been called to the fact that the term morphology has long been used in many fields of science to designate research on structural interrelations - for instance in anatomy, geology, botany and biology. ... I have proposed to generalize and systematize the concept of morphological research and include not only the study of the shapes of geometrical, geological, biological, and generally material structures, but also to study the more abstract structural interrelations among phenomena, concepts, and ideas, whatever their character might be. "(Zwicky,1966,p.34) (21)

Essentially, general morphological analysis is a method for identifying and investigating the total set of possible relationships or "Configurations" contained in a given problem complex. In this sense, it is closely related to typology analysis, although GMA is more generalised in form and has far broader applications. The approach begins by identifying and defining the parameters (or dimensions) of the problem complex to be investigated, and assigning each parameter a range of relevant "values" or conditions. A morphological box - also fittingly known as a "Zwicky box" - is constructed by setting the parameters against each other in an n-dimensional matrix (see Figure 18). Each cell of the n-dimensional box contains one particular "value" or condition from each of the parameters, and thus marks out a particular state or configuration of the problem complex.

For example, imagine a simple problem complex, which we define as consisting of three dimensions let us say "color", "texture" and "size". In order to conform to Figure 18, let us further define the first two dimensions as consisting of 5 discrete "values" or conditions each (e.g. color = red, green, blue, yellow, brown) and the third consisting of 3 values (size = large, medium, small) . We then have 5x5x3 (= 75) cells in the Zwicky box, each containing 3 conditions - i.e. one from each dimension (e.g. red, rough, large). The entire 3-dimensional matrix is a typological field containing all of the (formally) possible relationships involved.

The typological field format utilizes the dimensions of physical space to represent its variables, as in a Cartesian coordinate system. However, the number of coordinates that can be represented in physical space ends at three. (Typologies of greater dimensions-representing hyperspaces-usually get around this problem by embedding variables within each other. However, such formats quickly become difficult to interpret, if not hopelessly unintelligible.) Employing the morphological field format (Figure 19) liberates us from the spatial constraints of 3-dimensional space, and allows us to allocate of any number of dimensions. (22)

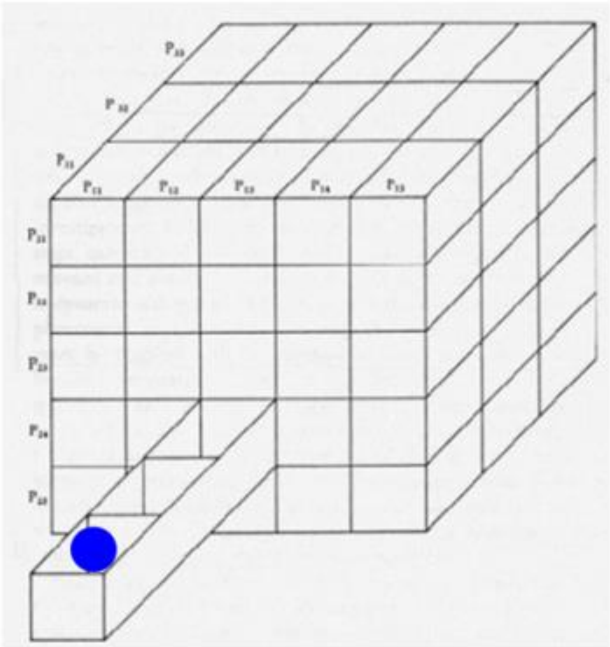


Figure 18 3-Parameter "Zwicky Box" in typological format, containing 75 (5x5x3) cells

Parameter 1	Parameter 2	Parameter 3
P1.1	P2.1	P3.1
P1.2	P2.2	P3.2
P1.3	P2.3	P3.3
P1.4	P2.4	
P1.5	P2.5	

Figure 19 3- *Parameter field in morphological format*

Table 5 Morphological Matrix for Possible Solutions

	Option 1	Option 2	Option 3	Option 4
Folding Mechanism	Hinge	Spring	Bearing	Pin
Closed Position	Down	Up	Up	Down
Stopping Mechanism	Spring	Lock	Spring	Seat
Mounting Mechanism	Bent Profile	Single Plate	Angle Bracket	Single Plate
Seat	Single Seat	Seat + Back Seat	Seat + Back Seat	Single Seat

The morphological matrix of the possible four options with different features had been generated and evaluated with the optimum and most suitable features according the Balteco AS requests, also design preferences of the student himself. Down below some of the features of the options had been stressed out due to their upside and downsides.

Option 1: In this specific solution maximum efficiency and durability for the folding feature had been prioritized but the downside was the cost of the hinge, spring, bent profiles; upon to that the resistance of the hinge and the spring against the water was questionable.

Option 2: This option again was providing the same features as Option 1, moreover an extra strength for the wall mount but the negative sides were again the resistance against the water plus the extra structure need for the spring lock mechanism. One additional feature for extra comfort and aesthetics in this option was, to add a backseat to the product.

Option 3: Angle brackets were the focus at this product to provide a housing for bearings and a back seat for extra strength to the mount structure. However the aesthetically, angle brackets were not suitable for the shower seat.

Option 4: This option had the most simple, easy solutions. Yet it had a strength problems with the single plate to wall.

As it can be even seen from the brief explanations of the options, every proposed solution had positive and negative aspects. Therefore using a morphological matrix among the best features of each offered solution might have given most logical product concept idea.

Table 5 shows us the selected features mainly due to their simple yet effective roles and aesthetical features. Since the product must be easy to use and appealing to the end user.

Selected Option 5:

Table 6 Morphological Matrix Result

	Closed Position	Folding Mechanism	Stopping Mechanism	Mounting Mechanism	Seat
Option 5	Up	Pin	Seat	Bent Profile	Seat + Back Seat

3.2 Concept Generation Development

With the help of the morphological matrix which parts must be the elements of the future product and which ones should be implemented in the concept generation phase had been set. Unlike the first attempt for the concepts, hand sketching had been the initial step to start the process.

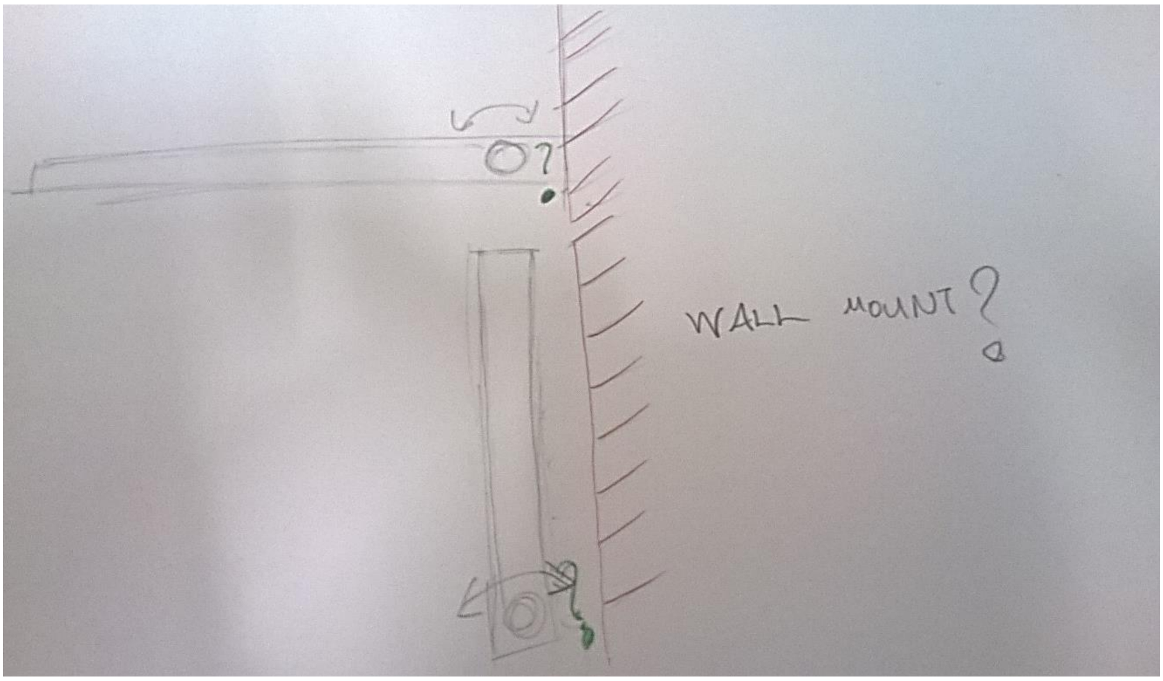


Figure 20 Sketch 1

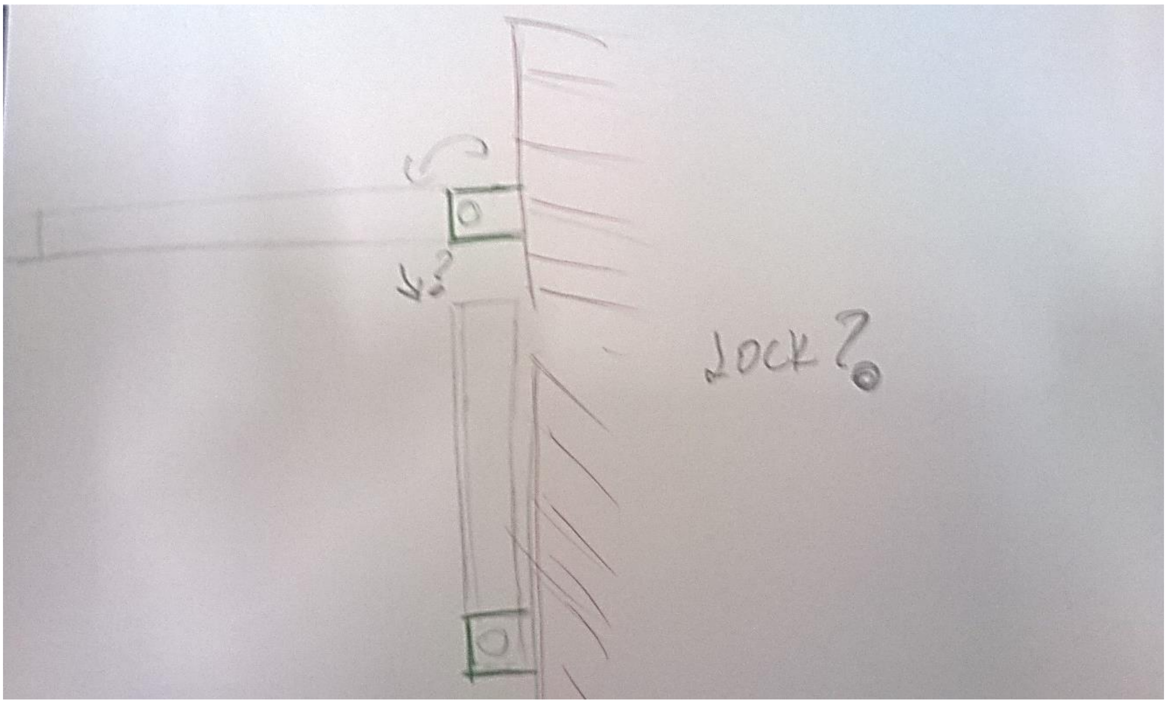


Figure 21 Sketch 2

As can be seen from the Figure 20 the initial idea was having the closed position by folding the seat up by rotating it around a simple pin and then the question was mounting the seat to the wall. The early idea was using L bracket as bent profile option. And at the Figure 21 we can see some primitive profile was added just to demonstrate on the sketch that it will be a mount from the sides. However a followed up question of locking the positions of folding up and down had been a spot to focus on.

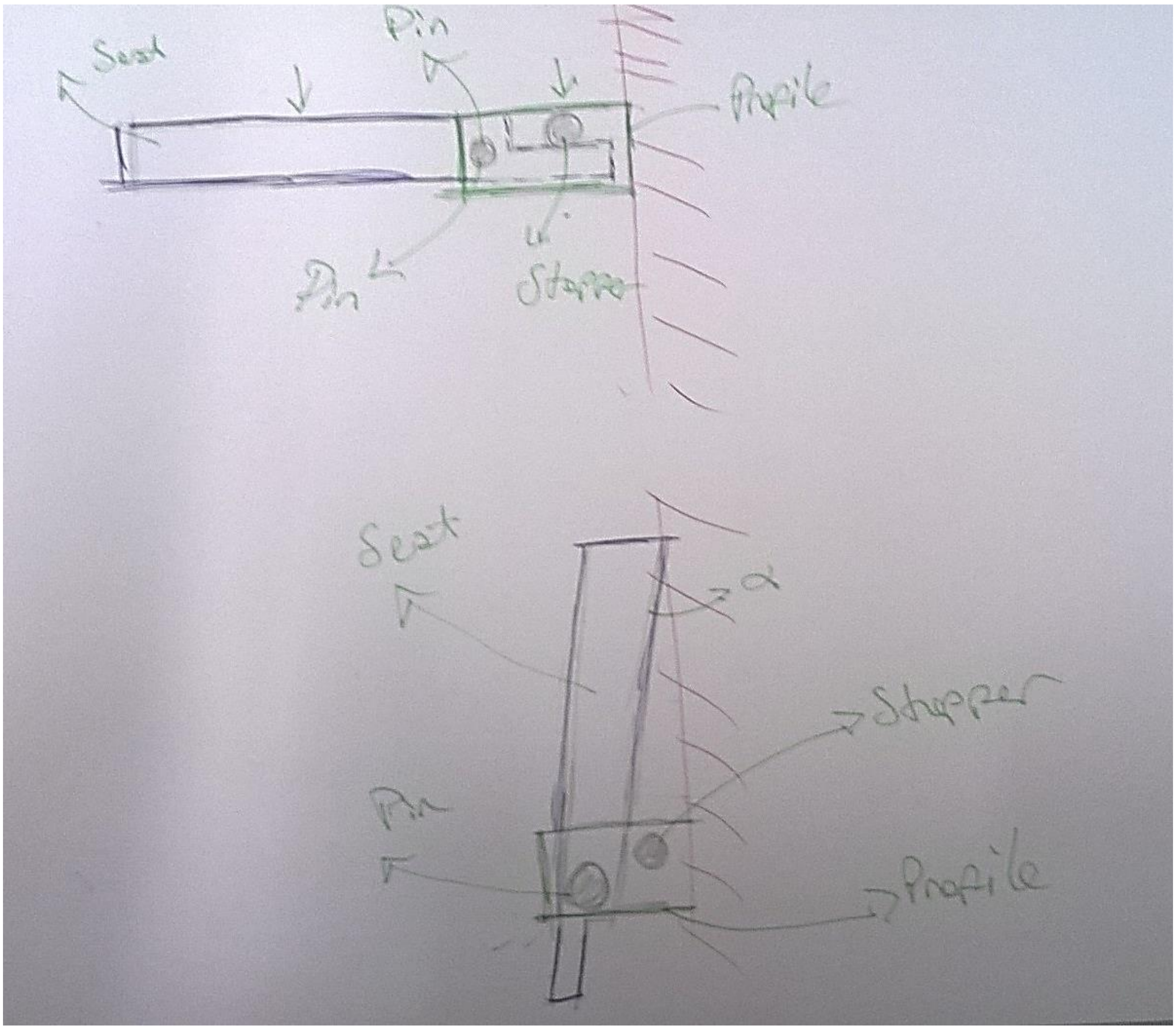


Figure 22 Sketch 3

Figure 22 shows that the folded down position locking problem had been tried to be solved by implementing a simple stopper which seat would lean to and hold on according to the simple momentum and statical norms. While the locking principle at folded up position thought as having and angle between the wall and the seat and let the weight of the seat itself lean towards the wall. With these two ideas, heavily detailed and complex technical structures had been eliminated for locking.

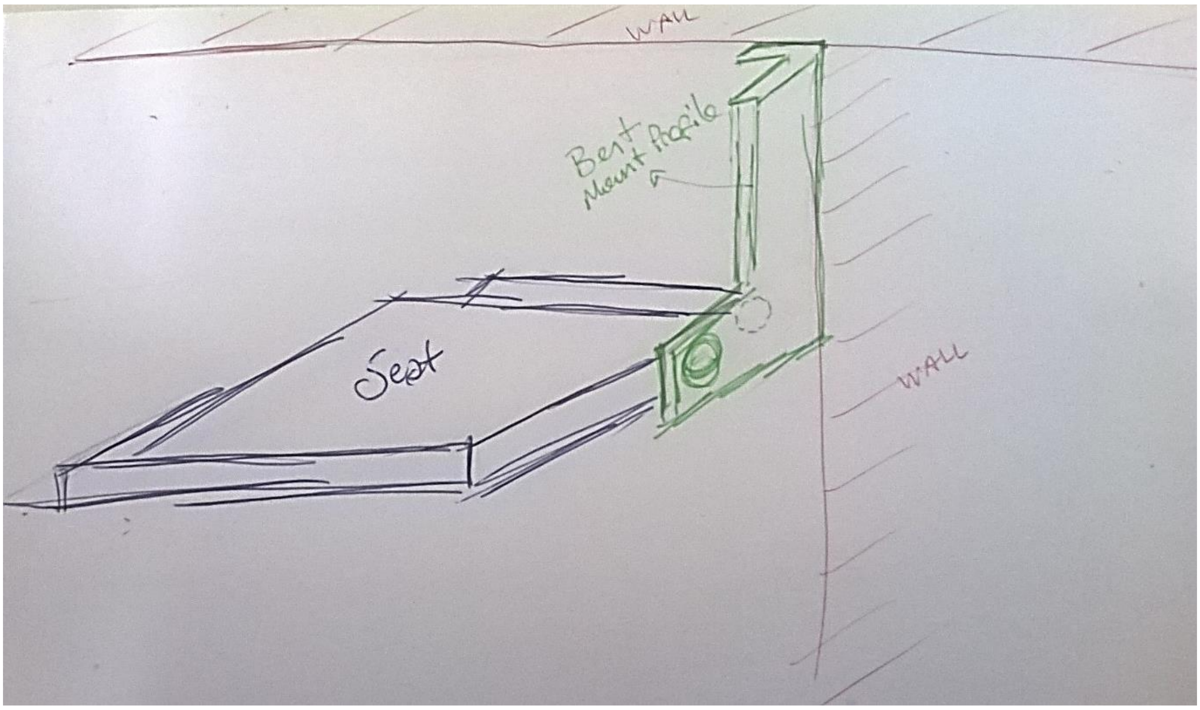


Figure 23 Sketch 4

The Figure 23 demonstrates that a longer bent profile idea had been sketched for the purpose of housing the pin, stopper and the possible backseat ideas. The mounting to wall option would be logical by using wall anchors and bolts through the holes on the both profiles and the wall.

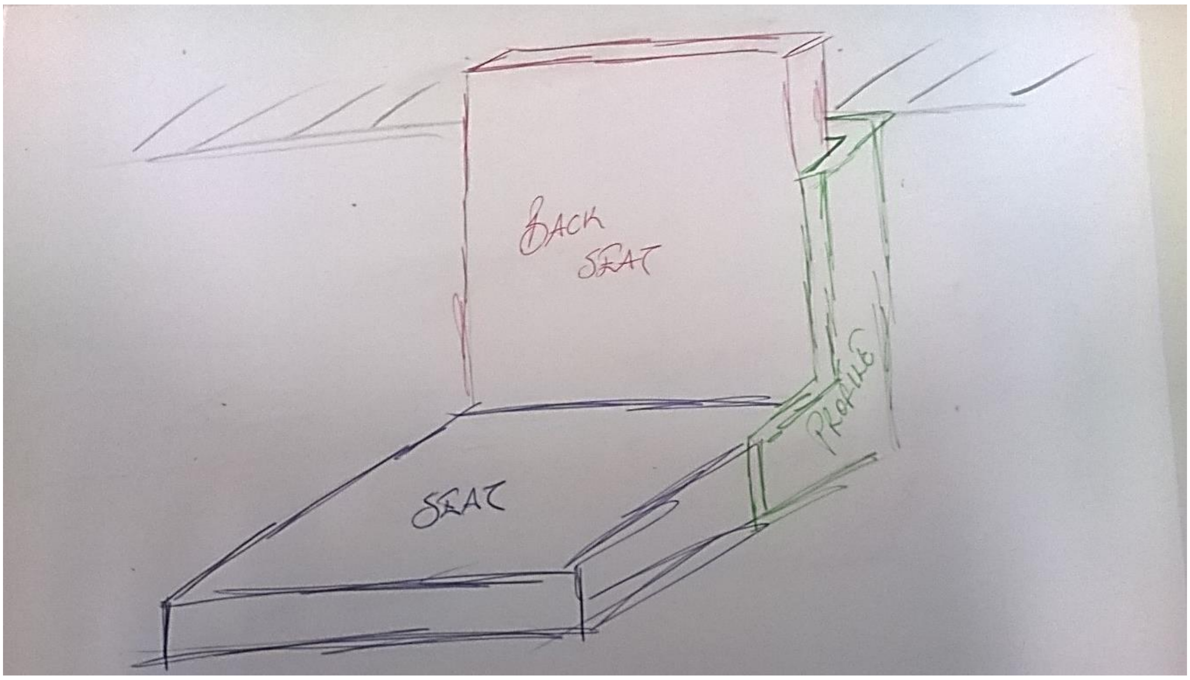


Figure 24 Sketch 5

Figure 24 demonstrates the initial idea of the long bent profile and its purpose for housing the back seat as well. With the aesthetical improvements which were taken into consideration, these sketches transformed to 3D Model.

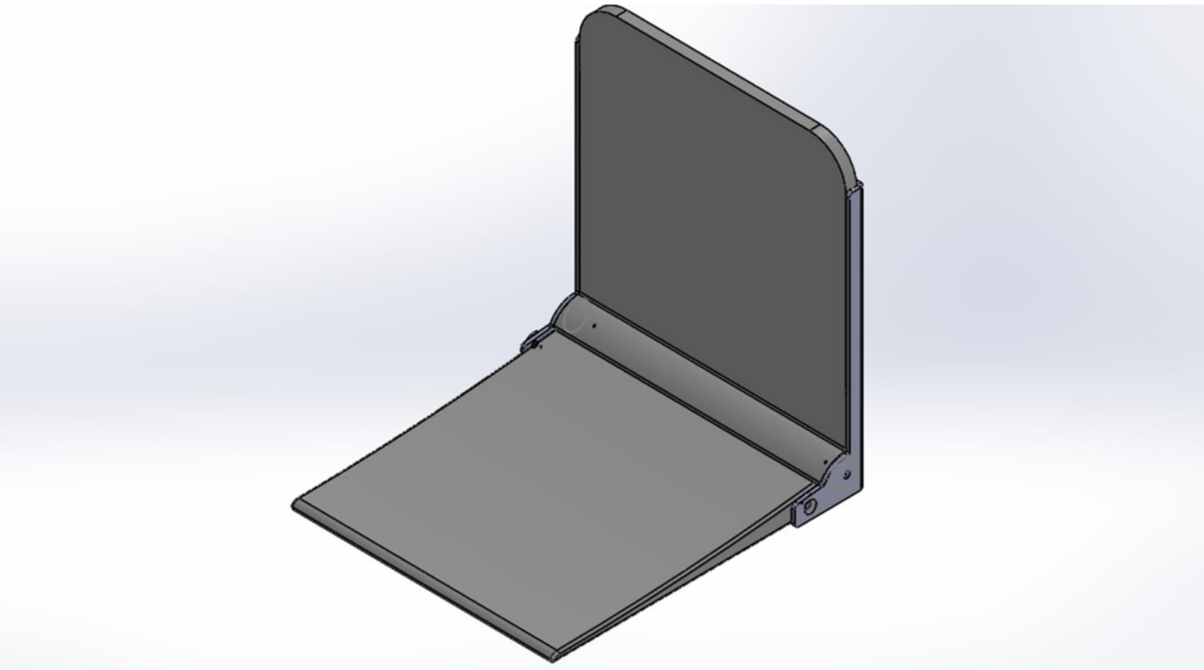


Figure 25 3D model of Sketches

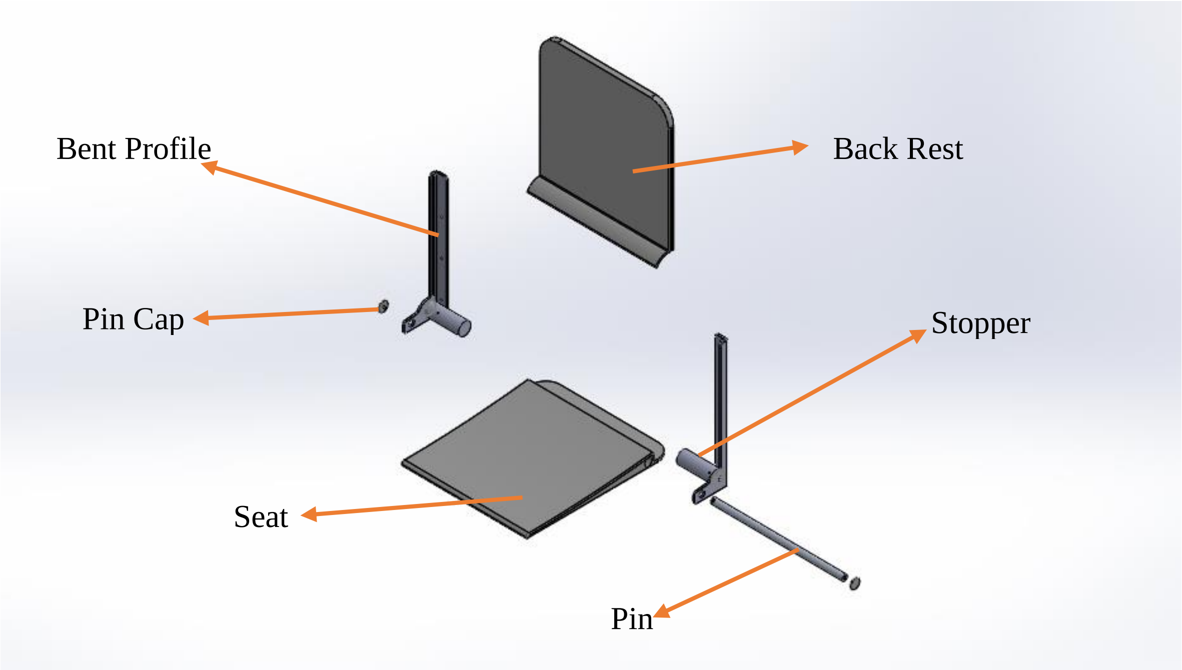


Figure 26 Exploded View of the 3D Model of the Sketches

Figure 27 Red area shows us the position and anatomy of the spine of the human beings while sitting ergonomically comfortable and healthy way. Thus on the Figure 28 we can clearly see the initial design flow of the back seat of seat concept. Figure 28 red area was designed to hide the folding mechanism visually. But as discussed the exterior radius is obviously would disturb the user and affect the showering experience in negative way.

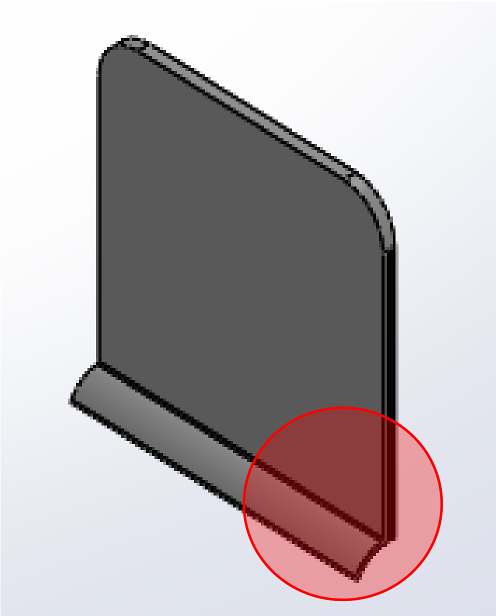


Figure 27 Design Flow of the Back Rest

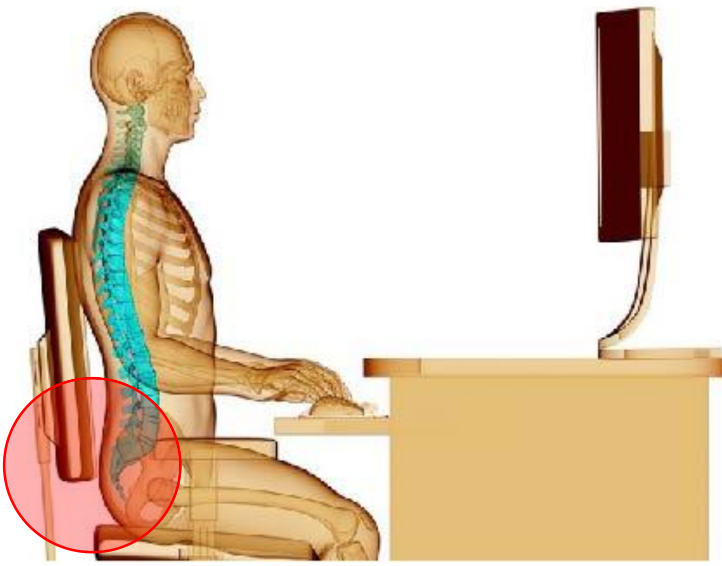


Figure 28 Ergonomic Sitting Position

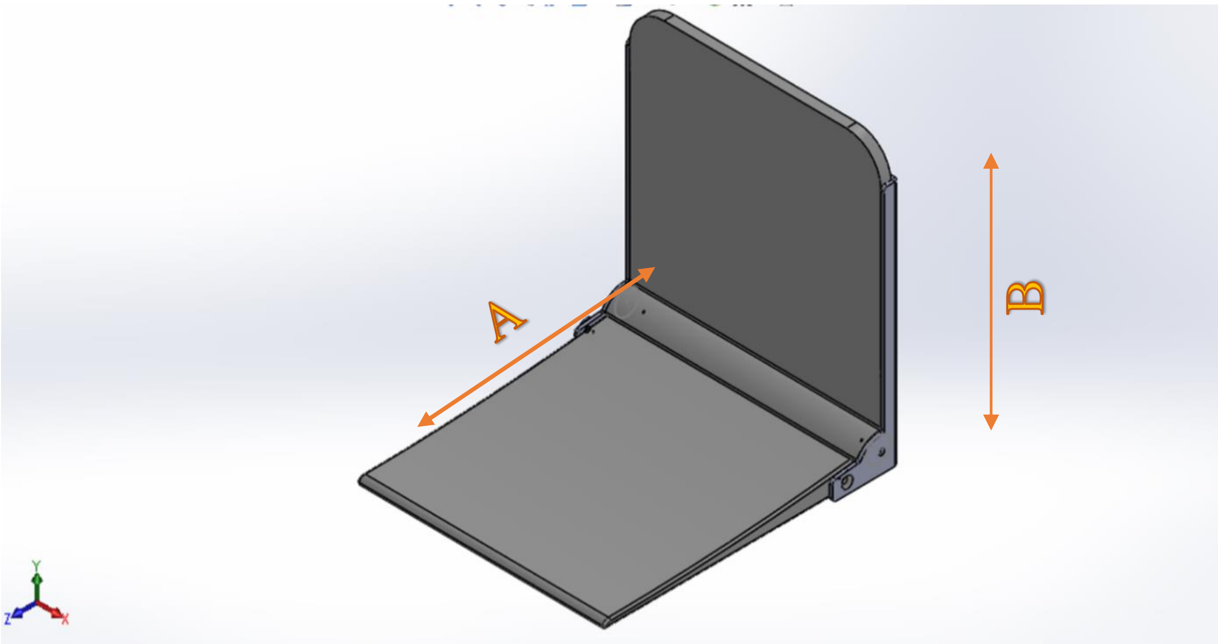


Figure 29 Proportion of the Seat and Back Rest

The renewed concept also got critics of having wrong proportions as can be seen at Figure 29. The sitting surface which is A was longer than the back rest area which was B. Thus this problematic dimensions arose questions about the design which surface is mounted to the wall and which space is for sitting. With acknowledging those changes which had to be done in the process, to perform strength calculations with FEA (Finite Element Analysis) method to the model to analyze how accurate is the principal of the design seemed a mandatory step.

3.2.1 Finite Element Analysis Definition

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variational calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures". By the early 70's, FEA was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, FEA has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition. (22)

There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture. (22)

FEA uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which will receive large amounts of stress usually have a higher node density than those which experience little or no stress. Points of interest may consist of: fracture point of previously tested material, fillets, corners, complex detail, and high stress areas. The mesh acts like a spider web in that from each node, there extends a mesh element to each of the adjacent nodes. This web of vectors is what carries the material properties to the object, creating many elements. (22)

A wide range of objective functions (variables within the system) are available for minimization or maximization:

- Mass, volume, temperature
- Strain energy, stress strain
- Force, displacement, velocity, acceleration
- Synthetic (User defined)

There are multiple loading conditions which may be applied to a system. :

- Point, pressure, thermal, gravity, and centrifugal static loads
- Thermal loads from solution of heat transfer analysis
- Enforced displacements
- Heat flux and convection
- Point, pressure and gravity dynamic loads

Each FEA program may come with an element library, or one is constructed over time. Some sample elements are:

- Rod elements
- Beam elements
- Plate/Shell/Composite elements
- Shear panel

- Solid elements
- Spring elements
- Mass elements
- Rigid elements
- Viscous damping elements

Many FEA programs also are equipped with the capability to use multiple materials within the structure such as:

- Isotropic, identical throughout
- Orthotropic, identical at 90 degrees
- General anisotropic, different throughout (22)

Types of Engineering Analysis

- **Structural analysis** consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation.
- **Vibrational analysis** is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibrational frequency of the material which, in turn, may cause resonance and subsequent failure.
- **Fatigue analysis** helps designers to predict the life of a material or structure by showing the effects of cyclic loading on the specimen. Such analysis can show the areas where crack propagation is most likely to occur.
- **Heat Transfer analysis** models the conductivity or thermal fluid dynamics of the material or structure .This may consist of a steady-state or transient transfer. Steady-state transfer refers to constant thermos properties in the material that yield linear heat diffusion. (22)

3.2.2 Material Selection

To conduct the FEA for the design, the materials had to be assigned to the each part of the structure. Selection of the materials are listed below, general information about the materials and the reasons of selection of the materials had been summarized in this section.

- Seat - Back Rest – Polyurethane,
- Mount Structures – Aluminium
- Fasteners – Stainless Steel

Polyurethane Elastomers

Polyurethane (or "urethane") elastomers are one type of a large family of elastic polymers called rubber. There are 14 types in general use. All of them have been commercially successful, but they are all different in several ways. These charts provide a quick initial screening guide. Thirteen of these elastic polymers or elastomers are called conventional rubber. That means because they are solids, they are mixed, milled, and molded by techniques which have been in use by the rubber industry for the past 80 years. Polyurethanes are liquids and can be cast in low pressure molds. Polyurethanes should not be confused with plastics, it is incorrect to refer to thermoset polyurethanes as plastic. Polyurethanes by definition are rubber. The general characteristics of rubber are:

- Can be highly deformed without breaking
- Ability to recover rapidly and repeatedly from deformation
- Deformation is large in proportion to the original dimensions
- Large deformations produced at relatively low stress levels
- Desired stress-strain properties can often be obtained by compounding.
- Stress-strain characteristics are non-linear, thus the material becomes stiffer with greater deflection and velocity of impact
- Affected by the environment and conditions under which they are employed

Like all engineered materials, Polyurethane has limits typically, polyurethane rubber should not be used in dynamic applications above (93C). When tested at (93C) their properties are generally only half of those measured at (25C). They heat age well however, and the effect of high temperatures up to (120C) for weeks on physical properties is almost completely reversible when tested again at (25C). We have some polyurethanes that perform well up to (150C).(23)

In most dynamic applications we recommend staying at temperatures below (70C). The normal, high property working range is (-40C to 70C). At (70C) the properties of the elastomer begin to show a decline. The bond between urethane and metal weakens considerably above (70C).

Generally, polyurethanes exhibit high hysteresis and low thermal conductivity. They do not dissipate heat built up by dynamic action quickly. Avoiding heat build-up in an elastomeric part is a paramount consideration in design. In practice, this is usually done by controlling the amplitude of the deflection. For instance, using urethane elements in series allow large deflections.

Long term exposure to hot, humid environments should be avoided. Some urethanes are much more resistant than others to this environment.

Certain chemicals such as concentrated acids and polar solvents attack polyurethanes, and polyurethanes should not be put into continuous service in these environments. (23)

The Distinction of Polyurethane Rubber

Polyurethane raw materials are liquid, which permits them to be pumped, metered, mixed and dispensed by machines under very precise control of temperature and ingredient proportions. They enter molds as a liquid at low pressure and are "cured" at the same elevated temperature as that which they are mixed. This unique characteristic allows us to mold very large urethane parts with thick cross-sections that are completely uniform throughout. (23)

Table 7 Comparison of Polyurethane to other Possible Materials (24)

	Outdoor Weathering	Wear Resistance	Coefficient of Friction	Impact Strength	Rigidity	Heat Distortion Temperature
ABS	Fair	Low	Medium	Moderate	Excellent	Good
Polystyrene	Poor	Poor	Medium	Poor	Excellent	Good
CAB (Butyrate)	Excellent	Low	Medium	Low	Excellent	Good
PVDF	Good	Fair	Low	Good	Good	Excellent

Table 8(Continues) Comparison of Polyurethane to other Possible Materials (24)

UHMWPE	Good	Excellent	Very Low	Excellent	Good	Good
HDPE	Fair	Good	Low	Good	Good	Good
LDPE	Fair	Fair	Medium	Good	Fair	Fair
LLDPE	Fair	Fair	Low	Good	Good / Fair	Good
PVC Flexible	Excellent	Fair	Medium	Varies	Varies	Varies
Polycarbonate	Excellent	Good	Medium	Good	Maximum	Good
Polyurethane	**Excellent**	**Excellent**	**Very High**	**Varies**	**Varies**	**Varies**
Nylon	Good	Good	Very Low	Good	Varies	Varies

Table 9 Properties of Polyurethane %10 %20 Glass Fiber, molding (25)

General Properties			
Polyurethane (10-20% Glass Fiber, Molding)			
Density	$1.22e^3$	$1{,}36\ e^3$	kg/m^3
Price	4.7	5.15	€/Kg
Composition Overview			
Composition (summary)	PUR + glass filler		
Base	Polymer		
Polymer class	Thermoplastic: Amorphous		
Polymer type	PUR		
% filler	10	20	%
Filler type	Glass fiber		
Composition Detail			
Polymer	80	90	%
Glass (fiber)	10	20	%
Mechanical Properties			
Young's modulus	3.4	6.2	GPa
Compressive modulus	3.4	6.2	GPa
Flexural modulus	3.4	5.5	GPa
Shear modulus	1.23	2.25	GPa
Bulk modulus	6.16	6.47	GPa
Poisson's ratio	0.371	0.389	
Shape factor	10		
Yield strength (elastic limit)	26.5	41.4	MPa
Tensile strength	33.1	51.7	MPa
Compressive strength	32.8	36.2	MPa
Flexural strength (modulus of rupture)	19.4	42.7	MPa
Elongation	3	70	%
Hardness - Vickers	7.9	12.4	HV
Hardness - Rockwell M	31	35	
Hardness - Rockwell R	45	55	
Fatigue strength at 10^A7 cycles	13.2	20.7	MPa

Aluminium Alloys The physical and mechanical properties of aluminium alloys are the basic reasons of its success as constructional material, able them also to compete with steel in the structural field (Mazzolani 1995a, b, 1998a). The following conclusions can be made:

- Aluminium alloys represent a wide family of constructional materials, whose mechanical properties cover the range offered by the common mild steels.
- Corrosion resistance normally makes it unnecessary to protect aluminium structures, even in aggressive environments.
- The lightness of the material gives advantages in weight reduction, but it is partially offset by the necessity to reduce deformability, which gives a high susceptibility to buckling phenomena.
- The material itself is not prone to brittle fracture, but particular attention should be paid to those problems in which high ductility is required.
- The extrusion fabrication process allows to produce individually tailored shapes, according to the requirements which are designed for.
- Large choice for the connection solutions, because the modem technology gives the possibility to use either bolting, riveting and welding, without any difficulties involved. (26)

Favorable Properties:

- Low density, about 1/3 of steel
- Good strength and toughness, similar to steel
- Easy shaping of sections through extrusion, not possible with steel
- Good corrosion resistance; many applications do not need surface protection
- Excellent properties at low temperature
- Excellent recyclability

In many structural applications aluminium's low density is the most important reason for its use. For application in transport this is obvious (less energy needed), but also in civil engineering it can be important, i.e. for movable bridges - also less energy needed - and for long span bridges less dead weight means a higher live load (traffic) capacity.

The strength levels of certain aluminium alloys are similar to structural steels. Aluminium and its alloys have inherent toughness at low temperatures; steel requires special grades/processing to overcome its intrinsic low temperature brittleness. Unlike steel, many aluminium alloys can be extruded, giving designers a wider range of possible cross-sections, as shown later on.

Corrosion resistance of aluminium is very good, which means that in many building and civil engineering applications aluminium can be used without any surface protection. In particular for long-life structures - for instance 100 years in civil engineering - the maintenance costs for aluminium are very low compared to steel.

And finally, aluminium is recycled to a great extent as it can be used time and time again without loss of properties and needing only 5% of the energy required for primary aluminium. (27)

Aluminium v Steel: General

Similarities

To start with the similarities of aluminium and steel:

- Structural applications of aluminium and steel are mostly similar;
- Design problems/processes are similar so an identical approach is used;
- The design rules for aluminium and steel (EC9 and EC3) are purposely very similar, see the first two reasons. (28)

Differences

However, there are important differences in physical as well as mechanical properties which have to be accounted for in the design process. The table on this page gives a comparison between the most important physical properties of aluminium and steel. The differences in properties, the consequences for structural behavior and how to deal with that in structural design will be elucidated below.

First of all, the low density of aluminium is the main driver for using it in many structural applications. The high strength to weight ratio is the number one reason for the development of the aircraft industry. Although its low weight is a favorable property, it can in some cases be a disadvantage; for example with cyclic loading the ratio live load/dead load is disadvantageous as compared to steel and so fatigue must be considered early in the design stage.

The low density makes an aluminium structure prone to vibrations and in these cases the dynamic behavior of the structure has to be considered. The Young modulus, E is important for the structural behavior. Its value is about 1/3 that of steel, but contrary to density, this is a disadvantage compared to steel. (28)

Table 10 Properties of Al-alloys

	5754-H26 (29)	6063–T6 (30)	6082–T6 (31)	Unit
Density	2.67	2.70	2.71	g/cm^3
Modulus of Elasticity	70.3	68.9	70	GPa
Poisson's Ratio	0.33	0.33	0.33	-
Tensile Strength	290	324	310	MPa
Yield Strength	245	248	260	MPa
Thermal Conductivity	125	200	172	W/m-K
Shear Modulus	25.9	25.8	26.4	GPa

These specific alloys which had been presented in the Table 9 had been chosen due to their common existence in the market, thus it was easier and cheaper to purchase profiles, tubes, sheet metals, etc.

Results of Finite Element Analysis

FEA has become a solution to the task of predicting failure due to unknown stresses by showing problem areas in a material and allowing designers to see all of the theoretical stresses within. This method of product design and testing is far superior to the manufacturing costs which would accrue if each sample was actually built and tested. (22)

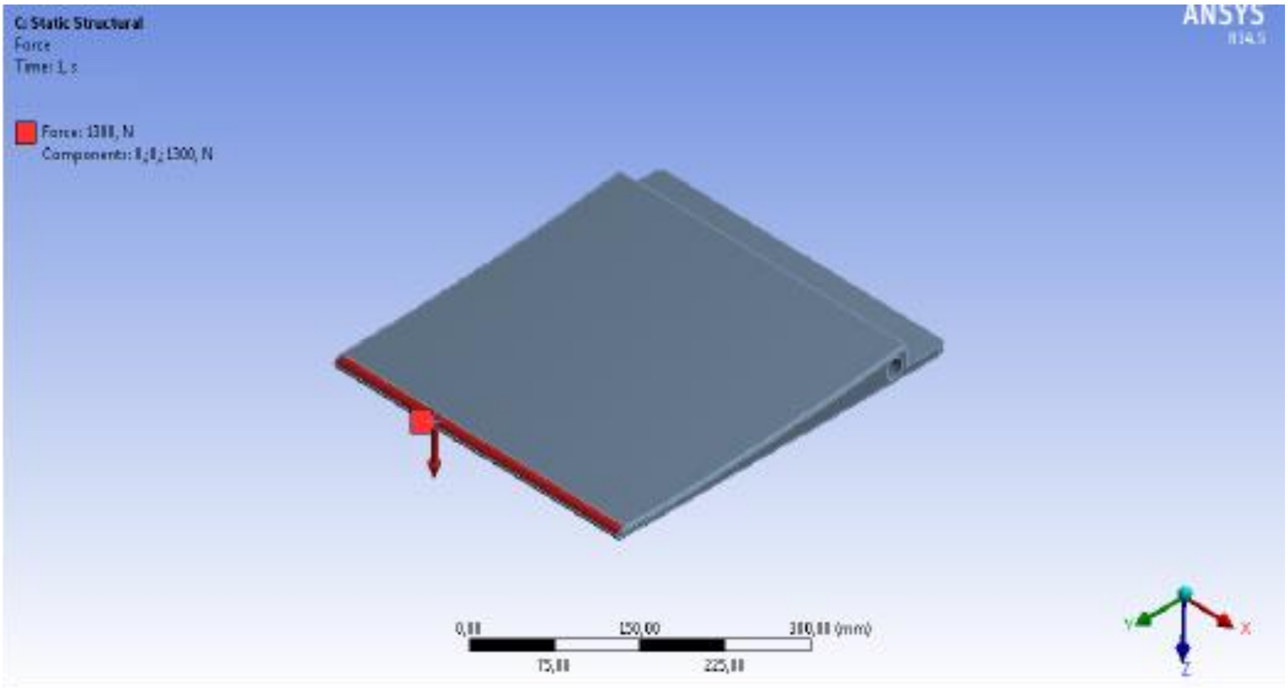


Figure 30 Applied Force Area

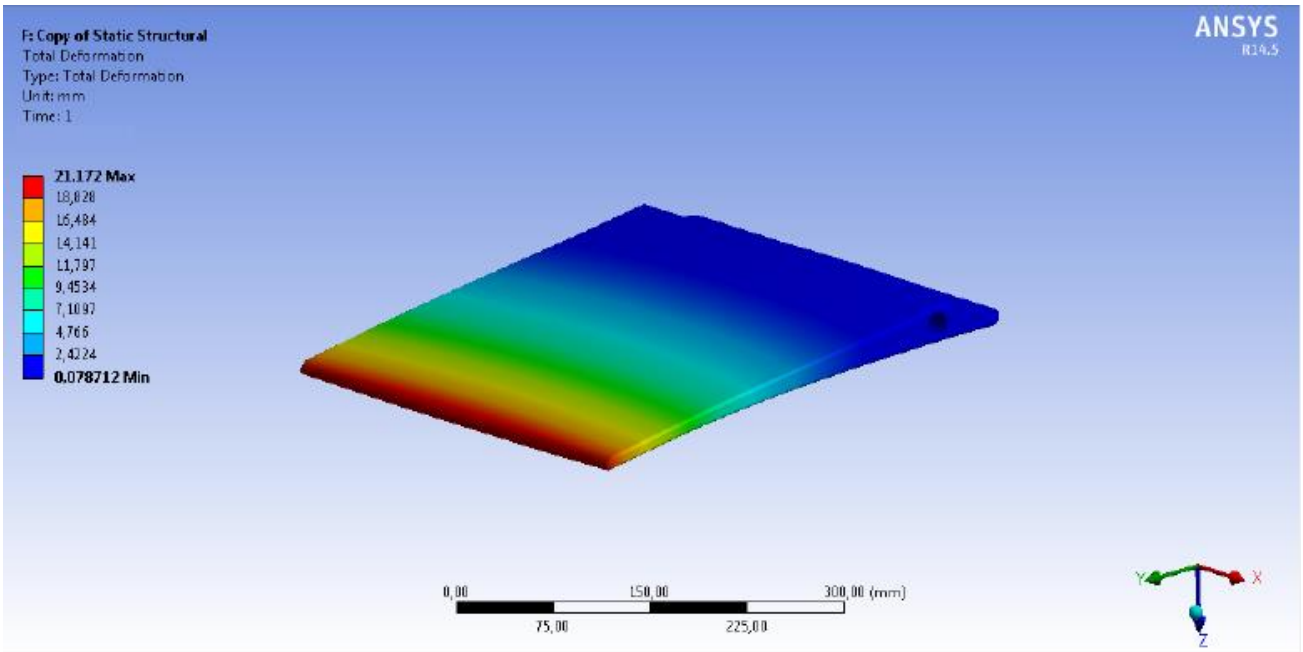


Figure 31 Deformation of the Seat

The methodology for the Strength Analyze was creating an extreme case for the test of the rigidity of the product. Therefore force applied to the edge of the seat with a weight of 140 kg. And the model simplified for the analyze time and boundaries set according to the design and function principles of the product, for the seat the material for this analyze had been decided as Polyurethane %10 glass fiber , molding . And the mechanical properties are taken from CES EDUPACK 2009 material selector software.

D (Density): 1.36 kg/m^3

Young's Modulus: 3.2×10^9 Pa

Poisson's Ratio: 0.371

Yield Strength: 26.5×10^6 Pa.

And applied force had been calculated according to the Newton's Law of Universal Gravitation which states that any two bodies in the universe attract each other with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. (32)

Every point mass attracts every single other point mass by a force pointing along the line intersecting both points. The force is proportional to the product of the two masses and inversely proportional to the square of the distance between them. (33)

That equation is Newton's universal law of gravitation.

$$F=G \times m_1 \times m_2 / r^2 \quad (3.1)$$

Where G is the universal gravitational constant. $G=6.67 \times 10^{11}\ Nm^2 / kg^2$ (34)

$$g=G \times m_2 / r^2 \quad (3.2)$$

Where m_2 is the mass of the Earth; $m_2= 5.98 \times 10^{24}$ kg.

r is the radius of the Earth; $r = 6.38 \times 10^6$ m. (34)

Plugging these numbers in, and the value of G, gives $g = 9.80\ m/s^2$.

$$F=mg \quad (3.3)$$

This is the Gravitational Force equation had been used for the analyze and roughly $g=10\ m/s^2$ acceptance applied. Therefore:

$$F=mg \quad (3.4)$$

$m=130$ kg, $g = 10 m/s^2$ $F=130 \times 10=1300$ N.

The outcome of the analyze was the deformation of 22 mm on the edge of the seat which was another valid argument to redesign the product itself to optimize the deformation of the seat. At this point an inspiration for the design from existing ergonomically designed chairs was, helpful step to follow and due to this purpose several images of the existing chairs had been acquired from the mentors. Two particular products ,which were showed in Figure 32, were simple and have good design values for ergonomics in design.

Figure 32 Ergonomics in Different Product Ranges

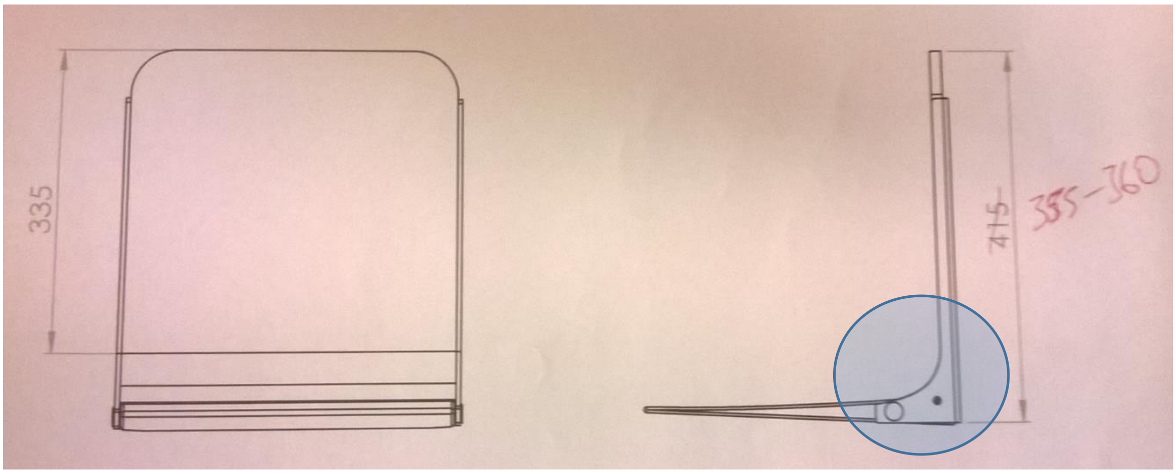


Figure 33 Sketch for Improved Ergonomics and Correction for the Dimensions

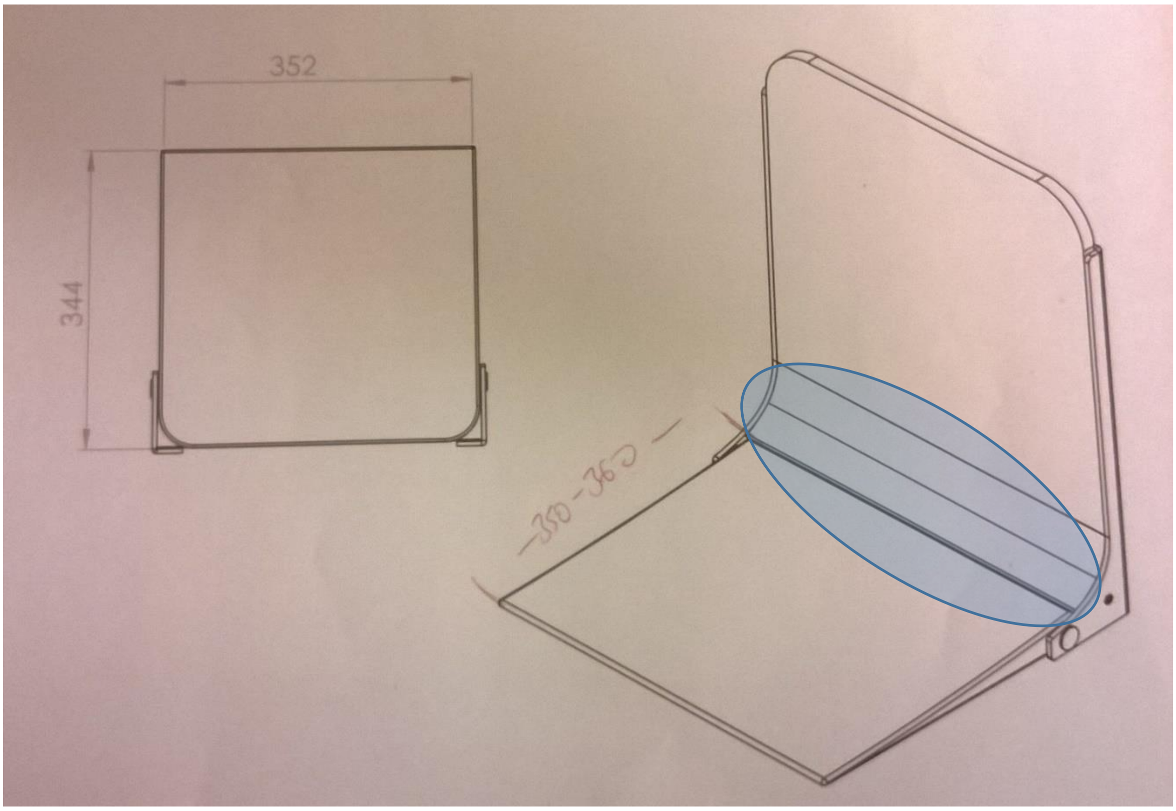


Figure 34 Sketch for Improved Ergonomics and Correction for the Dimensions

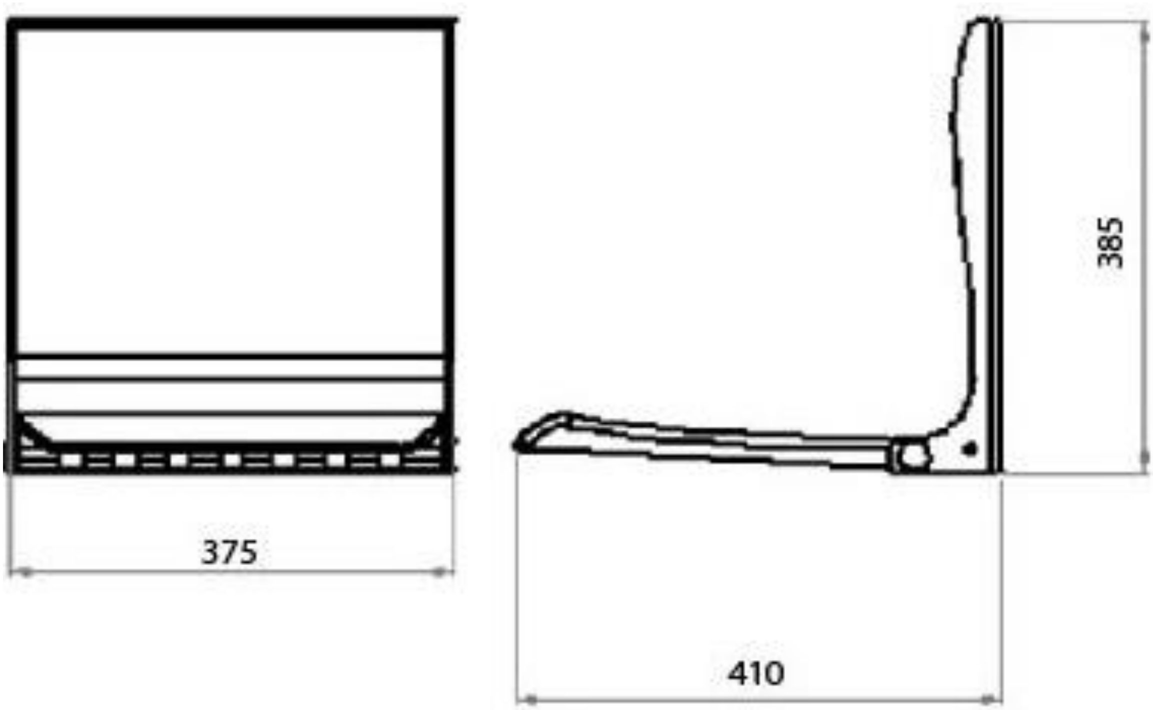


Figure 35 Sketch for Improved Ergonomics and Correction for the Dimensions 2

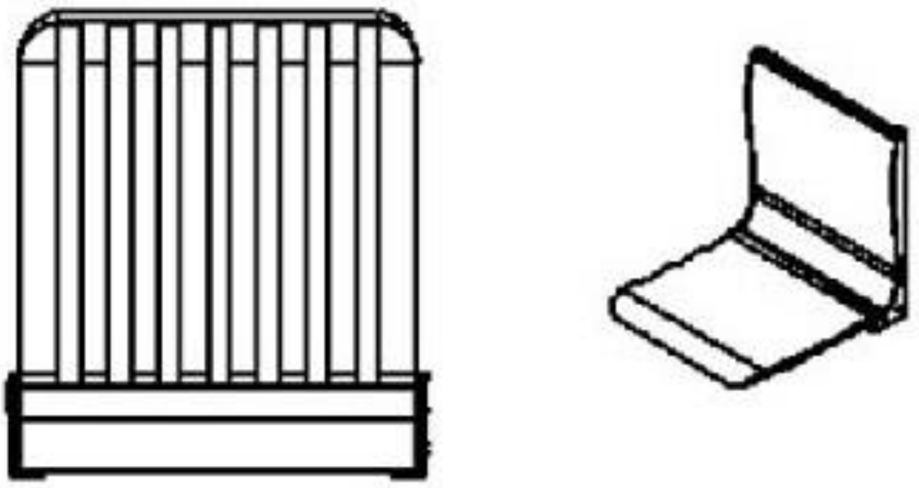


Figure 36 Sketch for Improved Ergonomics and Correction for the Dimensions 3

The improved design for the product had been visualized on the Figure 35. It is clearly seen that there was a drastic change for the design perspective. And the dimensions had been adjusted according to the mentor’s advices. Also can be seen that for the strength improvement, ribs from the same material as seat designed to give rigidity and stiffness to the seat. Although the swift feedback for that design was the ribs and the problem that they would create in molding. Molding for polyurethanes would be cheaper and easier for the uniform designed parts. By saying uniform design meant the spaces between ribs could be problematic as they would be sharper and affect the stress of the product and needs additional structures at the core part of the mold which would increase the pricing of the molding production process.

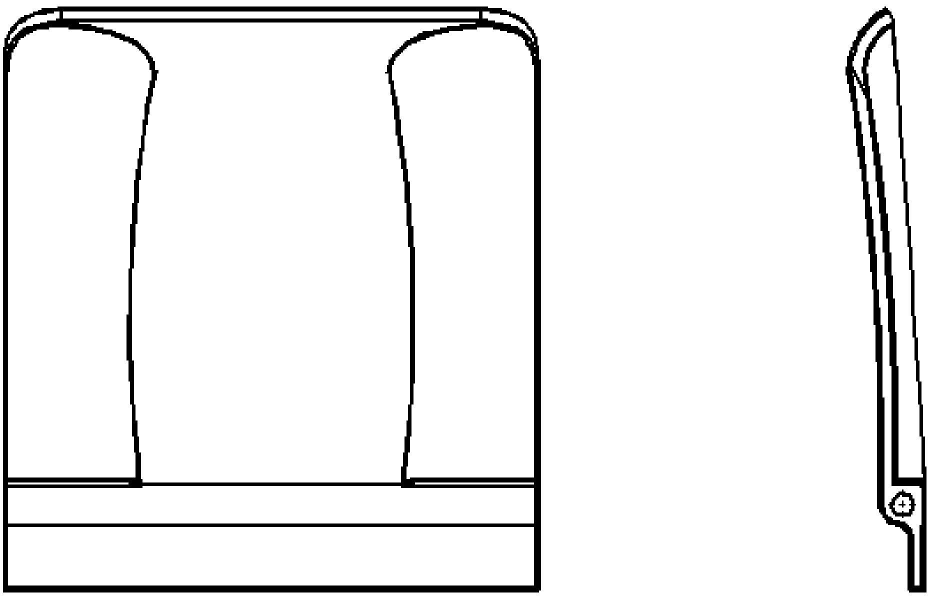


Figure 37 Uniform Seat Design for Easier Molding

Also as from the sketches it can be understood that there were changes among the mount structure as well, with the form design changes the sheet metal profile design also changes to have a clear and joint design with the back rest.

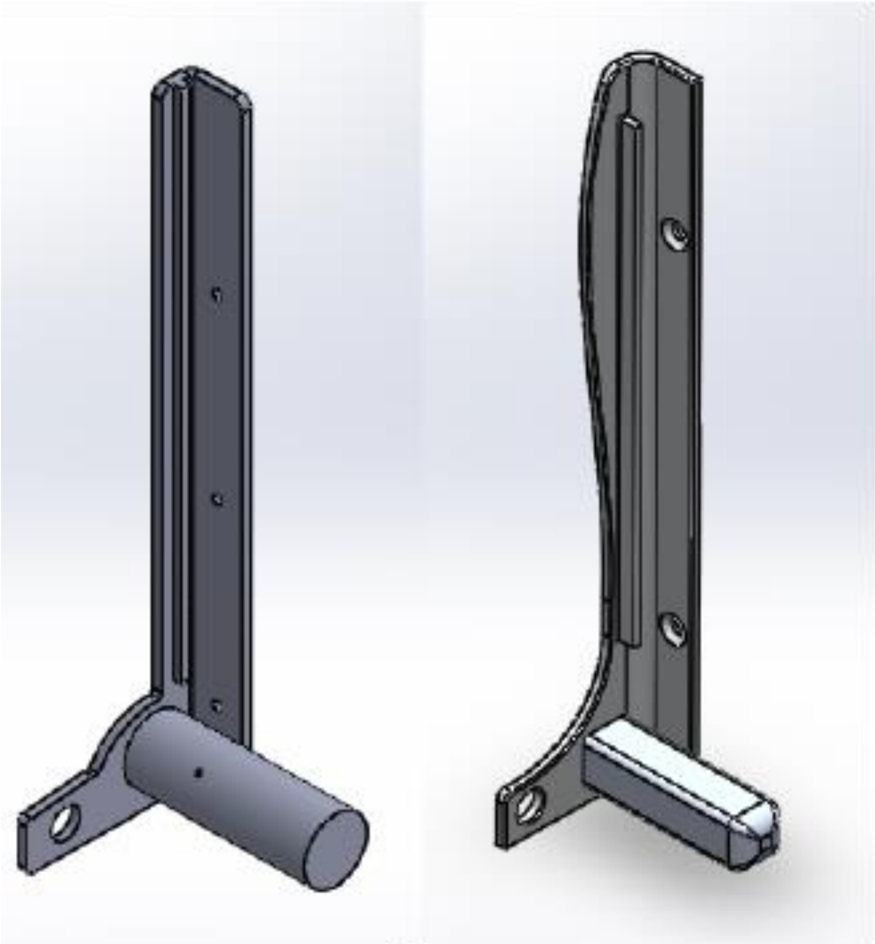


Figure 38 Improvements on the Mounting Profile

Figure 38 shows the mentioned changes at the profile with the changes of the back rest design, the outer line form is basically following the back rest general design lines to have the smooth transaction from the profile to the back rest and not to disturb the user's experience. Moreover it is noticeable that there were some changes in the stopper part. Being transformed from circular profile to rectangular profile was aiming to increase the touching surface for the stopper and the seat itself. With that additional surface it was easier to conduct a strength analyze and having a wider surface is improving also the strength of the product. In addition to that avoiding stress caused problems, sharp edges had been filleted on the rectangular profile as it can be seen. While there were improvements about the general design and the product, other critics had been occurred about the latest solution in the process.

Figure 39 shows the drawback of the outcome of the design in the term of compactness. The critics were “seat and the backrest was not speaking with themselves” meaning as it was seen as two different products and aesthetically lack of appealing vibes. Examples given as cinema seats which are generally folding seats and back rest meant to be female and male parts which defines each other. As a result of this feedback it was needed to change the form design again to find a balance between two essential parts of the product.

Figure39 Compactness of the concept.

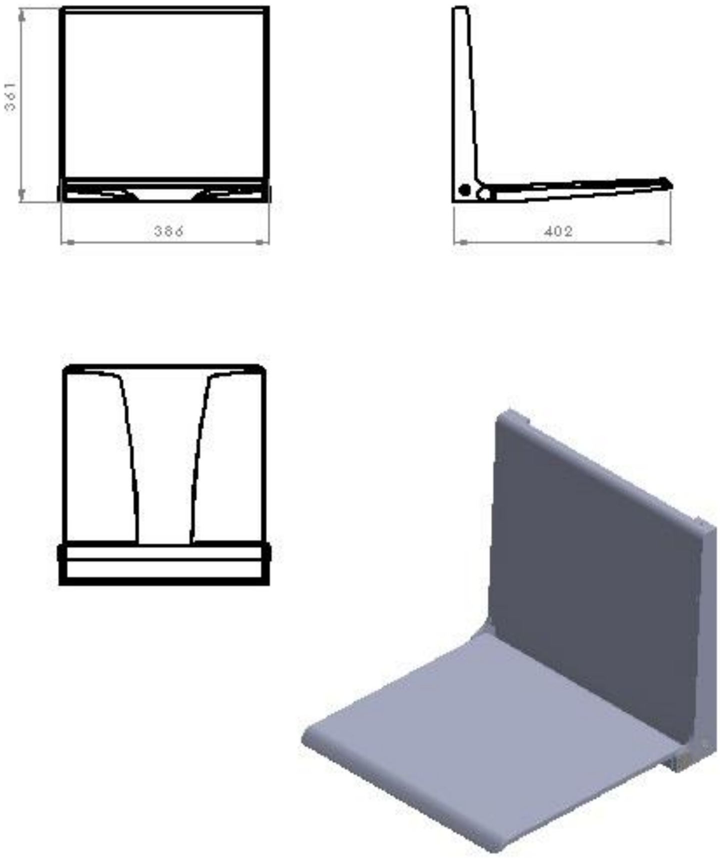


Figure 40 Improved Concept for Compactness

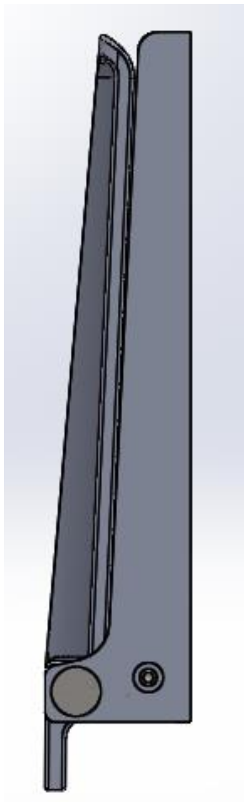


Figure 41 Folded Improved Concept

Figure 42 Exploded view of Improved Mount Structure

Figure 42 shows us the improvements that had been made about mount structure due to maintain better strength as it was done to aim the same purposes for the seat. Changes were listed below;

- Bent profile changed to two separated welded profile. Because bend radiuses were problematic according to the selected material.
- Two welded support plates between two mount profiles.
- Full length stopper tube between plates to have wider blocking surface for the seat.
- A threaded piece welded inside the tube to connect profiles and tube with a screw from out sides.

To sum up the changes between the concepts, scoring chart had been used to evaluate them and make a decision.

Table 11 Concept Options

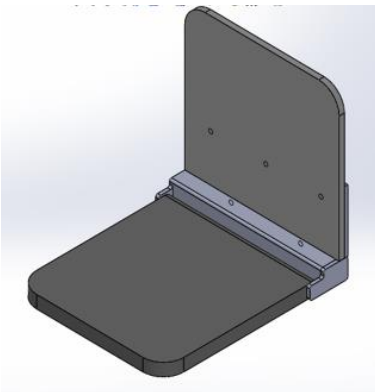
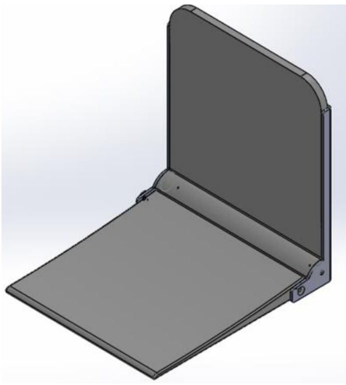
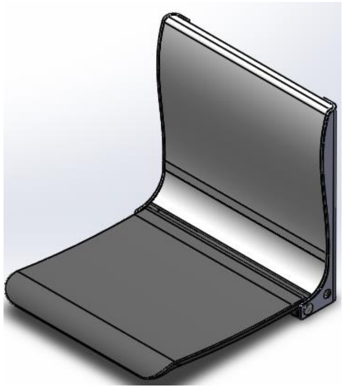
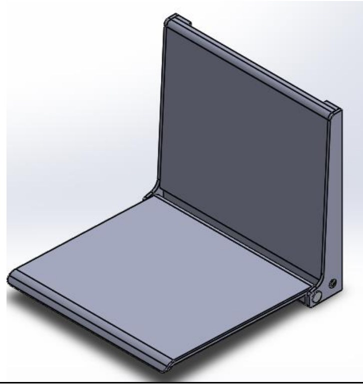
Option 1	Option 2	Option 3	Option 4
			

Table 12 Properties of the Concept Options

	Dimensions (Width &Depth)	Maximum Load Capacity Test	Compactness	Aesthetics	Production Ease
Option 1	360x360 mm	140 Kg	Overall look when folded	General Form Design	Molding and Machining Ease
Option 2	360x360 mm	130 Kg	Overall look when folded	General Form Design	Molding and Machining Ease
Option 3	432x368 mm	130 Kg	Overall look when folded	General Form Design	Molding and Machining Ease
Option 4	402-361 mm	120kg	Overall look when folded	General Form Design	Molding and Machining Ease

Table 13 Scoring Chart for Concept Options

	Dimensions (Width &Depth& Length)	Maximum Load Capacity Test	Compactness	Aesthetics	Production Ease	SUM
Option 1	2	3	3	1	2	11
Option 2	2	1	4	2	3	12
Option 3	4	4	2	4	3	17
Option 4	4	3	4	3	4	18

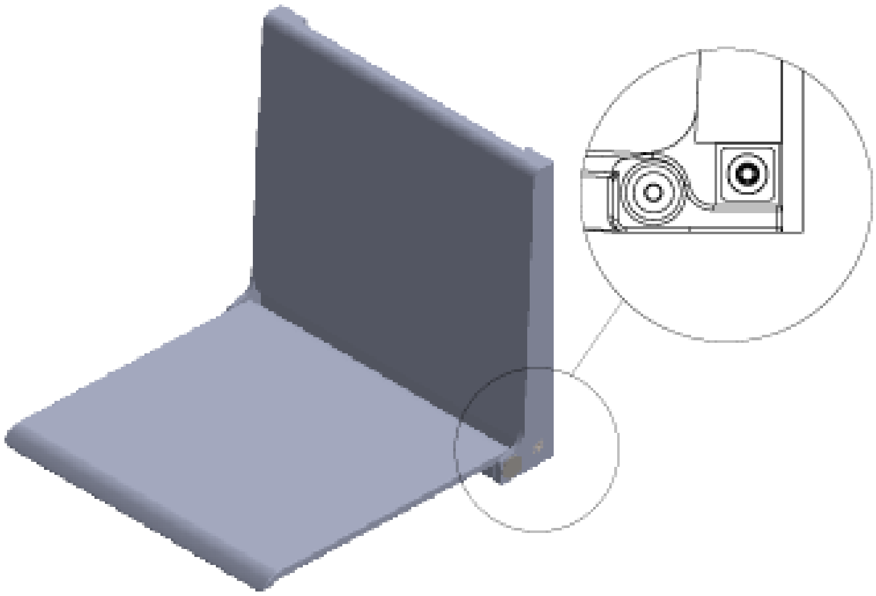


Figure 43 Detail View of the Option 4 Stopping Position

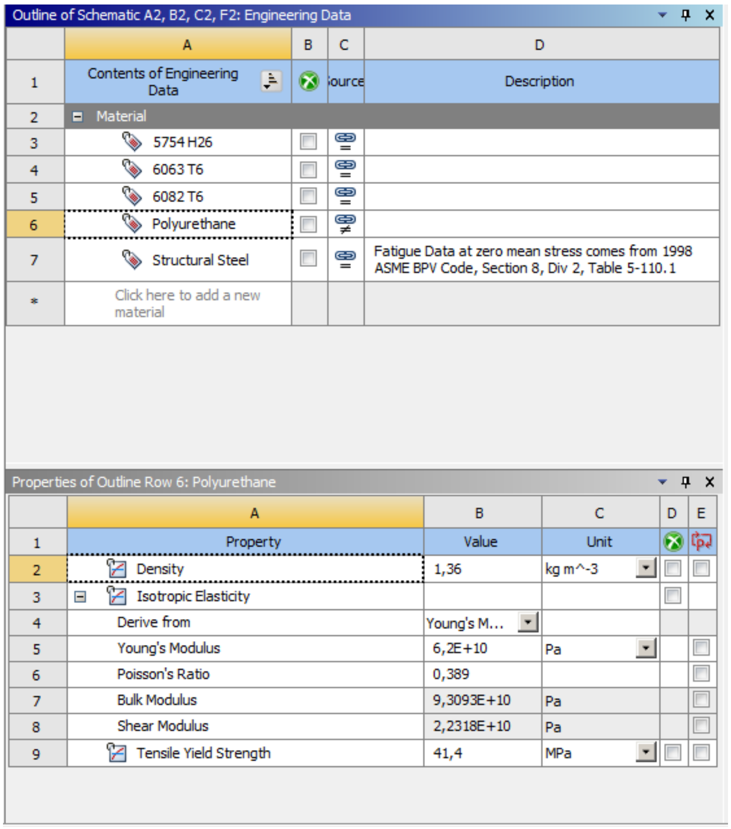
After the scoring chart had been concluded, it can be seen that the last concept was overall the best option and it was convincing to follow the last design and check the strength of the product by performing strength calculations with the help of Ansys Software.

3.3 Strength Calculations

Strength calculations were conducted with Ansys software and the module of Static Structural, to begin the calculations Solidworks 3D model file of the product imported to the Ansys software and materials had been defined in the Engineering Data section. The necessary selected material properties

- Density.
- Poisson's Ratio.
- Young's Modulus.
- Tensile Yield Strength.

were taken from Table 8 and Table 9 which had been presented previously in the paper.



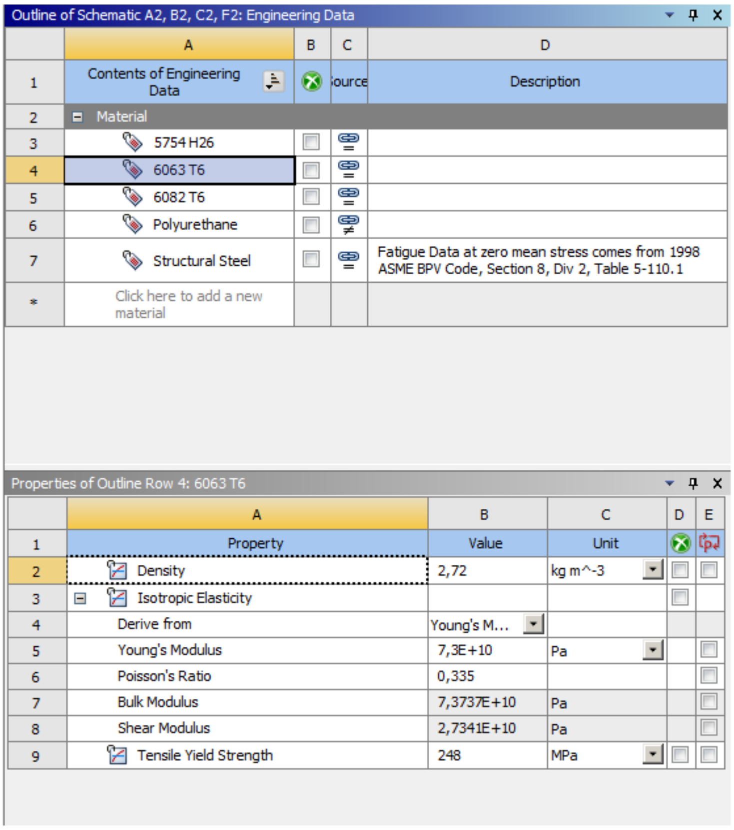
Outline of Schematic A2, B2, C2, F2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data		ource	Description
2	Material			
3	5754 H26			
4	6063 T6			
5	6082 T6			
6	Polyurethane			
7	Structural Steel			Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material			

Properties of Outline Row 6: Polyurethane

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1,36	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's M...			
5	Young's Modulus	6,2E+10	Pa		
6	Poisson's Ratio	0,389			
7	Bulk Modulus	9,3093E+10	Pa		
8	Shear Modulus	2,2318E+10	Pa		
9	Tensile Yield Strength	41,4	MPa		

Figure 45 *Properties Polyurethane %20 GF in Ansys Library*



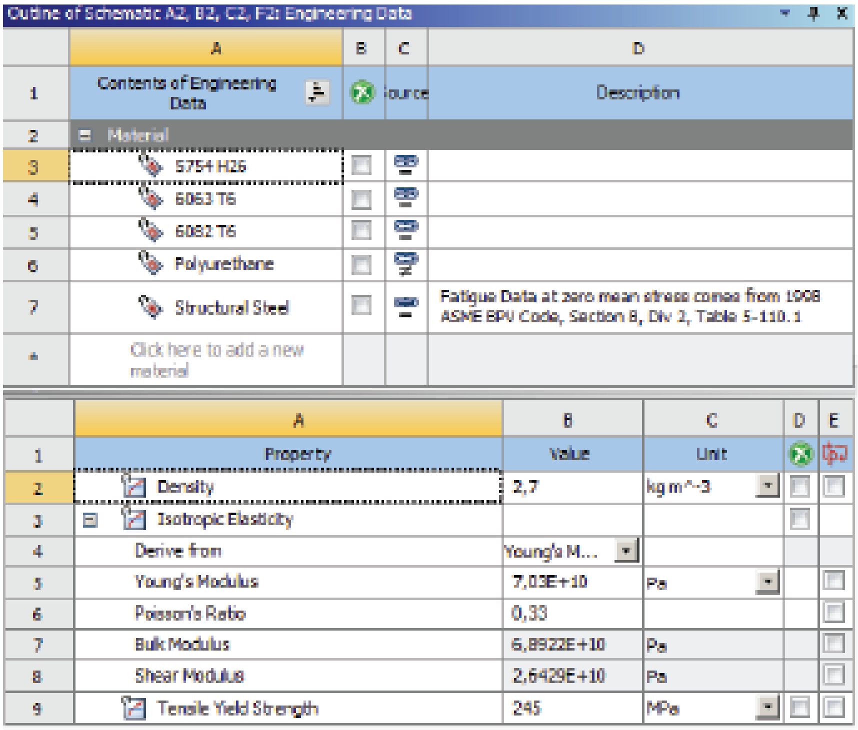
Outline of Schematic A2, B2, C2, F2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data		ource	Description
2	Material			
3	5754 H26			
4	6063 T6			
5	6082 T6			
6	Polyurethane			
7	Structural Steel			Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material			

Properties of Outline Row 4: 6063 T6

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2,72	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's M...			
5	Young's Modulus	7,3E+10	Pa		
6	Poisson's Ratio	0,335			
7	Bulk Modulus	7,3737E+10	Pa		
8	Shear Modulus	2,7341E+10	Pa		
9	Tensile Yield Strength	248	MPa		

Figure 44 *Properties for 6063 T6 Alloy in Ansys Library*

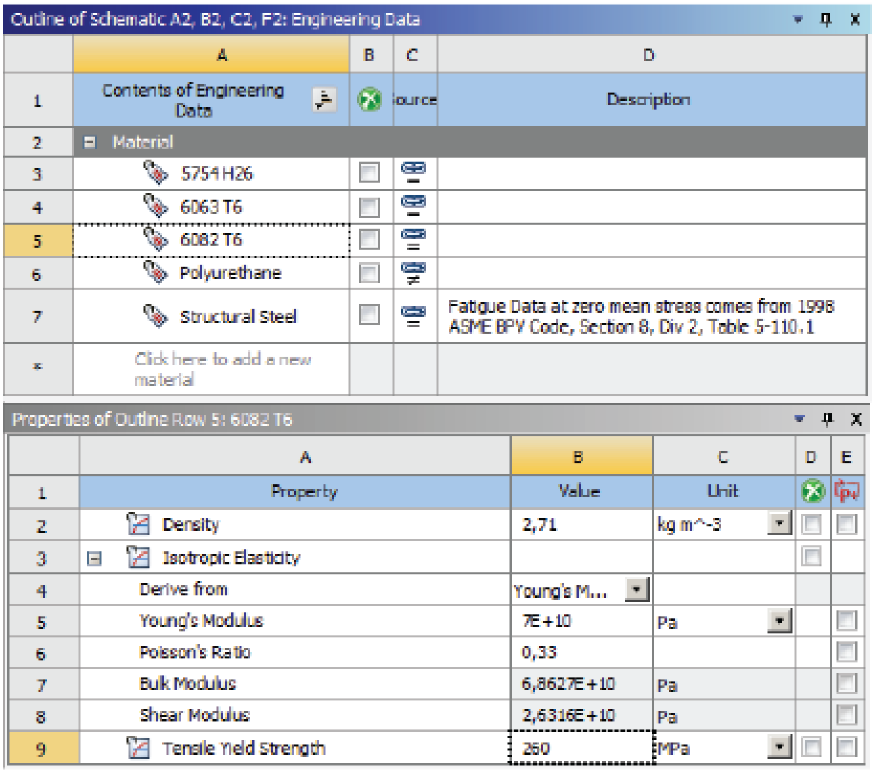


Outline of Schematic A2, B2, C2, F2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data		Source	Description
2	Material			
3	5754 H26			
4	6063 T6			
5	6082 T6			
6	Polyurethane			
7	Structural Steel			Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material			

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2,7	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's M...			
5	Young's Modulus	7,03E+10	Pa		
6	Poisson's Ratio	0,33			
7	Bulk Modulus	6,8922E+10	Pa		
8	Shear Modulus	2,6429E+10	Pa		
9	Tensile Yield Strength	245	MPa		

Figure 46 Properties for 5754 H26 Alloy in Ansys Library



Outline of Schematic A2, B2, C2, F2: Engineering Data

	A	B	C	D
1	Contents of Engineering Data		Source	Description
2	Material			
3	5754 H26			
4	6063 T6			
5	6082 T6			
6	Polyurethane			
7	Structural Steel			Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material			

Properties of Outline Row 5: 6082 T6

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2,71	kg m^-3		
3	Isotropic Elasticity				
4	Derive from	Young's M...			
5	Young's Modulus	7E+10	Pa		
6	Poisson's Ratio	0,33			
7	Bulk Modulus	6,8627E+10	Pa		
8	Shear Modulus	2,6316E+10	Pa		
9	Tensile Yield Strength	260	MPa		

Figure 47 Properties for 6082 T6 Alloy in Ansys Library

And the following step was editing the model in the Geometry module in order to simplify the model to reduce the analyze time. For that purpose:

- Suppressing unnecessary parts. (Back Rest, Fasteners.)
- Cutting the model to half since it was symmetrical.

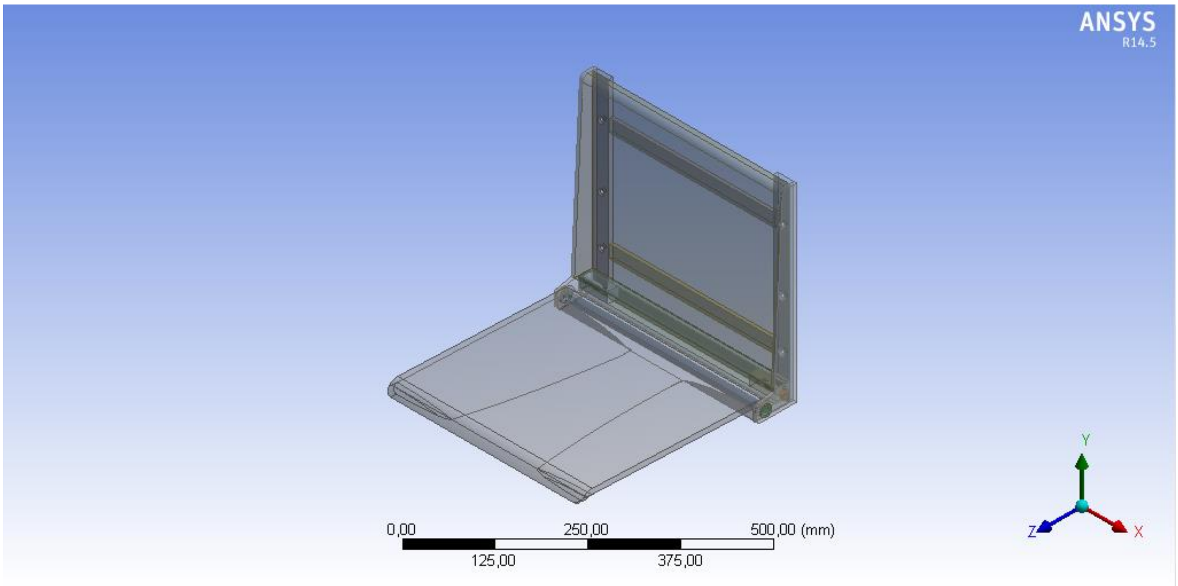


Figure 48 Full Model View in Ansys Geometry Module

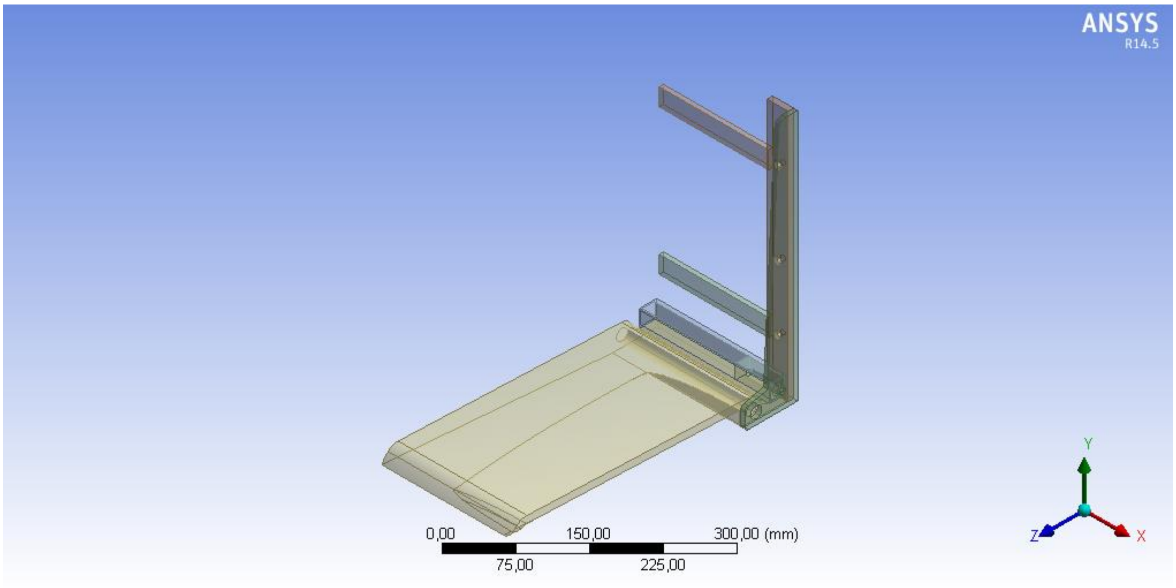


Figure 49 Simplified Model for the Analyze

Figure 49 demonstrates us that a plane created in the very middle of the model and that plane used to cut the model into half, and this model will be the base model for all the strength calculation scenarios. Continuous step was setting up the contacts and joints for the model.

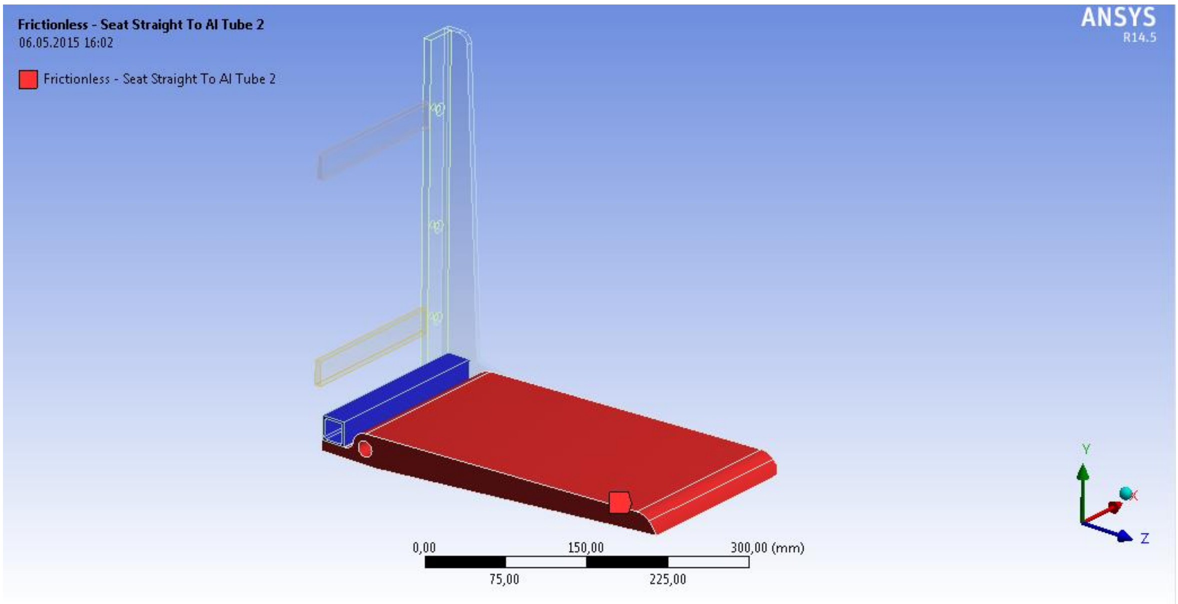


Figure 50 Contact Setting

Figure 50 expresses the extra contact setting for the model which was Frictionless Contact between the seat and the stopper tube.

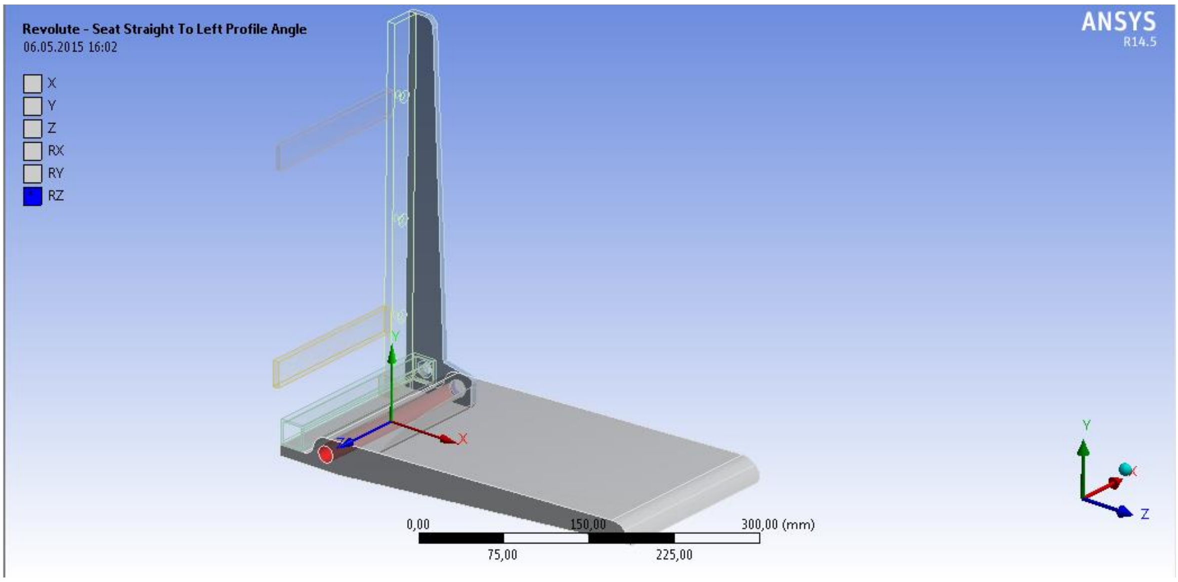


Figure 51 Joint Setting

In this step joint set to revolute to define the rotational movement of the seat around the pin. And the settings were as a reference the mount profile set and the mobile part was the seat's pin hole. Both parts behavior selected as deformable since the deformation were going to be calculated.

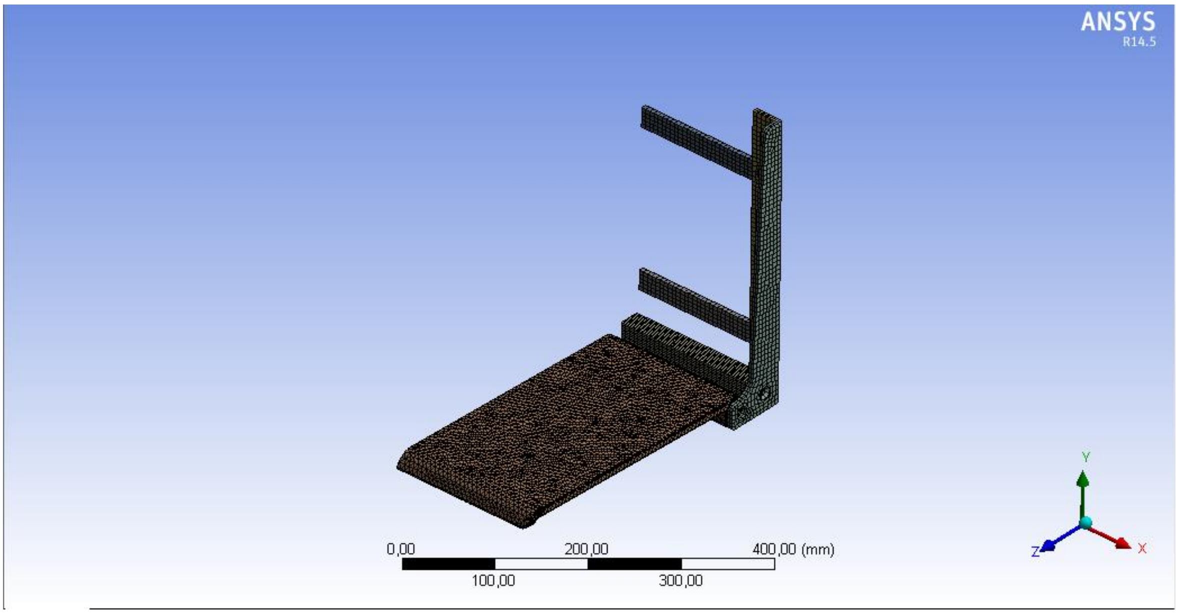


Figure 52 Meshing of the Model

Meshing step is the step to generate the nodes which will define the accuracy of the analyze and will let the software conduct to analyze as FEA principle the settings for the meshing were set as below:

- Type: Element Size
- Element Size: 6 mm
- Nodes: 111667
- Elements: 61485

After setting up the meshing criteria, the step of setting up the boundaries and applied force was followed.

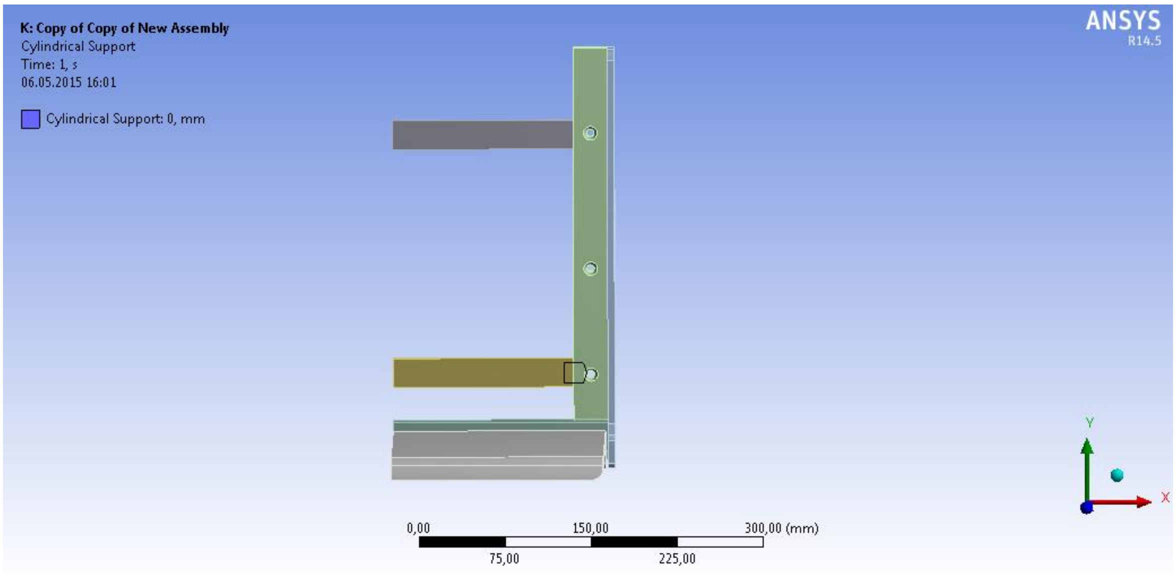


Figure 53 Cylindrical Support Setting

It is visual on the Figure 53 that cylindrical supports were chosen as the screw holes of the mount profile to the wall. And the tangential movement of the cylindrical support was set up to free movement.

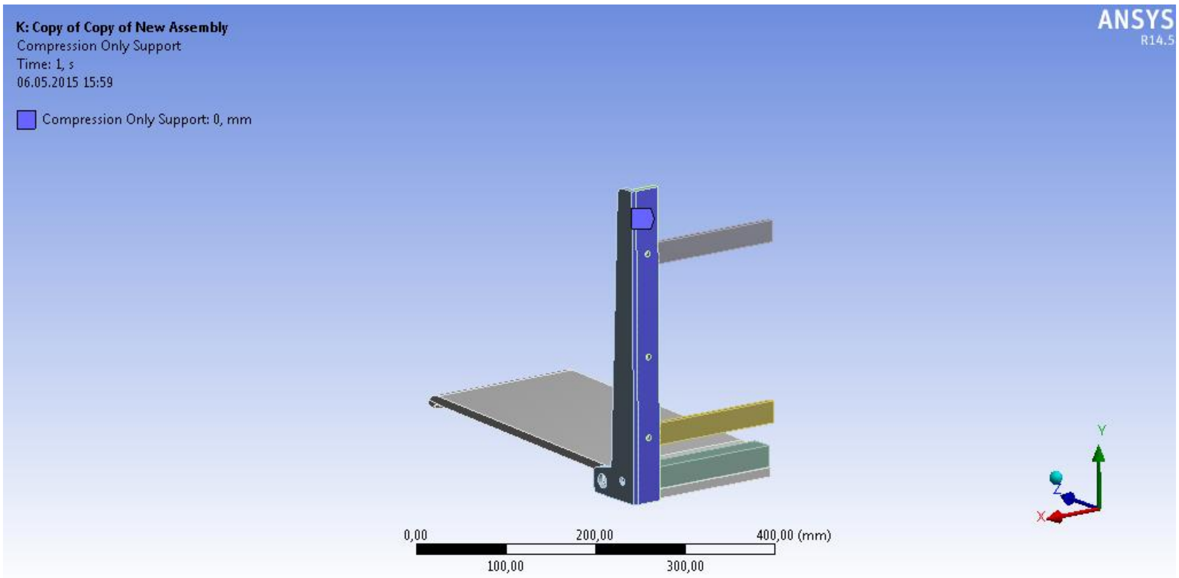


Figure 54 Compression Only Support Setting

Compression Only support had been defined as the touching surface of the mount profile to the wall. And the compression only support was providing a non-linear solution since we cannot think the profile as fixed support because the profile might have been bent in Y and Z Axis when the force was applied to the seat in the calculation process.

Previous steps were the preparation for the calculation, now the last step was defining the applied force which meant to be the weight of the user on the seat. On this phase the investigation of three different situations and the outcomes of those three situations were analyze in order to fulfill different weights and sitting positions had been presented.

3.3.1 Case 1

In Case 1 the scenario was set up as, a user weight of 70 kg and sitting on the middle of the seat surface. This case might be labeled as Normal Sitting Case as the 70 kg of a weight can be considered as average/light weight for a human being.

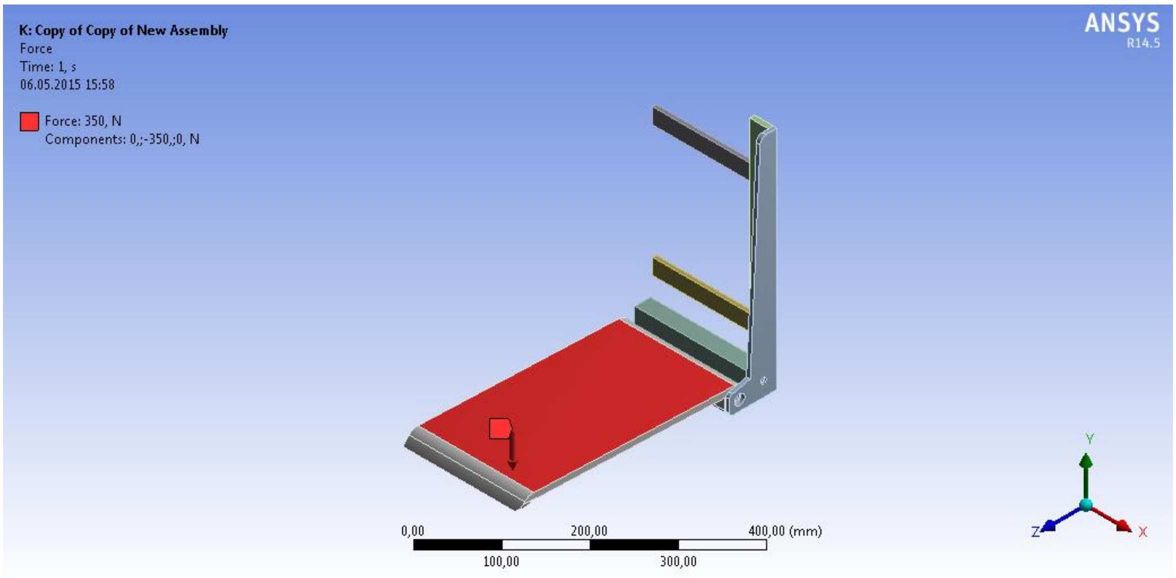


Figure 55 Case 1 Force Application

Figure 55 demonstrates that force applied to the main seat surface with F=mg Gravitational Force equation had been used for the analyze and roughly $g=10\ m/s^2$ acceptance applied. Therefore:

$F=mg \quad m=70\ kg,\ g = 10\ m/s^2$.

F=70x10=700 N.

And the model is half therefore the force had been divided by two as well. As a conclusion final applied force is:

$F_{final} = 350$ N.

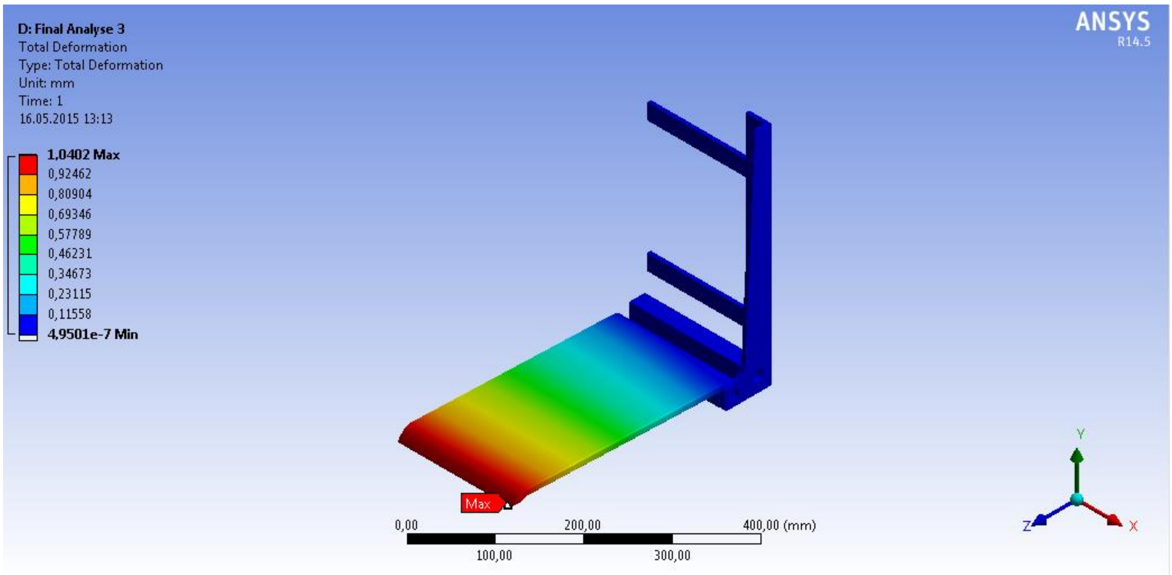


Figure 56 Total Deformation of Case 1

The max deformation had been calculated as d=1 mm on the edge of the seat as can be seen on the Figure 56. And this result shows us in deformation analyze, the design and the product is reliable and safe.

Next step was performing Equivalent (Von Mises) Stress Analyze to determine if the product fails or not due to its plasticity. Therefore briefly Von Mises Stress theory explained before the results.

Von Mises Stress

The Von Mises stress is an equivalent or effective stress at which yielding is predicted to occur in ductile materials. (35)

Use of Von Mises Stress

Von Mises stress is considered to be a safe haven for design engineers. Using this information an engineer can say his design will fail, if the maximum value of Von Mises stress induced in the material is more than strength of the material. It works well for most cases, especially when the material is ductile in nature. In the following sections we will have a logical understanding of Von Mises stress and why it is used.

When Does A Material Fail?

One of the easiest way to check when a material fails is a *simple tension test*. Here the material is pulled from both ends. When the material reaches the yield point (for ductile material) the material can be considered as failed. The simple tension test is a unidirectional test, this is shown in the first part of Figure 57.

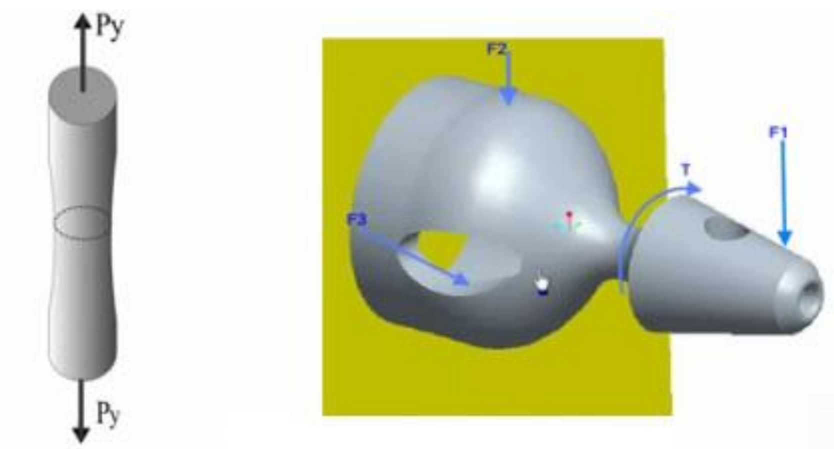


Figure 57 A simple tension test and a real life loading condition. (32)

Now consider the situation in second part of Figure 57, an actual engineering problem with a complex loading condition. Can we say here also, that the material fails when the maximum normal stress value induced in the material is more than the yield point value?

If you use such an assumption, you would be using a failure theory called 'Normal Stress Theory'. Many years of engineering experience has shown that normal stress theory doesn't work in most of the cases. The most preferred failure theory used in industry is 'Von Mises Stress' based. We will explore what Von Mises stress is in the coming section.

Distortion Energy Theory

The concept of Von Mises stress arises from the *distortion energy failure theory*. Distortion energy failure theory is comparison between 2 kinds of energies, 1) Distortion energy in the actual case 2) Distortion energy in a simple tension case at the time of failure. According to this theory, failure occurs when the distortion energy in actual case is more than the distortion energy in a *simple tension case* at the time of failure.

Distortion energy

It is the energy required for shape deformation of a material. During pure distortion, the shape of the material changes, but volume does not change. This is illustrated in Figure 58.

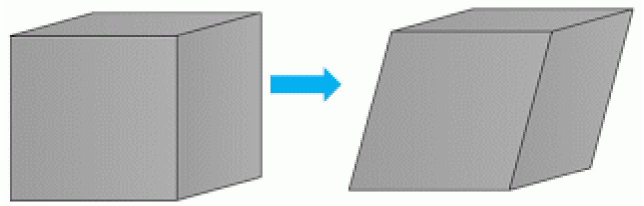


Figure 58 Representation of a pure distortion case (32)

Distortion energy required per unit volume, ud for a general three dimensional case is given in terms of principal stress values as:

$$u_d = \frac{1+\nu}{3E}\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right] \tag{3.5}$$

Distortion energy for *simple tension case* at the time of failure is given as:

$$u_{d,sim} = \frac{1+\nu}{3E}\sigma_y^2 \tag{3.6}$$

Expression for Von Mises stress the above 2 quantities can be connected using *distortion energy failure theory*, so the condition of failure will be as follows.

$$\left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}\right]^{1/2} \geq \sigma_y \qquad (3.7)$$

The left hand side of the above equation is denoted as Von Mises stress.

$$\left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2}\right]^{1/2} = \sigma_v \qquad (3.8)$$

So as a failure criterion, the engineer can check whether Von Mises stress induced in the material exceeds yield strength (for ductile material) of the material. So the failure condition can be simplified as

$\sigma_v \geq \sigma_y$ (36) (3.9)

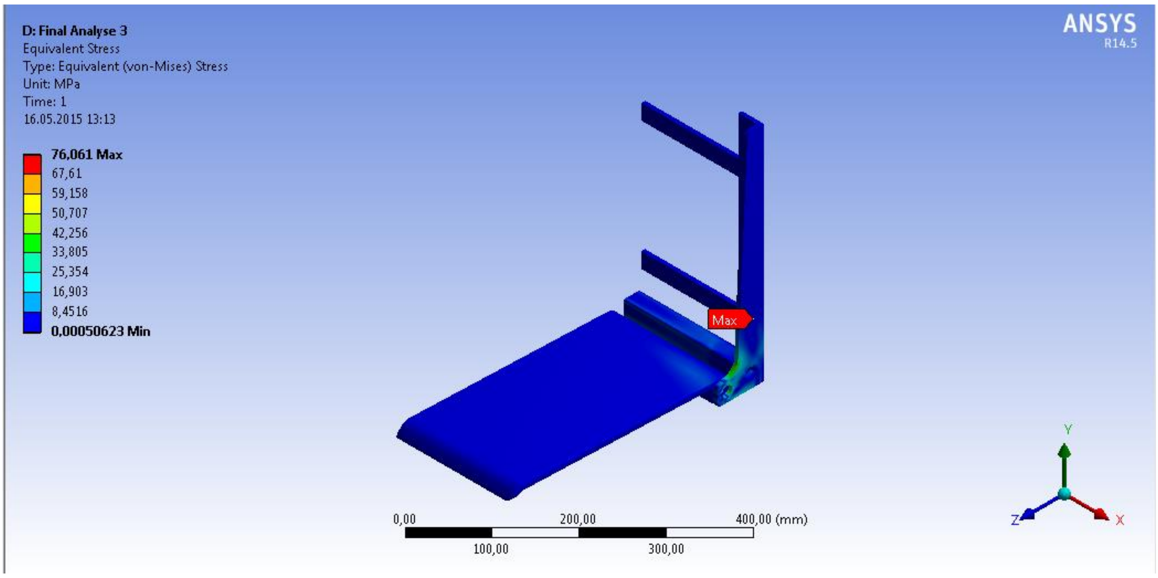


Figure 59 Von Mises Stress Results of Case 1

It is noticeable after the Stress Analyze the maximum point of stress is around the bottom screw hole of the mount plate. And the value of Von Mises Stress is σ_v=75 MPa. The Yield Strength for the Aluminium was σ_y = 245 MPa

$\sigma_y > \sigma_v$ so the product does not fail and the safety factor had been justified.

3.3.2 Case 2

In this Case, the analyze is the same sitting position but with a weight of a 130 kg to test the extreme heavy force circumstances over the product.

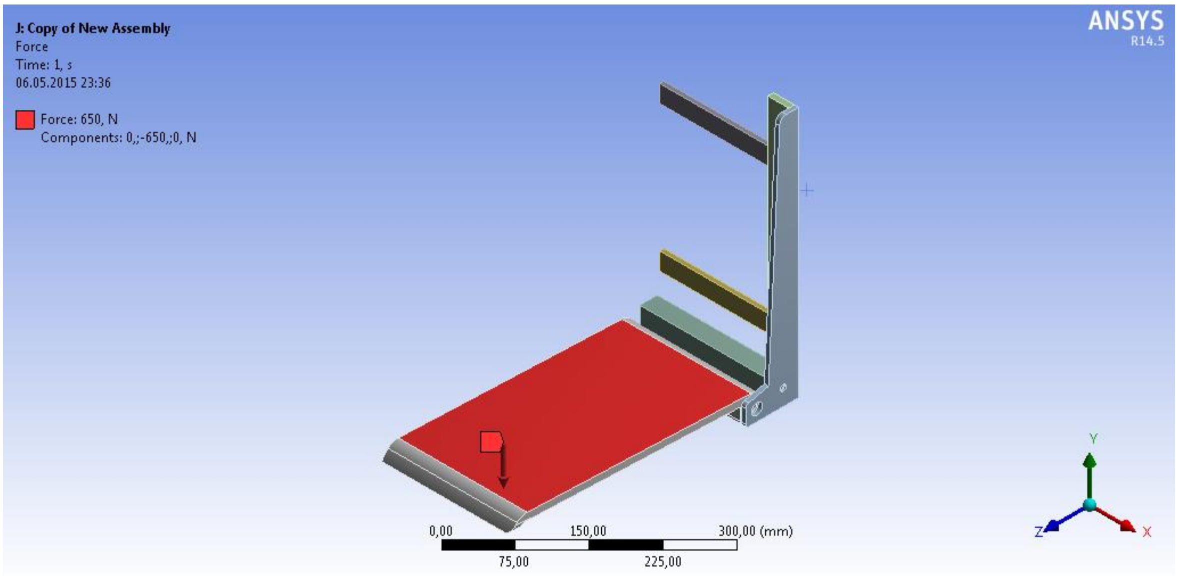


Figure 60 Case 2 Force Application

F=mg   m=130 kg, g = 10m/s^2

F=130x10=1300 N.

And the model is half therefore the force had been divided by two as well. As a conclusion final applied force is:

F_{final} = 650 N.

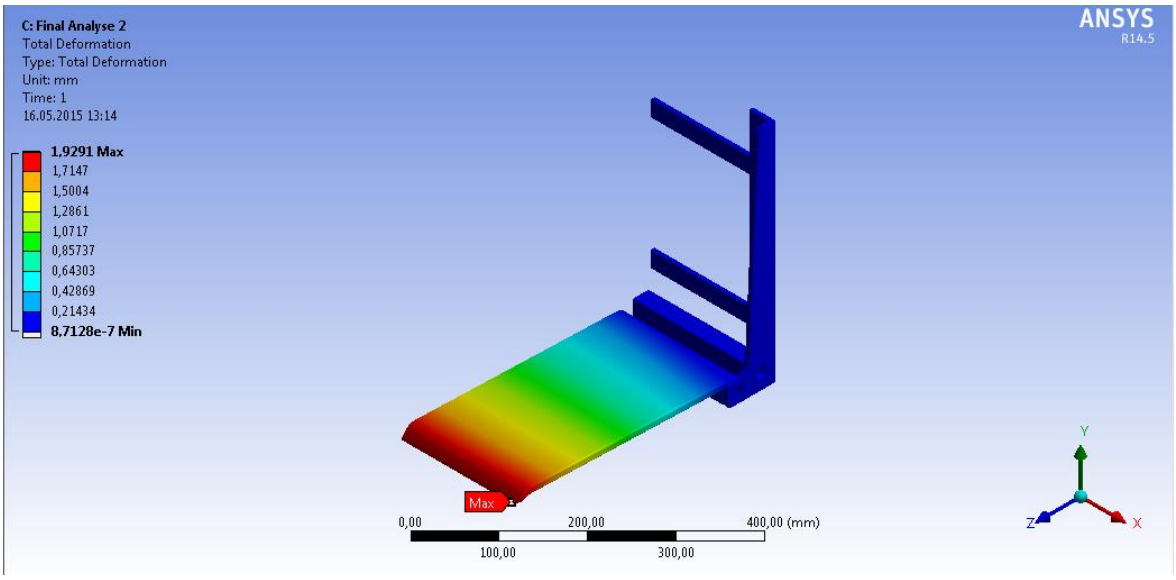


Figure 61 Total Deformation of Case 2

The max deformation had been calculated as d=1.9 mm on the edge of the seat as can be seen on the Figure 61. And this result shows us in deformation analyze, the design and the product is reliable and safe under the heavy weight of the user.

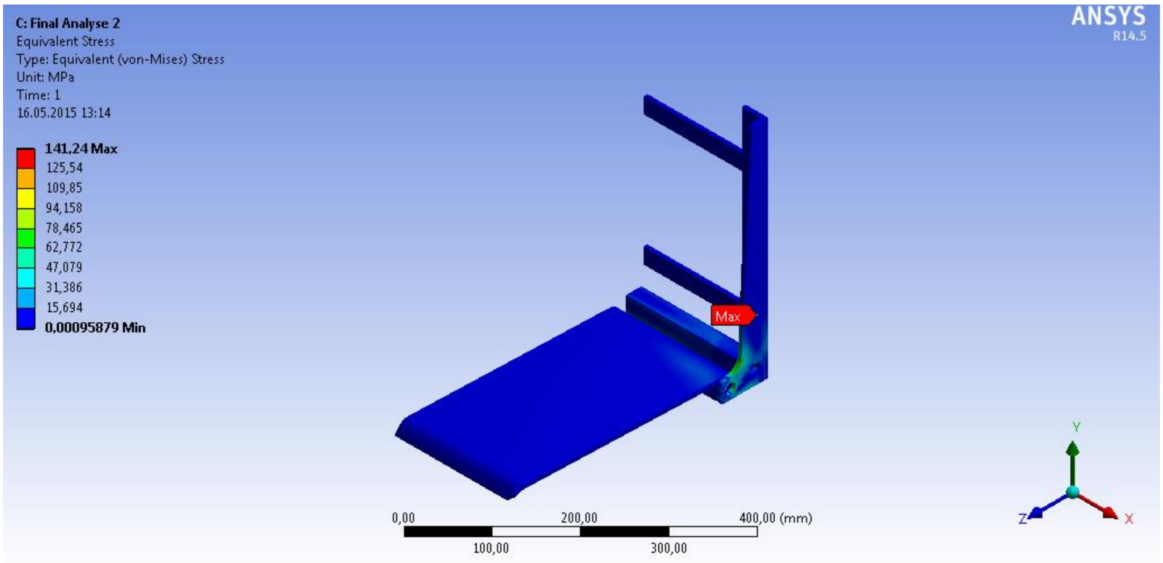


Figure 62 Von Mises Stress Results of Case 2

It is noticeable after the Stress Analyze, the maximum point of stress is again at the same place around the bottom screw hole of the mount plate. And the value of Von Mises Stress is $\sigma_{V=}$141 MPa. The Yield Strength for the Aluminium was $\sigma_Y = 245$ MPa.

$\sigma_Y > \sigma_V$ so the product does not fail and the safety factor had been justified in this case as well.

3.3.3 Case 3

Case 3 was considered as the most extreme case and performed as safety factor analyze for the product. In thıs analyze the user again considered as 130 Kg weight and sitting on the edge of the seat.

F=mg m=130 kg, g = 10m/s^2

F=130x10=1300 N.

And the model is half therefore the force had been divided by two as well. As a conclusion final applied force is:

$F_{final} = 650$ N.

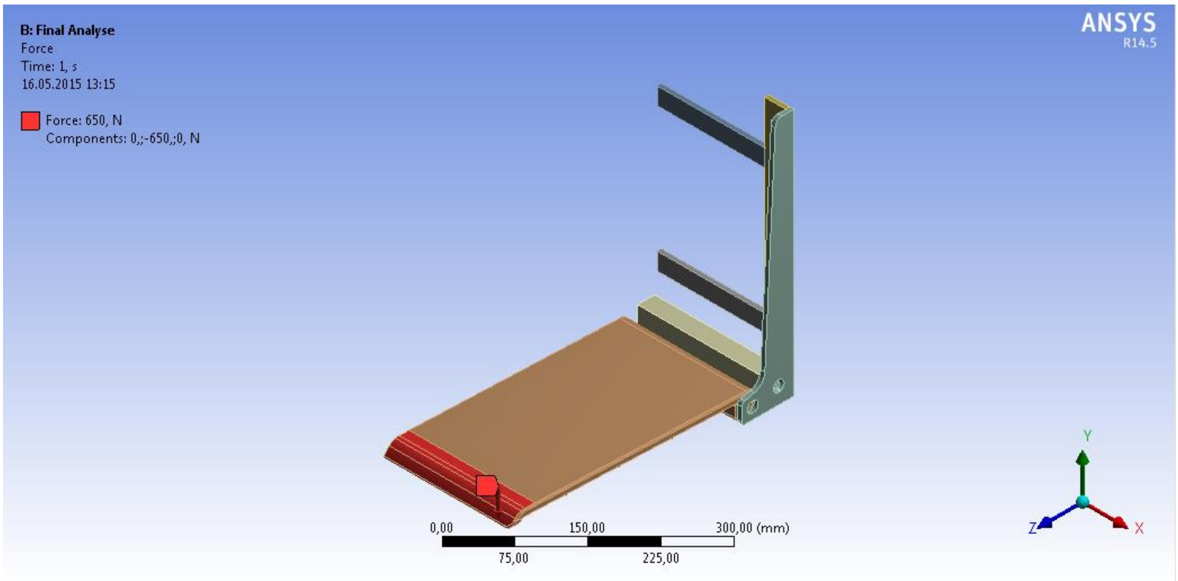


Figure 63 Case 3 Force Application

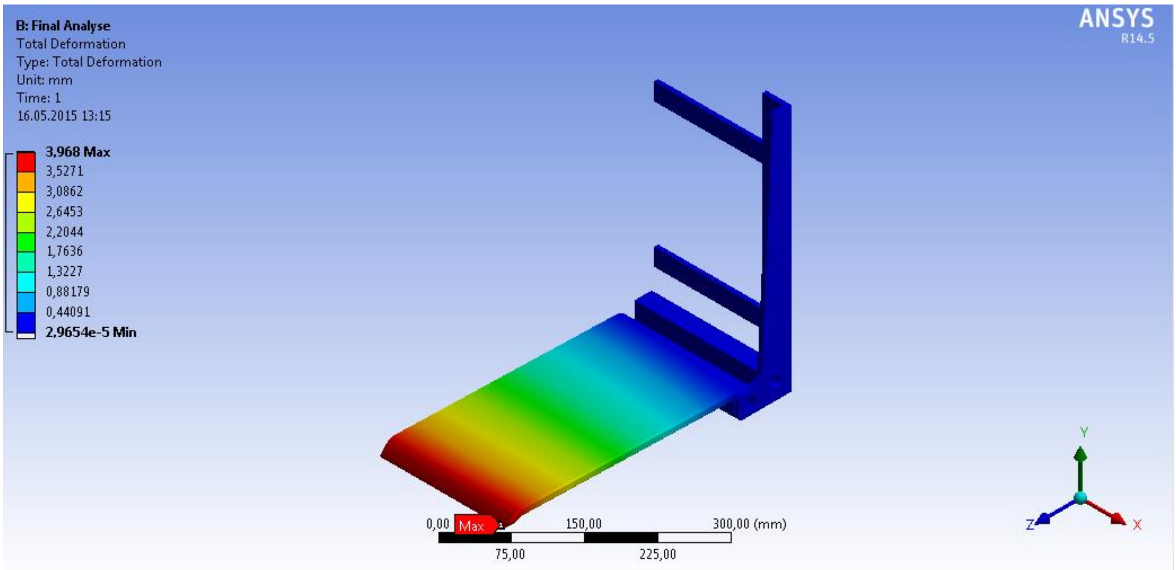


Figure 64 Total Deformation of Case 3

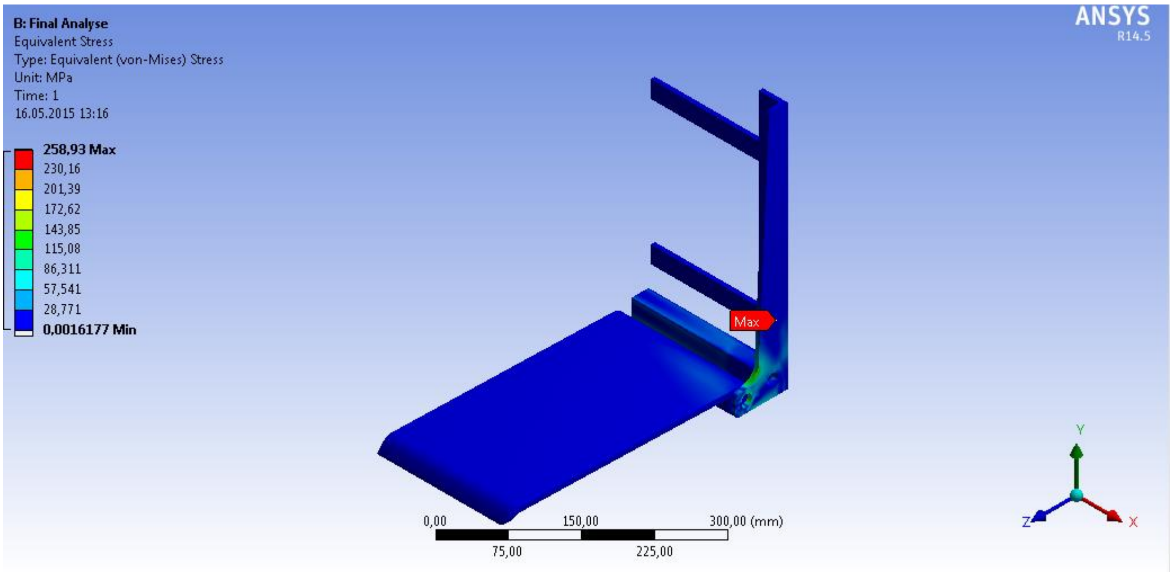


Figure 65 Von Mises Stress Results of Case 3

Figure 65 showed that in the worst case scenario Yield Strength of 245 MPa is lower than the Von Mises Stress of 259 MPa. In this situation the material considered as failed, and 130 Kg of the weight cannot be considered as appropriate weight for the structure.

Therefore the max weight of the user lowered to 120 kg and the strength analyze had been done accordingly to that circumstances.

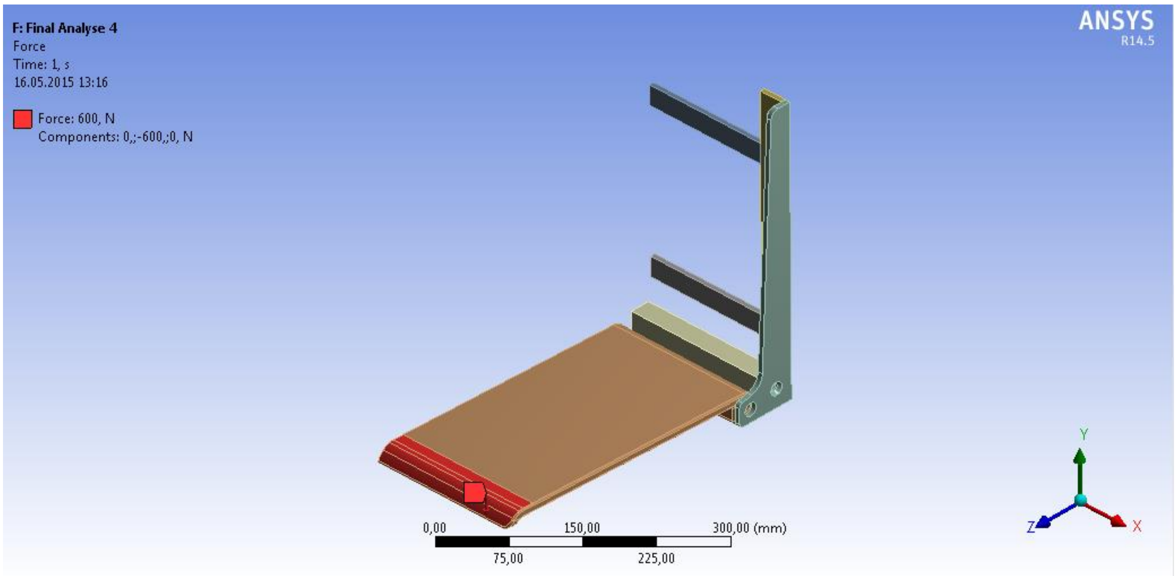


Figure 66 Case 4 Force Application

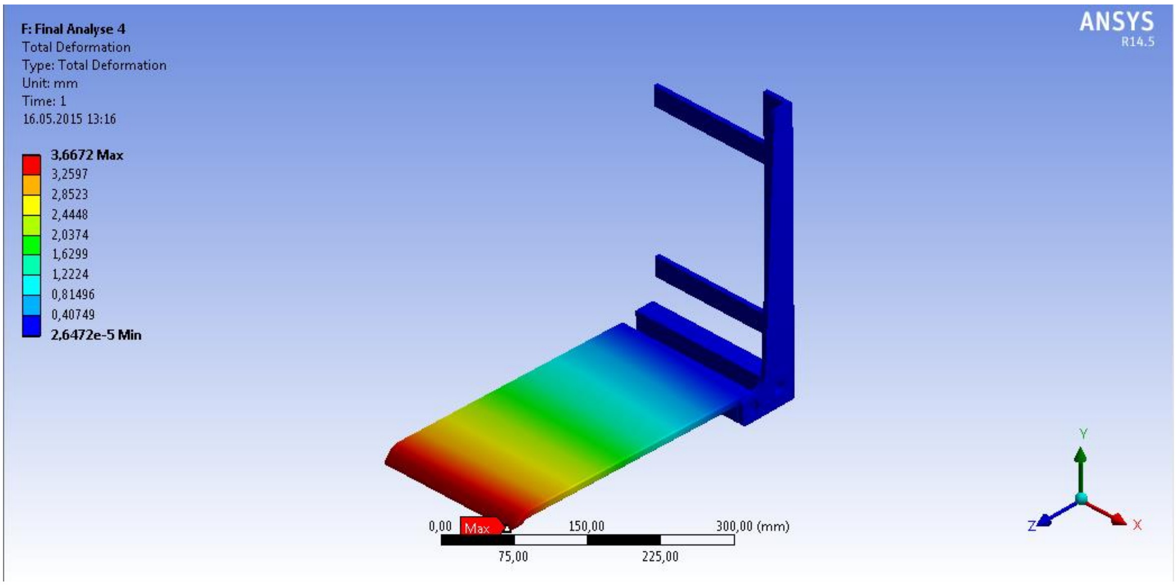


Figure 67 Total Deformation of Case 3

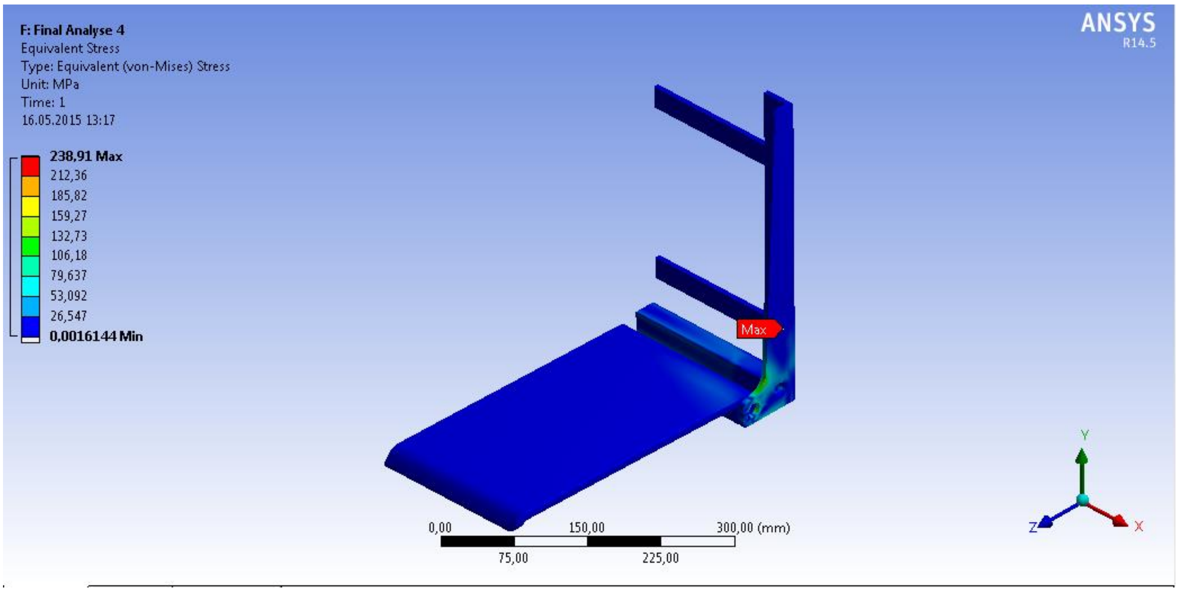


Figure 68 Von Mises Stress Results of Case 3

The value of Von Mises Stress is σ_V=239 MPa. The Yield Strength for the Aluminium was

σ_Y = 245 MPa.

$\sigma_Y > \sigma_V$ so the product does not fail and the safety factor had been justified in this worst case scenario under 120 Kg.

4. Cost Analyze

In this section, the crucial and very important aspect of the product development phase was investigated. The price of the product was calculated according to breaking down the product assembly into its parts and analyzing and calculating the price of the;

- Material Cost.
- Manufacturing Cost.
- Labor Cost.
- Overhead Cost (Software, Utilities, Consumables, etc.) Cost.

Also basic manufacturing processes which were going to be used for the production of the parts were briefly explained to have an insight about the existing technologies. To start the analyze, final exploded view of the assembly had been presented with the bill of materials to demonstrate the parts in a break down scheme.

4.1 Material Cost

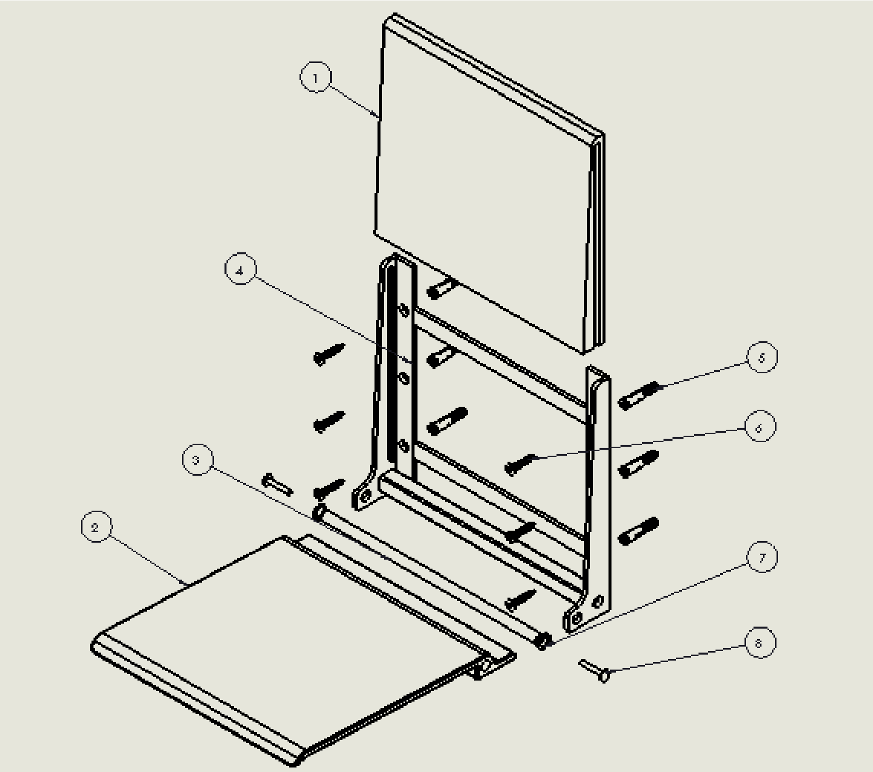


Figure 69 Exploded View of Final Assembly

Table 14 Motio Bills of Materials

Part No	Part Name	Material	QUANTITY	Drawing No
1	Back Rest	Polyurethane	1	M.01.01.00.00
2	Seat	Polyurethane	1	M.01.02.00.00
3	Pin	Aluminium	1	M.01.03.00.00
4	Mount	Aluminium	1	M.01.04.00.00
5	Ø8 Wall Plug	Plastic	6	
6	Din 7050 St8x45	Steel	6	
7	Ø16 Washer	Steel	2	
8	M8 Cap	Steel	2	

The cost analyze had been started with the Material Cost (Products which had been produced outside of Balteco AS) and initially **Part No 1 Back Rest** and **Part No 2 Seat**. The material of the products were Polyurethane and the suitable production method for it was RIM (Reaction Injection Molding).

In the RIM process first, the two parts of the polymer are mixed together. The mixture is then injected into the mold under high pressure using an impinging mixer. The mixture is allowed to sit in the mold long enough for it to expand and cure. If reinforcing agents are added to the mixture then the process is known as Reinforced Reaction Injection Molding

(RRIM). Common reinforcing agents include glass fibers and mica. This process is usually used to produce rigid foam automotive panels a subset of RIM is Structural Reaction Injection Molding (SRIM), which uses fiber meshes for the reinforcing agent. The fiber mesh is first arranged in the mold and then the polymer mixture is injection molded over it. (37)

Since it had been explained briefly, RRIM is the sub suitable method for the selected specific material with the 20% glass filling. Finnish company Artekno OY which had worked previously with Balteco AS about polyurethane molding was the main source for the cost inquiry since Balteco itself does not produce the polyurethane parts itself. After the inquiry the initial price for the products were listed down below.

Table 15 Initial Price of the Polyurethane Parts

	Finishing	Part Price (€)	Al. Mold Price (€)
Seat	Standard	53	6500
Back Rest	Standard	61	7100
			13600

Table 14 prices were the prices taken from Finnish company which labor, tax, utility costs are relatively high among other EU competitors. And it had been discussed with the Balteco AS staff that they had lower prices from Southern European producers. Moreover previous Polyurethane products which had been produced for Balteco from Italian companies had %30 cheaper prices. So this percentage had been applied to the initial price of the pieces. However mold prices were evaluated as average price compare to the other mold prices.

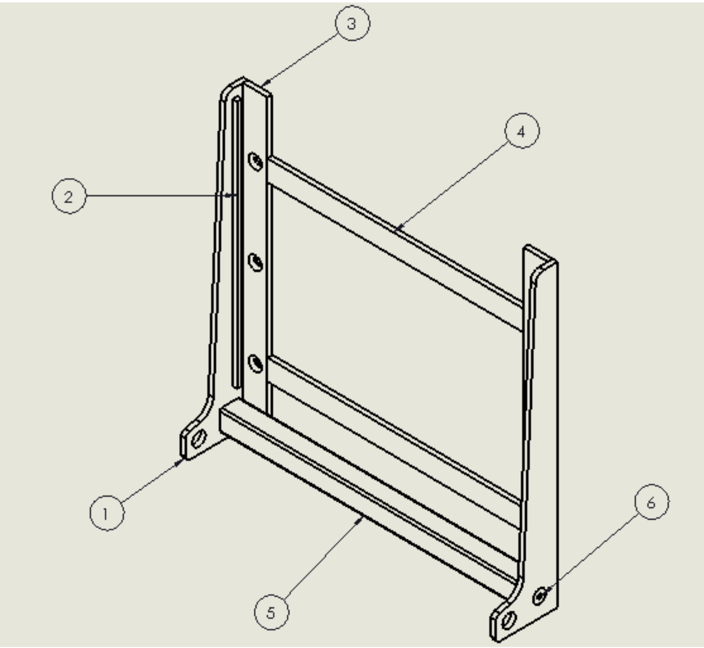
Final Seat Part Price: 53€ x 0.7 ≅ 37 €

Final Back Rest Part Price: 61€ x 0.7 ≅ 43€

These final prices included the painting in the standard finishing parts. In polyurethane production the painting is costlier than the product due to excellent finish requirements. These requirements need hand painting and it was all included in the **final price for the products which was 80€.**

After the polyurethane parts, aluminium pieces (plates, bars, profiles.) of the wall mount structure had been taken into consideration about their cost aspect. Therefore the structure were broken into separate drawing and bill of materials. The note must be taken that the stopper structure had been evaluated as different subassembly and had been analyzed separately due to the structural units of them was separate then plates. It consisted of square bar and a tube which could not have been cut from sheet metal.

Table 16 Bills of Materials of Mount Structure



Part No.	Description	Material	Quantity	Drawing No
1	Side Profile	Aluminium	2	M.01.04.01.00
2	Glide Bar	Aluminium	2	M.01.04.02.00
3	Mount Plate	Aluminium	2	M.01.04.03.00
4	Support Plate	Aluminium	2	M.01.04.04.00
5	Stopper	Aluminium	1	M.01.04.05.00
6	DIN 7991 M8 x 35		2	

Figure 70 Technical View of Mount Structure

As can be seen from the bill of materials Part No1, 3, 4 had been investigated. These parts must had been cut from aluminium sheet to be obtained in the desired shape. The cutting process was held by laser cutting method.

Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser most commonly through optics. The laser optics and CNC (Computer Numerical Control) are used to direct the material or the laser beam generated. A typical commercial laser for cutting materials would involve a motion control system to follow a CNC or G-code of the pattern to be cut onto the material. The focused laser beam directed at the material, which then either melts, burns, vaporizes away, or is blown away by a jet of gas. (38)

For cutting a base sheet metal of 1000 x 1000 mm Al had been selected and the Part Drawings had been nested into sheet metal according to reduce the scrap metal thus the cost. Nesting provided profiles for 9 pieces of end product.

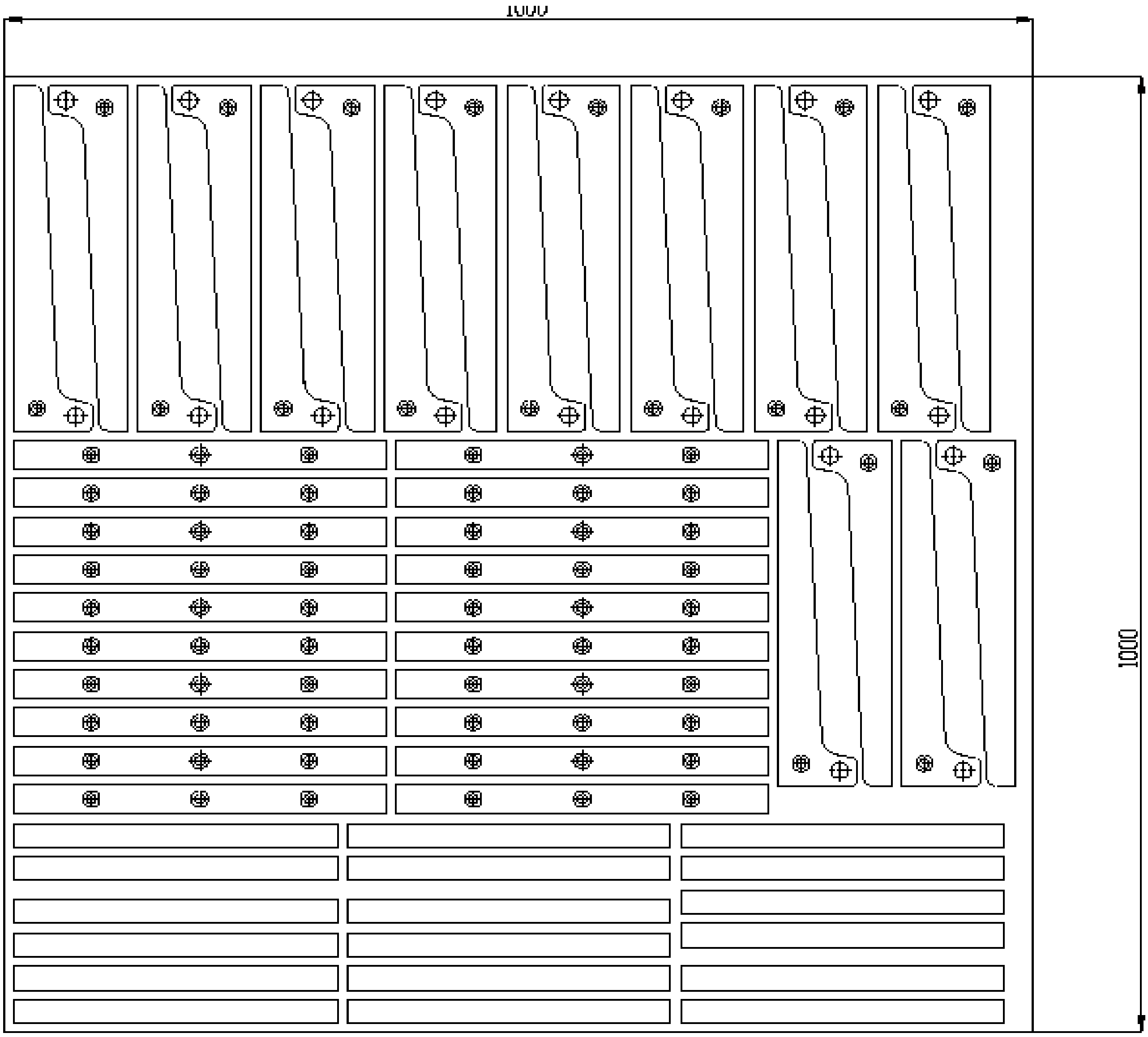


Figure 71 Nesting of the Al Profiles of Mount Structure

As in the Polyurethane part production Balteco AS is not cutting the profile themselves therefore the nesting had been sent to a company called Baltic Steel Center OÜ in order to have the price cost. After the correspondence had been conducted with them the price offer had been gathered.

The price was 114.05€+ VAT (%20).

And the final price for the nesting is 137€ but it had to be kept in the mind that it was for 9 end products therefore the price must be divided into one product's aluminium plates.

Final Price per 1 product = 137/9 ≅ 15 €.

These plates and the profiles were put together by welding. The welding method for the structure was MIG (Metal Inert Gas) method. MIG welding is an arc welding process which utilizes a wire as combined melting electrode and filler metal in a direct current (DC), electrode positive arc and inert shielding gas. Neither alternating current nor direct current, electrode negative arc has any practical application. The welding current, arc length and electrode wire speed are controlled by the welding machine and set by the operator. (39)

Table 17 Stopper Bill of Materials

Part No	Description	Material	Drawing No	Quantity
1	Tube	Aluminium	M.01.04.05.01	1
2	Thread Piece	Aluminium	M.01.04.05.02	2

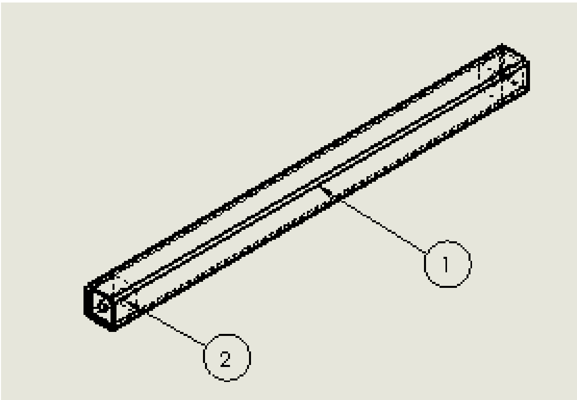


Figure 72 Stopper Technical View

For the stopper pieces, there was a drawing as a subassembly drawing which indicated additionally profiles and square bars which had to be cut and machined. Aluminium cutting can be done with various ways such as saws, saw machines, plasma cutting, laser cutting and water jet cutting, etc. For the machining a thread drilling must be done in order to have the thread screws.

In order to have structure constructed the technical drawings which were needed to welding, drilling and cutting sent to the partner company called Alman Brothers OÜ. For all the operations which were needed had been priced and done by that company and the price was

The price was 26.4€+ VAT (%20) = 31.7€

Powder Painting Cost

The powder coating process is very similar to a painting process except that the "paint" is a dry powder rather than a liquid. The powder sticks to the parts due to electrostatic charging of the powder and grounding of the parts. Any substrate can be used that can tolerate the heat of curing the powder and that can be electrically grounded to enhance charged particle attachment. The powder flows and cures during the application of heat. (40)

Several advantages of powder coating over paints are:

- Powder recovery for reuse.
- No VOC generation therefore no VOC destruction required.
- Can be more durable than paints (powder chemistry dependent).

Several disadvantages of powder coating over paints are:

- Can have less leveling than paint.
- Curing is typically more energy intensive than paint drying due to higher temperature requirements. (40)

After brief explanation of the powder painting, a contact had been set with the company called Inlook Color OÜ for the price inquiry of powder coating with RAL 1013. And the price was;

Table 18 Cost for Powder Painting Finish

Item	Unit	Quantity	Unit price(€)	Total Cost(€)	Total Cost + VAT(€)
Mount Structure	TK	1	5.63		
Minimum Bill	-	1	49.83	49.83	59.8

As it can be seen from the Table 17 the minimum bill was covering the price for 10 mount structure unit finishing so **for the finishing cost one unit finishing price of 5.63 € ≅ 6 € was taken into consideration.**

Powder Painting Cost Mount Structure Machining & Welding Price, Nesting and Cutting Price and Molded Polyurethane Piece Prices were considered as **Material Cost Price.**

Material Cost =6+80+15+31.7= 132.7 € ≅ 133€

4.2 Packaging & Control Cost

Packaging and Quality Control cost had been considered as a joint process after all the production and finishing process had been done and it had been considered as:

- 10 minutes for all the parts being eye checked.
- 10 minutes for packaging.

Therefore it had been calculated 20 minutes and the hourly labor cost was 30€/Hour and that made the **Packaging and Control cost as 10€.**

4.3 Total Cost

In this section there were additional cost which was called Overhead Cost which covered electricity, consumables, purchased items, logistics, etc. The **Overhead Cost was** calculated as %50 of Material Cost, Powder Painting Cost and Packaging & Control Cost Sum.

Table 19 Total Cost of Motio

<table>
<tr><td>Material Cost</td><td>133€</td><td rowspan="3">MOLDING COST</td><td rowspan="3">13600€</td></tr>
<tr><td>Packaging &Control Cost</td><td>10€</td></tr>
<tr><td>Overhead Cost</td><td>86</td></tr>
<tr><td>TOTAL COST</td><td>229€</td><td colspan="2">13600€</td></tr>
</table>

5. Conclusion

The Master Thesis focused on concrete product design idea and process of manufacturing with an emphasis to:

- Product Design Phase.
- Strength Analyzes.
- Cost Calculations.

With the combination of the engineering and marketing approaches, the thesis had a value of Product Development process. The Master Thesis did not focus on existing problems but rather to bring new values to the company and broaden the market in the specific field. During the thesis process both in the design research phase and the engineering approach; the methods and the tools which had been learned throughout the M. SC Design and Engineering curriculum.

Product design phase consisted of market research, user target group research, company meetings, and finalization of the design with all the required feedbacks.

Strength Analyzes had been done for different cases to examine the product's rigidity and stiffness and to see what would be the maximum weight that it could stand without breaking or failing. For analyzes, Ansys software was used which had been taught how to use in the D&E curriculum.

The final main part of the thesis was cost calculations which focused on the final cost of the entire product. The prices were gathered from companies which was expert about metal cutting, welding, finishing, molding, etc. since Balteco AS was not focusing on those production methods particularly.

As a conclusion another topic could be further developments. There can be design developments for further developments but the crucial one might be the production method of the shower seat. According to the results of the sales in the market after some certain amount of time, if the sales are lower than the expected a custom aluminium profile might be designed in order to eliminate the sheet metal cutting, welding costs. And the lowered cost could have compensated the lower sales of the product.

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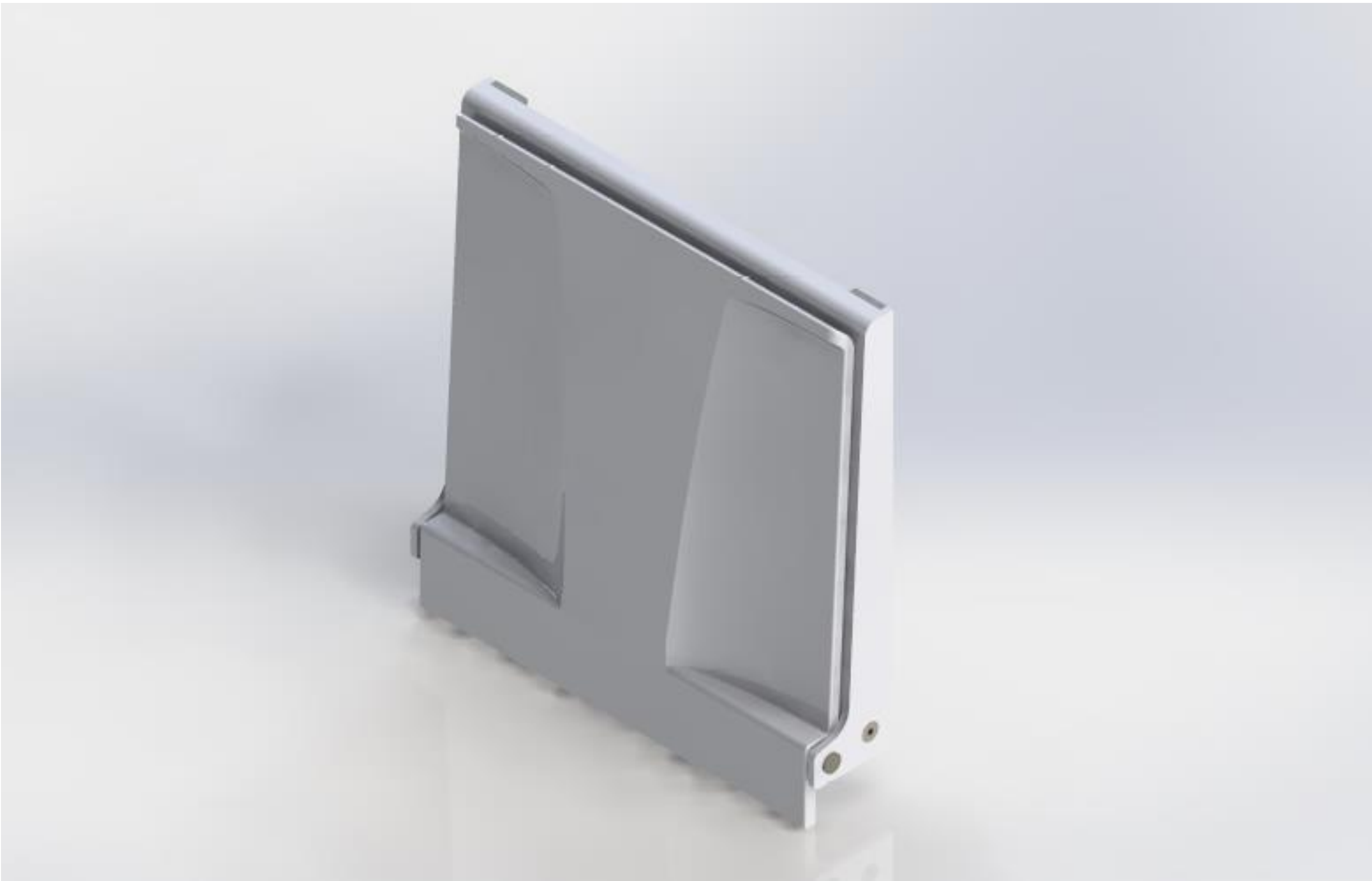
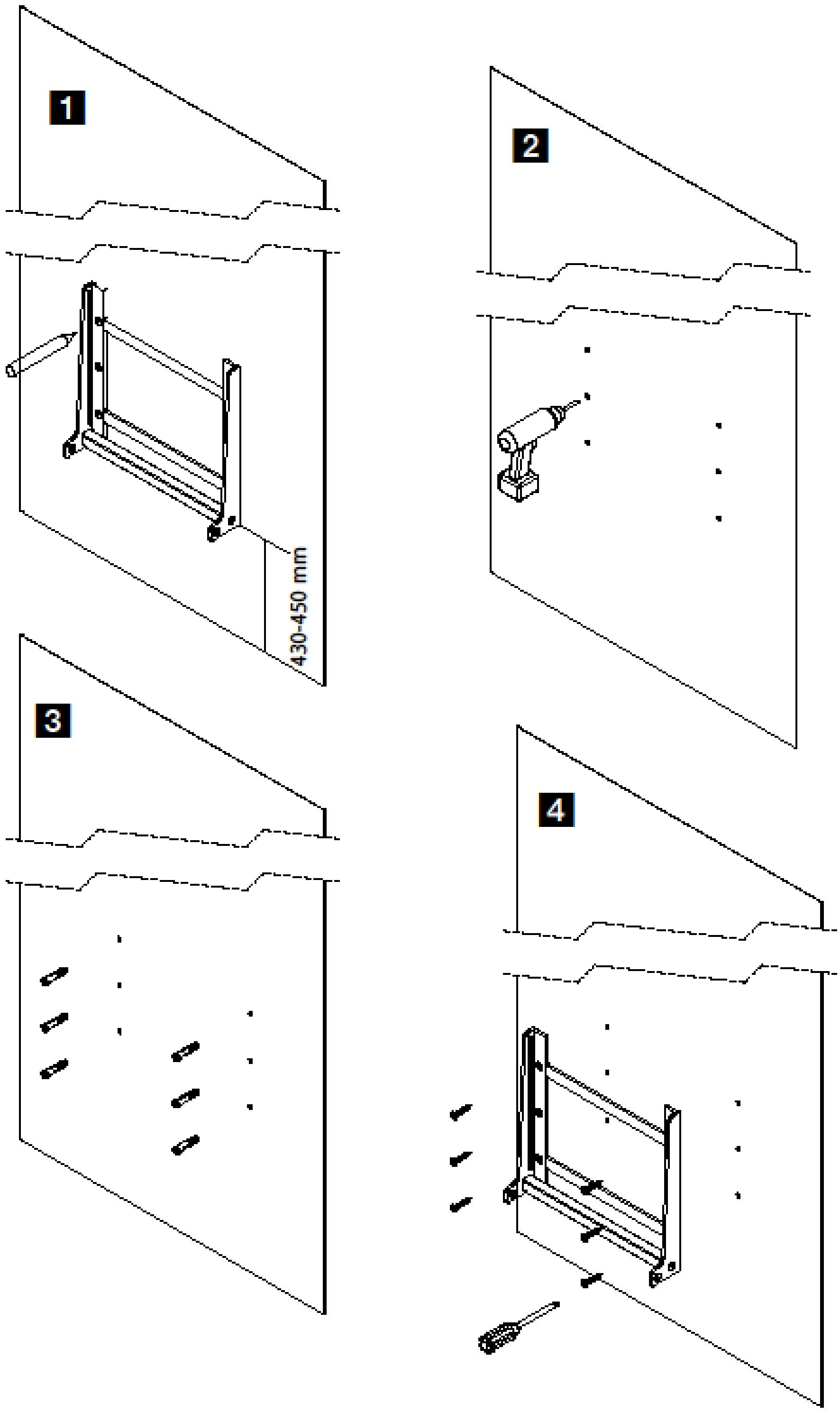
7. Appendix

7.1 Renderings

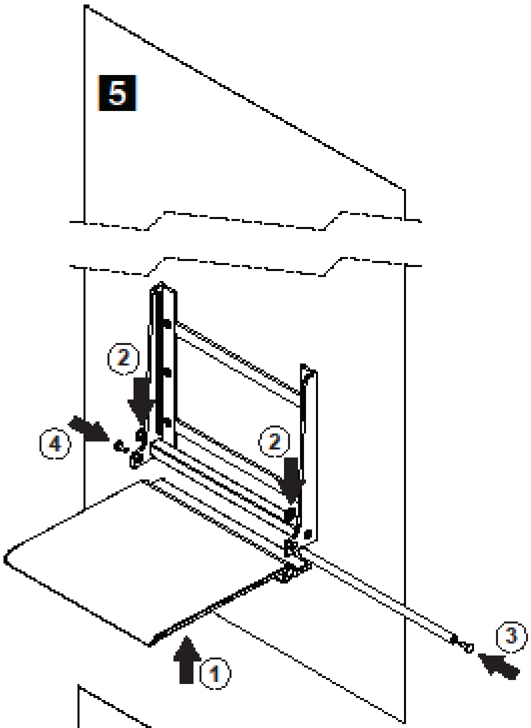


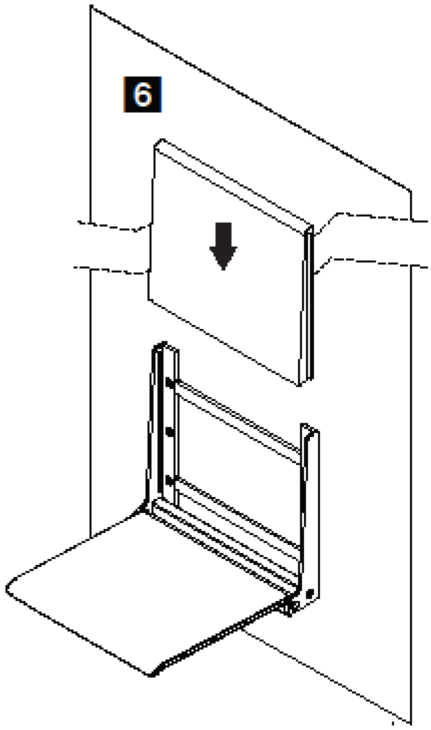
7.2 Assembly Manual

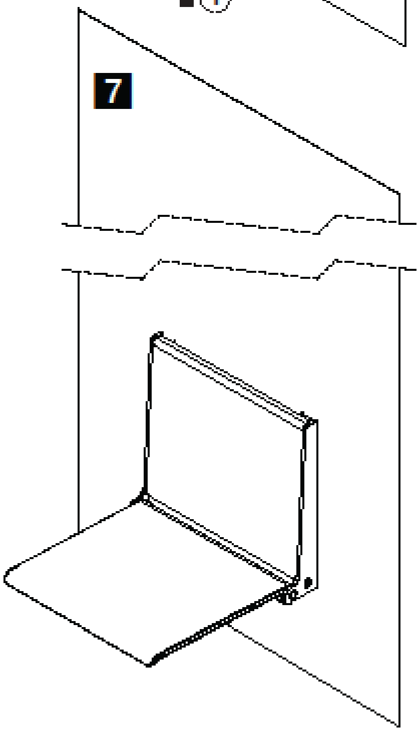
MOTIO ASSEMBLY MANUAL



MOTIO ASSEMBLY MANUAL







7.3 Technical Drawings