DESIGN OF FULL BODY WORKOUT MACHINE

Bachelor's thesis

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ABSTRACT

The purpose of this thesis was to design a full body workout machine. The main goal was to make a workout machine that was inexpensive, covered a small area and light in weight. This thesis was commissioned by HAMK University of Applied Sciences.

This topic was proposed by the author himself after realizing the need for an ideal workout machine that would fulfil all one´s requirements. He had been going to gym regularly for two years. Based on his experience, gyms were overcrowded with equipment targeting only a few body parts. Having seen the crowds at the gym, the bad weather conditions, the travelling time to get to the gym and expensive gym membership charges made him realize the need for a full body workout machine for private use.

The thesis project started with an internet search for similar products available in the market, and for the most important exercises to keep fit, with interviewing targeted users. The interviews were conducted with gym goers at two different gyms of Riihimäki and students of HAMK, to get an idea of people´s needs and expectations about an ideal workout machine.

This thesis contains design ideas for a full body workout machine, calculations for the selected design, pictures from CAD model, a cost calculation and a possible business model for production and marketing.

The results of this thesis project will be used as a base for the production of the chosen design.

Keywords Design, Workout, Full body

Pages 49 pages including appendices 4 pages

CONTENTS

Appendices

LIST OF FIGURES

1 INTRODUCTION

Health is the greatest wealth a person owns. Regular exercise is the foundation for a healthy life. This document contains designs and force calculations for a full body workout machine mainly targeted for private use. It is composed of four concept ideas from where the best idea was selected. Further design calculations were made for the selection of material and cross-section of structure for the selected idea.

Internet resources, personal interviews, market research were used as references in this project.

This document consists of pictures from CAD model of final design, links to market available components, price calculation and possible business plan for production and marketing. Manufacturing drawings are not included in this report due to its confidentiality.

2 EFFECTS OF PHYSICAL EXERCISES ON YOUR BODY

Nobody denies the fact that "exercise is a key for a healthy life". But how does exercise actually help you achieve a healthy life? Muscles use glucose and adenosine triphosphate (ATP) for contraction and movement. During exercise, muscles go through multiple contractions and movements, which require more ATP. Our body has a limited amount of stored ATP, so our body needs extra oxygen to create more, which is the reason why breathing increases with exercise and to deliver more oxygen to muscles the blood needs to pump faster, so we have a higher heart beat during exercise. (Klein 2013.)

During exercise, tiny tears occur in the muscles. These tiny tears make muscles grow bigger and stronger as they heal. This tear and healing of muscles is the reason we have muscle soreness after exercise. (Klein 2013.)

Increased heart beat does not only increase the oxygen flow to the muscles but also to the brain. An increased blood flow to the brain immediately makes the brain function at a higher level, making you feel more alert and awake during exercise and more focused afterwards. Different chemicals are released by the brain during exercise, one of the most commonly known ones is endorphin. This chemical tends to minimize the discomfort and pain and is also associated with feeling of pleasure, excitement and feeling of well- being and happiness. Exercise also helps in the growth of the new blood vessels, which results in a decrease in blood pressure. (Klein 2013.)

3 RESISTANCE TRAINING

“Resistance training is any exercise that causes the muscles to contract against an external resistance with the expectation of increase in strength, tone, mass and/or endurance” (Weil 2016).

Moving our body part during resistance makes one´s body used to with resistance, making us comfortable to make similar movements in our daily tasks. Our day to day activities involve many pulling, pushing, lifting and holding tasks. Training one´s body to similar movements in presence of resistance, strengthens the needed muscles group, which later helps in those movements.

Resistance can be provided with dumbbells, a rubber band, one´s own body weight, bottles of water or any objects that cause muscles to contract. In general, most exercise we perform at the gym are resistance exercises. (Weil 2016.)

As discussed in the first chapter, exercise performed in presence of resistance causes microscopic tear to the muscles cells, which are repaired by body and makes it grow stronger. This process of muscles fibre breakdown is called “catabolism,” and the process of repairing is called “anabolism”. Our muscles grow and repair when we are not working out, so it is necessary to give time between workouts before training same body part. (Weil 2016.)

“Resistance training is more important and far more effective than cardio for fat loss, and is essential part of your training programme” (Rosie Chee 2016).

According to Fitness Australia (2016), health benefits of resistance training are:

1. Improved muscles strength and tone- to protect joints form injury
2. Maintaining flexibility and balance
3. Weight management and increased muscles-to-fat ratio
4. Greater stamina
5. Pain management
6. Prevents from conditions like diabetes, heart disease, arthritis, back pain, depression and obesity
7. Improved mobility and balance
8. Improved posture
9. Improved sense of wellbeing
10. Avoidance of insomnia
11. Enhanced performance of everyday tasks

4 FULL BODY WORKOUT MACHINE

Full body workout machines are machines, where we can perform many different exercises targeting different muscle groups in our body with the same machine. Their main purpose is to give a variety of options in a single place. These machines are mainly targeted for private use.

Their target is to save space, time to travel to gym, extra gym expenses, unsuitable timings and ease of use. These machines are also called gym stations or multi gyms. They are a convenient alternative to improving fitness and staying healthy in a busy schedule. (fitnessexpo 2013.)

Figure 1. Body solid EXM 4000S multi gym station (Gymstarter n.d).

As shown in Figure 1, as to the target to save space, full body workout machines are not very small to fit into a small room. The space saved is compared to the space occupied by placing machines for individual exercise. Other than space, most gym stations in the market ranges from 800 euros to 5000 euros, depending upon multi-functionality, space and durability. Most available gym stations use weight stacks to make resistance change easy and quick. Using weight stacks increases the total weight of the machine, which makes the machine stationary.

5 RESISTANCE

As the main target of the exercising is to add resistance to the general movement of our body, the machine needs to provide the resistance by some means. The most common methods of resistance in existing exercise machines are weight plates and weight stacks. These methods use the weight concept for resistance, the heavier the load, the higher is the resistance. This makes the machine heavier for higher resistance exercises. For that reason, I tried to find some other possibilities to provide resistance. The use of lightweights, such as helical springs, constant force springs can be an option. I also tried to examine the possibilities of using dumbbells for resistance in the machine.

5.1 Weight plate

It is the most common resistance used in free weight exercises. Weight plates are available in different weight values. They are generally circular plate with a hole at centre to insert in a bar. They are also available in other shapes. Its outer dimension can depend on the size of weight but the central hole are generally two types: standard size and Olympic size. The central hole diameter for standard size weight plate is 25 mm and that of Olympic size plate is 50 mm. Maximum outer dimension for a Olympic weight plate is 450 ± 1 mm. (Johnson 2017.)

Plates are attached to a weight horn in the machine or in the end of bar. They can easily be added and removed from the machine.

Figure 2. Weight plate of different weight and sizes (Kiesling 2016).

Advantages
- Easy to add and remove from machine,
- Stored separately so it is not included in machine weight, which makes machine possible to move,
- Available in different sizes which allows buyers to buy according to their training level,
- Can be used in different machines, bars and also for free weight exercise.

Disadvantages
- Separate racking system required for storage,
- Should be put and taken out every time to change the resistance, which may cause injury if dropped,
- No quick change in resistance as you need to add or take out the weight plate.

5.2 **Weight stack**

Weight stack are the pile of weight plates stacked on top of each other. As shown in figure 3, plates are generally rectangular. They have a central hole top face to pass a weight selector bar and a hole on side to insert weight selector pin (with red top part in figure 3).

Figure 3. Weight stack with weight selector pin (ebay 2017).

The weight selector pin isolates the required weight by adding it to weight selector bar which is connected to cable. Cable transmits the weight resistance to the end part where the exercise is performed.

Advantages
- Easy to change weight
- Already in the machine so no need to re-rack
- Covers small space

Disadvantages
- Attached in machine so the total weight of machine is increased
- Can be used only in individual machine
- Only used with cable machines

5.3 **Helical spring**

Springs are mechanical element used to store energy or to provide resistance for tension or compression movement. Spring uses the stored energy to come back to its original shape and length. Due to its different function, it is a very widely used component in mechanical designing. (

Helical springs are spring which are coiled around a straight axis with uniform diameter and pitch from one end to other. Extension springs as shown in figure 4, resists the pulling force and try to retract to its initial length.

Figure 4. Tension helical spring (Verma springs n.d).

Force used to pull and retract spring follows Hook´s law, which is stated as

$$f = kx$$

Where k – spring constant, x- expansion or compression of spring.

Due to this property, helical spring does not give uniform force during expansion or retraction. Which can be a problem to use it as a resistance option on workout machine.

Advantages
- Light weight
- Large range of resistance
- Small in shape and size
- Cheap

Disadvantages
- Non uniform force
- Short life
- Limited range of motion

5.4 **Dual pulley constant force mechanism for helical spring**

There is a system to change the non-uniform force of helical spring to constant uniform force with use of dual pulley constant force mechanism as shown in figure 5. In this system, the cable connected to the spring rides in a variable radius input pulley grove, whereas the second output cable rides in a variable radius output pulley groove. (Duval 2010.)

Due to its patent and unavailability of standard part in market I was unable to use this system.

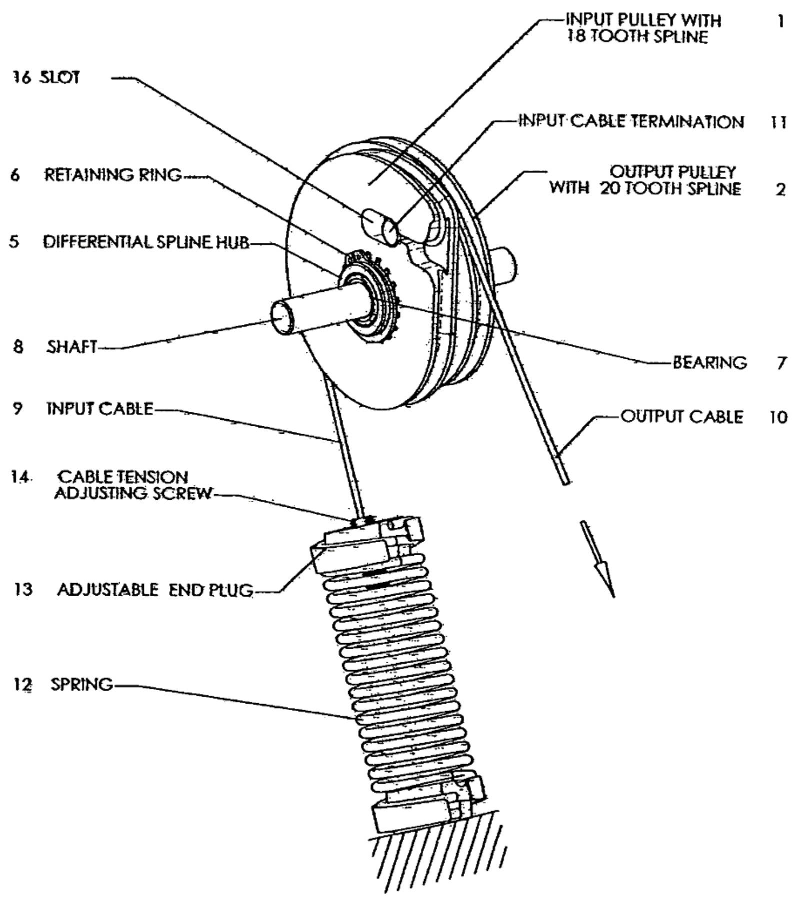


Figure 5. Dual pulley and spring assembly (Duval 2010).

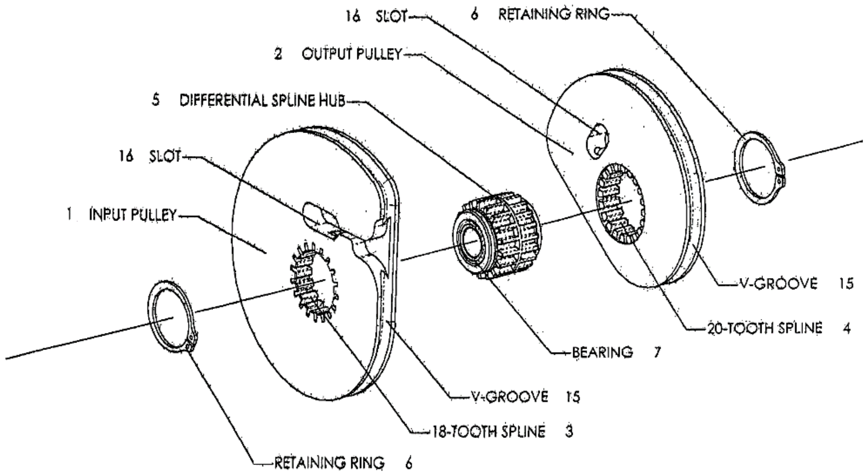


Figure 6. Dual pulley assembly with differential spline hub (Duval 2010).

Figure 6 shows the details of the double pulley and differential spline hub mechanism. Differential spline hub changes the rotation speed of pulley connected to the spring cable and the pulley connected to the output cable, to maintain the constant force. (Duval 2010.)

5.5 Constant force spring

The constant force spring is a kind of extension spring, which is made by winding the steel strip into a coil which exerts a nearly constant retaining force to resist uncoiling. These springs are used in a linear movement. (Allitwares 2012.)

Figure 7. Constant force spring (Allitwares 2012).

This spring can be assembled in different methods to increase the resistance.

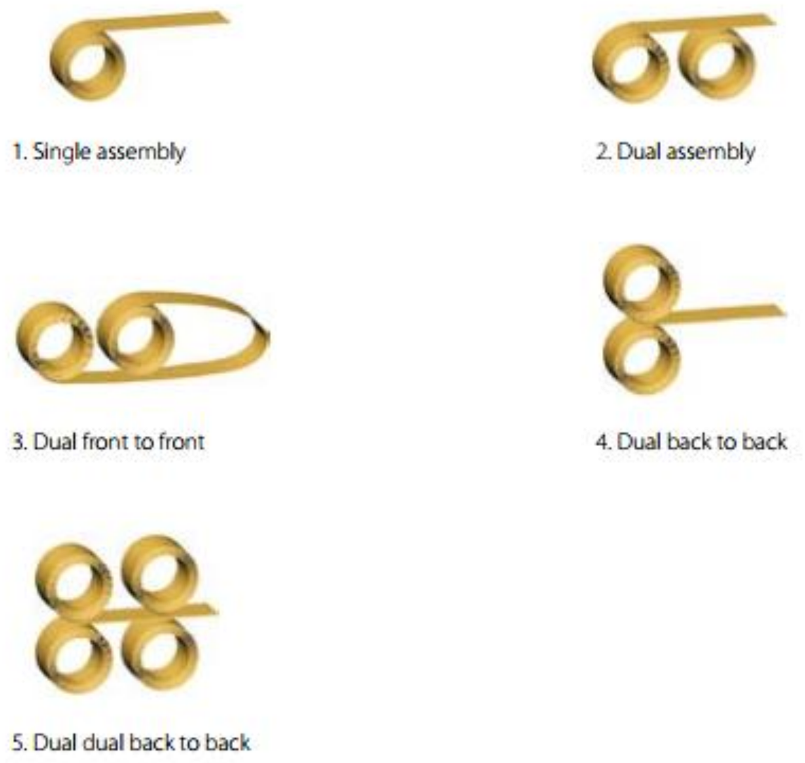


Figure 8. Constant force spring assembly to increase resistance (lesjoforsab n.d).

The resistance force generated by these springs were very small comparing to force we needed. It also had limited cycles of work life. These were the reason we could not use these spring as resistance provider in our design.

5.6 Dumbbell

Dumbbell are one of the most used means of resistance for varieties of exercises all around the world. They are made of two equal weights attached in two end of short round bar (usually just greater than palm width). It is generally used by gripping in between the gaps left by weights. As they are free weights, they can be used in different resistance exercises.

Figure 9. Pair of dumbbell (fitness-superstore 2017).

In this design, I planned to put a system where we can rack dumbbells and use them for resistance in cable exercises. They have wide range of applications beside, being used in machine.

The reasons I was not able to use this was because of their small size. This makes it not possible for exercises which needs higher resistance like squat. Adding more spot to hold more numbers of dumbbell makes machine bigger and limits the range of motion.

6 DESIGN PROCESS

The design of a product starts after we feel the need for a product in the market or sometimes come with a new idea. New products are also designed to overcome the problems in the existing design. All these design steps start with design requirements. The end point for a design process must provide the full specifications of a product which satisfies most of the design requirements. There are three steps in between the design requirement and the final product specifications: concept, embodiment and detailed design. (Ashby 2011, 16.)

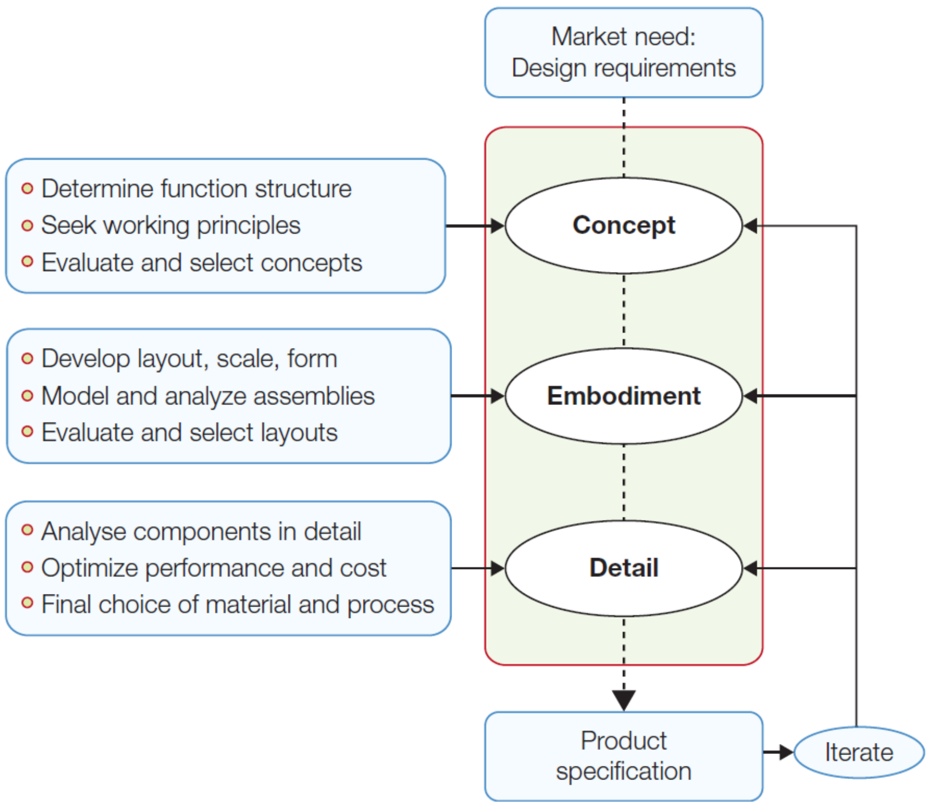


Figure 10. Design flow chart (Ashby 2011, 17).

Here, the design process was started with the identification of the problem, which was a need of cheap and simple full body workout machine. I felt the need after seeing the crowd at Loco motion gym in the evening between 4-5 pm, when most office goers get their time for exercising. I realized that if I could design a simple, small and cheap full body workout machine, it would benefit all the busy people and help them stay fit at their own homes.

I started with a general market examination in the internet, for available full body workout machines. Most of the available full body workout machines had similar problems such as: they were big in size, heavy, expensive, and not moveable.

I started with a few concept ideas to use available products and tried to make maximum use of them by changing or adding few features on them. Use of an available product in the market helped to reduce the price but the covering space, lightweight, multi-functional and mobility aspects were not achieved as desired.

Therefore, I came with two new ideas, where I used the principles of different existing machines.

Here in this report I have made a detailed design, a design analysis, a cost calculation and a CAD model for the selected idea for a machine.

6.1 Design requirements

As a design process runs around the design requirements, this is a most important factor which influences the end result. The main goal of a design requirement should be that the product should perform the required function. Beside its function, a design requires many other factors such as cost, space, durability, appearance and more. (Ashby 2011).

To know more about people´s needs and wants in this field, I went to different gyms, and sports centres, and interviewed people about their views on an ideal workout machine. The questionnaire that was used for interviews is enclosed as appendix 3.

Beside personal interviews, I searched for different articles and books regarding the most important exercises people needed to perform to stay fit and healthy. I also studied products and their drawbacks.

Based on my studies and interviews, I prepared the following list of requirements for my design:

- Multifunctional (able to perform different exercises targeting different body parts)
- Cheap (few hundred euros for one time purchase/ up to 2000 euro in instalment)
- Covering small space (space of a table or sofa)
- Durable
- Moveable/ light.
- Focusing on muscles groups like- chest, arms, stomach, leg
- Focusing on exercises like- Pull up, bench press, cables, leg press

6.2 Material selection

The material selection is the process of identifying the desired profile function and requirement of a design and comparing it with real engineering material property to find the best match. (Ashby 2011).

As shown in Figure 11, the first step in the selection process was to translate our design requirements to material property related terms. For that, design requirements were expressed as function, constrains, objectives, and free variables. Where, function was what the design was supposed to do. Constrains were a list of functions which should strictly be met and which were desired but not obligatory. Objectives were what was to be maximized or minimized. This step was called translation. (Ashby 2011).

After this, an index, which would help to maximize the performance of the given design, was found. This index is called material index. This index would separate candidate materials that are capable of doing the job. With the material index, few materials are selected for possible future option. Ranking is done among the selected material using the material index value. (Ashby 2011).

Here the highest ranked material may not be the best option. So, before selecting the appropriate material, selected materials should be examined. This should include: how was the material´s performance in earlier design? What is the most used material in similar designs and benefits?

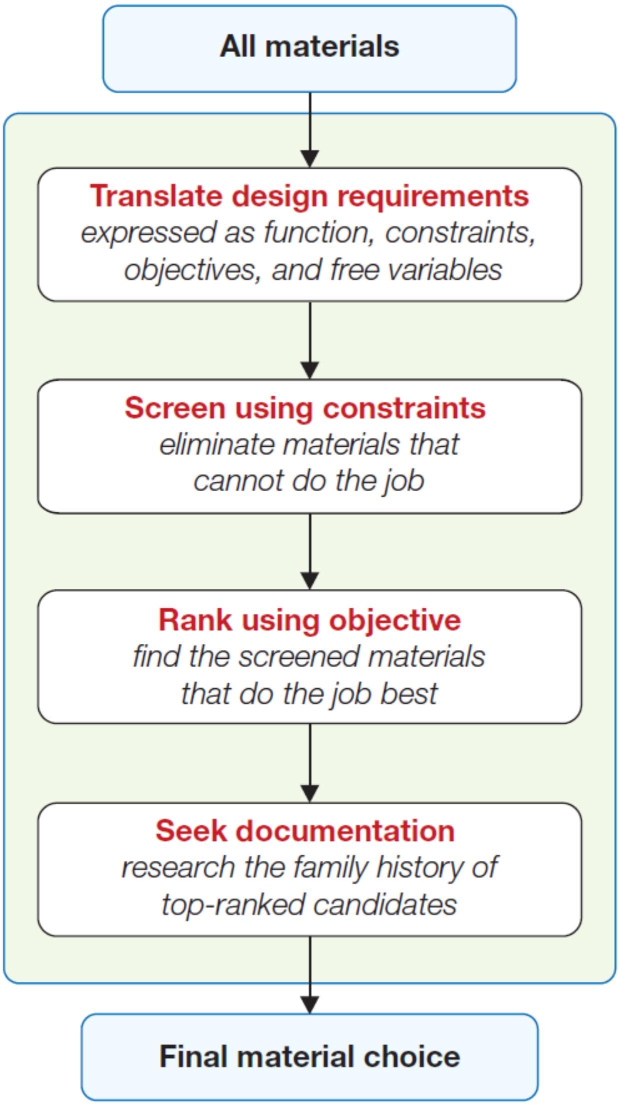


Figure 11. Strategy for material selection (Ashby 2011, 103).

In Table 1, I have translated our design requirements to function, constrain, objective and free variables.

Table 1. Design requirements for workout machine

Function	Workout machine
Constrains	Length is specified Stiffness: must not deflect too much under designed load Strength: must not fail under design loads
Objectives	Minimize mass Minimize cost
Free variables	Cross section area Choice of material

Function, Objective, and Constraints	Index
Tie, minimum weight, stiffness prescribed	$\frac{E}{\rho}$
Beam, minimum weight, stiffness prescribed	$\frac{E^{1/2}}{\rho}$
Beam, minimum weight, strength prescribed	$\frac{\sigma_y^{2/3}}{\rho}$
Beam, minimum cost, stiffness prescribed	$\frac{E^{1/2}}{C_m \rho}$
Beam, minimum cost, strength prescribed	$\frac{\sigma_y^{2/3}}{C_m \rho}$
Column, minimum cost, buckling load prescribed	$\frac{E^{1/2}}{C_m \rho}$
Spring, minimum weight for given energy storage	$\frac{\sigma_y^2}{E \rho}$
Thermal insulation, minimum cost, heat flux prescribed	$\frac{1}{\lambda C_p \rho}$
Electromagnet, maximum field, temperature rise prescribed	$\frac{C_p \rho}{\rho_e}$

ρ = density; E = Young's modulus; σ_y = elastic limit; C_m = cost/kg; λ = thermal conductivity; ρ_e = electrical resistivity; C_p = specific heat

Figure 12. List of material indices for respective function, objective, and constrains combination (Ashby 2011, 115).

From the list of material indices as shown in figure 12, we acquired the material index for stiffness with a minimum mass and at a minimum cost

$$M_1 = \frac{E^{1/2}}{C_{v,R}}$$

The material index for strength with a minimum mass and at a minimum cost

$$M_2 = \frac{{\sigma_f}^{2/3}}{C_{v,R}}$$

Where E: Young´s modulus of elasticity

$C_{v,R}$: Relative cost per unit volume

σ_f : Ultimate tensile strength

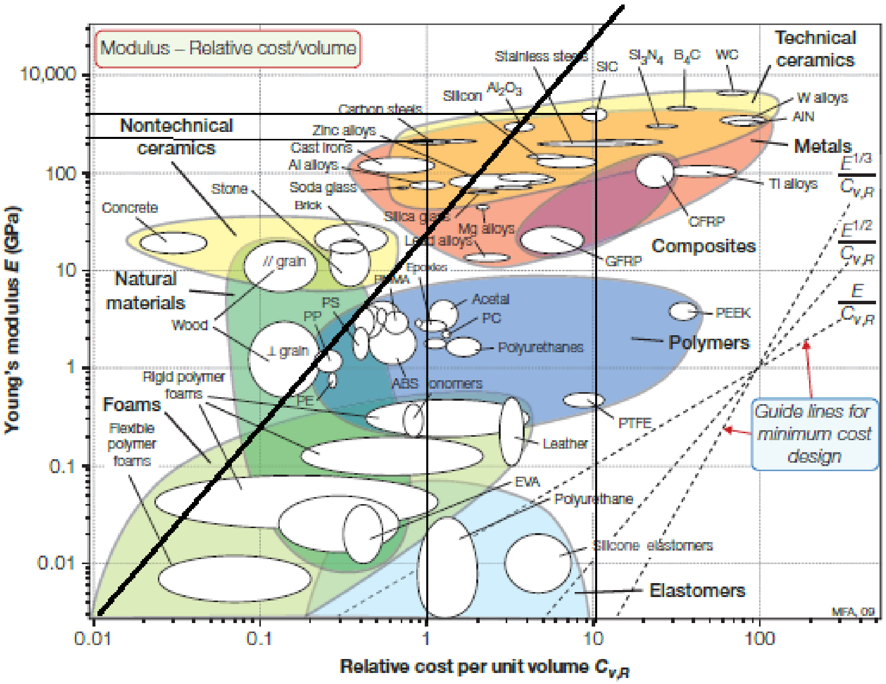


Figure 13. Young´s modulus against relative cost per unit volume (Ashby 2011,93).

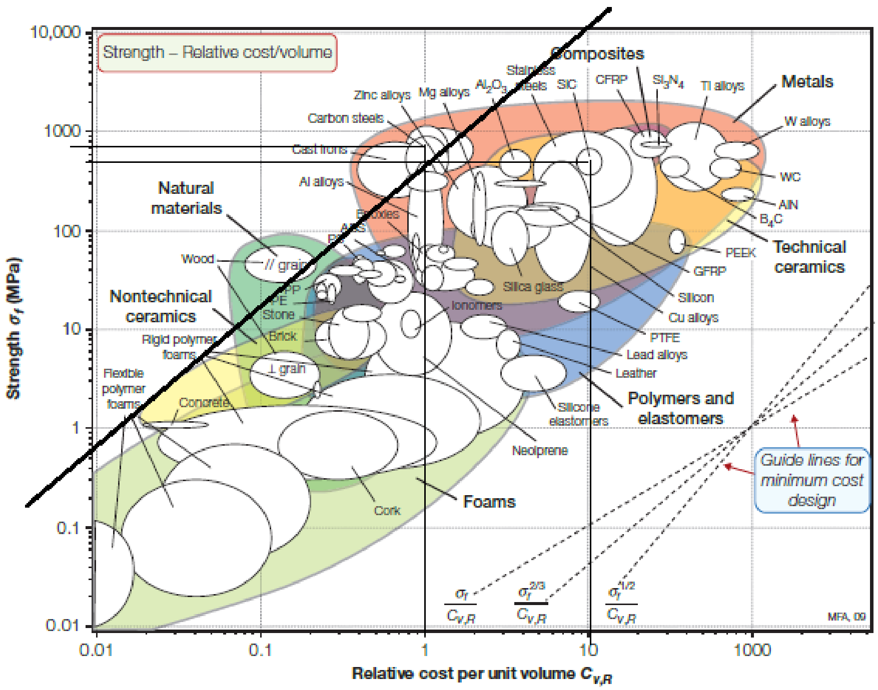


Figure 14. Strength against relative cost per unit volume (Ashby 2011, 94).

Based on the graphs shown in Figures 13 and 14, the following materials were chosen as potential materials:

1. Carbon steels
2. SiC

M_1 for carbon steel = 210/1 = 210
M_1 for SiC = 400/10 = 40

M_2 for carbon steel = 750/ 1 = 750
M_2 for SiC = 600/10 = 60

It became clear that carbon steel was the best and only option with us to achieve our objectives.

6.3 **Design concepts**

6.3.1 Idea 1

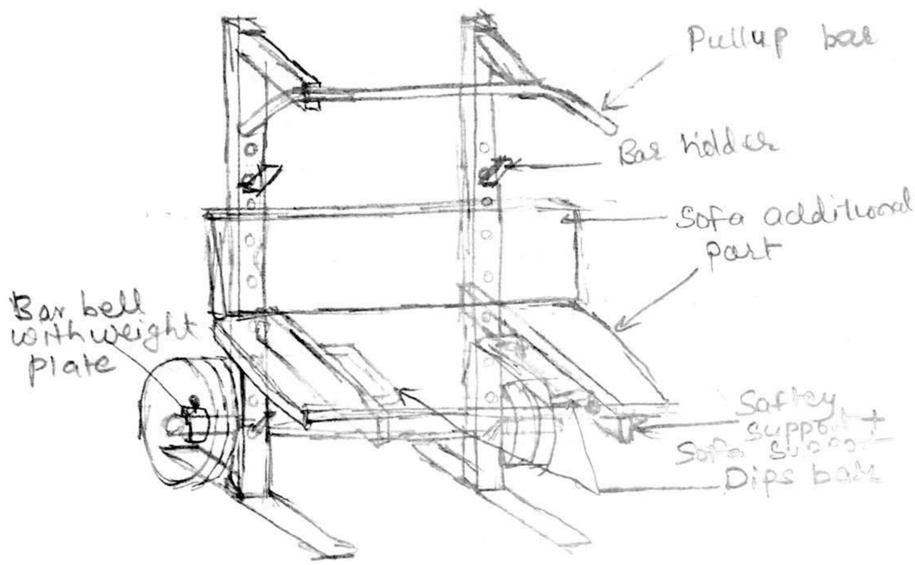


Figure 15. Sketch for Idea 1

The idea shown in Figure 15 was generated from an existing squat rack. A pull up bar was added and a safety support was designed to fix the sofa/bench parts so that this structure could be used as a sofa after workout. There is space left under the sofa to store the weight bar. Pull up bar can be designed to be foldable so that it will not be visible after workout.

Possible exercises to perform
- Pull ups
- Dips
- Barbell exercises such as squat, deadlift, arm curl, bench press, military press and many more

Advantages
- Components available in the market
- Can be used as a sofa, so it will not occupy separate space in a room

Disadvantages
- Heavy
- Less options for exercise
- not for beginners

6.3.2 Idea 2

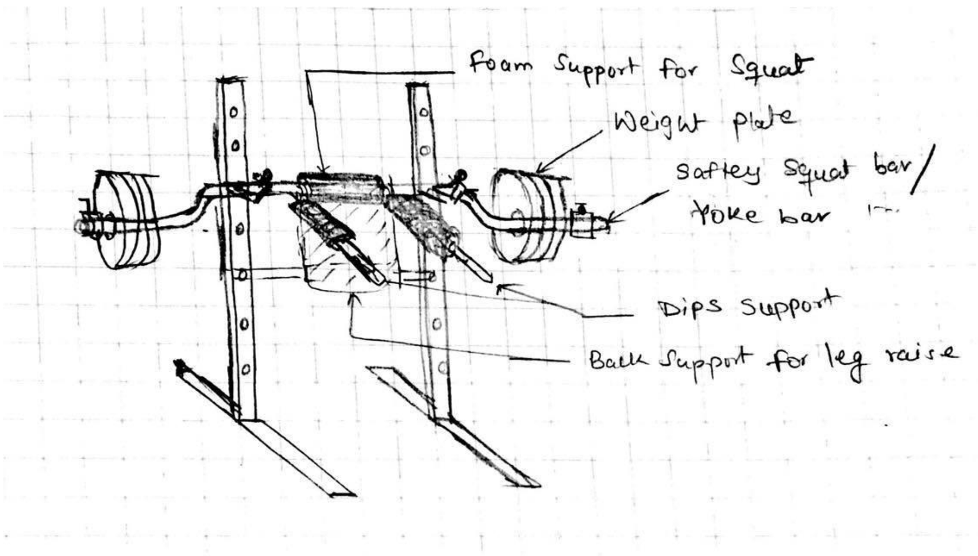


Figure 16. Sketch for Idea 2

The design shown in Figure 16 also uses available products in the market. The yoke bar/ safety squat bar is a new design for the replacement of a general straight barbell used in squats. By its name we know it is safer for squatting than a straight bar. With foam rolled bar to give comfort in resting the bar on the shoulder and easy holding with extended rod, makes it easier and safer for squatting.

My idea was to use this bar also for pull ups, dips and leg raises. For this purpose, the bar should be fixed, not a rotating one. Additional back support is added to support leg raise.

Possible exercise to perform
- Squat
- Pull ups
- Dips
- Leg raise

Advantages
- Components available in the market
- simple in design

Disadvantages
- less options of exercise
- space covering
- not for beginners

6.3.3 Idea 3

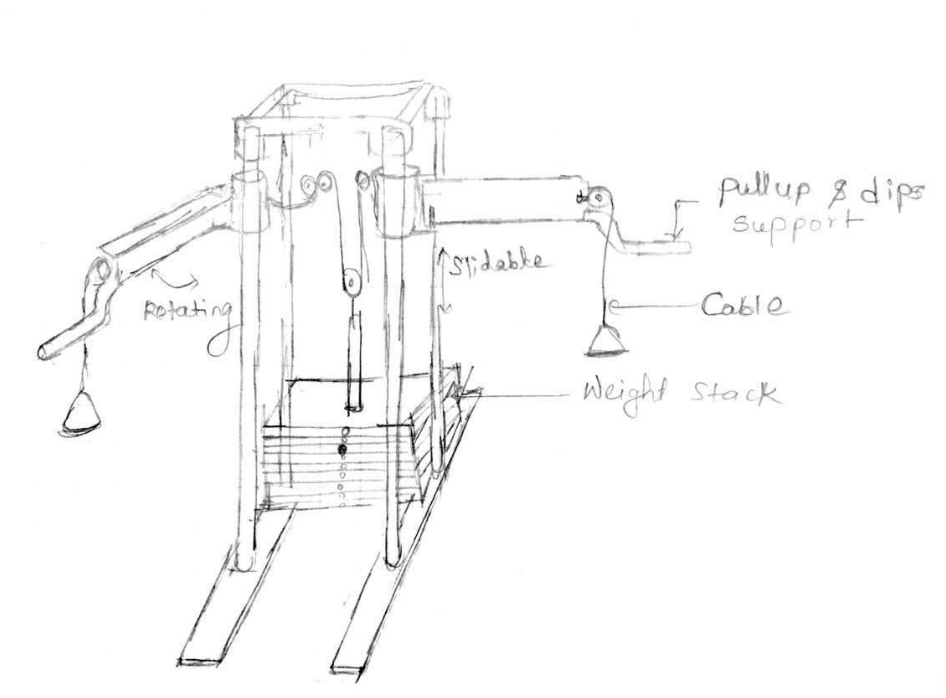


Figure 17. Sketch for Idea 3.

The idea shown in Figure 17 includes two arm beams, which are sliding and rotating around poles. The arm beams are made of hollow square cross-section beams. Cables that are attached to the weight stack are brought through the pole using pulleys making it possible to perform cable exercises with changing height and angle. Bended rods were attached on the end of both arm beams, which was used for pull-ups and dips.

Possible exercises
- Pull ups
- Dips
- Cable exercises
- Leg raise
-

Advantages
- Multifunctional
- Resistance is provided by a weight stack so no extra resistance required

Disadvantages
- Height
- Difficult to assemble by a single person
- Difficult to move
- Covers a large area

6.3.4 Idea 4

Figure 18. Idea 4.

The idea shown in Figure 18 is a mixture of different existing machines with other additional features. This machine provides wide options for exercises.

The general concept started by seeing a hack squat machine. Hack squat machines are only used for lower body exercises including squat and calve raises. This machine had a fixed body with two arm beams in front. The arm beams had a pin joint allowing it to rotate in the vertical direction. The arm beams were rested on shoulder to perform squats and calves raise exercises. Weight plates were added to the weight horn at each arm beam for resistance.

In our design in Figure 18, arm to pillar connection was changed, making it possible to move both in the vertical and horizontal direction keeping the joint fixed. The joining points were designed to make it possible to stop the arm beam at many different angles which allowed the user to perform a variety of exercises. An integrated seat, four different options to connect resistance, use of weight plates and a compact design made this design a perfect match for our design requirements.
A list of possible exercises can be found in Appendix 1

Advantages
- Multifunctional
- Smaller space
- Moveable
- Seat included
- Changeable resistance with single load
- Modular design
- Ground clearance
- Easy assembly and disassembly
- Different working angle.

Disadvantages
- Use of weight plates as resistance needs adding and removing of weight plates
- More expensive than the previous ideas.

6.4 **Selection of ideas**

There were different ideas presented as to the possible solution satisfying the given design requirements. The different ideas had their own strengths and fulfilment of design requirements. The ideas did not meet all the requirements to the fullest. Therefore, we compared all the ideas to the design requirements to find out the best solution.

In Table 2, the ideas are given points from 0 – 5 depending on how well they fulfilled an individual design requirement. The higher the number the better the achievement of idea to the requirement. For example: If idea 1 gets 1 in cost and 5 in space, it means the idea is expensive to manufacture but covers a very small space.

Table 2. Comparison of ideas

Ideas	Multifunctional	Space	Mobility	Weight	Cost	Total
Idea 1	3	4	2	3	3	15
Idea 2	1	3	4	4	4	16
Idea 3	5	3	3	3	2	16
Idea 4	5	5	5	3	2	20

Based on Table 2, we found that, all the design ideas had good strength and met the design requirements. Idea 4 had the highest score of 20 out of 25 and idea 1 had the lowest score i.e 15 out of 25. Both idea 2 and 3 had a total of 16 points. So, we concluded that idea 4 was the best idea among all and we continued with its calculations and detailed design.

7 FINAL IDEA

Idea 4 was selected as the best design idea and further calculation and modelling were performed on it. Figure 19 shows a photorealistic view of our model. This figure was created using creo 4.

Figure 19. Final model.

7.1 **Cable and Pulley connections**

A weight plate was used as the resistance and the resistance system was on the backside, a cable was used to transfer resistance to the desired location. Pulleys were used to carry the cable and allow a good linear movement to pull the resistance.

A total of 27 pulleys were used with different sizes and in different location to transfer the resistance to two different output options. Pulleys of sizes 90mm and 50 mm of outer diameter was selected.

Three sets of cables were used in the complete design. Two sets of chains were also used to keep the cable under tension during the change in the resistance location.

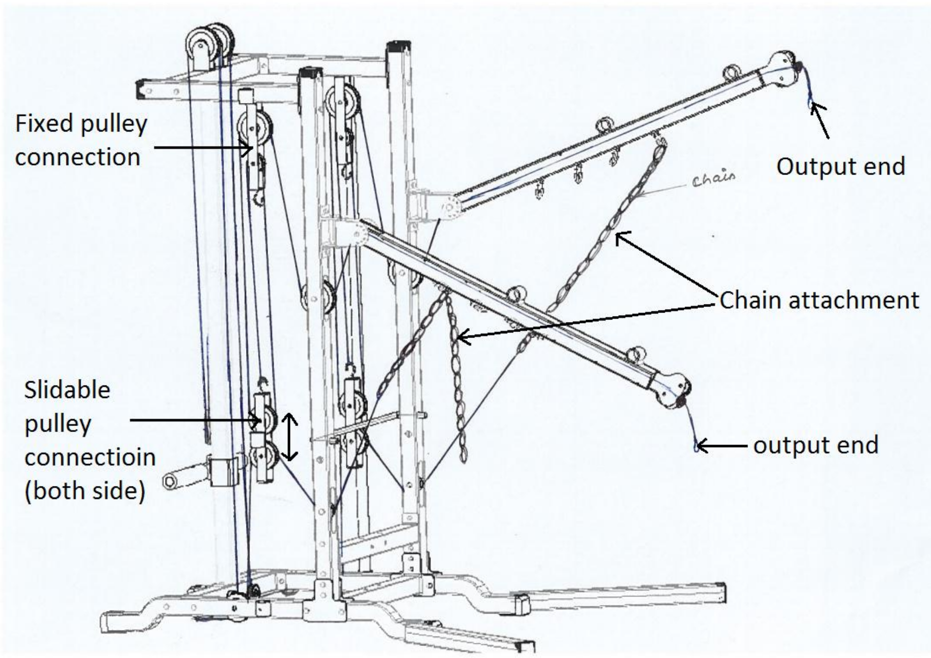


Figure 20. Cable pulley connections.

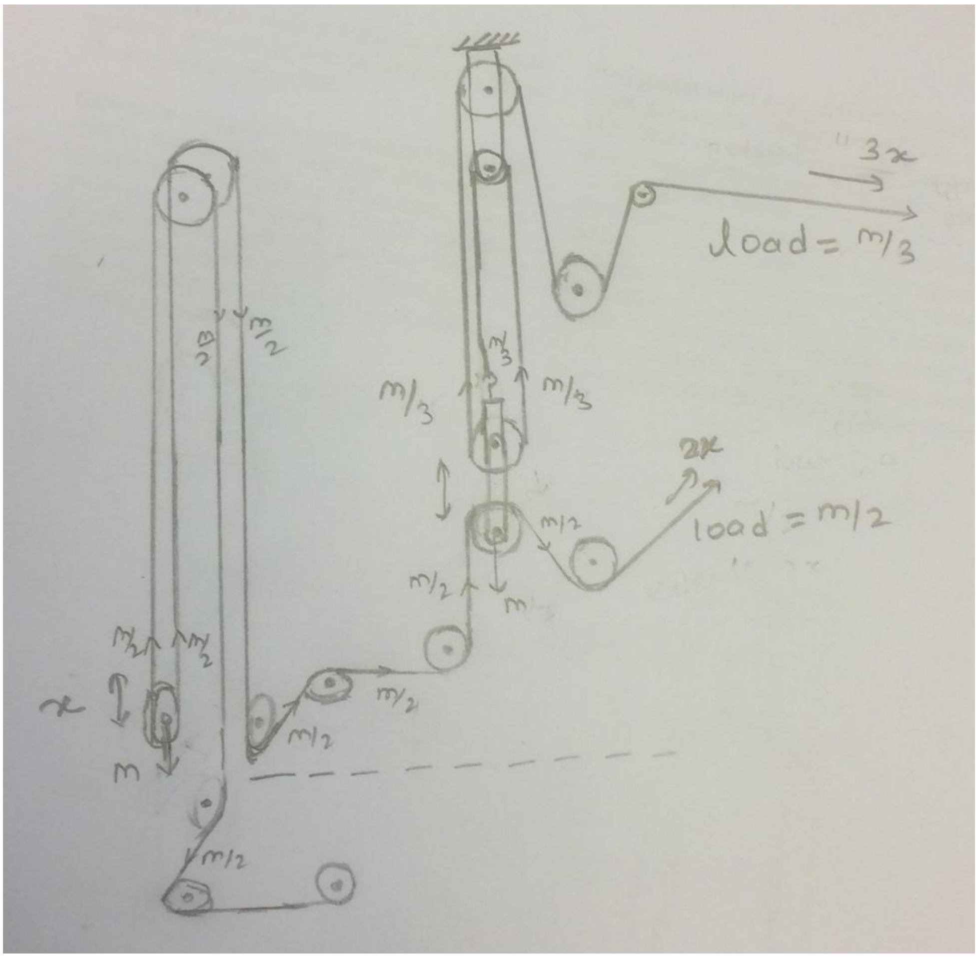


Figure 21. Free body diagram for cables.

7.2 Beam selection

The main structures for this design were beams. In the selection of the cross-section of the beam, we considered the most critical part in the design to be the arm. The arm had three forces acting along its length so it was the most critical part. There were four different locations for resistance connections. We considered the force which was acting at the middle of the length to result the maximum bending moment.

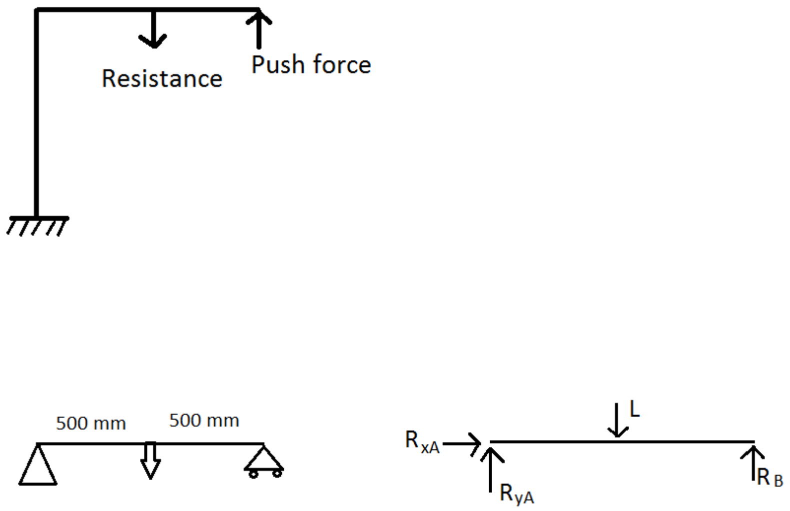


Figure 22. Free body diagram of arm

From the free body diagram, we derived the following:

$$\sum f_x = R_{xA} = 0$$

$$R_{xA} = 0$$

$$\sum f_y = R_{yA} + R_B - L = 0$$

$$\sum M_A = -R_B * 1 + L * 0{,}5 = 0$$

$$R_B = L/2$$

$$\sum f_y = R_{yA} + R_B - L = 0$$
$$R_{yA} + L/2 - L = 0$$
$$R_{yA} = L/2$$

The maximum load in this design is used for squat exercises. The maximum weight performed in squat was 570 kg. Therefore, we determined the maximum load L to be 300 kg.

L= 300kg = 2943 N
R_B= 1471.5 N
R_{xA}= 1471.5 N

Maximum bending moment
M_{max} = R_B/ 0,5 = 735.75 Nm

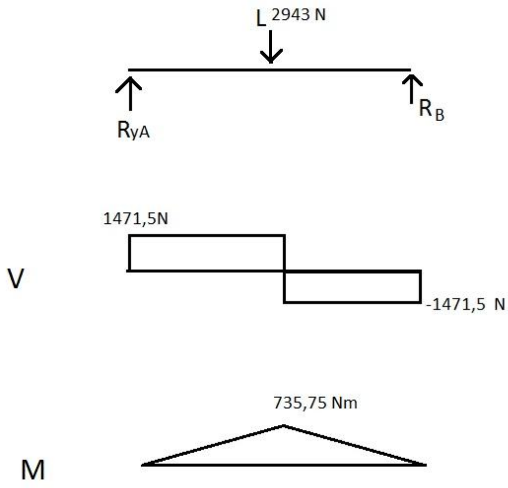


Figure 23. Shear and bending diagram

From the materials, we selected structural steel as the material for the body.
Thus,

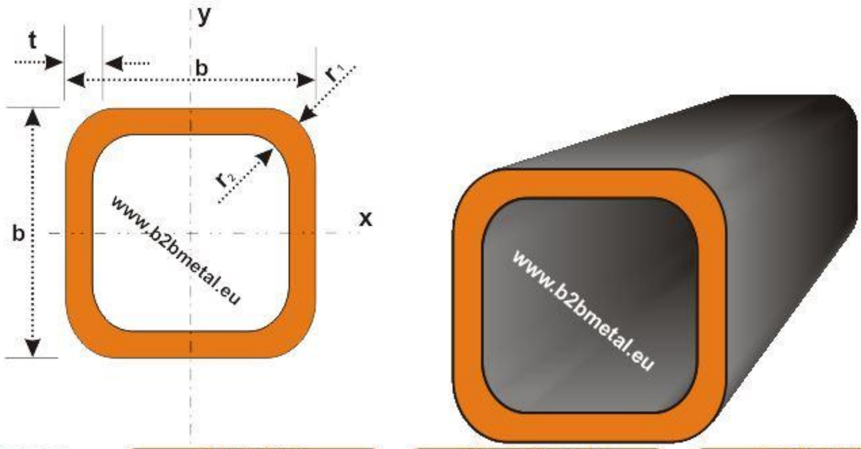
Yield stress, σ_{yield} = 345 N/mm^2
Allowed stress, σ_{allw} = σ_{yield} / Safety factor = 345/2 = 172.5 N/mm^2
Stress on the beam, σ_{stress} = -M_{max}/z
where z : second moment of area

$$\sigma\, stress \;\leq\; \sigma allw$$

$$\frac{M_{max}}{z} \leq \sigma_{allw}$$
$$Z \geq \frac{735{,}75 Nm}{172.5 N/mm^2}$$
$$Z \geq\; 4.277\; cm^3$$

Based on the calculation and size property from Figure 24, a 40*40*3 beam is strong enough to hold the possible load. From the market research, we found that, all the accessories like rubber cap and pads are available for 50*50*2. Due to this reason, we chose 50*50*2 mm structural steel beam.

EN 10219:1997



Nominal dimensions	Thickness	Corner radius		Nominal weight 1m	Cross-section	Second Moment of Area	Radius Of Gyration	Section Modulus	Plastic Modulus	Torsional Constants		Section Surface Area
		External	Internal							Inertia	Modulus	
b	t	r1	r2	M/m	A	I	r	Z	S	J	C	As
mmxmm	mm	mm	mm	kg/m	cm2	cm4	cm	cm3	cm3	cm4	cm3	m2/m
20	2	4	2	1.05	1.34	0.692	0.72	0.692	0.877	1.21	1.06	0.0731
20	2.5	5	2.5	1.25	1.59	0.766	0.694	0.766	1	1.39	1.19	0.0714
25	2	4	2	1.36	1.74	1.48	0.924	1.19	1.47	2.53	1.8	0.0931
25	2.5	5	2.5	1.64	2.09	1.69	0.899	1.35	1.71	2.97	2.07	0.0914
25	3	6	3	1.89	2.41	1.84	0.874	1.47	1.91	3.33	2.27	0.0897
30	2	4	2	1.68	2.14	2.72	1.13	1.81	2.21	4.54	2.75	0.113
30	2.5	5	2.5	2.03	2.59	3.16	1.1	2.1	2.61	5.4	3.2	0.111
30	3	6	3	2.36	3.01	3.5	1.08	2.34	2.96	6.15	3.58	0.11
40	2	4	2	2.31	2.94	6.94	1.54	3.47	4.13	11.3	5.23	0.153
40	2.5	5	2.5	2.82	3.59	8.22	1.51	4.11	4.97	13.6	6.21	0.151
40	3	6	3	3.3	4.21	9.32	1.49	4.66	5.72	15.8	7.07	0.15
40	4	8	4	4.2	5.35	11.1	1.44	5.54	7.01	19.4	8.48	0.146
50	2	4	2	2.93	3.74	14.1	1.95	5.66	6.66	22.6	8.51	0.193
50	2.5	5	2.5	3.6	4.59	16.9	1.92	6.78	8.07	27.5	10.2	0.191
50	3	6	3	4.25	5.41	19.5	1.9	7.79	9.39	32.1	11.8	0.19
50	4	8	4	5.45	6.95	23.7	1.85	9.49	11.7	40.4	14.4	0.186
50	5	10	5	6.56	8.36	27	1.8	10.8	13.7	47.5	16.6	0.183
60	2	4	2	3.56	4.54	25.1	2.35	8.38	9.79	39.8	12.6	0.233
60	2.5	5	2.5	4.39	5.59	30.3	2.33	10.1	11.9	48.7	15.2	0.231
60	3	6	3	5.19	6.61	35.1	2.31	11.7	14	57.1	17.7	0.23

Figure 24. Steel square beam specification (b2bmetal 2014).

Property for the selected beam is given as follows:

Width: 50 mm
Wall thickness: 2 mm
Mass per unit length (M/m): 2.93 kg/m
Second moment of inertia (I): 14.1 cm^4
Cross section area (A): 3.74 cm^2
Second modulus (Z): 5.66 cm^3

Next set of bigger beam was also used in few parts like weight horn, seat beam and telescopic feet for seat. This set of beam was used as sliding part outside the 50*50 beam, so the chosen size is 60*60*2 mm. This give enough clearance for small beam to slide inside it.

The dimension for length of different components can be found in appendix 2. From appendix 2, total length of beam required in the design is
50*50*2: 14420 mm
60*60*2: 965 mm

8 CHECKING STANDARDS

Our design involves the human accessibility, so it should satisfy all the human accessible standards. The SFS anthropometry standards for the human body was taken for the designed dimensions. The human body of the males with percentile above 95 and the females below 5 were taken as the reference. The machine was designed to make it possible to use by both group of the people which covers more than 90 percent of the human population.

Table 3. Comparing the model dimension to the SFS anthropometry standards (SFS-EN 547-3)

	Male 95 (mm)	Female 05 (mm)	Machine dimension (mm)	Remarks
Arm reach vertical (for pull-ups)	2240	1796	1960 max.	The height was reachable from the ground for male 95 and higher for female 05. The male 95 group has to bend his leg at knee to perform the full range of pull-ups. The height of the machine is adjustable for a lower height person.
Arm reach front (reaching	804	640	632	The safety rod was at well reachable

safety stop rod)				distance for the both group of peoples.
Shoulder height (for squat)	1539	1242	Variable	The height of the arm can be adjusted from 1400-870. This allows both group to stop and lift the arm easily while performing squats.
Height to elbow (for leg lift)	1207	945	1236	This was the height of the arm beam when it was kept at parallel to the floor. There was enough clearance for both group of peoples to perform leg raises.
Body width from side view	331	210	400	This space was calculated to find if there was enough space during the pull ups. The value shows that there is good enough space.
Seat height	480	347	415	The given dimension for the male and female is when the thigh is parallel to the floor. The people with smaller height should keep their leg at angle to the

				floor to touch the floor.
Height to the head when seated (length of the seat)	967	801	800 - 850	The length of the seat is enough to rest the head while performing different exercise.
Height to the shoulder (seated shoulder press)	660	520	min of 475	Minimum height of the beam is lower than the shoulder height, which allows user to perform full range of motion and stop it after finishing.
Length from the elbow to the wrist (arm rest pad for leg raise)	373	282	400	There is good distance to hold the grip to perform stable leg raise.
Body width when seated	400	328	300	The seat width is smaller to allow the user to put their legs on both side of seat to make more comfortable and stay stable.
Arm distance (rear view)	558	387	550 and variable	The arm distance is noted to find the location for the arm pad which effects the width of the machine.

9 DESIGN DETAILS

9.1 Pillar beam

The pillar beam is the main support in the design. This beam holds the arm beams, the seat assembly, and pulleys. The weight sliding beam is also connected to the pillar. Figure 25 shows the position of the pillar beam in the assembly. This beam is connected to the base part using two M8*75 bolts, which are bolted to a plate connected to base. The beam selected was 50*50*2 mm structural steel beam. The height of the pillar was 1500 mm.

Figure 25. Pillar beam in assembly.

9.2 Arm beam

The arm beams were the main output source of the machine. This part was connected to the pillar using a double degree freedom connection. This connection allows the beam to rotate around two axes. Four D rings were welded to the lower part of the beam, which were used to connect the resistance cables in different distance to the output ends. The resistance increased as the cable was connected closer to the output end. This feature allowed the users to use same weight in the weight horn and perform four sets of exercise with a changing resistance. The change in the resistance with change in the distance is shown in Appendix 4.

As shown in Figure 26, the foam pad holder was installed on both end of the arm beam. The foam pad was installed at the output end to perform squats and calve raises. Similar foam pad was installed to next end to perform the leg raise.

The safety stopper rod was installed on the outer side of the beam which allows the user to stop the beam at different heights while performing exercises.

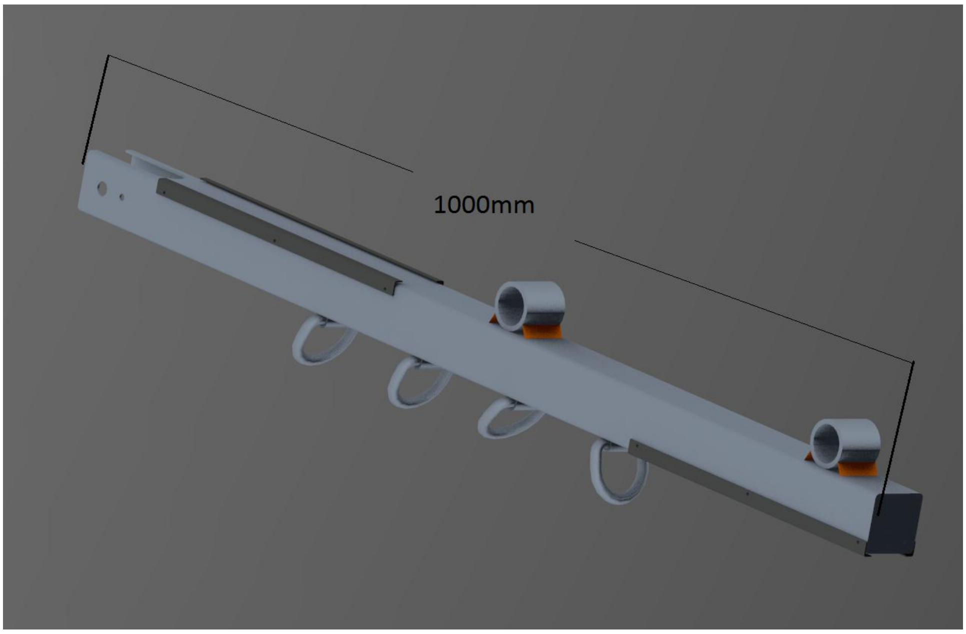


Figure 26. Arm beam with D-ring, foam pad holder and rod holder.

9.3 Base support

The base support is the structure made using two angled beams connected using connecter beams. The connector beams were 500 mm apart. The area covered by the base support was the total floor area covered by the product at a stable condition. The beam used was 50*50*2 structural steel beam. As shown in Figure 27, the beam was bended to an angle of 130° and re-bended to straight keeping the ground clearance of 50 mm. Two additional beams were attached to the working end of the support. They had a pin connection to the base support allowing it to rotate to front when needed and closing back when not in use. This additional rotating beam increases the stability of the design by keeping centre of gravity of the structure inside the covered area.

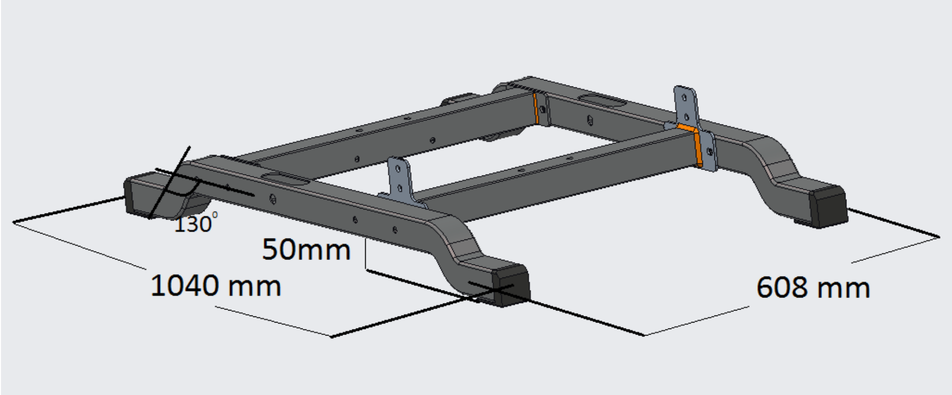


Figure 27. Base support.

9.4 **Pillar arm connection**

Pillar arm connection connects the arm beam to the pillar beam allowing the arm beam to rotate around two different axes.

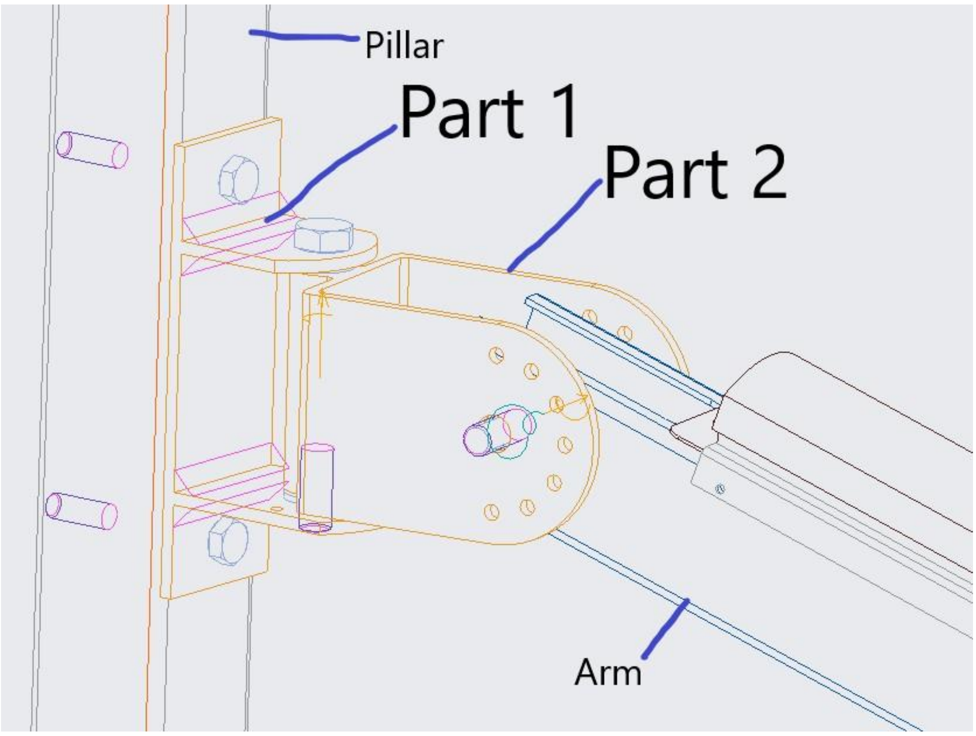


Figure 28. Arm to pillar connector with degree of freedom displayed.

Arm to pillar connector has two components to allow rotation in two different axes. A pin is used to connect the part together. Arm beam was connected using M10* 65 bolt to the connecting part. As shown in Figure 28, connecting parts has holes to insert the stopper to hold the part in different height and angle. Each arm can be placed in 32 different positions using this connection. Two M8*75 bolts were used to fix the arm to the pillar.

9.5 Weight guiding beam

The weight guiding beam is the vertical guide pole, which guides the weight horn moving in the vertical direction. A weight horn slides over the weight guiding beam so this beam should be polished to reduce friction. As shown in Figure 29, the beam is fixed at a base support on the bottom and on a connecting beam on the top. The top connecting beam was connected to two beams, which were supported on the pillars. The length of the beam should be calculated so that the weight horn has enough distance to travel during all exercises. The length of this beam influences the total height of the machine.

The length of the beam in this design was determined taking the cable flyes exercise as the maximum cable pulling exercise. In this exercise, the cable is pulled using the arms wide and pulled in front of the body.

The total length of the cable to be pulled will be the distance covered by the arm placed wide apart and bringing it to front. From SFS standards, the maximum distance to the palm for people of group M95 is l= 804 mm. So, the length of the cable extended is = πl/2

The length extended = $\frac{\pi * 804}{2} = 1262\ mm.$

From the cable connection, the cable end will move three times more than the mass. So, the mass movement due to one cable extension is = $\frac{1262}{3} = 420mm$

The movement of the mass when the cable is pulled by both arm at the same time is = 2*420mm = 840 mm

Beside this length, there should be enough clearance for the weight plate to move. So, the maximum diameter of an Olympic weight plate is = 450 ± 1 mm (Johnson 2017).

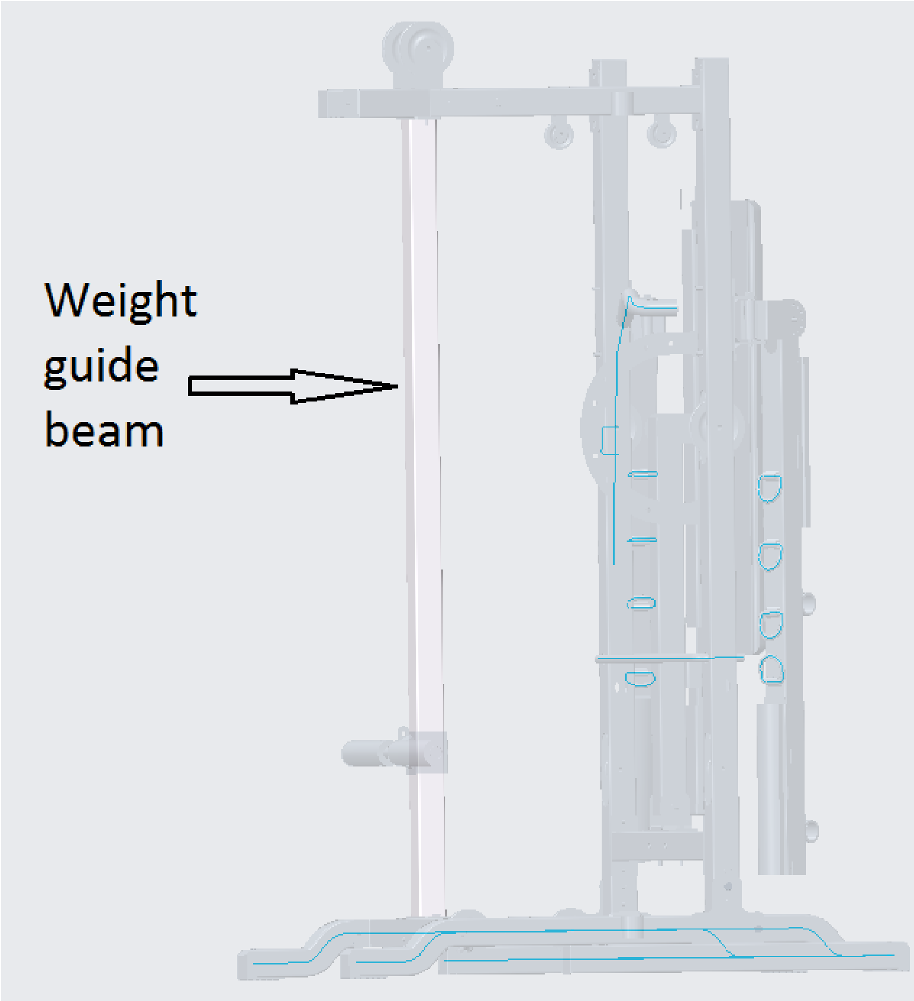


Figure 29. Weight guide beam in assembly.

So, adding the clearance for the weight plate, the total length of the bar need to be 1290 mm. Keeping space for a rubber bumper pad and some clearance, the total length of the beam was selected to be 1400 mm.

9.6 Weight horn

The weight horn was the part where the weight plates are hanged. We have a rectangular sliding pole, so the central part of the weight horn was a rectangular hollow beam where circular rod was welded. The circular rod was welded to the hollow beam with plate supporting as shown in Figure 30. An additional plate was also welded on the top part of welding plate to hook the cable as shown in Figure 30. The rod used was of diameter 25 mm to hold the standard size weight plate. An additional pipe can be added on the top to make the diameter 50mm to suit the Olympic standard weight plate´s centre diameter.

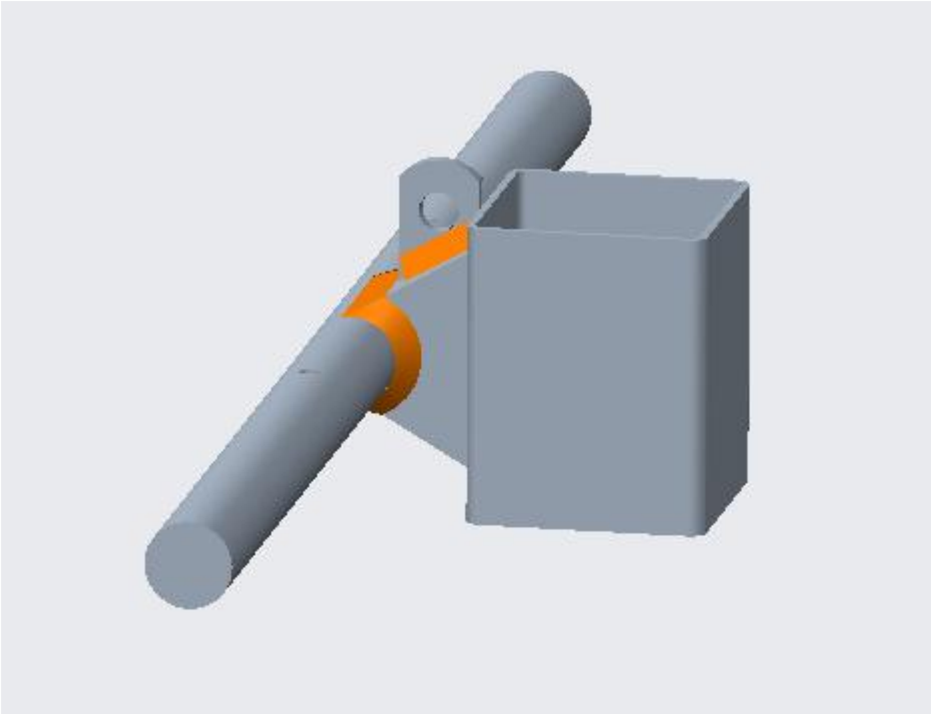


Figure 30. Weight horn with a rod diameter 25mm.

9.7 Seat

This design had an integrated seat with many working angles. This seat can be used in many different exercises. The seat assembly had a removable additional seat. This additional seat was used when the bench is at angle.

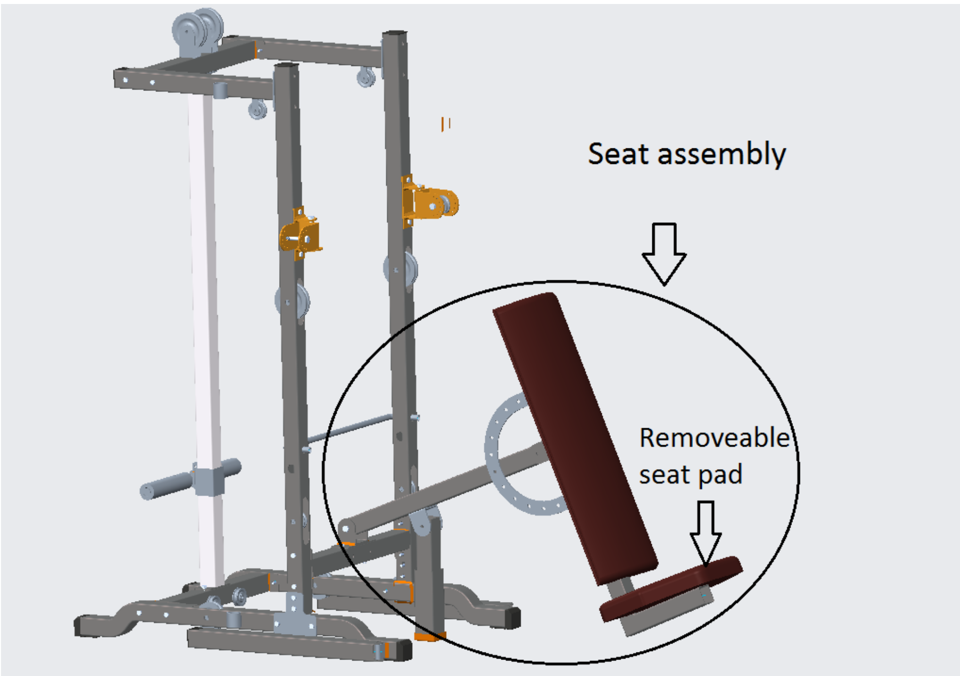


Figure 31. Seat assembly.

The seat was assembled at the end of 800 mm beam using a pin joint making it possible to rotate 180°. A hemi circle plate was attached to the seat making it possible to stop at 12 different angles. A seat assembly was attached to a connecting beam which was bolted to two adjacent pillars. The seat at vertical position was used for back support during the leg raise exercise.

9.7.1 Removable seat pad

An extra seat pad could be added to make the bench possible to use at different angles. This seat can be used for many different inclined bench exercises. This makes the machine free from adding an extra bench to perform cable exercises. A pad can be adjusted at two different heights depending on the working angles and heights.

9.7.2 D plate

A hemi circle plate was added to the seat beam, with holes in it. Holes were used to stop the bench at twelve different working angles. A retractable locking pin was used to select the hole making it easy and quick to change the working angle.

9.7.3 Telescopic feet

Changing the angle of the bench plate makes the bench end touch the ground and difficult to use. The telescopic feet lift the seat assembly to fit the height to the angled seat.

9.8 Cable

The cables are the main means of the resistance transfer in most of the exercise equipment. Due to its flexible and strong property, they are very reliable means of the resistance transfer.

The load in our design was on rear part, so the cable was used to pull the load. There were three sets of cable in the design, two with the length of 4450 mm and one with the length of 8550 mm.

Figure 32. Cable for gym machines (Bodysolid 2017).

9.9 **Pulley**

The pulley is a simple machine used to change the direction of the force and to add mechanical advantage to the system. Pulleys are the round disc which rolls around a fixed central axel. They have groove or grooves on their edge which helps rope, cable, chain or belt to run over it. (Nashua 2000)

Figure 33. Pulley (sportsmith 2017).

Our design uses cable to transfer the resistance, where pulleys were used to change the direction of cable and to increase the mechanical advantage as well.

Three different sizes of pulley were used in different locations to allow the cable to run above it. The pulley locations and orientations can be seen in “cable and pulley connection” section.

9.10 Cable output end

The cable output end is the end component attached to the arm. The cable attached to the resistance is deliver through this component.

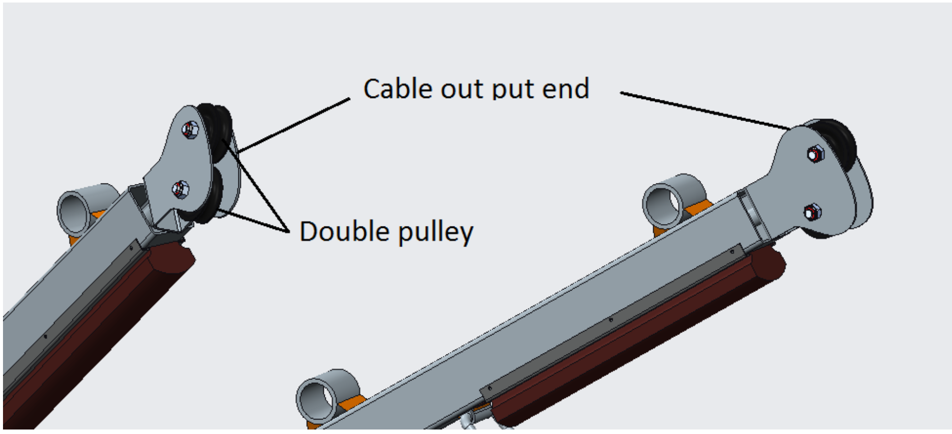


Figure 34. Cable output end connected to arm.

As shown in Figure 34, there were two pulleys attached to each end components. This allowed the cable to be delivered smoothly in both over and under situations. This component was swivel, that is, it will rotate around the axis without rotating other components. This allows the cable to align at the centre and run across the groove of the pulley at different working angles.

9.11 Foam support pad

The foam pad was a pad, which makes the arm beam comfortable to rest on the shoulder. Two pads with same dimension were used on top part of the arm to rest arm during leg raise exercise. Both cases need good comfort for user, so the pad thickness was selected to absorb good force. The pad was inserted on a track on both place. A pin was used to fix the pad to the arm.

9.12 **Safety rod**

As the arm had different working angles, it should be stopped at different heights and angles. But for some exercises like squats, shoulder press, calve raises, the vertical movement should be free. Depending on the exercise, the safety rod had different uses. The safety rod had four different positions of stopping which allowed it for different uses. This safety rod was placed to keep the arm beam at the proper height to start the squat. It can be rotated to make the vertical movement free while performing exercise. It can be placed back after finishing the movement. The handle of the safety rod is at 632 mm from the farthest end of the arm beam.

9.13 **Weight storage horn**

We used weight plates for resistance. We will have many weight plates of different sizes for different exercises. Storing them in the proper place will be challenging while they are not in use. This design has its own weight storage horn to rack the weight plate when they are not in use. These weight horns as shown in Figure 35 are available in market, so they are replaceable as well.

Figure 35. Weight storage horn (amazon 2017).

9.14 **Retractable lock pin**

The retractable lock pins are standard locking pin available in market, which has lock, and release mechanism. These pins have different locking and releasing mechanism. This system makes changing the hole position easy and quick. The pin in Figure 35 has pull and release mechanism. Spring is used inside it to pull the pin back to its initial position.

Figure 36. Retractable locking pin (Globalindustrial 2017).

9.15 **Retractable wheel**

The retractable wheels are wheels that are attached to a body without the wheel touching the ground. As shown in Figure 36, they have foot pedals which when pushed down, pushes the wheel to the ground and elevates the body off the floor. This allows the user to make the machine fully stable and fully moveable both in the same design. This system is mostly used in the body that needs a good stability while performing the work but also needs to be moved.

This system makes our design fully stable while exercising and moveable when needed. Each wheel can hold up to 45 kg. Four retractable wheels, two at front and two on the back were used in this design. So, the total weight of the system should be less than 180 kg before using these wheels.

Figure 37. Retractable wheel (Amazon 2017).

9.16 **Other accessories**

In our design, we deliver the resistance to the end of the arm using the cables. We need different kinds of cable attachments to perform different exercises. Using proper attachments make it easier and effective to transfer the resistance from the machine to the desired muscles group during workouts.

Figure 38. Gym cable attachment (amazon 2017).

The most important attachment for our design are pull handles. They come in pair and can be attached on two output ends on same time. Each handle was used for each hand. These handle could be used for different exercises like, arm curl, lat pulldown, chest flyes, shoulder press, rowing, shoulder flyes and many more.

10 COST ESTIMATION

One of the main aim in this project was to make the machine affordable. Table 4 shows the total cost estimation for this product.

Table 4. Cost estimation of the machine.

Part	**Price per unit**	**Quantity**	**Total in EUR (1= EUR0.8486) (GBP1=EUR1.138)**
Square beam 50*50*2	EUR 5.65	14.5 m	81.92
Squares beam 60*60*2	EUR 7.08	1 m	7.08
Pulley of size 90 mm	USD 7.23	17	104.3
Pulley of size 50 mm	GBP 11	10	125.18
Cable of diameter 3mm	EUR 44.5	for 15m	44.5
Cable Accessories	USD13.93	1 set	11.82
Square rubber end cap	USD 3.88	6	19.75
Rubber end cap for base	USD 7.28	4	24.71
Rubber end cap for telescopic feet	USD 5.88	1	5.88
Retractable wheels	USD 65	1 set of 4	55.16
Retractable lock pin	USD 13.25	2	22.5
Screws and nuts	EUR 1	55	55
Steel plate of 4mm thickness	EUR 54.8	1 m^2	54.8
Seat pad	GBP 69.99	1	79.66
Foam support	GBP 37.74	2 Pairs	85.90
Steel pipe 30 *2	EUR 2.91	5 m	14.58
Steel pipe 36*2	EUR 4.16	0.5m	2.08
D ring	EUR 18.03	set of 10	18.03
Olympic plate adopter	EUR 24.22	1 pair	24.22
Steel chain	USD 42.5	2m	72.13
Total			EUR 904.52

11 BUSSINESS MODEL

Most designs are made for commercial purpose. Beside product being functional, it should always attract the user. Product sales is needed to keep the production process going. Our machine was also designed to be a commercial product.

From the design requirements, we know that reducing the product cost was our main goal. Making the machine affordable to common people can increase the sales of the product and eventually increase the profit.

The targeted costumers for this product were the busy peoples who want to stay fit on their own home. Beside them, this product could also be a good option for the hospitals and the training centres where people trains for recovery. Due to the compact design of machine, it could be placed on a corner of room when it was not in use. It could be setup with a very little assistance and most parts were easily assessable. Changing the resistance was easy, making it comfortable for the people recovering from injury.

Most products available in the market which targets full body were bigger in size. Price was also a major factor due to which people did not own a product.

Comparing our design to the products available in the market as shown in Figure 39, we can see the difference in the cost for buying the machines that could perform the functions which our single machine did. The space covered by our design was significantly small as compared to products available in market. This makes our model better than those products in market.

This compact and cheap design would be a perfect solution for private use. Beside it, it could also be an option for office corner. Sitting on chair for whole day makes our body tired and lazy. This machine would help worker to stretch body and increase the blood flow to the muscles. The increased blood flow increases the activeness of the worker and increases the productivity.

Figure 39. Our model compared with market products with similar function.

12 CONCLUSION

The machine designed in this thesis satisfied all the set requirements. Making it possible to work for all the body parts and keeping the size small were the most important achievements for this design. Most components used in the design were available in market. Same size of the beam was used at nearly 80 % of the machine body. Simple production processes like drilling, cutting, welding and bending were used to give the shape of the body. These factors will help to reduce the production cost of the machine for the mass production. The replacement parts will also be easily available for users. As the machine was designed to be assembled at user´s location and by themselves. The components were made straight to minimize the package size and the joining were done using screw and anti-slip nut, preventing it from loosening during use.

To conclude, this thesis gave a potential product design, which would transform a corner of a room to a complete gym. Beside this, it gave me valuable experiences in machine designing and project management. It increased my level of knowledge in the selection of machine components, creo modelling, workout machines, strength calculations and product searching. This project helped to increase my skills on critical thinking, time management, report writing and product marketing. All these experience, knowledge and skills will be very helpful to be a perfect designer in my working life.

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Appendix 1

1. List of possible exercises in idea 4:

- Pull ups
- Dips
- Squat
- Calves raise
- Shoulder press
- Leg raises
- Cable shoulder press
- Cable chest press
- Cable crossover
- Cable crunch
- Cable deadlift
- Cable arm curls
- Cable triceps press
- Cable delt fly
- Cable lat pulldown
- Inclined cable chest press
- Inclined cable flyes.

Appendix 2

2. Length of beams

50*50*2 beam

Part name	**Dimension (**mm**)**	**No. of piece**	**Total length**
Pillar beam	1500	2	3000
Arm beam	1000	2	2000
Weight guiding beam	1400	1	1400
Base support (bend included)	1150	2	2300
Connecting beam	500	4	2000
Top joining beam	500	2	1000
Seat beam	800	1	800
Extending leg	600	2	1200
Seat telescopic feet (section 1)	220	1	220
Beam for additional seat	250	2	500
TOTAL			14420 mm

60*60*2 beams

Part name	**Dimension (**mm**)**	**No. of piece**	**Total length**
Beam with seat pad	700	1	700
Seat telescopic feet (section 2)	190	1	190
Weight horn beam	75	1	75
TOTAL			965 mm

Appendix 3

3. Questions for interview

I. Introduction

Name:

How long have you been going to gym/training?s:

How often do you train?:

Training goal (muscle gain/ increase strength/ fit or other):

II. Do you know about market available multi-functional gym machine/ gym station?

Multi- functional gym machine are machines, which are designed to perform different exercises focusing different body parts.
Market available product costs from few hundred euros to thousands of euros depending upon the options of exercise possible, durability, and comfort of use.

III. Why haven´t you own one of it yet?

IV. What do you want in a perfect multi-functional gym machine?
(Space, cost, most important exercises, durability, appearance..)

Appendix 4

4. Calculation of reaction force at output end while changing the resistance in four different joining options

$F := 100kg \qquad d := 625mm \qquad y := 975mm$

$$R_B = \frac{F \cdot d}{y} \qquad R_B := \frac{F \cdot d}{y} = 64.103 \cdot kg$$

$d1 := 265mm$

$$R_B := \frac{F \cdot d1}{y} = 27.179 \cdot kg$$

$d2 := d1 + 120mm$

$$R_B := \frac{F \cdot d2}{y} = 39.487 \cdot kg$$

$d3 := d2 + 120mm$

$$R_B := \frac{F \cdot d3}{y} = 51.795 \cdot kg$$

$d4 := d3 + 120mm$

$$R_B := \frac{F \cdot d4}{y} = 64.103 \cdot kg$$