REALIZATION OF A WORKING PROTOTYPE OF WEARABLE-CHAIR

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REALIZATION OF A WORKING PROTOTYPE OF WEARABLE-CHAIR

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A report submitted
in fulfillment of the requirements for the degree of
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DECLARATION

I declared that this project report entitled "Realization of A Working Prototype of Wearable-Chair" is a result of my own work except as cited in the reference.

Signature : ....…………......

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Date : ....…………..….

APPROVAL

I hereby declare that I have read this project and in my opinion this report is sufficient in terms of scope and the quality of the award of the degree of Bachelor of Mechanical Engineering.

Signature : ....…………………......

Supervisor's Name : Dr. Shamsul Anuar Bin Shamsudin

Date : ....……………………...….

DEDICATION

I dedicate this report to my beloved family, lecturers and dearest friends

ABSTRACT

Declining health rate among the factory workers is worrisome. Some of the reason is due to overwork that could cause back pain, headache, muscle fatigue and more. Thus, to overcome the muscle fatigue problem, chairless chair or wearable-chair has been invented. This device lets the user to sit on it anytime and everywhere by equipping the device on the users' legs. The purpose of this study is to develop and realize the new design of the chairless chair by implementing methods and techniques of mechanical engineering design and manufacturing process. Before furthering to 3D model development, a survey is done among factory workers, doctors and lecturers to get valuable data for this project. From the data, a House of Quality was used to determine the engineering details for the product also the important technical details to be prioritized in the design. From the House of Quality data, few conceptual designs were made and evaluated to obtain the final design. The final design is then modeled by using SolidWorks. To determine the functionality of the 3D model, two analyses were conducted. The first one was a motion study analysis. This analysis was conducted to observe the motion of the model if it were to put in the actual situation where the gravity and extra forces took place. The second one was stress analysis. The purpose of this analysis was to determine the endurance of the product and to define the critical stress area so that improvements can be made in the design to achieve a factor of safety of more than one for the whole model. Then, further manufacturing processes were discussed.

ABSTRAK

Penurunan kadar kesihatan dalam kalangan pekerja kilang adalah merisaukan. Antara penyebabnya adalah bekerja keras yang boleh mengakibatkan sakit belakang, sakit kepala, keletihan otot dan sebagainya. Untuk mengatasi masalah keletihan otot, "chairless chair" ataupun "wearable-chair" telah pun diinovasi. Alat ini membolehkan penggunanya untuk duduk pada bila-bila masa dan dimana-mana sahaja dengan memakainya di kaki pengguna. Tujuan kajian ini dijalankan adalah untuk membina dan mewujudkan sebuah rekabentuk yang baharu dengan menggunakan kaedah dan teknik rekabentuk kejeruteraan mekanikal dan proses pembuatan. Sebelum melanjutkan pada merekabentuk model 3D, sebuah kajian soal selidik telah dilakukan dalam kalangan pekerja kilang, doktor dan pensyarah untuk mendapatkan data yang berguna untuk projek ini. Daripada data tersebut, sebuah "House of Quality" dilakukan untuk mengenalpasti butiran kejuruteraan untuk produk dan juga butiran teknikal yang penting untuk diutamakan dalam rekabentuk ini. Daripada "House of Quality", beberapa konsep rekabentuk dihasilkan dan dinilai menggunakan "Weighted Decision Matrix" untuk mendapatkan rekabentuk konsep akhir. Rekabentuk konsep akhir ini kemudianya dimodelkan menggunakan Solidwork. Untuk menentukan keberfungsian model 3D tersebut, dua analisis telah dilakukan. Yang pertama adalah "motion study analysis". Analisis ini adalah untuk melihat pergerakan model dalam situasi sebenar dimana daya graviti dan daya tambahan berlaku. Yang kedua adalah "stress analysis". Tujuan analisis ini adalah untuk menentukan ketahanan produk dan untuk menentukan kawasan stress yang kritikal supaya pembaikpulihan dapat dilakukan pada rekabentuk untuk mendapatkan "factor of safety" lebih daripada satu untuk keseluruhan model. Kemudian, proses pembuatan dibincangkan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Wearable-chair is one of the genius inventions in world history. There are not many wearable-chair designs in the current market. The companies involved in the invention of this device are from Swiss, Japan and a few European countries.

The world's first chairless chair was designed by the Swiss studio Sapetti and developed by Noonee in Zurich in 2014. "The idea came from wanting to sit anywhere and everywhere, and from working in a UK packaging factory when I was 17," says Keith Gunura, the 29-year old, CEO and co-founder of Noonee (Jacopo, 2018).

Figure 1.1: Chairless chair designed by Sapetti (Stinson, 2018)

It has a bold design of exoskeleton. It can also be carried anywhere and designed for the workers to be able to walk normally and can sit wherever they wanted to and adjustable to suit with the user's height (Baba-Mail, 2018). It has a push button to lock the frame at the desired angle, and the device will not touch the ground unless in a static position. It has a belt and also wraps to tie the device with legs (Jacopo, 2018). But, it is not an easy task to design for ergonomics and let the users move freely when using the chairless chair.

Another design is the Archelis, which means walk-able chair in Japanese. The main objective of making the Archelis is to help the medical surgeon and industry workers to overcome fatigue from long hours of standing. It is totally designed and manufactured in Japan (En.wikipedia.org, 2018).

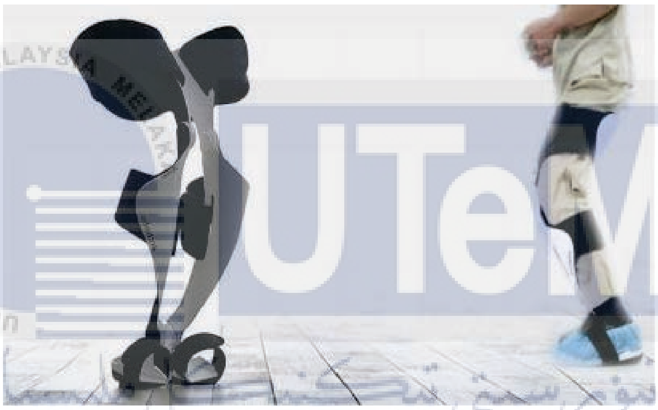


Figure 1.2: The Archelis wearable-chair (Nikkei Asian Review, 2018)

Not only Noone and The Archelis invented chairless chair, but there is also a simpler design, Ofrees (See Figure 1.3) which priced at more than USD 950 per item (Aouf, R, 2018).

Figure 1.3: Ofrees wearable-chair (Aouf, R, 2018)

The main reason why all chairless chairs were invented is to reduce time standing for industry workers also able to prevent back pain thus improve workers health. Other reason would be to eliminate the use of conventional chairs in a workplace in order to have more space.

1.2 Problem Statement

Wearable-chair is less practicable in Malaysia because of a few reasons. The main reason is the price. The price of one chairless chair with the least attractive design is more than USD 950. The designs that using titanium as its frame material and hydraulic piston powered are expensive. Another reason is, all products are manufactured in European countries and Japan makes it more expensive. Other than that, there are components inside the wearable-chair that are consuming energy from the battery, this is considered as less environmentally friendly because some batteries are non-rechargeable. Most of the current chairless chairs have a large belt to secure around the waist. This size of the belt is not comfortable to use because it traps heat and blocks body movements.

1.3 Objectives

The objectives of this project are:

i. To design a wearable-chair that meets customer needs using computer-aided design (CAD) software.

ii. To do motion study and stress analysis on the wearable-chair design using CAD software.

iii. To manufacture a working prototype of the wearable-chair.

1.4 Scope

The scopes of this project are:

i. Obtaining customer requirements on safety, appearance, materials and more for wearable-chair.

ii. Use a proper design tool to translate customer needs into engineering properties.

iii. Developing conceptual designs using concept generation method and make concept evaluation and selection to choose the best conceptual design.

iv. Developing a 3D design of the final conceptual design by using CAD software.

v. Simulating the stress analysis and motion analysis.

vi. Building a prototype based on the final conceptual design using appropriate tools and techniques.

vii. Testing the prototype.

viii. Writing a full project report.

CHAPTER 2

LITERATURE REVIEW

2.1 The Archelis Wearable-Chair

The Archelis in Figure 2.1 was designed by Yokohama-based mold factory, Nitto, along with Chiba University's Center for Frontier Medical Engineering, Hiroaki Nishimura Design, and Japan Polymer Technology (En.wikipedia.org, 2018).

Figure 2.1: The Archelis (Source: Google Image)

Their aim is to help surgeons. There are surgeries that take more than 5 hours to complete, for example, laparoscopy. Long hours of surgeries cause muscle fatigue on the surgeon. Also, the operation table is high that it leads to the same problem (En.wikipedia.org, 2018).

This device does not use electric, made of carbon segments and materialize with hook and loop closure it is safe to use in the surgery room. This device parts such as thigh and shin are adjustable and flexible makes it comfortable to use for long hours of usage. Its size is 78x40x30cm and weighs up to 5kg (Digital Trends, 2018). It has straps that cover wearer legs and buttocks and also cushion that acts as supports on shin and thigh (Nikkei Asian Review, 2018).

In 2015, the company had improved the device's stretchy belts and become more reliable as the users can change sitting position on their own. They did this by partnering with Chiba University's Center for Frontier Medical Engineering to create technology to make equipment to fit human bodies (Digital Trends, 2018).

2.2 Noone Chairless Chair

Noone chairless chair (Figure 2.2) was first designed by Swiss studio Sapetti and it is designed primarily for manufacturing environments, where workers are required to stand for long periods of time and allows its wearer to sit down whenever and wherever they need to (Baba-Mail, 2018). The Chairless Chair Noone chairless chair are sold directly to businesses for their staff use including training on how to operate it (Newatlas.com, 2018).

Figure 2.2: Noone Chairless Chair (Newatlas.com, 2018)

Noonee Chairless Chair is an effective way to help decrease physical strain and increase productivity. It has waist belt stirrup and thigh straps. The user will position himself and adjust the switchable lock to lock the device position to sit on it. It uses hydraulic powered to support user weight. This exoskeleton device can be instant support when user bending, crouching or squatting (Baba-Mail, 2018).

It is mostly made of lightweight and durable engineering plastic, polyamide, weighs around 3.4 kg (Newatlas.com, 2018). This newest Noone chairless chair has lesser weight and more aesthetic compared to its previous version. It suits people of different heights, body size, and can be fitted to any kind of safe-footwear (Baba-Mail, 2018).

2.3 Ofrees Wearable-Chair

Ofrees wearable-chair is a foldable chair (See Figure 2.3). The main frame is made from aluminum 7075, the material has excellent durability lightweight, and has tensile strength almost equal to iron. The wearable-chair uses an alloy in the form of zinc as its main material (Aouf, R, 2018).

Figure 2.3: Ofrees wearable-chair folding picture (Aouf, R, 2018)

Ofrees is pre-install. The equipment shown in Figure 2.4 are rubbercap, gaiter, mainframe, backpack, and waistbelt. The mainframe is foldable, and it can be folded into two, then put it in a backpack to carry around.

Ofrees design is genius, only the mainframe is made of metal, and the rest are made of fabric and small components (Aouf, R, 2018). This makes it easier to be folded and to fit in a backpack. Also, to make this small mainframe strong, they use a strong material that as strong as iron but lighter so that it is easy to be carried.

Figure 2.4: Ofrees wearable-chair equipment (Aouf, R, 2018)

This design comes in many sizes, S to 2XL, S is for a person with 145cm tall up until 154cm, 2XL is for 183cm tall and above (Aouf, R, 2018). It uses velcro on both gaiter and waistbelt makes it easier to equip. These two components wrap wearer's waist, shin and calf to provide more comfort while wearing it. Figure 2.5 below shows a front, side and rear view of a person wearing Ofrees wearable-chair.

Figure 2.5: Ofrees wearable-chair on a person (Ofrees.com, 2018)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to develop a detailed design of the chairless chair. The flowchart of the project is shown in Figure 3.1 This project is started by studying the recent models available in the market. After the engineering characteristics of the models have been identified, the survey is conducted to obtain the customer requirements. From survey analysis, the project is proceeded with the House of Quality (HOQ) to define the important characteristics. Then, proceed with the concept generation process and concept selection. Lastly, the detailed design of the product is reported.

3.2 General Processes

Project flowchart is developed to ensure the smooth running of the project by arranging each process accordingly. There are 13 processes involved in this project based on Figure 3.1. The processes include in the project flowchart are listed and explained as below;

1. Title registration

   Students are required to choose and register their title in psmonlinesystem.net website.

2. Literature review

   Journals, articles, or any materials regarding the project will be reviewed. The product regarding this project is rarely reported. Thus, most of the information is gained through reliable websites.

3. Customer needs survey

   A survey will be conducted to obtain requirement needs data from the customers.

4. Concept generation

   A few conceptual designs will be generated using the morphological chart.

5. Concept evaluation

   All conceptual designs will be evaluated using Weight Decision Matrix method.

6. Concept selection

   One conceptual design that has the highest score will be selected as the final conceptual design.

7. Structural shape and material selection

   Based on the final conceptual design, the techniques to develop a 3D design will be produced, and its materials are selected.

8. Part design

   3D design of the final conceptual design will be developed by using CAD software.

9. Detail design analysis

   The 3D design will be analyzed by using stress simulation analysis to get its safety factor and to focus on modifying critical stress area.

10. Testing

    The product will be tested and decide on its marketing.

11. Procurement and fabrication

    The materials for the product will be prepared and the product will be fabricated.

12. Assembly

    The product will be assembled.

13. Full report

    A report on this study will be written at the end of the project.

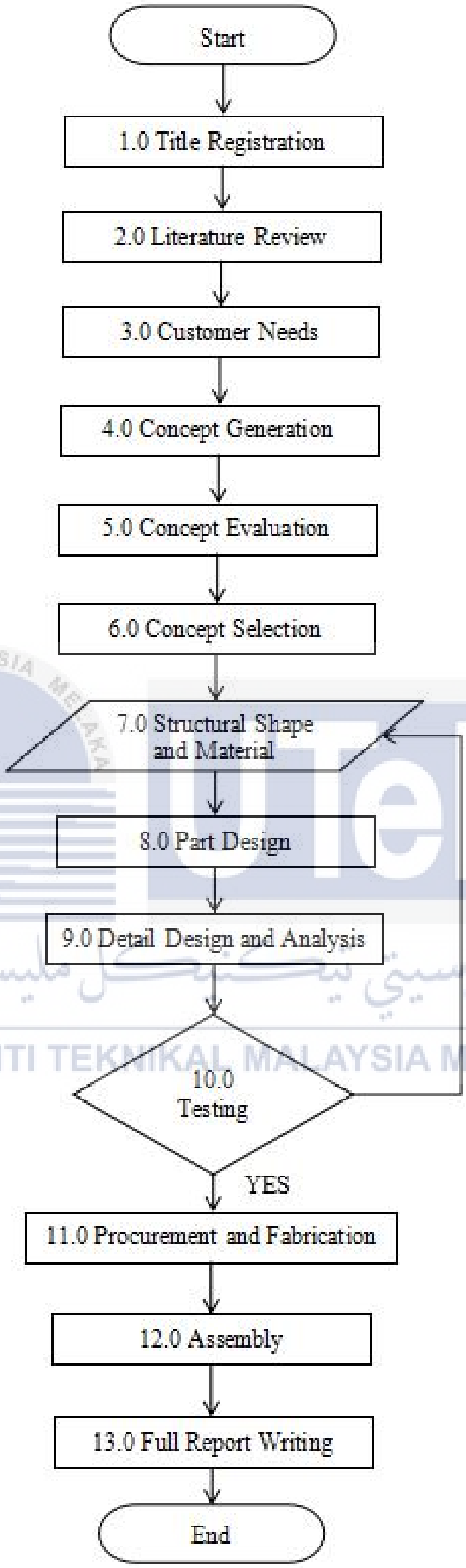


Figure 3.1 Project flowchart

This project has to be completed in two semesters, a total of 5 chapters of which, 3 chapters have to be done in the first semester, and the rest is in the next semester. In order to complete this project, Figure 3.2 shows the timeline of how this project will be conducted in both semesters. Total of 32 weeks are needed to complete this project. The longest process is report preparation process which takes 16 weeks to complete. In semester 2, the report draft is needed to be submitted by week 14 to proceed with the presentation and report marking. Lastly, in week 15 and 16, the report is resubmitted both hard and soft copy to the supervisor, panel and faculty.

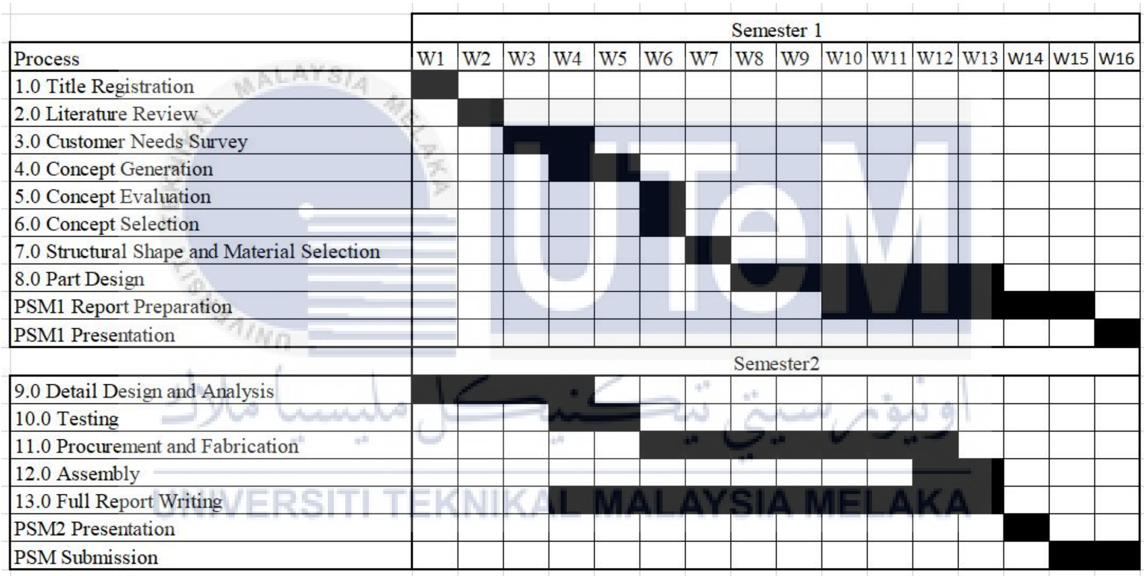


Figure 3.2: PSM Gantt chart

3.3 Survey Analysis

The purpose of this survey is to collect customer needs data from potential customers. The respondents are chosen from several working fields that might need this device during working. The working fields include doctors, engineers, technicians, industrial designers and lecturers with an engineering background. This survey is limited to experienced workers only, and students responses will not be included in this finding, the main reason is to get the most reliable data from potential customers with knowledge and experiences.

This survey has been conducted started from 16th September to 6th October of 2018 and 31 respondents took part in this survey. The method used to deliver this survey is by using Google Form application. In this application, a link was generated from the survey made by using this application. The link then can be shared to the public. By clicking on the link, it will direct the respondent to the online survey form. This application also can generate charts from responses received.

In this survey, there are two sections, the first section is to collect respondents demographic data such as gender, age, job and field of study. The second section is to collect their responses on wearable-chair. They can choose more than one answer for each question in section two.

3.3.1 Section 1 of Survey Analysis

i) Gender

From Figure 3.3, 31 respondents, 77.4% equals to 24 people is male and another 7 person is female.

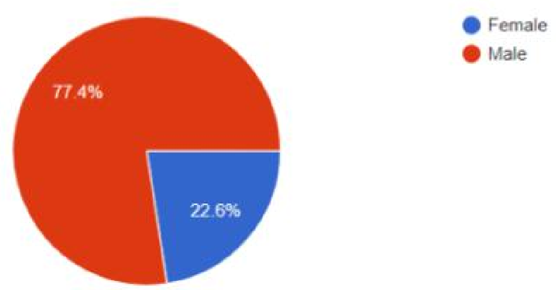


Figure 3.3: Pie chart of respondents gender

ii) Age

From Figure 3.4, most of the 31 respondents are more than 30 years old and the only 1 respondent is more than 50 years old and older.

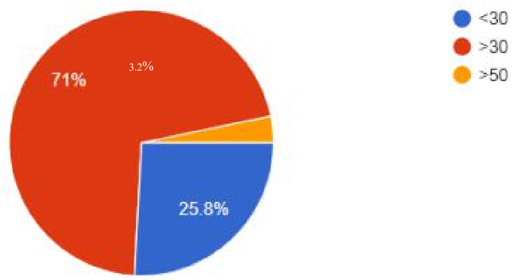


Figure 3.4: Pie chart of respondents age

iii) Occupation

From Figure 3.5, 51.6% the dominant or equals to 16 respondents are lecturers while doctors and industrial designers have the same percentage of 6.5% that makes them two persons in each occupation.

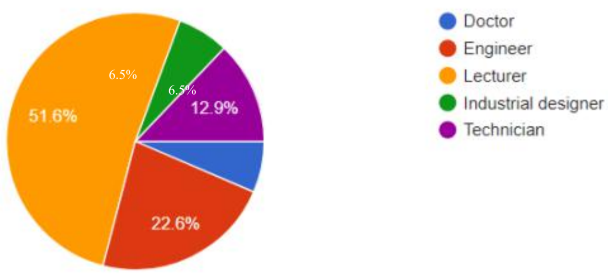


Figure 3.5: Pie chart of respondents occupation

iv) Field of Study

From Figure 3.6, most of the respondents, which are 24 over 31 people, are engineering graduates.

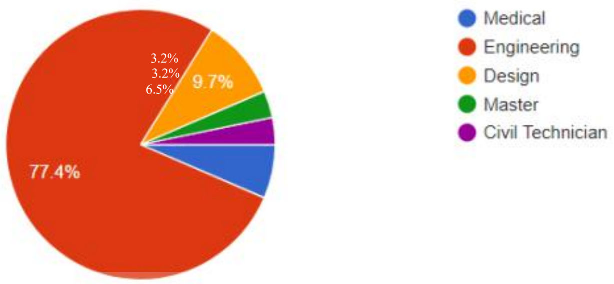


Figure 3.6: Pie chart of respondents field of study

3.3.2 Section 2 of Survey Analysis

i. Restriction/setup before/during/after use:

For this question, based on the bar graph in Figure 3.7, almost all of them wants the wearable-chair to be easy to wear and use.

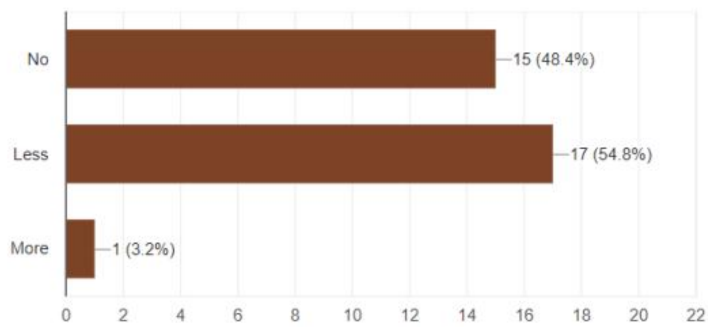


Figure 3.7: Bar graph of respondents rating on restriction/setup before/during/after use

ii. Material use

From Figure 3.8 below, for material weight, respondents mostly prefer lightweight and strong material. Also, they prefer the wearable-chair it to be non-hazardous/poisonous.

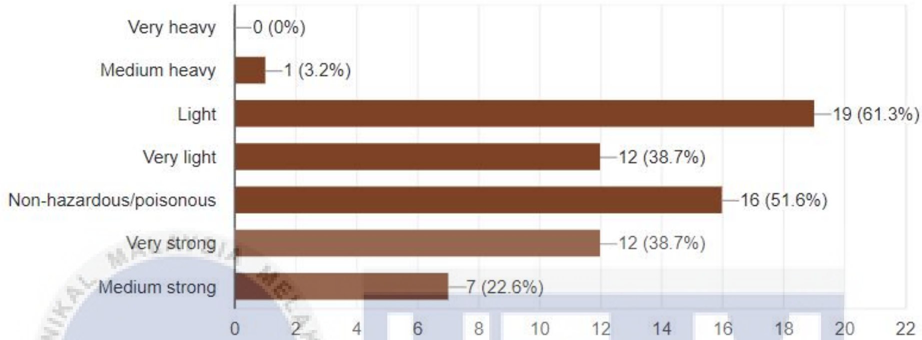


Figure 3.8: Bar graph of respondents rating on the chosen material

iii. Size

As for the product size, based on the bar graph below (See Figure 3.9), adjustable size is most preferred by the respondents and small frame as its frame.

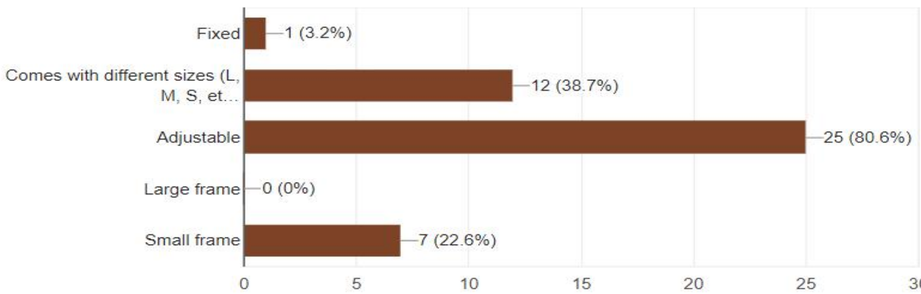


Figure 3.9: Bar graph of respondents rating on size

iv. Appearance

The bar graph in Figure 3.10, shows 22 votes for the products to be attractive but they prefer it not to be colourful and one person suggested it to be modern and stylish.

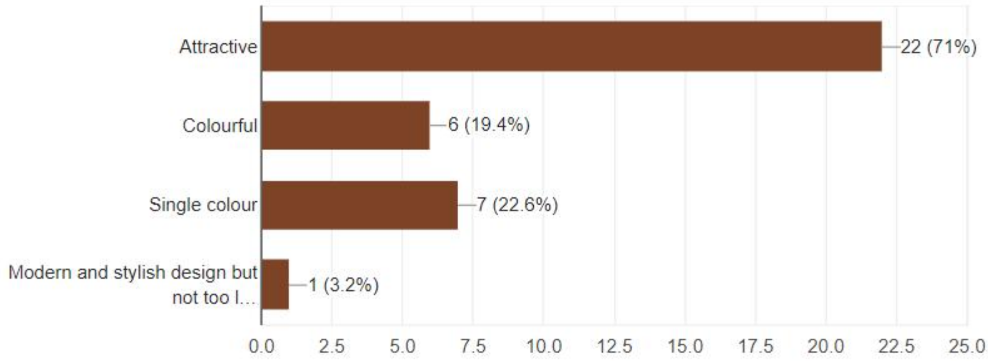


Figure 3.10: Bar graph of respondents rating on appearance

v. Back padding

For the back padding, in Figure 3.11 below, they prefer it to have a medium and soft cushion, curved shape, medium heat-resistant, medium or smooth surface and also one suggested it to be well ventilated.

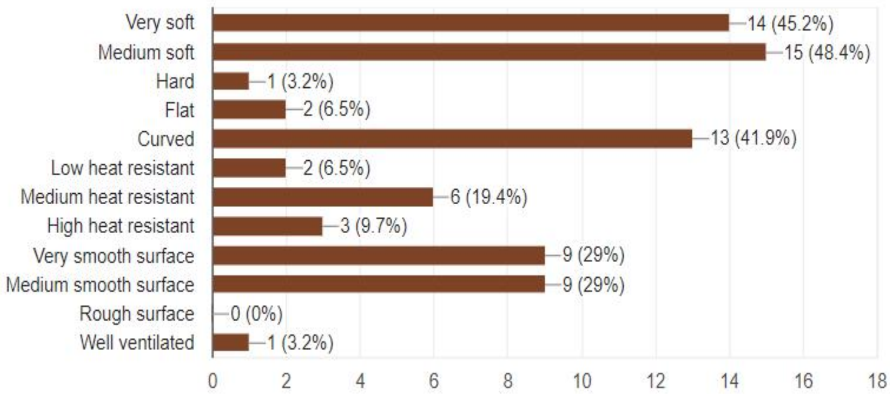


Figure 3.11: Bar graph of respondents rating on back padding

vi. Safety

Based on Figure 3.12 below, respondents prefer the product to be safer.

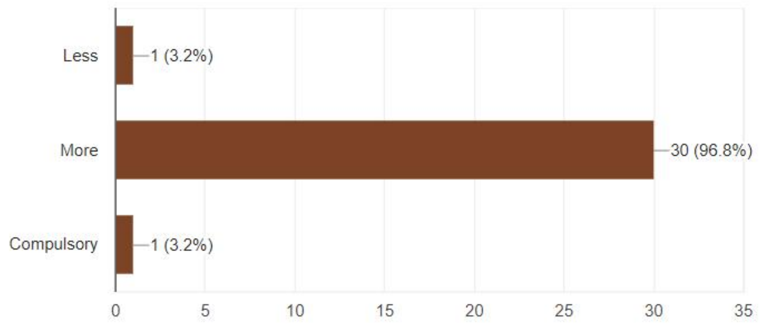


Figure 3.12: Bar graph of respondents rating on safety

vii. Angle of Rotation

In Figure 3.13, the majority voted adjustable wearable-chair.

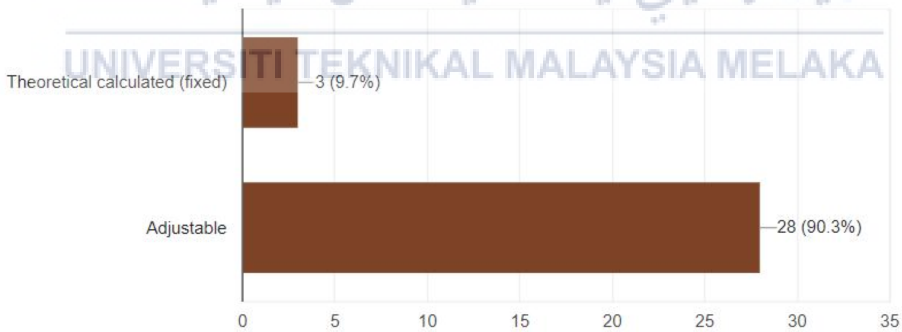


Figure 3.13: Bar graph of respondents rating on the angle of rotation

viii. Durability and Serviceability

Based on Figure 3.14 below, more than 20 respondents chose it to be as durable as it can and high serviceability.

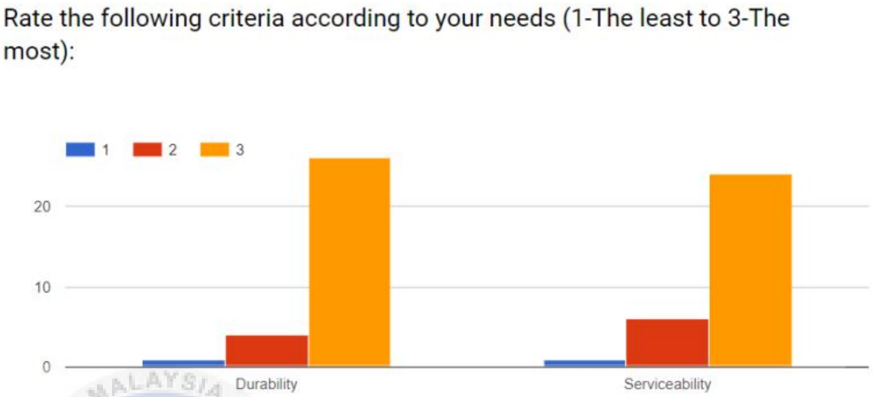


Figure 3.14: Bar graph of respondents rating on durability and serviceability

ix. Price

Based on the pie chart below (See Figure 3.15), a price below than RM1000 is acceptable for most respondents. Some suggested the wearable-chair to be cheaper and costs not more than RM200.

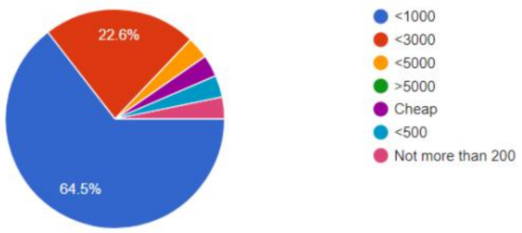


Figure 3.15: Pie chart of respondents rating on price

x. Suggestions

By referring to the Figure 3.16 below, there is a total of 6 suggestions submitted in this survey. The suggestions highlight the price, it functions, ergonomics, size, durability, and foldability. For its price, respondents suggested that it should be RM200 since the budget for this project is RM200, also it must below than market price, and the price must be parallel with the product worthiness. The respondent also highlighted that doing more trials to prove that the product works as required. In addition, to be more concern on user comfort and appearance. They also focused on adjustable features. The size should be adjustable to fit with users size.

Price should reflect the final product worth.
For this type product, the main factor is it's function. It is very important that the product to be functioned as per requirements. So, many experiments and trials have to be made to proof that the idea works.
The user's comfort is also very important.
The design must look comfortable, durable and stylish.

The size must be adjustable as different people have different height so for the sake of comfort for the people who will be using it, the wearable chair must be well- adjustable, well-flexible and can withstand difference load of the users

Rm 200

Foldable

Mampu milik dan rendah dari harga kerusi pejabat di pasaran

Good

Figure 3.16: List of respondents suggestions

3.4 Functional Decomposition

Functions should be broken down as fine as possible. Functional decomposition is a process to break down functions. This process is represented as a functional structure. A functional structure consists of the following:

i. A boundary box

ii. An overall function

iii. Function tree

iv. The known flow of material energy and information

3.4.1 A Boundary Box

A boundary box in Figure 3.17, consists of input and output. It is a simple way to show the mechanism. In this project, the product should be able to use the user weight to rotate some parts in the product.

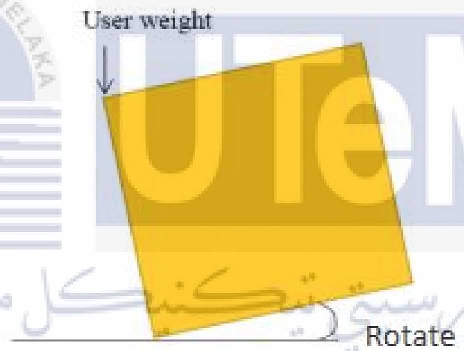


Figure 3.17: A boundary box of wearable-chair

3.4.2 Overall Function Diagram

This diagram below (See Figure 3.18) describes how this product can achieve the output, which stops rotating. This product should be able to stop rotating and withstand user weight by using supporting tools, cam and cam follower and an adjuster when the user is applying its weight on the product.

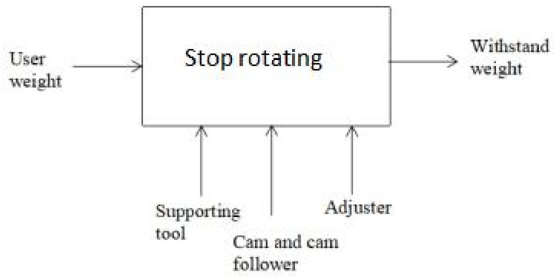


Figure 3.18: Overall function diagram of wearable-chair

3.4.3 Function Tree

Figure 3.19 below shows how the product functioning. To withstand user weight, the user must equip this device on his legs, and then when s/he bends her/his knees, it will move the supporting tools and hit the stopper so that the user can sit on it.

Figure 3.19: A function tree for wearable-chair diagram

3.4.4 Known Flow of Material Energy and Information

The diagram below (See Figure 3.2) shows what energy requires for it to function and the components involve. This product uses force to moves the supporting tools to hit the stopper so that it can withstand weight applied. The source of this force is generated when users equip the device and bend their legs to sit.

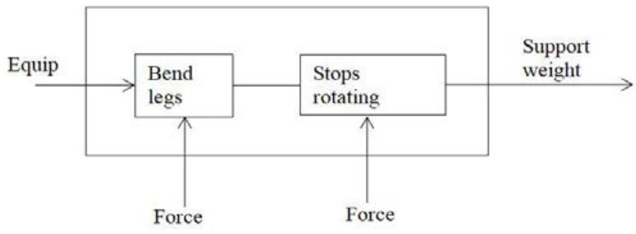


Figure 3.20: A known flow of material energy and information for wearable-chair diagram

3.5 Quality Functional Development

3.5.1 House Of Quality

House of Quality is a tool used in this project to translate customer requirements, market research and benchmarking data into prioritized engineering targets to be met by new product design.

In Figure 3.21 below, several customer needs had been listed in to be analyzed its priority using the House of Quality including possible technical details of this product. The highest demand for customer needs is easy to use, lightweight material and low cost. The highest total of customer needs to be calculated is serviceability followed by safety and size variety. While, technical details that should be focused on are to follow international standard, joints in the products, and its ergonomics.

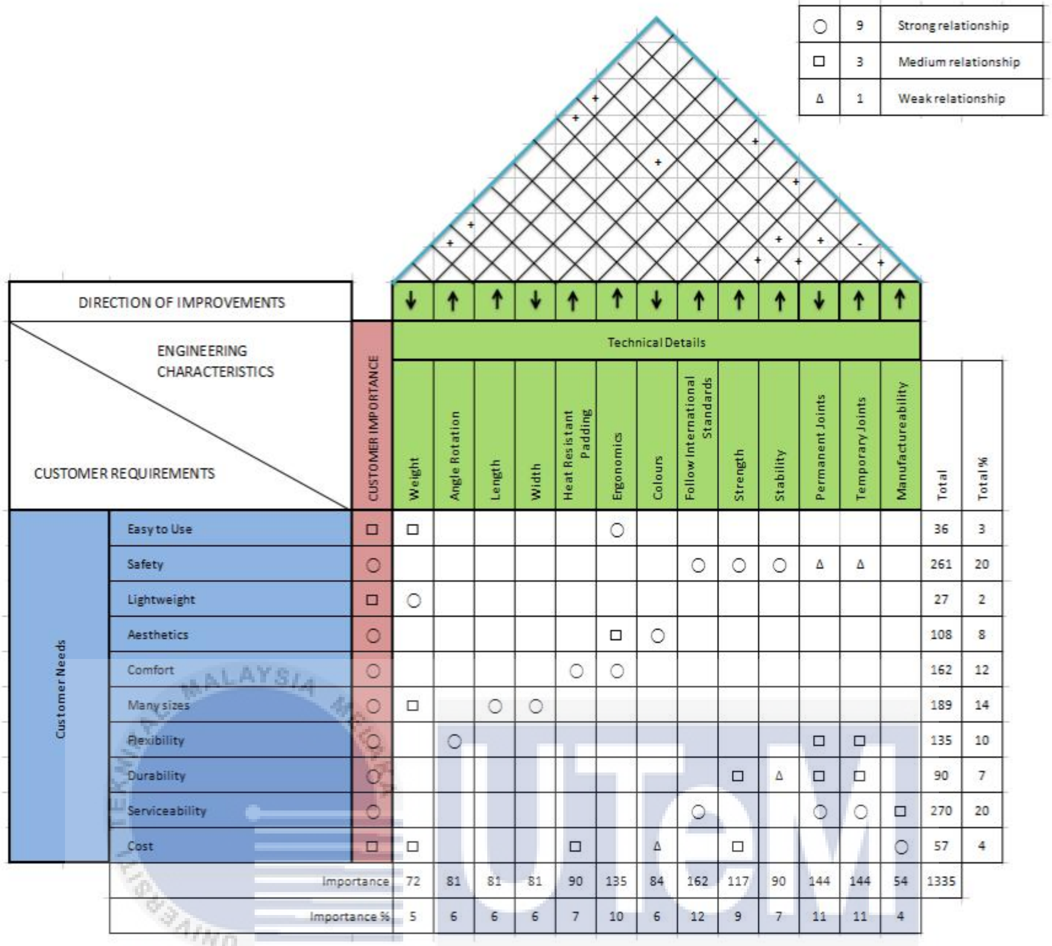


Figure 3.21 Project House of Quality

3.6 Product Design Specification

The product design specification is important in designing a product. It is a comprehensive set of constraints. The parameters in this tool are to guide the concept generation. Table 3.1 below shows the product design specification for this project.

Table 3.1: Product Design Specification

User needs	Manufacturing	Service life	Market
Industrial	Wood	Maintenance-6	Online market
workers	Metal	months	Hardware shop
Officers	bar/plate/rod	Easy to operate	Mass media
Ambient	Lathe	Easy to maintain	advertisements
temperature	Milling	F. S=3	Supermarket
environment	Welding	Warranty	Local suppliers
Indoor use	Grinding	provided	Local market
	Bolt and nut	Factory installed	<RM500/unit
	Screws	Metal disposal	>5years in
	Polished wood	operation	market
	surface finishing	<100kg user mass	
	<500 units/year		

3.6.1 User Needs

The target user of this product is among industrial workers and officers. They need this device while working inside the factory in which the environment would be in ambient temperature.

3.6.2 Manufacturing

This product was made of wood and several kinds of metals. It would be best if the device is lightweight, thus 1.5kg is set to be the max mass of the product. A wearable-chair to weigh 1.5kg is not an easy task, but weight is still needed to be considered because higher weight makes a wearable-chair hard to use. It is suggested to use common fabrication techniques such as welding, grinding, milling, and lathe machine. The fasteners must be easy to maintain because this product is aimed to last long, thus screws, bolt and nut are selected as fasteners. The surface must be polished to have a good appearance.

3.6.3 Service Life

The product must exceed the safety factor of 3.0 to ensure that the product can last long. It must be maintained at least once in 6 months and broken parts need to be repaired. User mass must not exceed 100kg to avoid failure and it must also easy to be operated and maintained. Also, if it is factory installed, it has a better probability to avoid manufacturing failure. This product must come with a warranty to ensure the quality of the product. Also, the material must be able to be disposed using an appropriate method.

3.6.4 Market

To ensure that this product can stay more than 5 years in the market, continuous advertising is needed. The advertisement must be by using mass media so that it could reach to as many customers as it can. This product can be found in the supermarket, hardware shop and online market with expected price less than RM500 per unit. It is a plan to have local manufacturers to manufacture the product in order to achieve minimal production cost. Also, this product must be available in the local market before it can enter the international market.

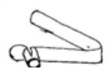
3.7 Concept Generation

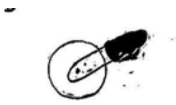
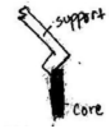
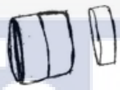
3.7.1 Morphological Chart

A morphological chart is a collection of product sub-functions. All the possible solution can be included in this chart. The purpose is mainly to provide choices to choose to form different designs.

In Table 3.2 below, the sub-functions included are device position, seat type, height adjuster, stopper, frame, and harness lock. There are not many components involve in this product, but there are few combinations to produce a better design.

Table 3.2 Morphological chart

Sub-function	Solution			
a. Device position	1.  Behind leg	2.  At front and behind		
b. Seat type	1.  Double flat seat	2.  Single curvy seat	3.  Harness	4.  Single flat seat
c. Height adjuster	1.  Linear position ratchet	2.  Push Button Spring		

d. Stopper	1.  Adjustable	2.  Fixed		
e. Frame	1.  Curved	2.  Plate	3.  Cylindrical	4.  Square/rectangular
f. Harness lock	1.  Bag lock	2.  Velcro	3.  Plastic lock	

a. Device position

Existing models came out with different device positions. Thus, perhaps by adding the positions into the morphological chart, we could satisfy some of the customer needs.

For the device to be equipped on behind the legs, makes it easier to design for the mechanism of the wearable-chair because there is enough space behind the legs. Differ from the other position, which is at front and behind, the device acts like a cloth wrapping around the legs with least mechanisms included. This position is more complex to be designed for its mechanism, and it might be expensive in cost due to material durability for small mechanisms. However, both have advantages and disadvantages.

b. Seat type

There are four seat types added into the range; double flat seat, single flat seat, single curvy seat, and harness. These seats contribute to different mechanical properties. Double and single flat seat is suitable for a wide range of user body size than other seat types. However, the single flat seat offers movement flexibility to the user. Single curvy seat offers more comfort to the user, while harness will secure the body but to equip the harness can be a difficult task to be performed.

c. Height adjuster

There are many types of height adjuster in the market, but only the easier and simpler designs are included in this chart. The reason is easy to use, and the device is not within eyesight range, thus it could be hard to reach. By making it easier to use will helps. Linear position ratchet is a slider with slots, to make it usable in this design, few more components must be added to it so that it won't slide off of the locked place. While push button spring is much easier to use, it can be found in most walking sticks, but the material and its design could result in failure when extra stress is added to it.

d. Stopper

Stoppers are added to make the device static while the user is sitting on it. The stoppers that are considered are adjustable and fixed. Adjustable stopper allows the user to set the desired angle. Fixed stopper is simpler, it is permanently attached to the device, even though the device can only function on a single angle, it is stronger than adjustable stopper and less restriction upon using it.

e. Frame

There are four frames in the chart which are, curve, plate, cylindrical and square or rectangular. The smaller the frame, the easier to use because of less body contact. However, all of these have their own advantages and disadvantages.

Curve frame is a comfort, but it could be a problem in leg movement, and user body size would not be fit in. While plate frame is easy to use but in a certain position, it could be deformed. The cylindrical frame is stronger in vertical, but it bends easily when not in a vertical position. The rectangular frame offers different wide and base but heavier.

f. Harness lock

The harness is used to keep the device attached to the legs. There are few harness lock included in the chart; bag lock, velcro and plastic lock. Bag lock is commonly used in bags, and it is easy to use and last longer, also comes in many sizes. Velcro is easy to adjust than other locks. But after sometimes, it will wear out. While a plastic lock is to tighten the harness. The plastic lock is easy to use and flexible but the harness will loose after a long period.

3.7.2 Conceptual Design Generation

Conceptual design is the process of idea expression through sketches. The components used in the sketches are selected from the morphological chart. Few sketches have been made by combining solutions in the morphological chart.

I. Conceptual design 1

This design is focused on lightweight design (See Figure 3.22) and Table 3.3 shows its sub-function. The material chosen for the frame is a polymer, and the frame is thin. This design is suitable for users that often walks and only sit for a while. It has fixed stopper and uses bag lock to its harness makes it an on-the-go chairless chair. However, this design is limited to small body size due to its leg shaped frame, but it is relevant because of the chosen material is a polymer and the frame is thin.

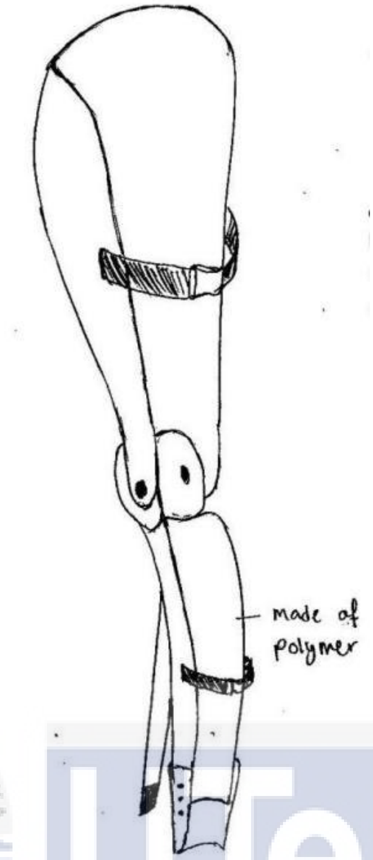


Figure 3.22: Conceptual design 1

Table 3.3: Components of the morphological chart in conceptual design 1

Sub-function	Solution
a	1
b	2
c	2
d	2
e	1
f	1

II. Conceptual design 2

This design is focused on easy to equip (See Figure 3.23) and Table 3.4 shows its sub-function. The user only needs to equip once with only one harness each leg. It has adjustable stopper makes it more flexible. The uses of a metal plate as its frame makes it lighter. But user movement is limited due to a double flat plate that makes contact with the body as the user moves their legs. This device is suitable for workers that sit in a longer time than standing.

Figure 3.23: Conceptual design 2

Table 3.4: Components of the morphological chart in conceptual design 2

Sub-function	Solution
a	1
b	1

c	1
d	1
e	2
f	3

III. Conceptual design 3

Conceptual design 3 focuses on appearance (See Figure 3.24) and Table 3.5 shows its sub-function. The use of wood as covers makes it different than current market models. The uses of single flat seat offer more legs movement flexibility. The harness lock chosen in this design is Velcro because it is easy to put on. Also, it is height adjustable. This device is suitable to use in the office due to its classy appearance, and its large frame offers higher durability than other designs.

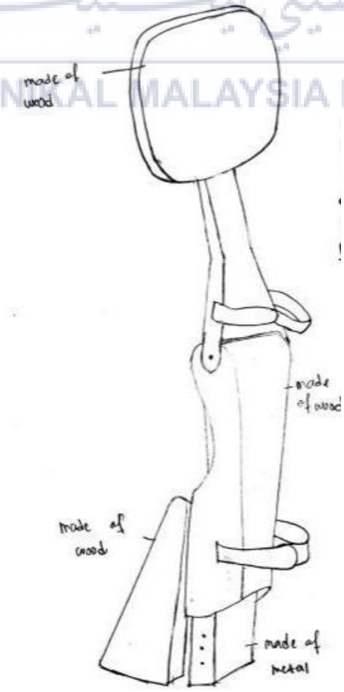


Figure 3.24: Conceptual design 3

Table 3.5: Components of the morphological chart in conceptual design 3

Sub-function	Solution
a	1
b	4
c	2
d	2
e	4
f	2

IV. Conceptual design 4

This design concept is easy to store (See Figure 3.25) and Table 3.6 shows its sub-function. Differ from conceptual design 1, this design uses plate and cylindrical frame to have a small frame. It does not limit to any body sizes, but it can withstand high load if a strong metal is used. It is equipped with velcro harness and push button spring height adjuster. However, the stopper is fixed.

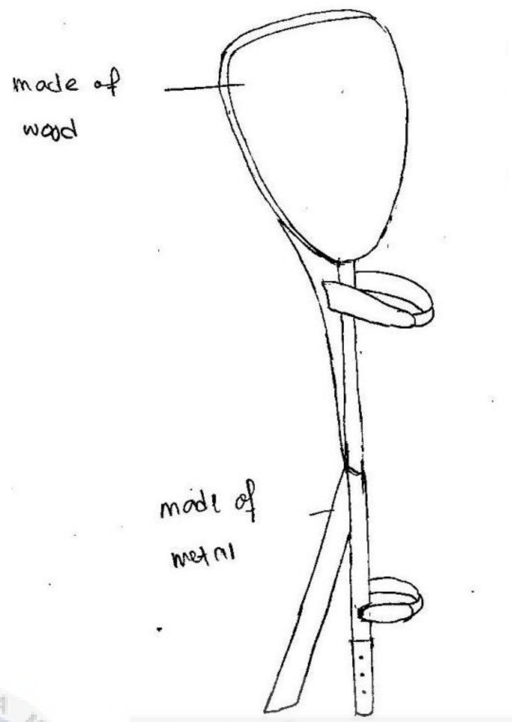


Figure 3.25: Conceptual design 4

Table 3.6: Components of the morphological chart in conceptual design 4

Sub-function	Solution
a	1
b	4
c	1
d	2
e	2 & 3
f	2

V. Conceptual design 5

This conceptual design uses less metal (See Figure 3.26) and Table 3.7 shows its sub-function. To use less metal, the metal chosen would be stainless steel. To reduce cost and product weight, it has no seat except on the metal plate that designed to support and large harness to support the body during seating. It uses bag lock as harness lock also height adjuster. This device is suitable even for bigger body size. Stainless steel is a strong metal along with the lower frame that in cylindrical shape gives extra support. The frame is small, and it provides high leg movement flexibility. This device is a fixed stopper, and it is more suitable for outdoor use.

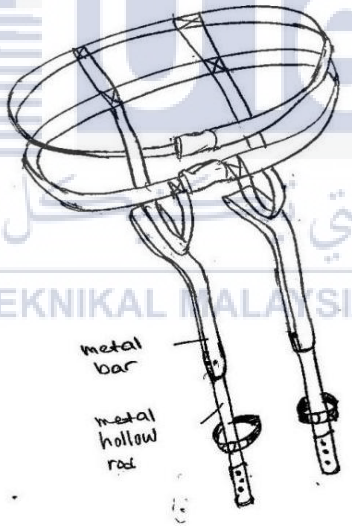


Figure 3.26: Conceptual design 5

Table 3.7: Components of the morphological chart in conceptual design 5

Sub-function	Solution
a	1
b	3

c	1
d	2
e	2 & 3
f	1

3.8 Concept Evaluation and Selection

Concept evaluation includes comparisons and decision making. It is to decide which concepts have the highest potential for becoming a quality product.

3.8.1 Weighted Decision Matrix

The tool used in this process is the Weighted Decision Matrix. The evaluation done is as in Table 3.8(a) and Table 3.8(b) below.

Table 3.8(a): Weighted decision matrix table

		Conceptual Design 1		Conceptual Design 2	
Criteria	Importance Weight (%)	Rating	Weighted rating	Rating	Weighted rating
Easy to use	3	2	0.6	4	1.2
Safety	20	4	8	4	8
Lightweight	2	4	0.8	2	0.4
Aesthetics	8	4	3.2	1	0.8
Comfort	12	2	2.4	2	2.4
Many sizes	14	0	0	3	4.2
Flexibility	10	1	1	1	1

Durability	7	1	0.7	3	2.1
Serviceability	20	4	8	3	6
Low cost	4	0	0	2	0.8
Total	100		24.7		26.9

Table 3.8(b): Weighted decision matrix table

Conceptual Design 3		Conceptual Design 4		Conceptual Design 5	
Rating	Weighted rating	Rating	Weighted rating	Rating	Weighted rating
2	0.6	2	0.6	1	0.3
4	8	2	4	3	6
2	0.4	4	0.8	4	0.8
4	3.2	2	1.6	1	0.8
4	4.8	2	2.4	1	1.2
3	4.2	4	5.6	3	4.2
3	3	4	4	4	4
2	1.4	1	0.7	3	2.1
2	4	3	6	4	8
3	1.2	4	1.6	2	0.8
	30.8		27.3		28.2

From this evaluation, the highest weighted rating falls to conceptual design 3 (See Figure 3.24) with a total score of 30.8. This design is highest in safety, and the reason is that it is ergonomics. The polished wood covers would not harm users and avoid sharp edges of metals inside the cover. After safety, the second highest weighted rating goes to comfort. The reason why this design offers comfort to its user is the surface area of the body contact with upper covers and its seat. It provides more support and comfortable to sit on. The least rating falls to lightweight. It is not too heavy because the combination of metals and wood makes it lighter than using only metal as its material. Few modifications can be made to achieve product weight less than 1.5kg so it is easy to walk while wearing the wearable-chair.

3.9 Detail Design

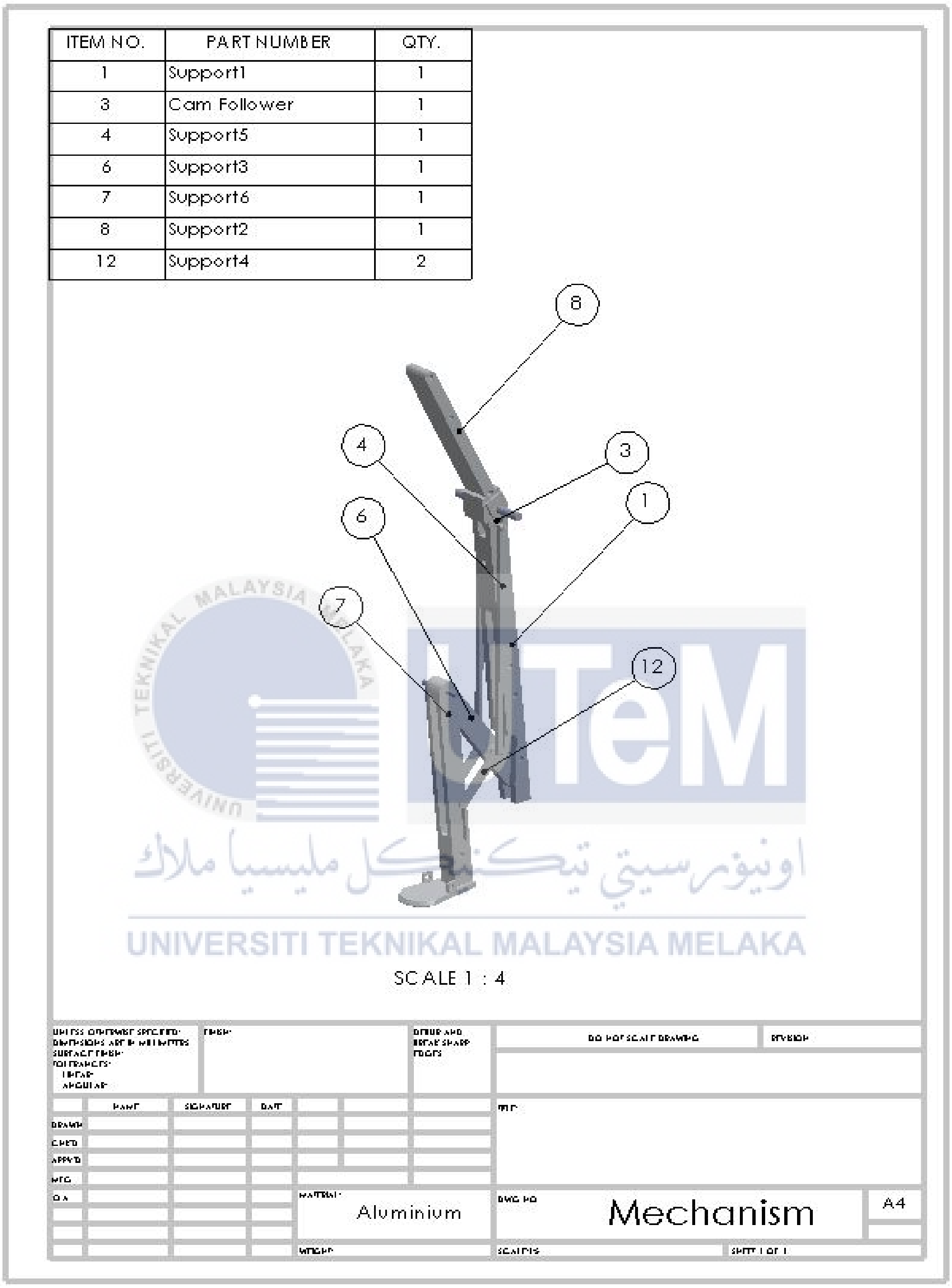
SolidWorks 2016 CAD software is used to develop a 3D model of this project. All the 2D drawing are in 3rd angle projection and ISO standard. There are working mechanism parts, the cover, the core, and connectors.

3.9.1Mechanism

3.9.1.1Mechanism Part Assembly

In Figure 3.27 below, there are 7 different parts in the mechanism of the wearable-chair. Support2 is supposed to deliver force to move Support6 part. There is a cam in Support2 and a cam follower that motivate all movement in the mechanism.

The material used is 6061 aluminum alloy, aluminum is lightweight but not as strong as iron. The base in Support6 is widened to add stability. While Support4 and Support5 are members to keep the mechanism in place while moving, and Support1 acts like a base of the mechanism because it would not be moving.



ITEM NO.	PART NUMBER	QTY.
1	Support1	1
3	Cam Follower	1
4	Support5	1
6	Support3	1
7	Support6	1
8	Support2	1
12	Support4	2

Figure 3.27: Wearable-chair mechanism part assembly

3.9.2 Wearable-Chair Assembly

Figure 3.28 shows the full assembly of a wearable-chair in this project. There are 30 different parts in the assembly including nut and threaded rods.

Core2 is the base, to adjust the height, push button can be adjusted to any of the holes on Core2 part.

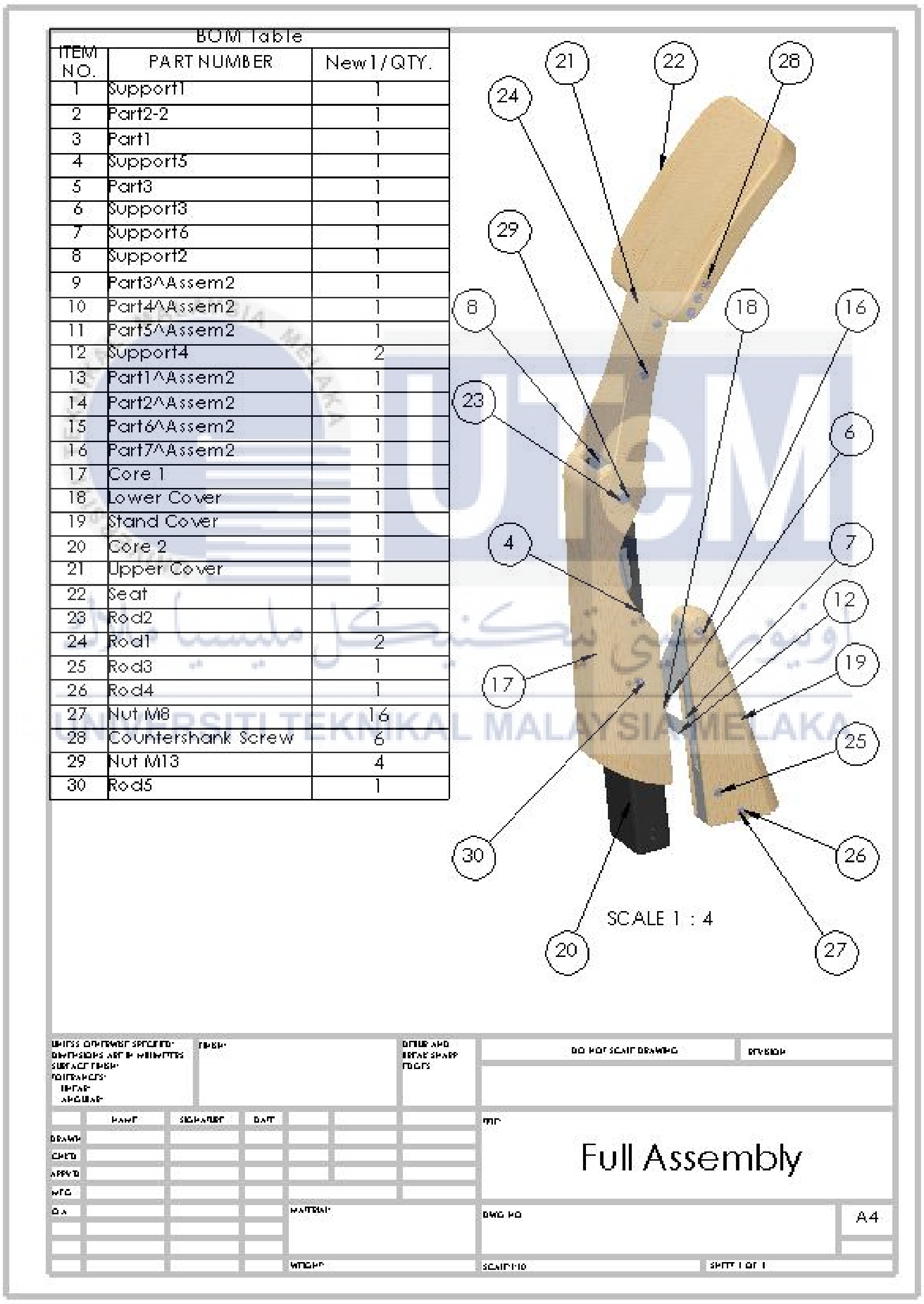


Figure 3.28: Wearable-chair parts assembly

3.9.2.1 Cover Part Design

For covers, pine wood gives a nice appearance, also to protect the wearer from touching the sharp edge of the metals. And to avoid dusk from getting into the mechanism parts.

3.9.2.2 Core Part Design

For core parts, the metals selected is iron steel, because the load will be transferred to core1. Holes on the Core1 is to reduce weight since iron steel is heavy. These two parts are assembly with height adjuster and spring to keep them attached to each other

3.9.3 Seat Part Design

The seat is made of pine wood to give out good appearance and lightweight. Also, it is easy to shape to get the shape in the drawing below.

3.9.4 Fasteners

In order to ease maintenance operation, this product uses bolt, nut and threaded rod to non-permanent joints. And in order to ease the manufacturing process, the use of the fasteners is standardized in size of M6.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Introduction

This chapter explains the result of simulation analyses that have been performed in order to verify the workability of the product before the fabrication process and the fabrication processes suitable for specific parts.

4.2 Simulation Analysis

Simulation analysis is conducted to identify failures in the design and to observe any unwanted event that might occur during the analysis for further improvement in the 3D design. In this project, there are two types of simulation analyses involved which are motion analysis and stress analysis.

In both simulations, only several parts of the design that have been included in the design assembly to perform the simulation. Figure 4.1 shows the assembly and bill of materials of the assembly design used in the simulations. Fasteners and covers are the components that have been excluded in the analysis.

For fasteners, it is used in the real product to hold the parts in place thus, their function in this design can simply be replace using mate and join features in the software. As for the covers, their movement depends on the mechanism and some of them are fixed, thus they can also be excluded from the analysis.

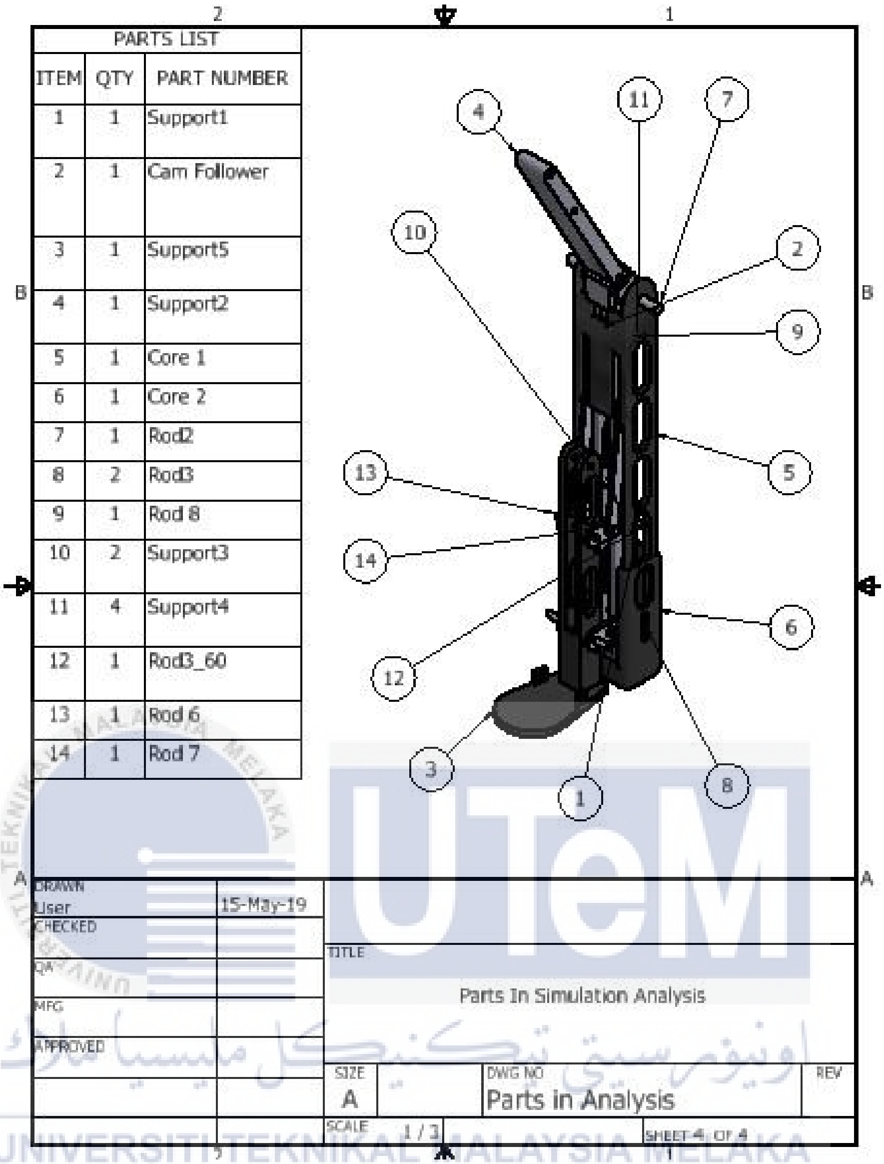


Figure 4.1: Bill of material of part assembly used in simulation analysis

4.2.1 Motion Analysis

Motion analysis is performed using SolidWorks software to analyze the usability of this design. This method can predict the motion of the product when load or torque is applied. Before running the analysis, there are few restrictions that need to be defined, such as, contacts, load, gravity and more. For this design, the restrictions applied are contacts and torque.

4.2.1.1 Constraints Applied in Motion Analysis

Based on Figure 4.2 below, there are four components that should react when they touch each other. Which means the force should be delivered to these components to achieve the motion required. Supposedly, the force from Support 2 should be able to move Support 5. Thus, components that are touching Support 2 until the components that are touching Support 5, including Support 5 should be added to the contact. The elastic properties selected for this contact is an impact, because the analysis should show the result of the motion when they collide.

While contact selections in Figure 4.3 below are Support 2 and Cam Follower. The cam in Support 2 must be able to deliver the torque to the cam follower so that it can move the mechanism.

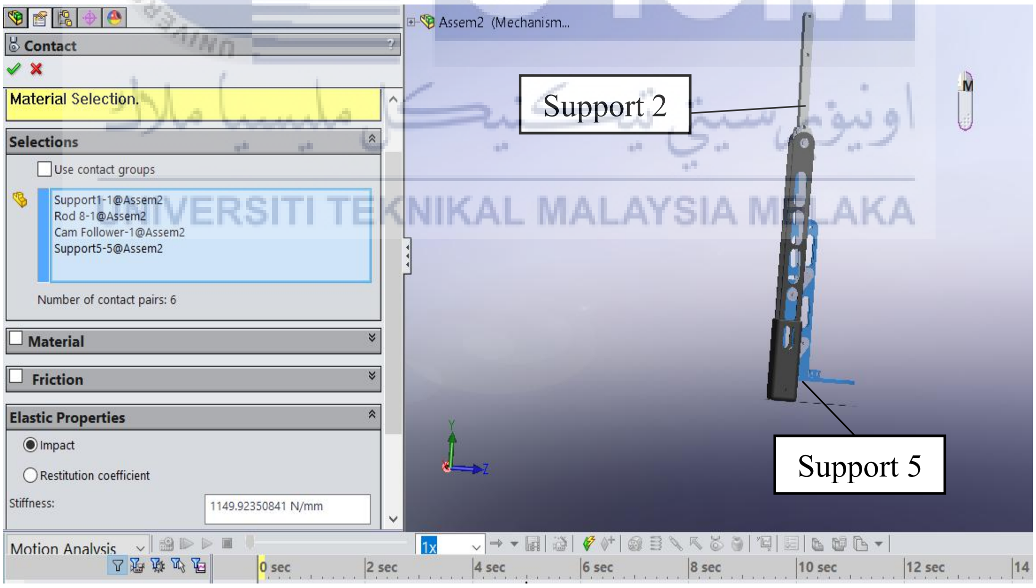


Figure 4.2: Contact applied in motion analysis (a)

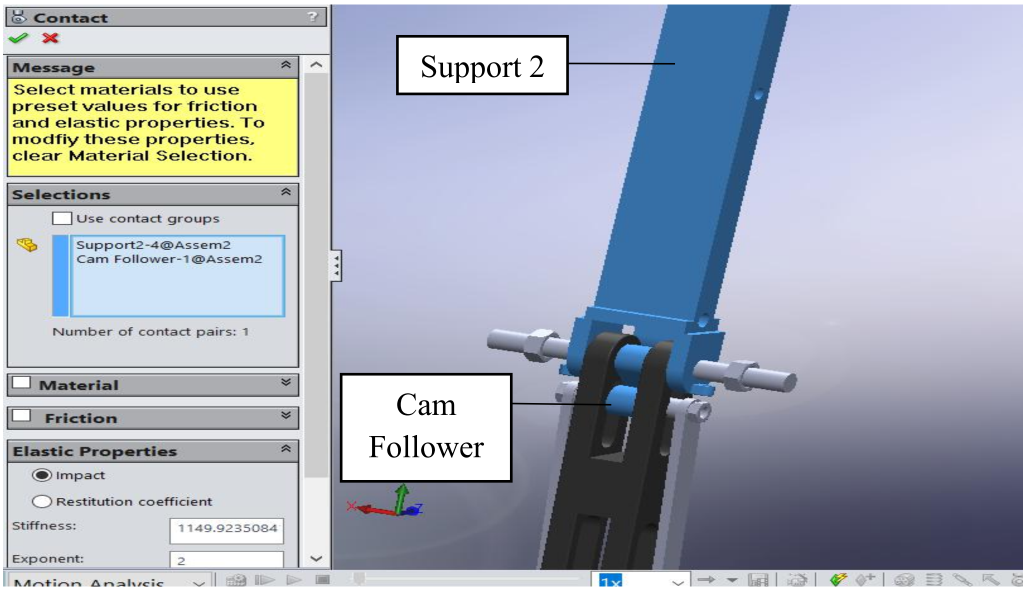


Figure 4.3: Contact applied in motion analysis (b)

Next restriction is torque applied. Based on Figure 4.4 below, torque of 100Nm is applied on Support 2. The reason 100Nm is chosen is that, low torque should be able to move the mechanism.

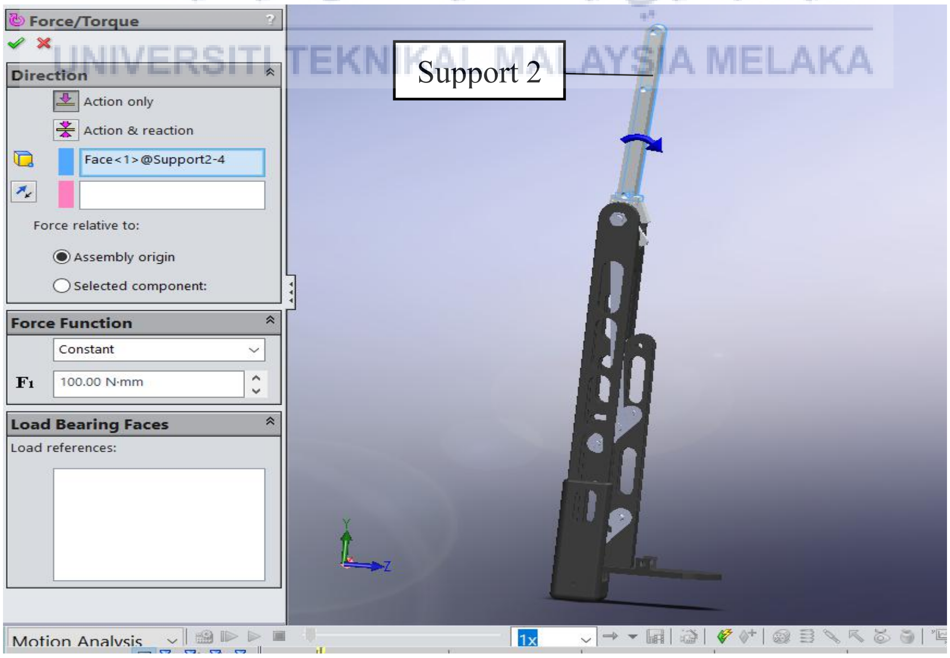


Figure 4.4: Torque applied in motion analysis

4.2.1.2 Motion Analysis Result

The result obtained is shown in figures below. Figure 4.5 shows the initial motion. The model is started to move as shown in Figure 4.6 and lastly, the final result is at the 5th second showed in Figure 4.7.

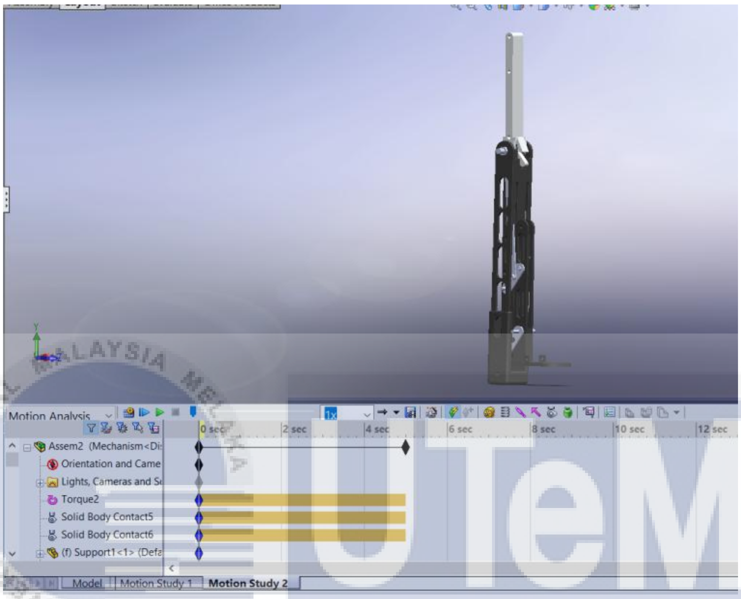


Figure 4.5: Initial result of motion analysis

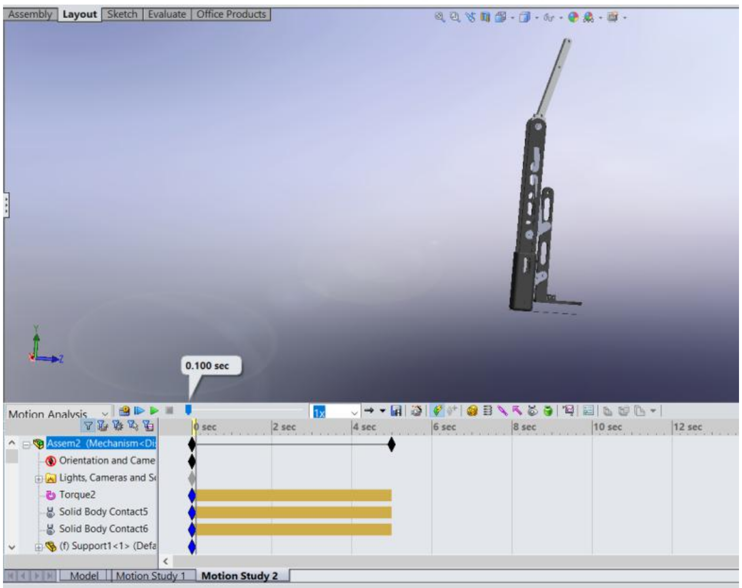


Figure 4.6: Result in 0.1 second of motion analysis

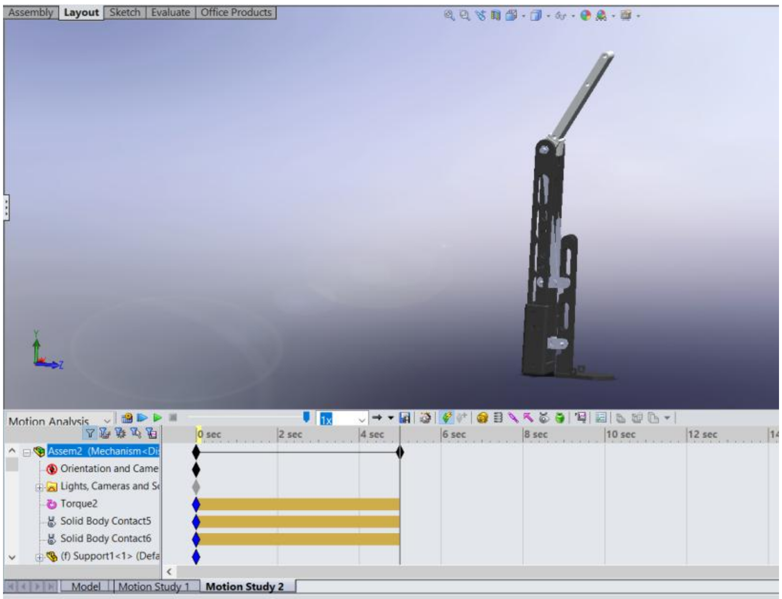


Figure 4.7: Final result of motion analysis

The motion analyzed is satisfied with the motion needed for this product to function well. Thus, no modification is needed to be done.

4.2.2 Stress Analysis in Design Assembly

Stress analysis is performed using Inventor software. It is to predict the region of stress occurs in the components that are involved in the analysis. This analysis is able to calculate the Von Mises Stress, principle stresses, displacement, safety factor, mass, volume and more.

4.2.2.1 Constraints Applied in Stress Analysis

Stress analysis can only be calculated when the load and the fixed object is defined. In this design, the design base should be fixed to hold the load. The gravity applied is direct to the ground by using the standard earth gravity value. Then, the force of 490N is applied normally to Support 2, which is about 50kg of load. Each side of this prototype should be able to withstand 50kg of load, a total of 100kg load for a pair. Figure 4.8 shows the direction of forces and the fixed components applied.

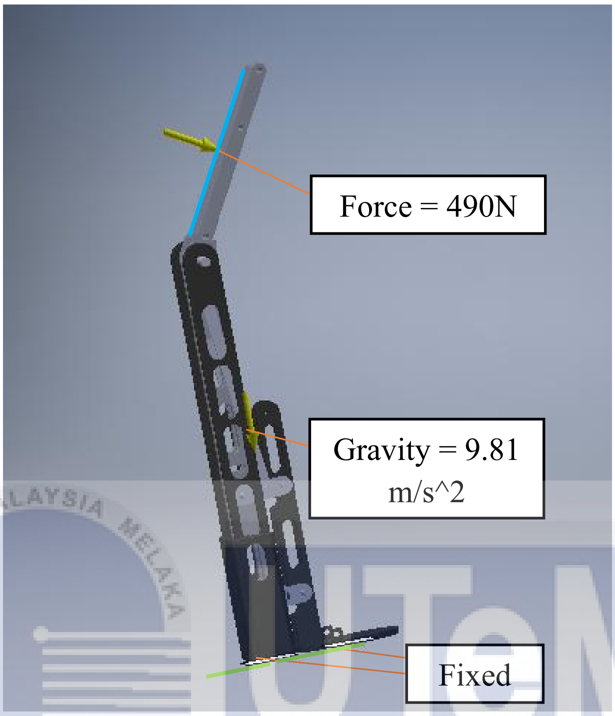


Figure 4.8: Constraints applied in stress analysis

4.2.2.2 Materials Applied and Its Characteristics

In this simulation analysis, the stress calculated is based on the material applied to each component. Table 4.1, Table 4.2 and Table 4.3 below show the characteristics of iron, aluminum and stainless steel. These materials are applied in the components that took place in the simulations. For each component involved in the simulations are included in any of the tables below.

Iron is applied to some support and all core components to give extra strength since the function of these components is to support the load applied. While stainless steel is applied on the cam follower because the cam follower is representing the bearing. Other components are made of aluminum. The function of the components stated in Table 4.3 is only to guide the movement of the mechanism. Thus, aluminum as the material use would be the best fit for its purposes.

Table 4.1 Iron material applied

Name	Iron	
General	Mass Density	7.15 g/cm^3
	Yield Strength	811 MPa
	Ultimate Tensile Strength	997 MPa
Stress	Young's Modulus	168 GPa
	Shear Modulus	65.1163 GPa
Part Name(s)	Support1	
	Support5	
	Support2	
	Core 1	
	Core 2	

Table 4.2: Stainless Steel material applied

Name	Stainless Steel	
General	Mass Density	7.85 g/cm^3
	Yield Strength	275.8 MPa
	Ultimate Tensile Strength	448 MPa
Stress	Young's Modulus	200 GPa
	Poisson's Ratio	0.287 ul
	Shear Modulus	77.7001 GPa
Part Name(s)	Cam Follower	

Table 4.3: Aluminum material applied

Name	Aluminum 6061	
General	Mass Density	2.7 g/cm^3
	Yield Strength	275 MPa
	Ultimate Tensile Strength	310 MPa
Stress	Young's Modulus	68.9 GPa
	Poisson's Ratio	0.33 ul
	Shear Modulus	25.9023 GPa
Part Name(s)	Rod2	
	Rod3	
	Rod 8	
	Support3	
	Support4	
	Support4	
	Support3	
	Support4	
	Support4	
	Rod3_60	
	Rod3	
	Rod 6	
	Rod 7	

4.2.2.3 Von Mises Stress

The result shown in Figure 4.9 is an image of the actual situation of the product when load is applied. The maximum stress calculated is 317.9 MPa. It is observed that the minimum stress region almost covers the entire product, thus the product is durable on the blue region.

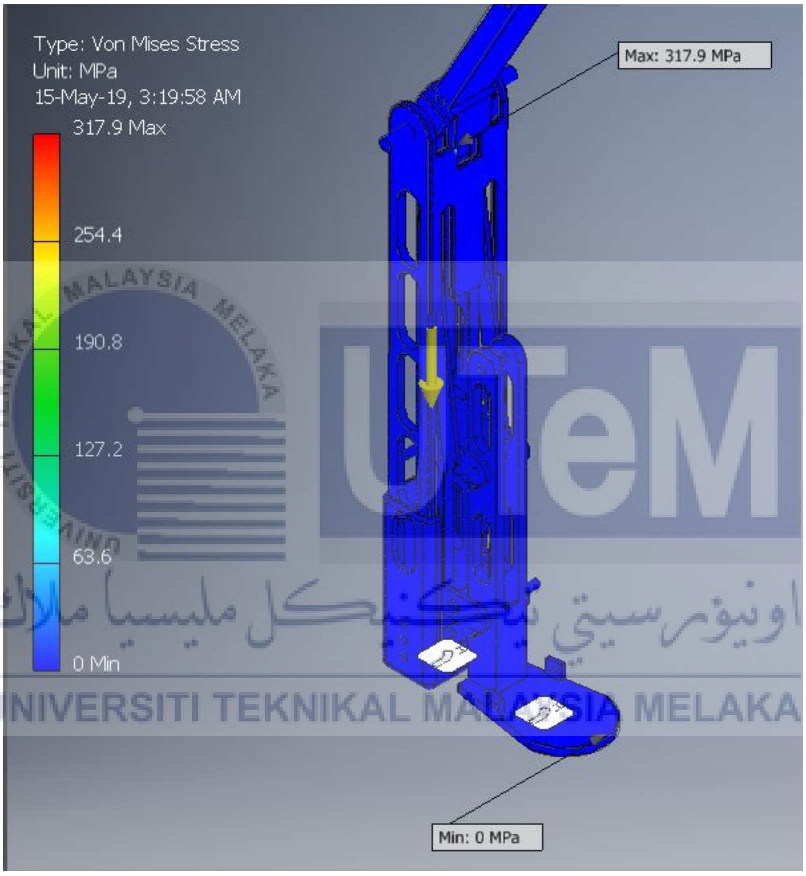


Figure 4.9: Result of Von Mises Stress

According to Figure 4.10, the maximum stress occurs at the surface contact between Support 2 and Core 1. This happens because the area of contact is too small thus the pressure is higher in that area.

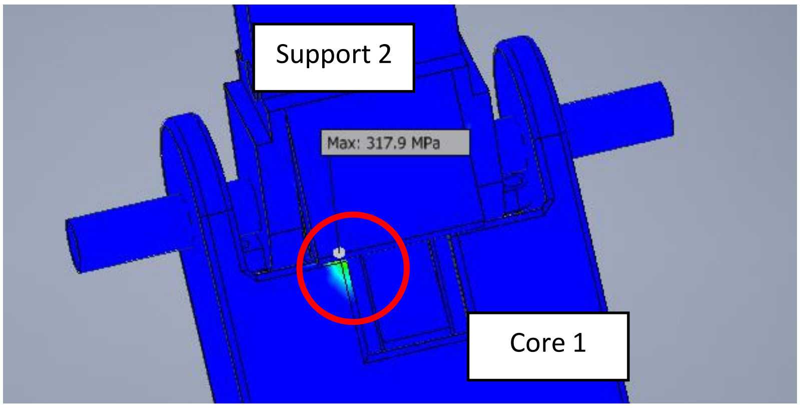


Figure 4.10: Maximum stress area

4.2.2.4 Factor of Safety

The factor of safety can also be automatically calculated using stress analysis. Figure 4.10 below shows the factor safety result calculated in this design. The maximum and minimum safety factor is 15 and 1.72 respectively. It is observed that the lowest safety factor is at the cam follower surface. This design will not fail because the safety factor has achieved more than 1.

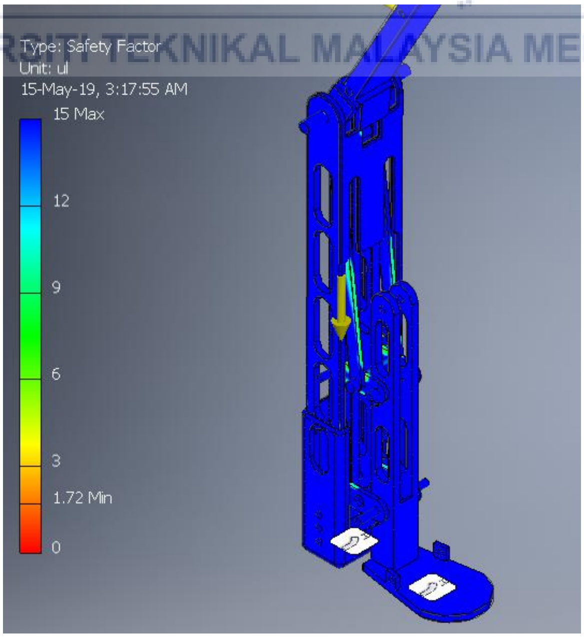


Figure 4.11: Safety factor generated by simulation analysis

4.3 Budget and Costing

The budget allocated for PSM students is RM200 per person. The budget is only valid for consumable materials for the project fabrication. Table 4.4 below shows the consumable material needed for this project.

Table 4.4: Project material list

Material
Pine Wood (12x1x8mm)
Aluminum Round Bar (16x1000mm)
Iron L-Bar (80x4000mm)
Iron Bar (40x35x200mm)
Fasteners

The faculty can only provide material of aluminum round bar and iron L-bar. According to the survey done to the material traders in Taman Perindustrian Malim Jaya, the iron bar can only be purchased for 6m long, and for the specification required for this project, the price is almost RM1,000 for one purchase. Other than that, the pine wood is affordable, only RM 20 for the project pine wood. For the fasteners, it is assumed that the cost will be less than RM 30.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the literature study, the shape, appearance and mechanism used in the current products as well as the main purpose were determined. To develop a new product that has similar functions as the current products, a survey was done. The survey purposes to identify the customer needs and wants were achieved. By using the data from the survey, an analysis called House of Quality was conducted and prioritize engineering characteristics for the design were identified. Then, the data from the House of Quality, five conceptual designs were made, one final conceptual design was then selected among the conceptual designs by using weighted design matrix evaluation. The final conceptual design was then successfully developed by using CAD software which is SolidWorks. After modelling, the 3D design was analyzed for motion study and stress analysis. Both analyses were conducted using SolidWorks and Inventor software respectively. Both analyses showed positive result and the product should be able to function in the actual situation and it will not fail since the stress analysis showed that the model's factor of safety is more than one. Then, this design can be realized as a working prototype. Due to limited budget and resources, the prototype for this design was unable to be developed and tested. Thus, the manufacturing process that should have been conducted to realize this prototype has been suggested along with the design optimization method for future research on this study.

5.2 Recommendations for Future Work

There are few things that can be made to improve this product design and to ease the fabrication process of the product for future use.

5.2.1 Fabrication Process

Fabrication process that will be used is simple metal cutting, material removal and welding process. The processes are described below;

a) Metal cutting process

Basic metal cutting tools such as saw and grinder can be used because the material used is not too strong and not too large.

b) Material removal process

To create holes and slots in the slot (see Figure 5.1) for the iron material parts, it is suggested to use a milling machine. The thickness of the plate in the design is quite thick. It is very convenient to use a milling machine than other tools. Milling process also gives nice product finishing. While aluminum rods can go through the lathe process to reduce its diameter.

Figure 5.1: Support1 perspective view

c) Welding process

Any permanent joins in the design can be joined by using MIG welding.

5.2.2 Design Optimization

Design optimization is to optimize the parameters selected in the design. With the design optimization process, the size and material use can be reduced, then, result in cost and inventory saving.

For the future study, it is recommended to do topology optimization. Topology optimization is to optimize design layout within a given space, for a given set of loads and boundary condition. In other words, it remains the outer shape while removing some of the material within the shape boundary.

This technique can be done by using software that has this feature such as;

a) Limitstate

b) COMSOL

c) SolidWorks

d) GENESIS

e) ANSYS

f) Fusion360

Figure 5.2 below shows the result of topology optimization done in random product.

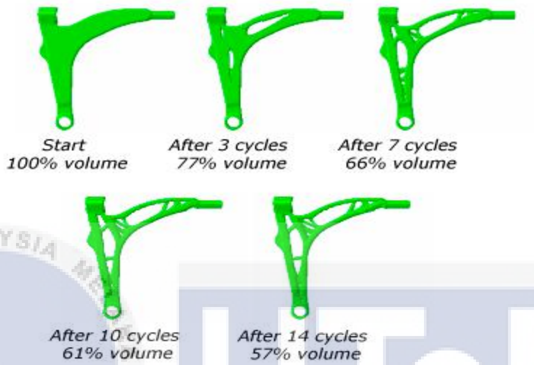


Figure 5.2: Random object used topology optimization (source: Google Image)

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APPENDIX A

Survey Questionnaire

A Questionnaire Of Wearable-Chair For General Use

Name of questioner: Adinda Hadirah Binti Mohd Zin

Institute: Universiti Teknikal Malaysia Melaka

Questionnaire purpose: To collect data from respondents on wearable-chair design criteria for undergraduate project use in designing process of a new wearable-chair.

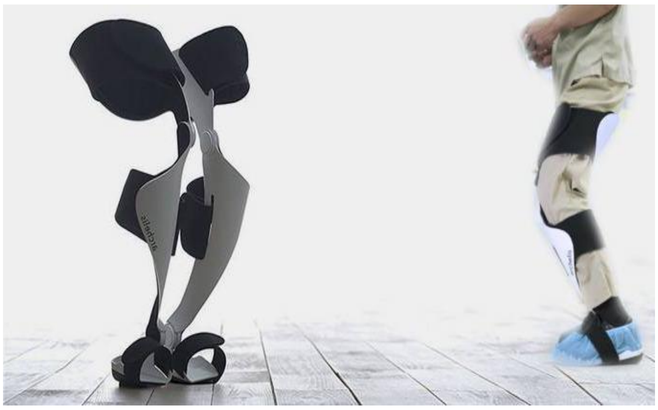
Gender : [ ] Female [ ] Male

Age : [ ] < 30 [ ] > 30 [ ] > 50

Occupation : [ ] Doctor [ ] Industrial designer [ ] Lecturer
[ ] Engineer Others:____________

Field of study : [ ] Medical [ ] Engineering [ ] Design
Others:____________

wearable-chair is a device which can be equipped on the user legs. This device functions like a chair, user can lean back to sit with it. The purpose of this device is mainly for sitting support in workplace. Picture below are the current models in market.

In my project, I have been assigned to design a wearable-chair which can be used in any part of the work field. This device is able to reduce workload during long hours of work while standing, provide more work space, reduce back pain and increase working efficiency.

As a person who would want to use this device on the future, what criteria would you prefer/suggest for a wearable-chair?

Choose **ANSWER/S** for each questions below, your answers **CAN BE MORE THAN ONE.**

1. Restriction/setup before/during/after use:

   [ ] No [ ] Less [ ] More

   Others:____

2. Material use:

   [ ] Very heavy [ ] Medium heavy [ ] Light [ ] Very light

   [ ] Non-hazardous/poisonous [ ] Very strong [ ] Medium strong

   Others:____

3. Size:

   [ ] Fixed [ ] Comes with different sizes (L, M, S, etc) [ ] Adjustable [ ] Large frame [ ] Small frame

   Others:____

4. Appearance:

[ ] Attractive [ ] Colourful [ ] Single colour

Others:____

5. Back padding:

[ ] Very soft [ ] Medium soft [ ] Hard [ ] Flat

[ ] Curved [ ] Low heat resistant [ ] High heat resistant [ ] Very smooth surface [ ] Medium smooth surface [ ] Rough surface

Others:____

6. Safety:

[ ] Less [ ] More

Others:____

7. Angle of rotation:

[ ] Theoretical calculated (fixed) [ ] Adjustable

Others:____

8. Cost:

[ ] Expensive [ ] Cheap [ ] Relevant

Others:____

9. Rate the following criteria according to your needs:

1-The least to 3-The most

Criteria/Rating	1	2	3
Durability			
Serviceability			

10. Suggestions:

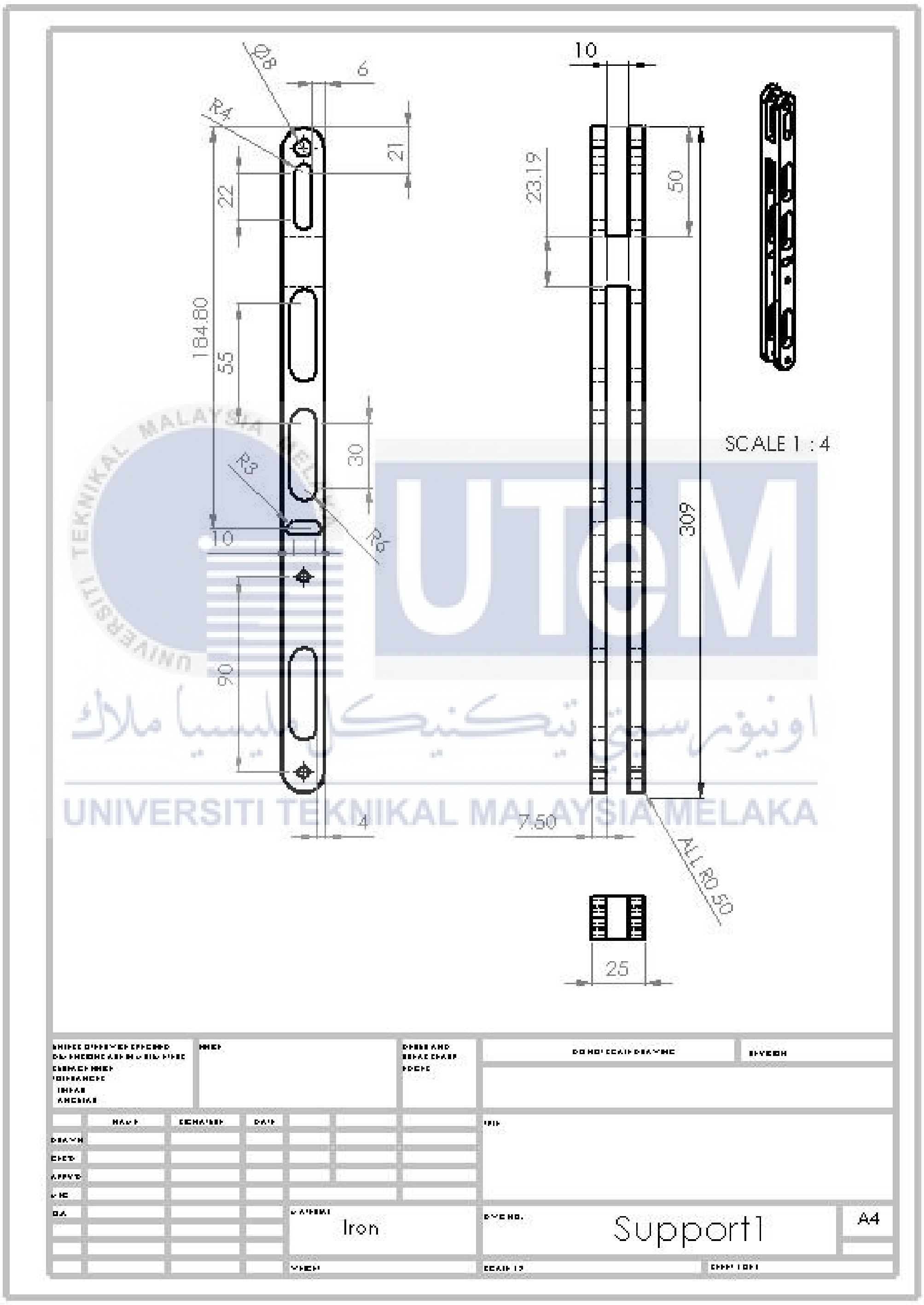
____

____

Thank you.

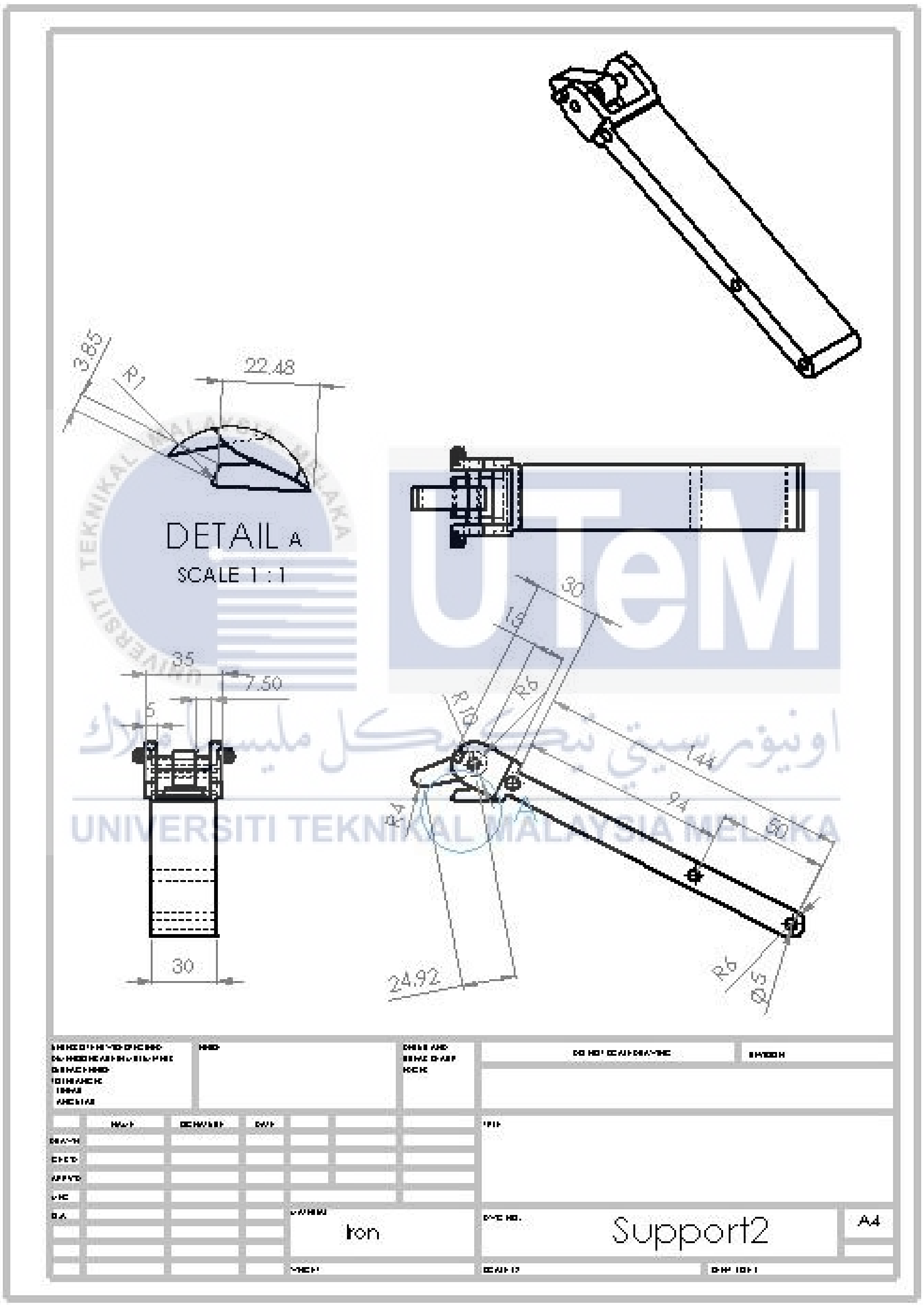
APPENDIX B1

Support1 2D drawing



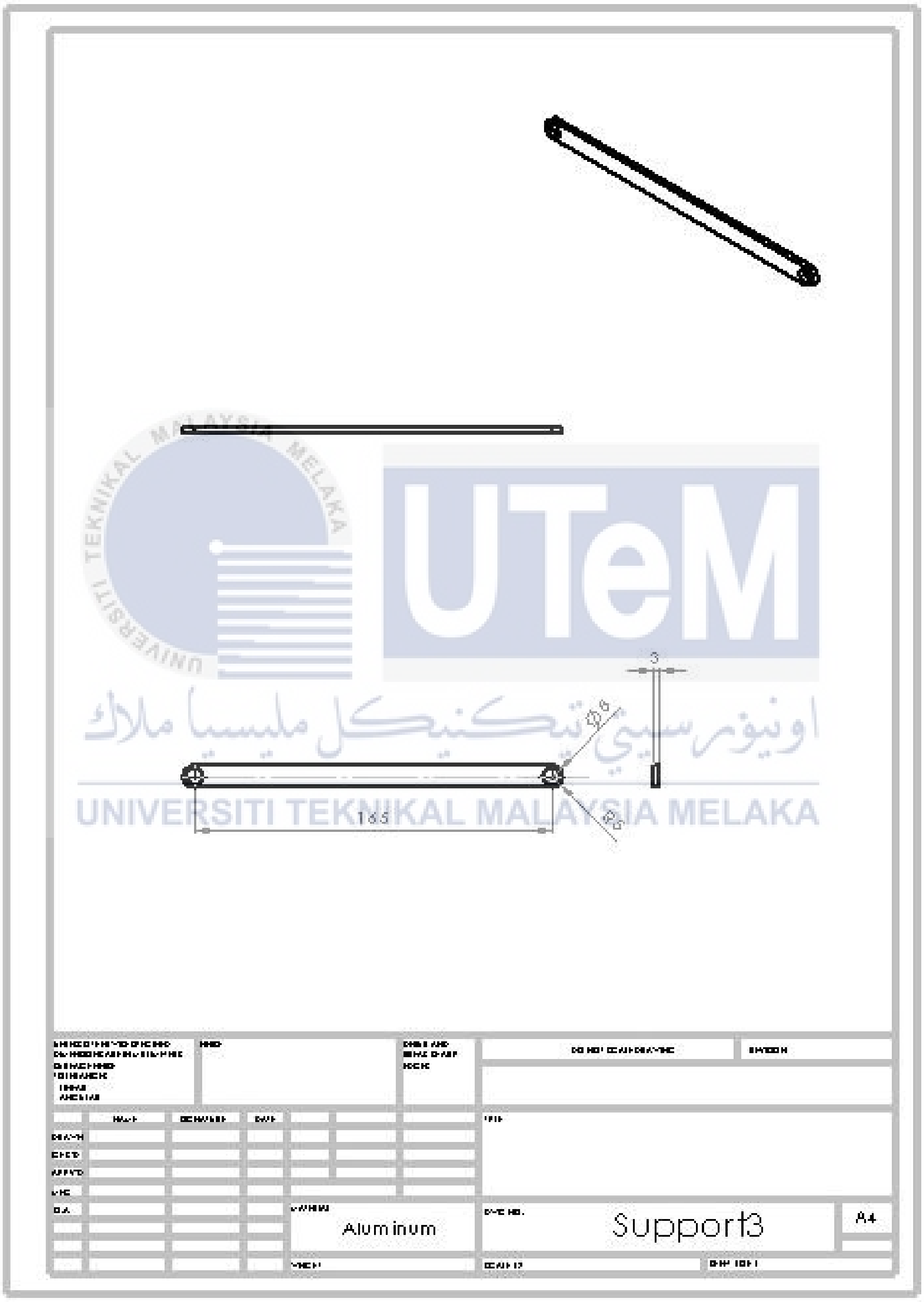
APPENDIX B2

Support2 2D drawing



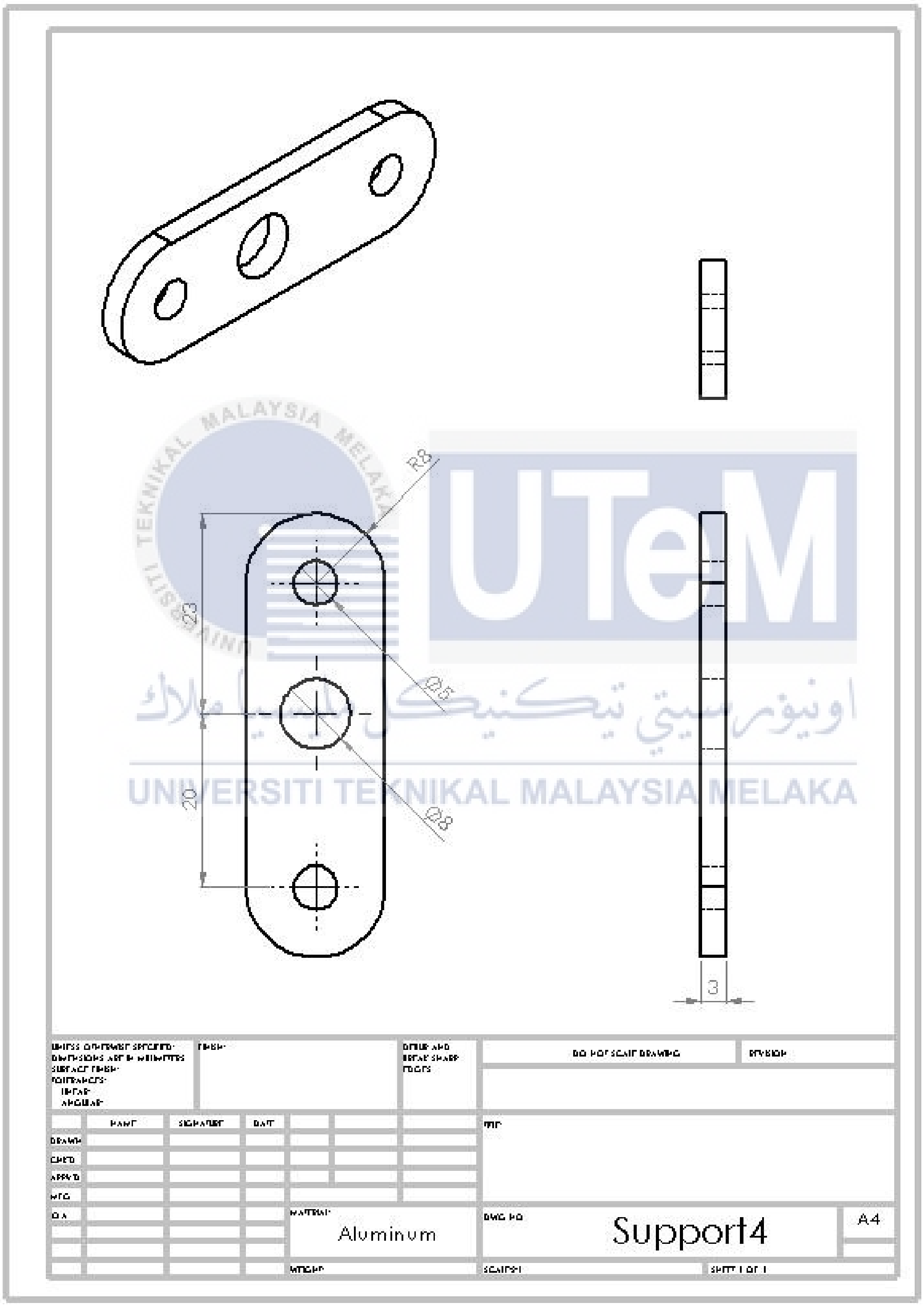
APPENDIX B3

Support3 2D drawing



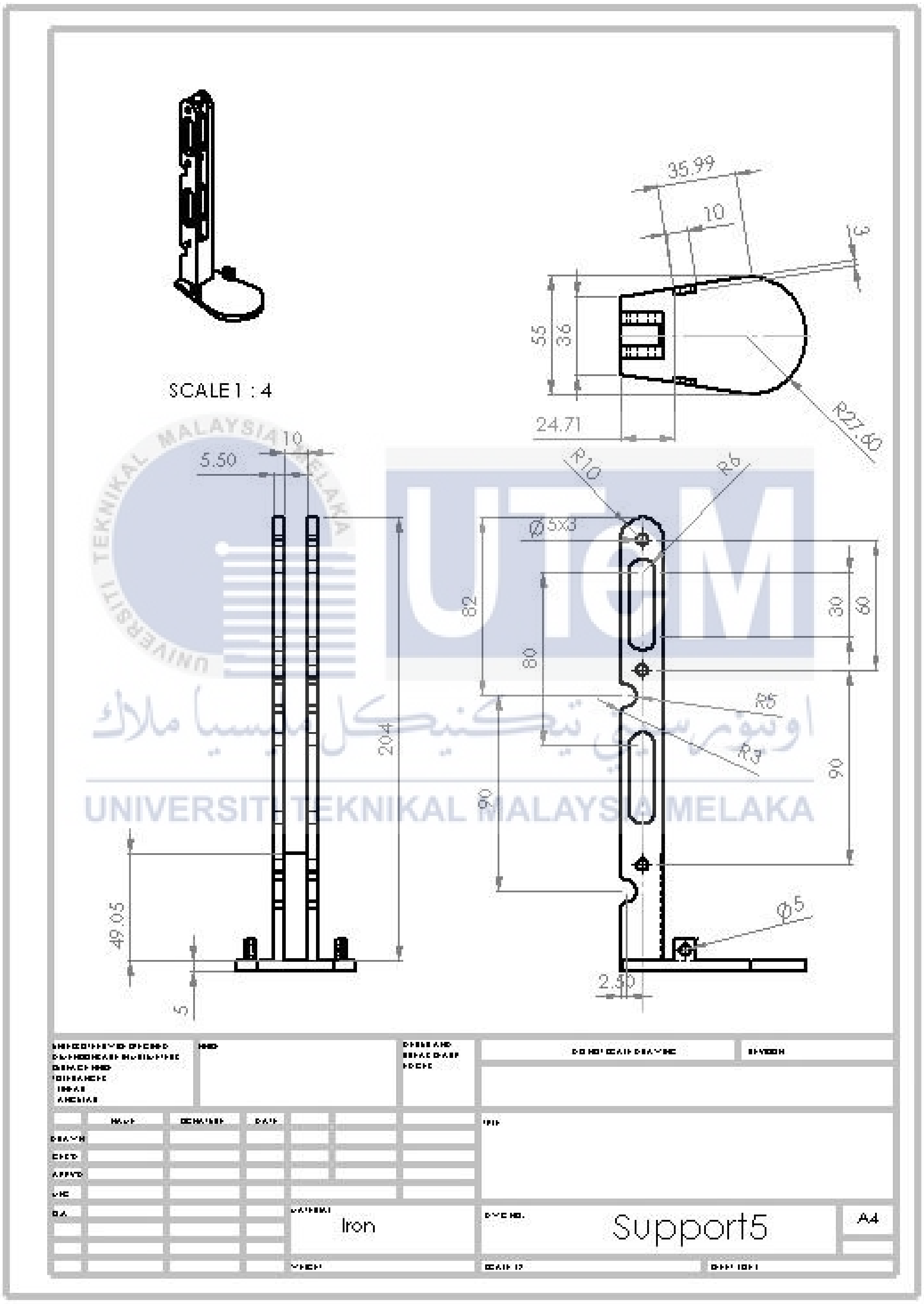
APPENDIX B4

Support4 2D drawing



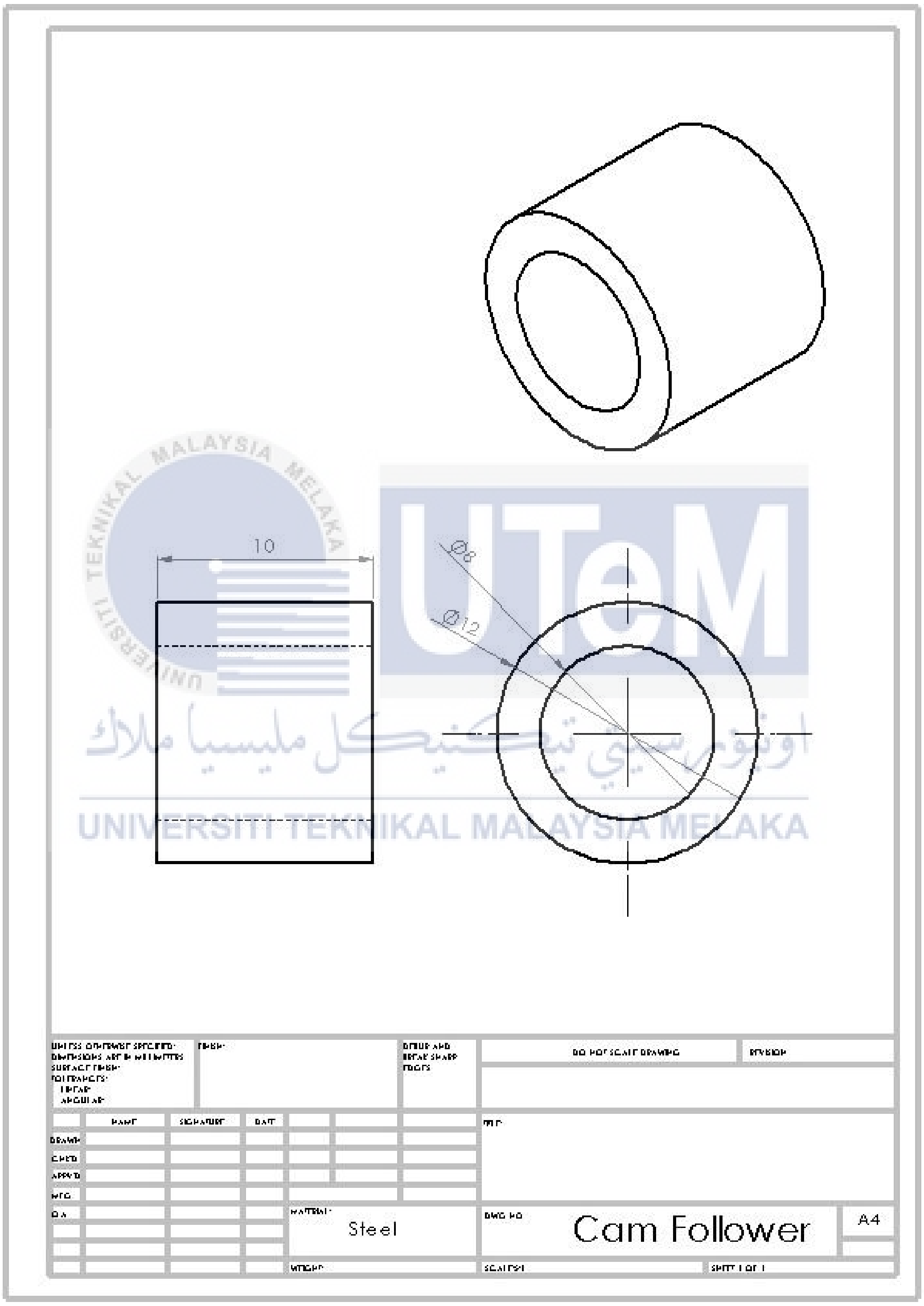
APPENDIX B5

Support5 2D drawing



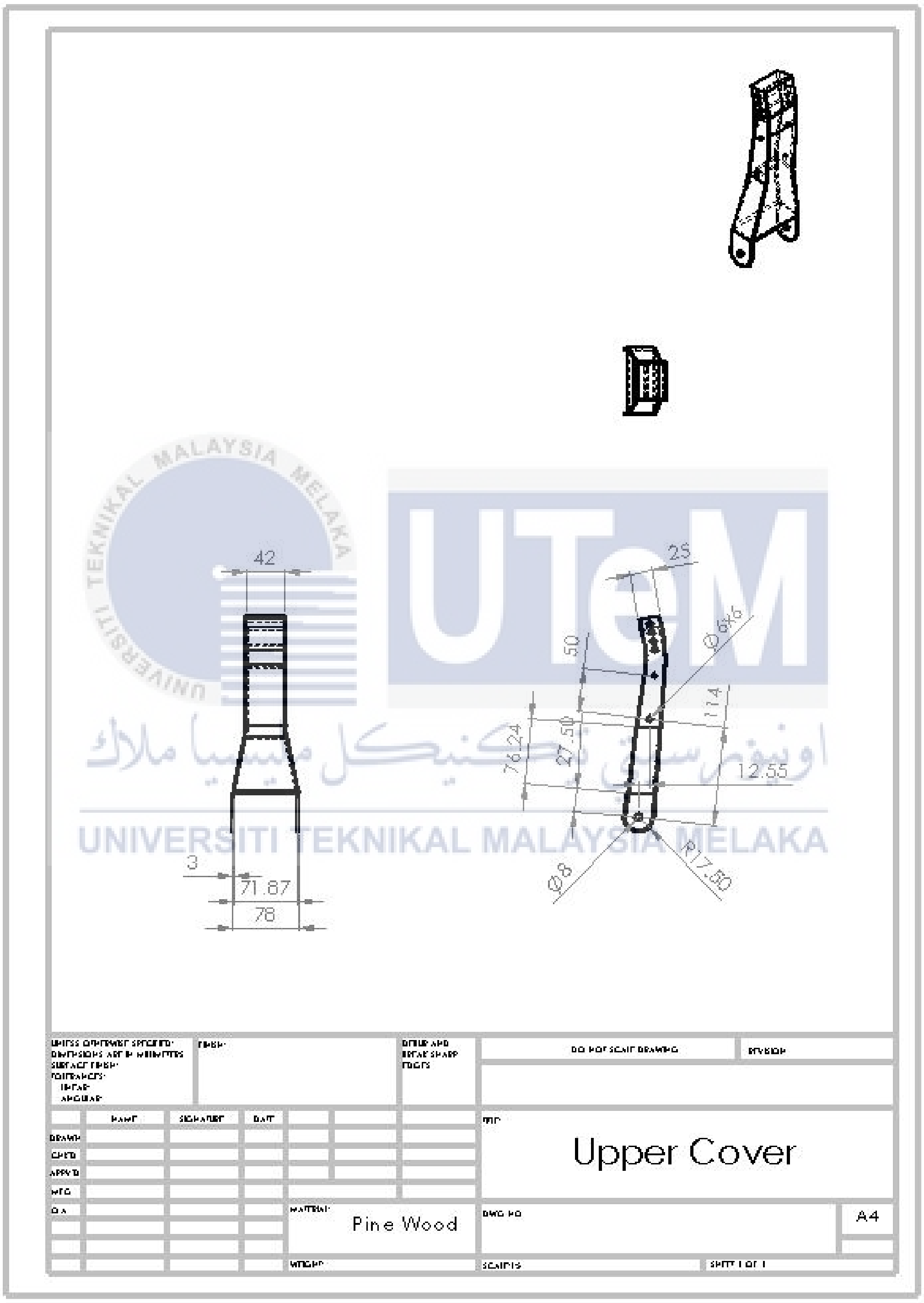
APPENDIX B6

Cam follower 2D drawing



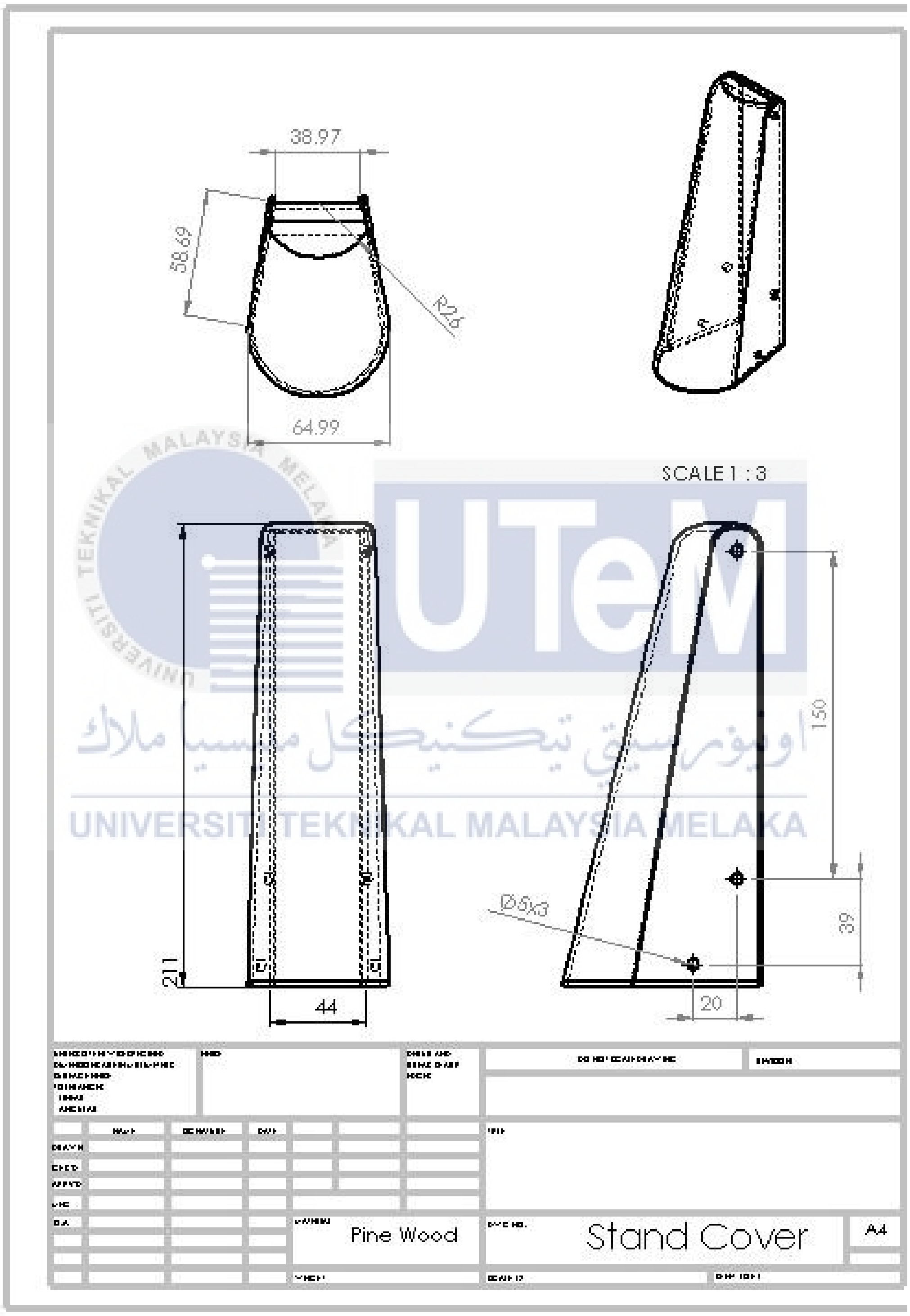
APPENDIX C1

Upper cover 2D drawing



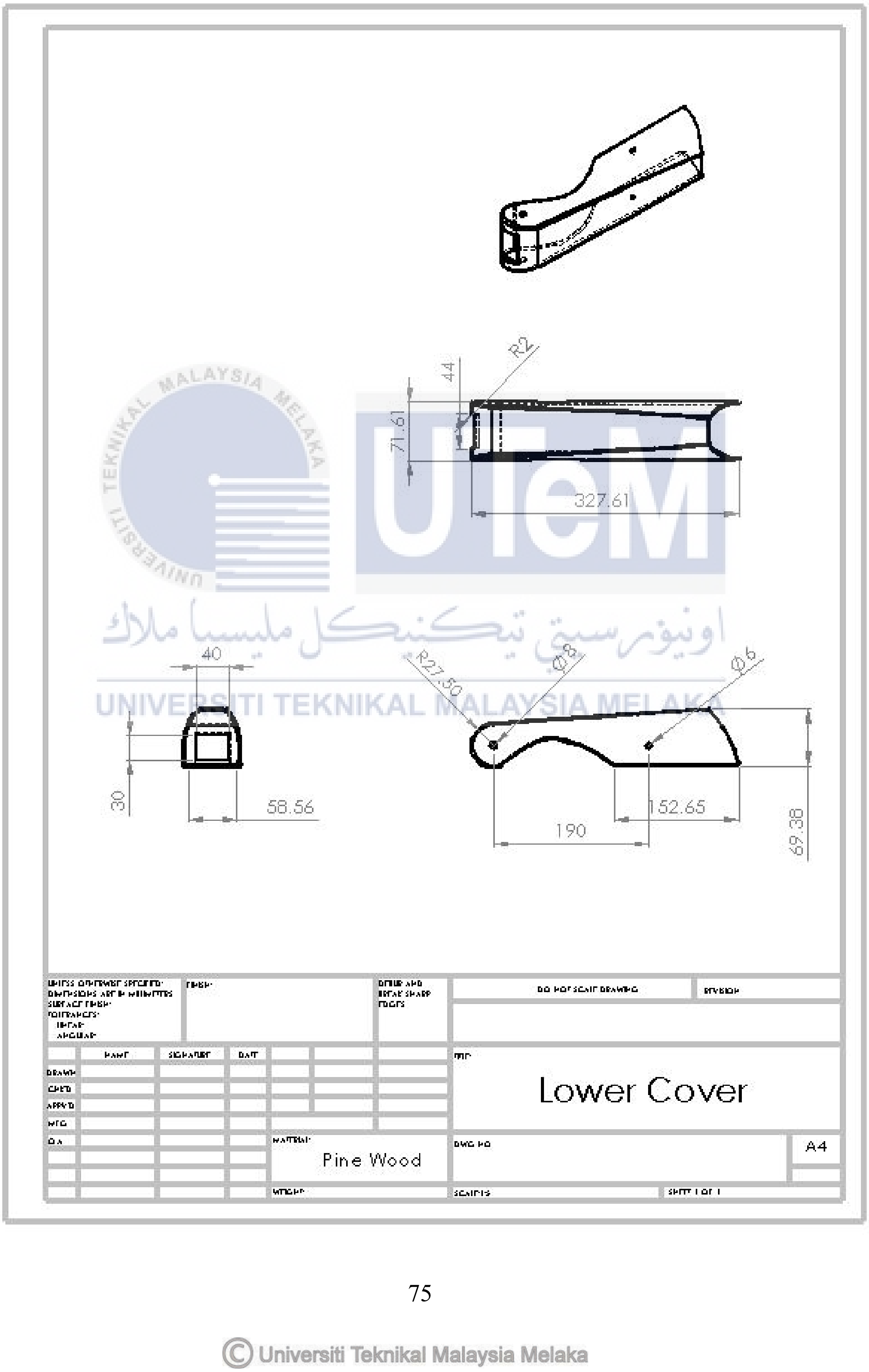
APPENDIX C2

Stand cover 2D drawing



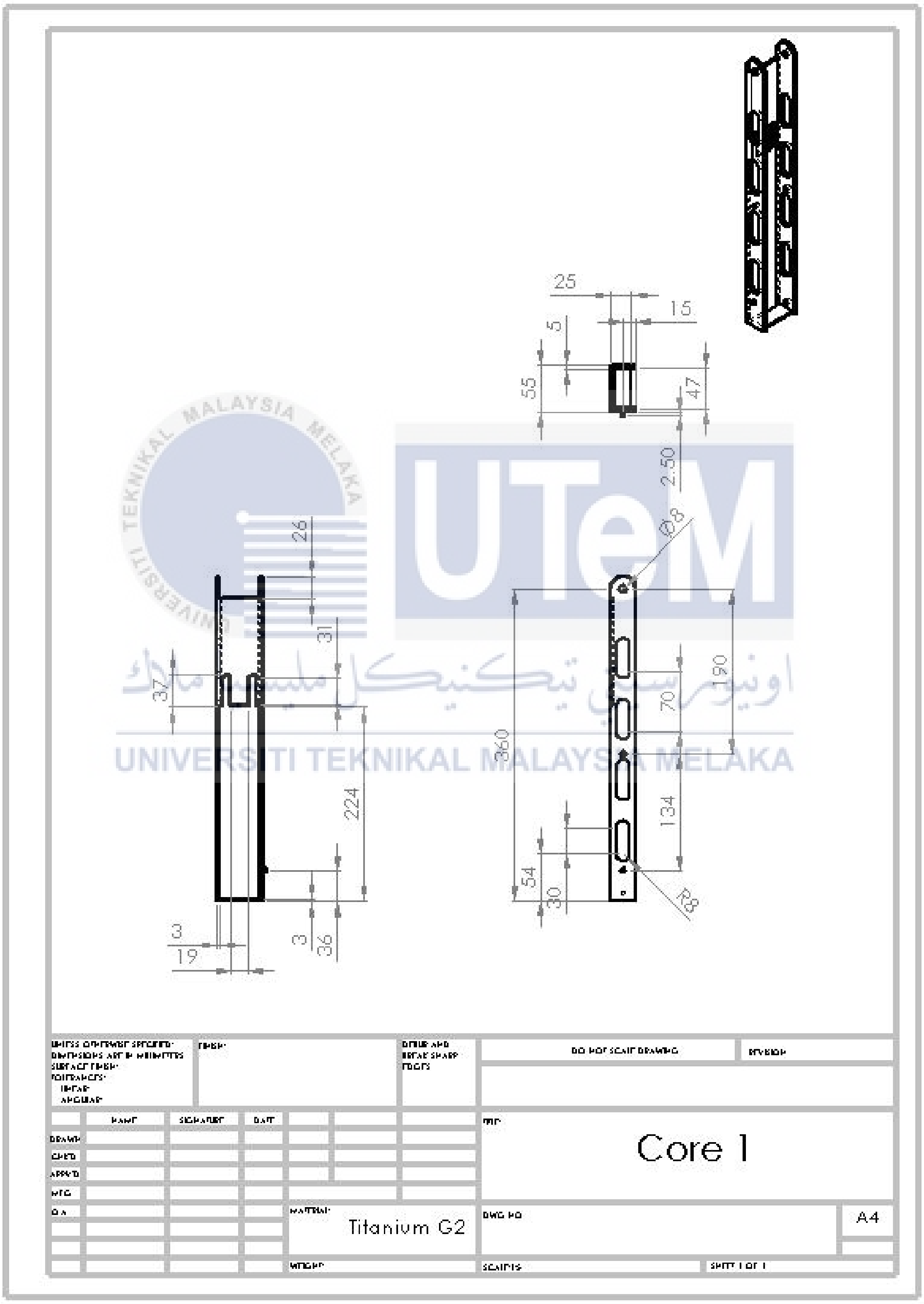
APPENDIX C3

Lower cover 2D drawing



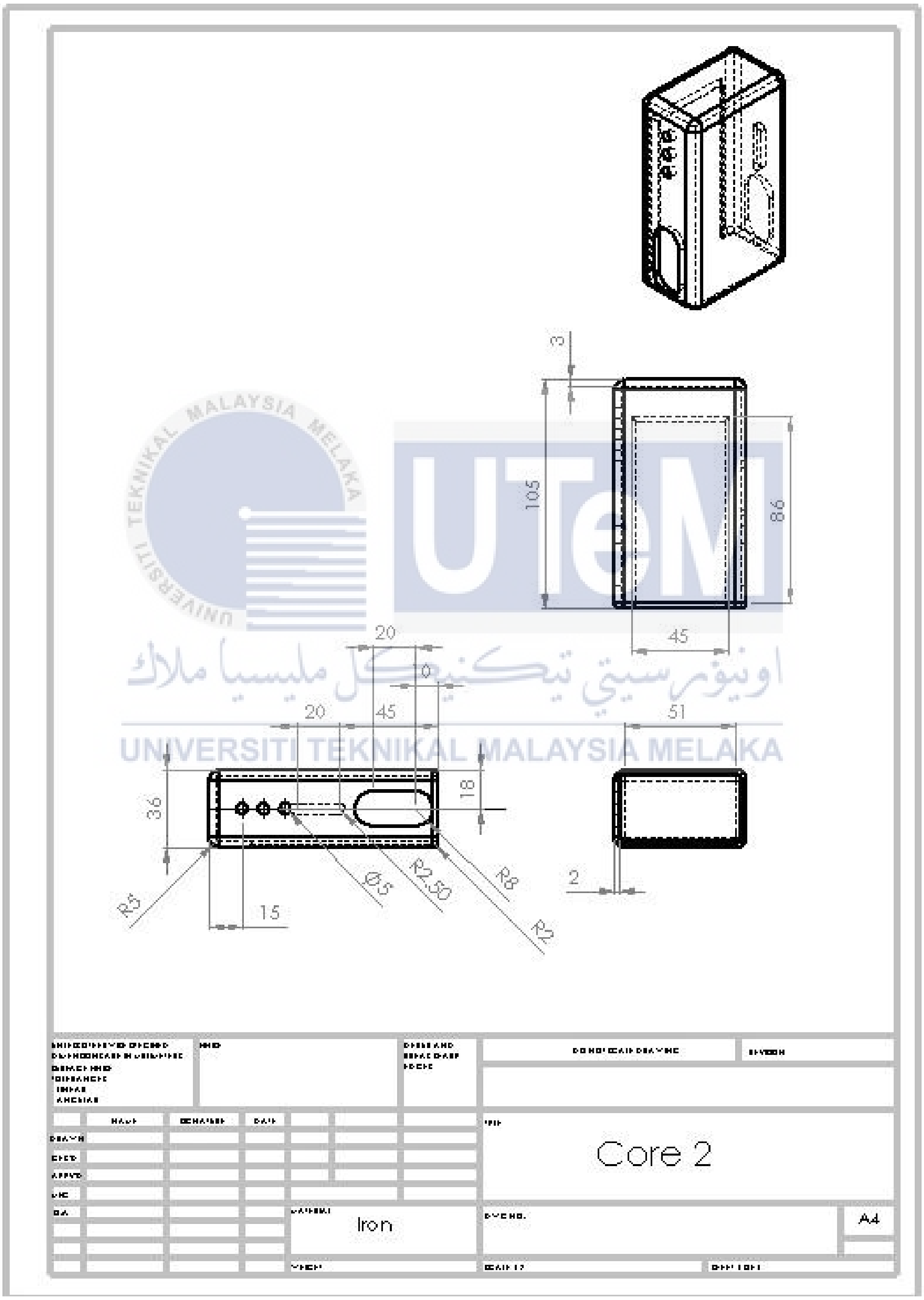
APPENDIX D1

Core1 2D drawing



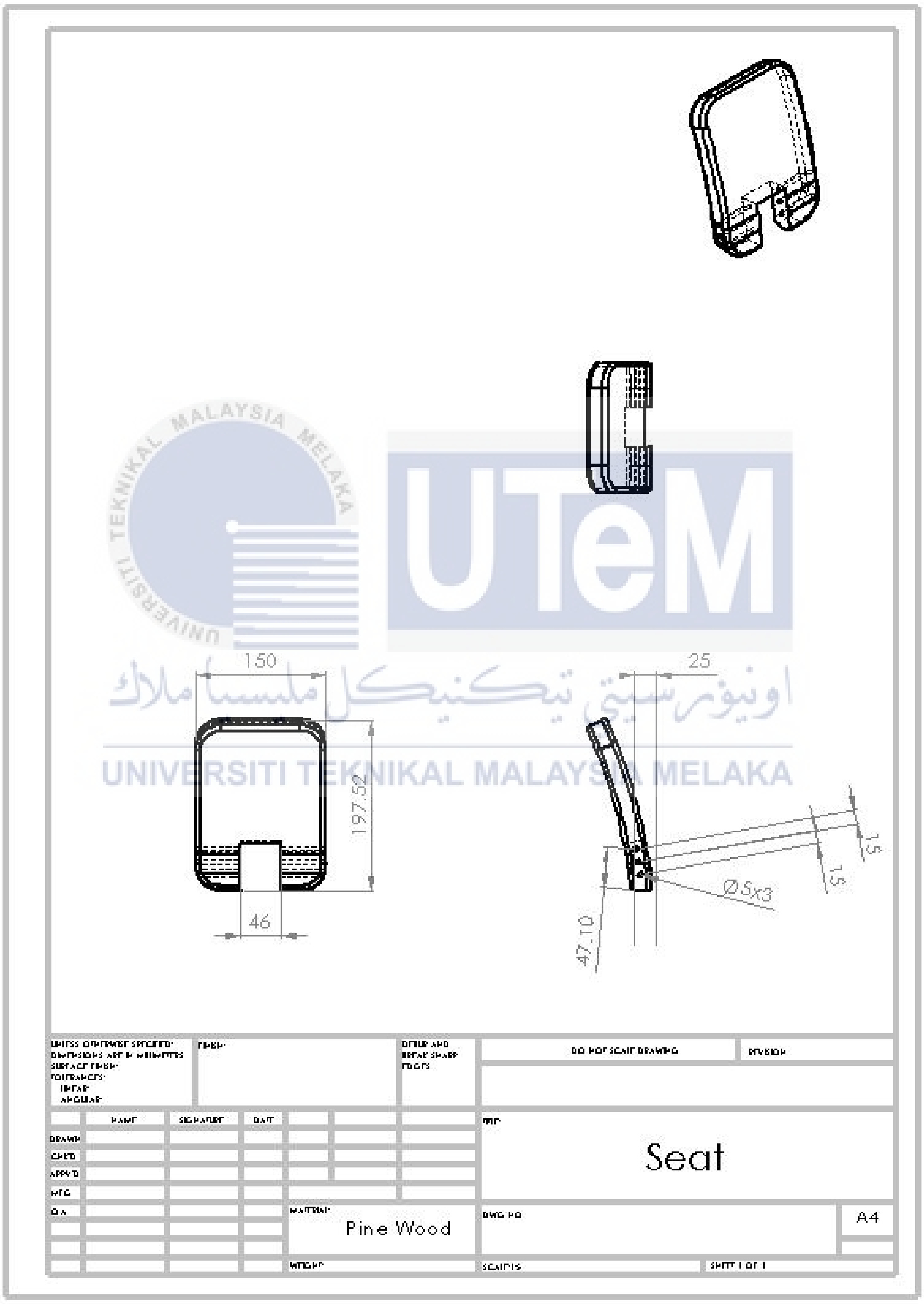
APPENDIX D2

Core2 2D drawing



APPENDIX E1

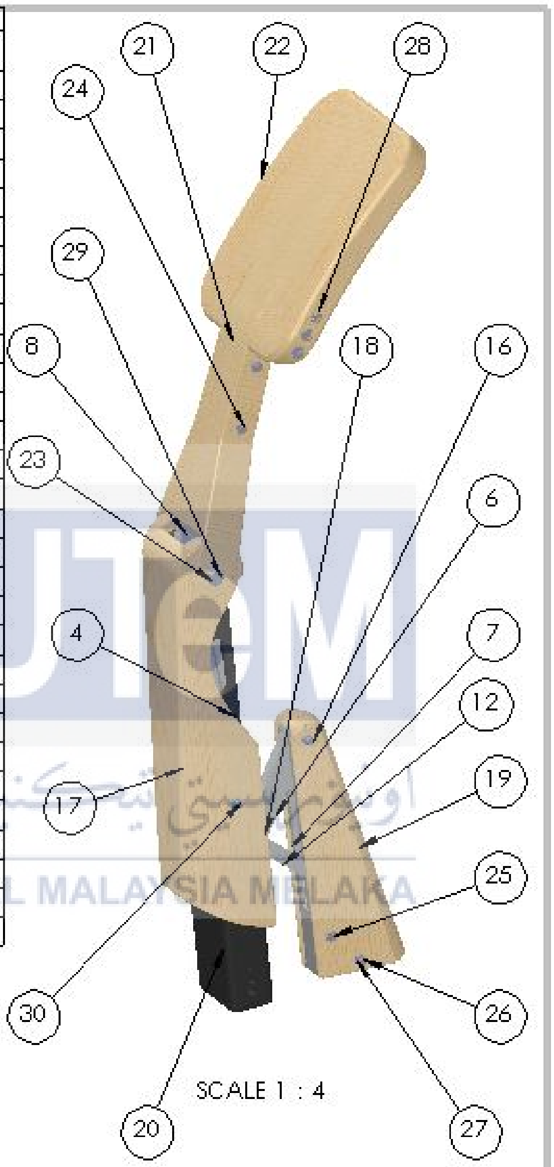
Seat 2D drawing



APPENDIX F1

Full assembly drawing

ITEM NO.	PART NUMBER	New1/QTY.
1	Support1	1
2	Part2-2	1
3	Part1	1
4	Support5	1
5	Part3	1
6	Support3	1
7	Support6	1
8	Support2	1
9	Part3^Assem2	1
10	Part4^Assem2	1
11	Part5^Assem2	1
12	Support4	2
13	Part1^Assem2	1
14	Part2^Assem2	1
15	Part6^Assem2	1
16	Part7^Assem2	1
17	Core 1	1
18	Lower Cover	1
19	Stand Cover	1
20	Core 2	1
21	Upper Cover	1
22	Seat	1
23	Rod2	1
24	Rod1	2
25	Rod3	1
26	Rod4	1
27	Nut M8	16
28	Countershank Screw	6
29	Nut M13	4
30	Rod5	1

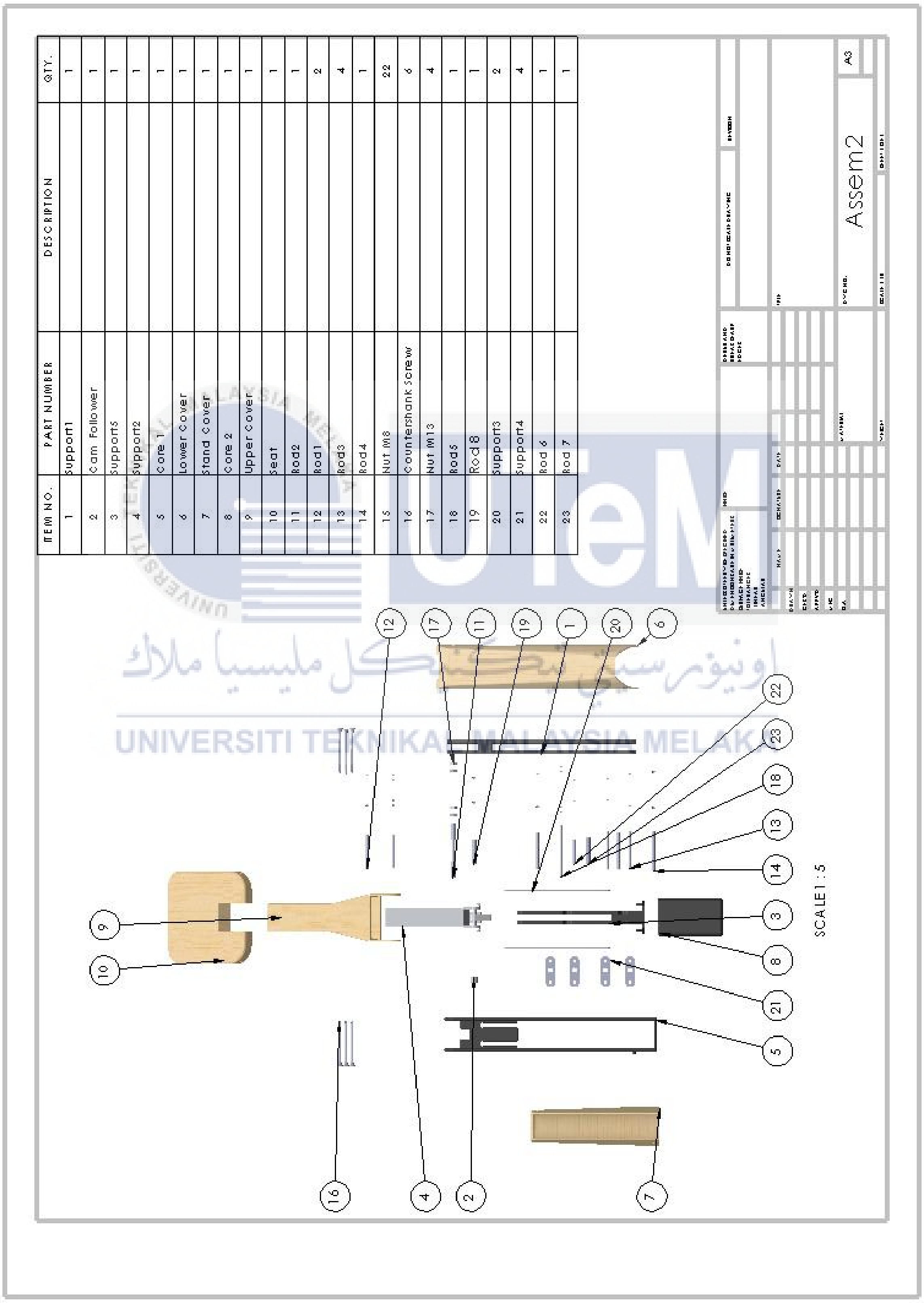


Full Assembly

A4

APPENDIX F2

Full exploded view



ITEM NO.	PART NUMBER	QTY.
1	Support1	1
2	Cam Follower	1
3	Support5	1
4	Support2	1
5	Core 1	1
6	Lower Cover	1
7	Stand Cover	1
8	Core 2	1
9	Upper Cover	1
10	Seat	1
11	Rod2	1
12	Rod1	2
13	Rod3	4
14	Rod4	1
15	Nut M8	22
16	Countershank Screw	6
17	Nut M13	4
18	Rod5	1
19	Rod8	1
20	Support3	2
21	Support4	4
22	Rod 6	1
23	Rod 7	1