Design and Fabrication of Curb-Climbing Mechanism for a Wheelchair using 3D Printing Technology

by

Lye Siew San

14896

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2015

Universiti Teknologi PETRONAS
32610 Bandar Seri Iskandar,
Perak Darul Ridzuan,
Malaysia

CERTIFICATION OF APPROVAL

Design and Fabrication of Curb-Climbing Mechanism for a Wheelchair using 3D Printing Technology

by

Lye Siew San

14896

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

DR KHURRAM ALTAF

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

LYE SIEW SAN

ABSTRACT

The main problem that the wheelchair users faced is very limited movement where ordinary wheelchairs are unable to climb curb or stairs and this bring troubles to the users where they cannot use public transport or even go out from their houses. Various scopes and designs of different curb climbing wheelchairs were studied and reviewed based on the past researches and designs did by others. This project came out with a design of mechanism of wheelchair that can climb a curb manually. The rear wheels of the wheelchair were modified into bearing-like wheels together with curb climbing handles. CATIA software was used in this project for drafting and detailed 3D modeling. The function ability of the wheelchair mechanism prototype and proving of idea was tested by 3D printing rapid prototyping and the results shows that the idea was a success.

ACKNOWLEDGEMENTS

Thank you Universiti Teknologi Petronas for given chance for the author to have chance for doing the Final Year Project of design a curb-climbing mechanism of wheelchair using 3D printing technology that is available in Universiti Teknologi Petronas. Thank you for Petronas company for sponsor the author for the whole project for the materials and the fees of the course.

Special appreciation is to be given to supervisor Dr Khurram Altaf for given very good supervisory job during the whole period of doing the project. Dr Khurram also gave a lot of encouragement and mentally support so that the author would not give up during facing the problems occurred during the project period. Besides, Dr Khurram also gave physically help where during the process of 3D printing and assembly of the mechanism.

The author also would like to show appreciation to family members and friends that supported the author and gave mentally support throughout the project period.

Table of Contents

List of Figures

List of Tables

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

3D printing technology is now an arising potential technology which uses the method of additive manufacturing in doing models, prototypes and real functional things. 3D Printing Industry (2014) mentioned that additive manufacturing is quite different from the ordinary existing manufacturing technologies which it builds up the parts layers by layers additively at a very small increasing scale. 3D printing was invented since 1984 by Charles Hull and continues to be research by people until present and these researches and design process will be continue on in the future (T. Rowe Price Connections, 2011). This is due to 3D printing technology brings a lot of advantages. 3D printing is capable to do many complex designs where it is very difficult or impossible to do with the ordinary traditional manufacturing techniques such as casting (Tyagi, 2012). In this case, 3D printing save a lot of time, money, materials, manufacturing processes and manpower in the design, testing and manufacturing and assemble process of a new product. The reasons that 3D printing technique is chosen for this project is that it is expected to see increase of build rates by each 3D printer in the future where labor costs can be reduced (Roland Berger Strategy Consultants GmbH, 2013). On the other hand, Roland Berger Strategy Consultants GmbH also mentioned that it is also expected that the manufacturing material powder prices to be going down in the future where this actually can reduce the costs of the products being produced. So, 3D printing enable people to think of more creative and innovative ideas and they are all possible to be achieve by 3D printing technology (Srinivasan and Bassan, 2012).

1.2 PROBLEM STATEMENT

There are some surveys and researches done on the wheelchair users regarding the problems usually faced by them. The results showed that users on wheelchairs feel very limited movement which is only can move in same floor and it is very hard for the usage of public transport or even just go out from their house. An issue being raised up here about whether wheelchairs can climb curb.

So this project is going to resolve the problems for the main problems usually faced by wheelchair users which the mechanism can be done by using 3D printing prototyping. To solve the problems that users face every day, curb climbing mechanism can be one of the solutions (Leo & Gennaro, 2011). The curb climbing mechanism should be can climb can also descend a curb safely and smoothly (Leo & Gennaro, 2011).

1.3 OBJECTIVE

- To design and fabricate a concept model of manually curb climbing mechanism of wheelchair via functional prototype by 3D printing technology.

1.4 SCOPE OF STUDY

- To study about the scope of curb climbing wheelchair and the function ability of the new design curb climbing mechanism of wheelchair.

CHAPTER 2

LITERATURE REVIEW

2.1 SCOPE OF 3D PRINTING

According to McMath (2006)

> Fabricating components for research and development work presents a special problem. In general, the quantities required are very small, making the delays associated with traditional manufacturing processes unacceptable. Rapid prototyping has evolved specifically to address this challenge. Based on a variety of additive processes, rapid prototyping can produce components in days, or sometimes hours, rather than weeks, and without extensive labour costs. Rapid prototyping has become suitable for the one-off production of complex fully-functional models, and can even be used to manufacture components in reasonably-sized production volumes. (p. 40 – 43)

2.1.1 Applications of 3D Printing

3D printing technology can be applied in many different sectors in industries. In medical and dental sector, people use 3D printing technology to produce medical devices such as hearing aids, orthotic insoles for shoes especially for people who met accidents and sick of diabetes (3D Printing Industry, 2014). 3D Printing Industry mentioned that medical implants also being carried out where the supports, bones and even organs are being 3D printed to assist in this area and it does help on a lot of people who sick of fracture of bones and etc. 3D Printing Industry also mentioned that 3D printing technology is used in aerospace industry for product development and prototyping for some of the parts of the aircraft. There is a first 3D printed robotic aircraft created on 2011 where it save a lot of money and 3D printing technology allows the wings of the airplane to be built in elliptical shape which can improve the efficiency besides reduce costs and time of manufacturing (T. Rowe Price Connections, 2011).

3D printing also being used in automotive area for prototyping and developing improve materials of automotive parts while on the other hand 3D printing technology actually helps out in jewellery, fashion, art, design, sculpture, and architecture sector in reducing the steps of fabrication and maximize the creativity (3D Printing Industry, 2014). 3D Printing Industry also mentioned that 3D printing is also looking forward to be a process of food production in the future.

2.1.2 Materials Available for 3D Printing

ZPrinter ® 450 is the 3D printer that will be used in this project. The types of materials that are suitable for this 3D printer to print are zp130 which is known as the High Performance Composite powder, zp131 which is also known as the Premium Performance powder, zp140 which is also known as High Performance Plus powder (Z Corporation, 2007) and zp150 which can produce stronger parts with nice color which also consists of incredible whiteness and water cure finishing option (Z Corporation, 2010). The zp130 has high feature definition, vibrant colors, good dimensional accuracy and high strength with infiltration while the zp131 can print very tough objects, has extreme accuracy with nice colors (Z Corporation, 2007). The zp140 has water cure post-processing option available, lower costs and has the brightest white color among all the materials (Z Corporation, 2007). This project used material zp150 for the printing of the mechanism for prototype because of the availability of this material in Universiti Teknologi PETRONAS and to produce strong parts for testing purpose.

2.2 SCOPE OF WHEELCHAIR

Cross (2012), Waugh (2013) and Armstrong, Borg, Krizack, Lindsley, Mine, Pearlman and etc. (2008) defined wheelchair as a manually or electric powered mobile wheeled device and seating support system which it can consist of three or more wheels which usually provide seating position for the usage of people with mobility impairments.

2.2.1 Types and Usage of Wheelchair

There are varieties of wheelchairs in the market nowadays. TABLE 1 below shows the several types of wheelchairs and usage of each type of wheelchair.

Table 1: Types and Usage of Wheelchair (Source: Waugh (2013) Glossary of Wheelchair Terms and Definitions Version 1.0 and Weinberg & Mignolo (2012) 35 Wildly Wonderful Wheelchair Design Concepts)

No.	Types	Usage
1	Manual wheelchair	Ordinary wheelchair which need the users or an assistant to move the wheelchair.
2	Sport wheelchair	Specifically designed for sports such as racing, dancing and basketball.
3	Variable positioning wheelchair	Available to provide alternative positions other than sitting position, such as standing, tilt, recline, laying down and other positions.
4	Aisle wheelchair	Used in narrow aisles such as on aircrafts.
5	Activities of Daily Living (ADL) wheelchair	Used for daily living activities functions such as for shower, bath and toilet.
6	Specialty power wheelchair	Designed for specific functions such as stairs climbing and balancing purpose.

2.2.2 Criteria of Wheelchair

A wheelchair is consider suitable and appropriate generally based on a few conditions such as when the wheelchair can achieve the needs of users and surrounding conditions, can provide a proper fit and suitable support, is tested safe and have a long-lasting life which does not spoil easily, design is safe where will not cause injuries to the users or assistants, available in the market of the country and the price is affordable by the user (Armstrong, Borg, Krizack, Lindsley, Mines, Pearlman, et al., 2008). Armstrong and etc. (2008) also mentioned that it is very important that a wheelchair actually allows mobility disable people so that they can work or study and participate in normal daily works and life. Thus, a wheelchair must fit the users well and provide a good postural support to the users so that can reduce the pressure and increase comfort of the users as they spend most of the time on the wheelchair – their second legs (Armstrong, et al., 2008).

In designing the wheelchairs, the strength of the materials must be taking into account to avoid failure or spoil of the wheelchair during function time (Armstrong, et al., 2008 and Brubaker, 1989).

Brubaker (1989) stated that there are still a lot of areas to be improved in wheelchairs. According to Brubaker (1989)

1) Frames can have higher strength to lower weight ratio
2) Reduce the steps for manufacturing processes
3) Tires and wheels need to be improve in wear-resistance without affecting the ride of wheelchair users so that the tires and more durable and long-lasting
4) The seating materials need to increase the comfort, durability and ease of cleaning functions

Figure 1 shows the components of an ordinary wheelchair.

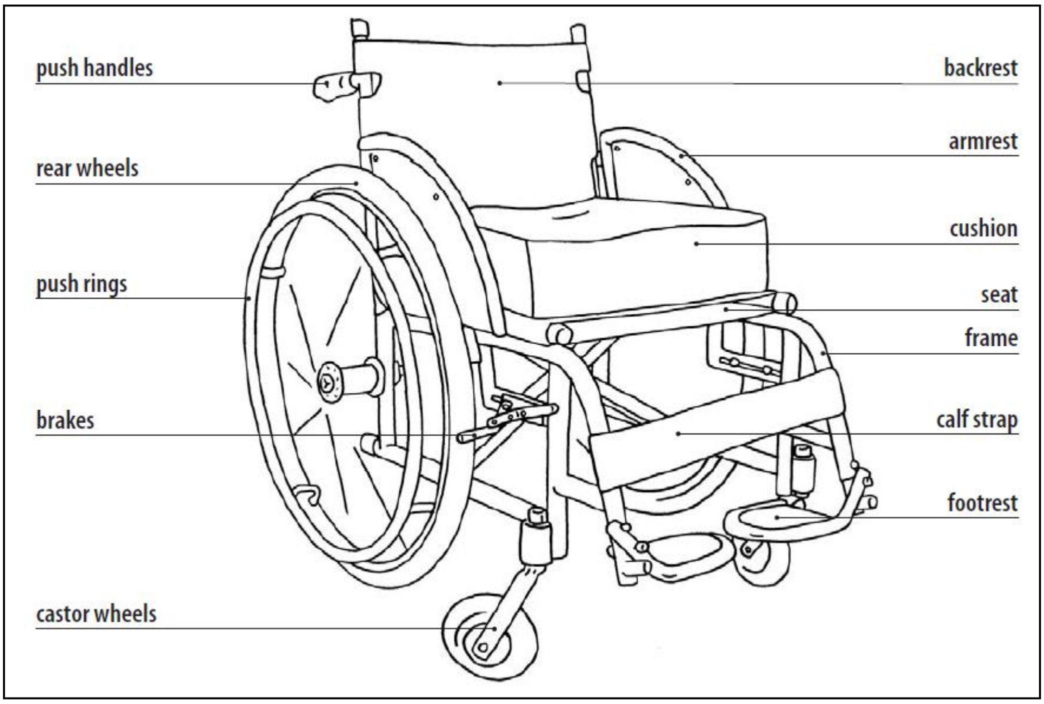


Figure 1: Components of Ordinary Wheelchair (Source: Armstrong, et al. (2008) Guidelines on the Provision of Manual Wheelchairs in Less Resourced Settings)

2.3 IDEA OF MECHANISM OF CURB-CLIMBING OR STAIRS-CLIMBING WHEELCHAIRS

As to be discussed in the section below are the designs of other researchers of curb-climbing or stairs-climbing wheelchair. These designs' considerations and results are being considered and be reference when making the design for curb-climbing mechanism of this project.

2.3.1 Leo, Alex and Gennaro's design (2011)

Leo, Alex and Gennaro (2011) design the wheelchair to run with DC battery and linear actuator. Their mechanism of climbing is combination using linkages, chains, sprockets and gears to lift up and to descend the wheelchair. Their total wheelchair lifting and descend process is about fourteen seconds and it is tested safe and make sure the wheelchair user is remain horizontal and stable in position. Leo, Alex and Gennaro (2011) also mentioned that in normal condition which is without climbing or descending a curb, the wheelchair is still able to move using the big wheels and the small wheels. The design is as shown in Figure 2.

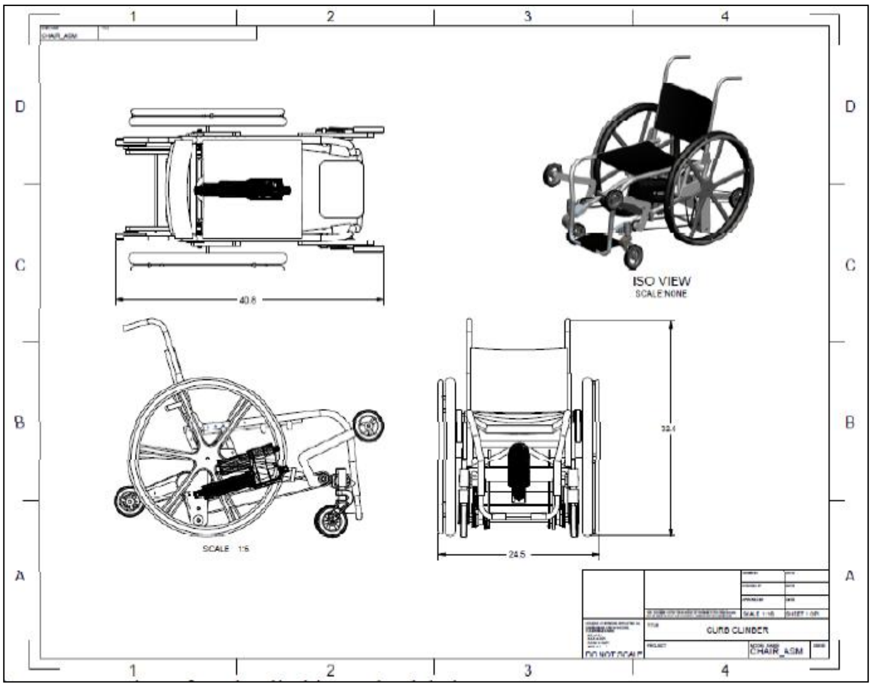


Figure 2: Design of Curb Climbing Wheelchair of Leo, Alex and Gennaro (Source: Leo, Alex and Gennaro (2011) Curb Climbing Wheelchair)

2.3.2 Ekachai and Teerapol's design (2011)

Ekachai and Teerapol (2011) design their wheelchair as a stair climbing wheelchair which attached of two five-spoke wheels and slot plates on the wheelchair. The five-spoke wheels usage is to climb the stairs while the function of slot plates is slide the rear big wheels of wheelchair (Ekachai & Teerapol, 2011). Their wheelchair is powered by an electric motor. During process of climb stairs, the rear big wheels of wheelchair will slide to the front part of the wheelchair and go back to original position when it is moving on the floor (Ekachai & Teerapol, 2011). Ekachai and Teerapol's wheelchair can go up and come down the stairs with 200mm maximum riser height and 80kg maximum payload. The design of Ekachai and Teerapol is as shown in Figure 3 and Figure 4.

Figure 3: Ekachai and Teerapol's Wheelchair with Two 5-spoke Wheels and Slot Plates (Source: Ekachai and Teerapol (2011) A Prototype of a Stair-Climbing System for a Wheelchair)

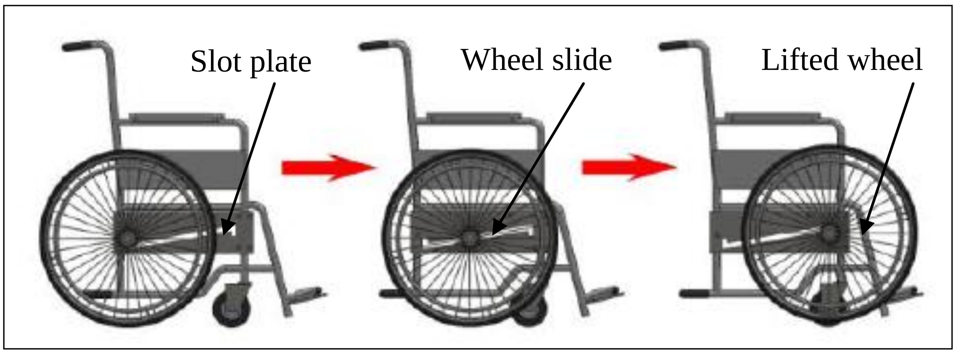


Figure 4: Slot Plate Function of Wheelchair (Source: Ekachai and Teerapol (2011) A Prototype of a Stair-Climbing System for a Wheelchair)

2.3.3 Murray and Takakazu's design (2003)

Murray and Takakazu had come out with a design of wheelchair mechanism with high single-step capability on 2003. "The mechanism is based on front and rear wheel clusters connected to the base (chair) via powered linkages so as to permit both autonomous stair ascent and descent in the forward direction, and high single-step functionality for such as direct entry to and from a van." was written by Murray and Takakazu (2003). The design is as shown in Figure 5 and Figure 6.

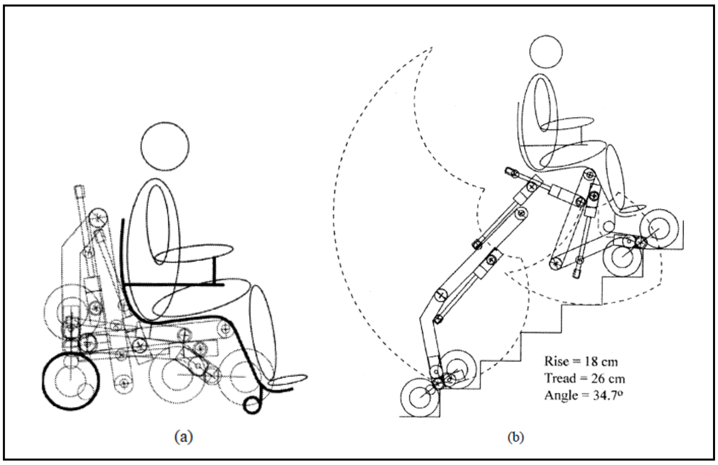


Figure 5: Murray and Takakazu's High Step Stair-Climbing Mechanism in (a) Barrier-free Mode and in (b) Stair-climbing Mode (Source: Murray and Takakazu (2003) Modelling of a Stair-Climbing Wheelchair Mechanism with High Single-Step Capability)

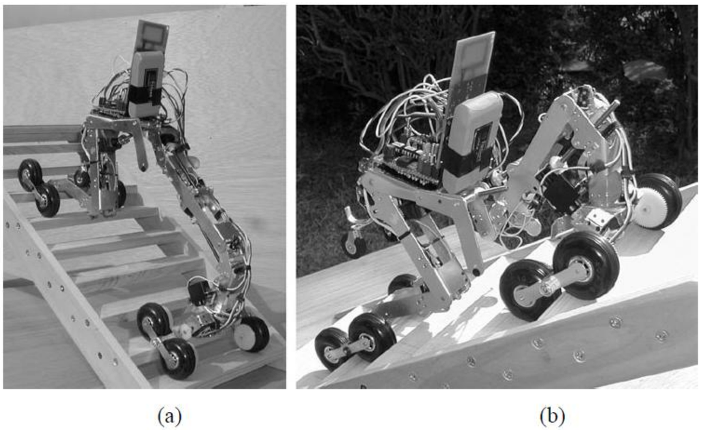
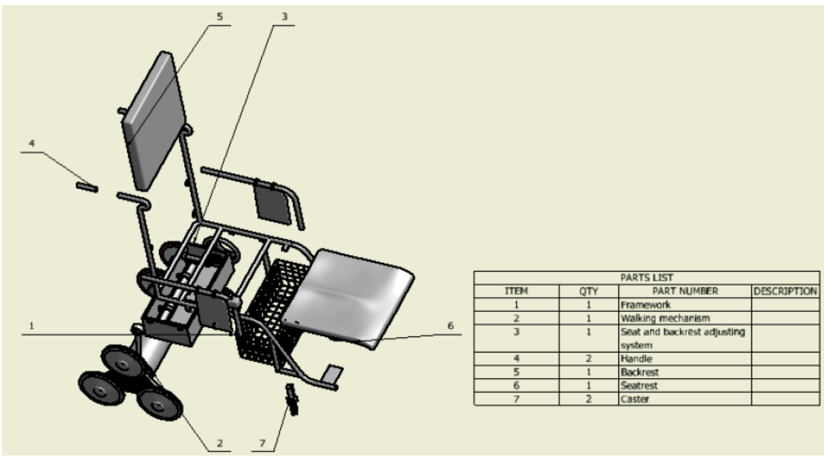


Figure 6: Murray and Takakazu's Stair Climb Operation when (a) Ascent and (b) Descent (Source: Murray and Takakazu (2003) Modelling of a Stair-Climbing Wheelchair Mechanism with High Single-Step Capability)

2.3.4 Lin & Xi's design (2012)

Lin & Xi (2012) designed their wheelchair which can works in 3 modes which are to climb stairs, in powered and manual mode. They design the seat backrest can be adjust according to the centre of gravity before the ascent and descent process and they had design a locking system to make sure the wheelchair is safe to be used. Their wheelchair design has some advantages as compared to tacked stair-climbing wheelchair, leg stair-climbing wheelchair and auxiliary stair-climbing wheelchair where it has lighter weight, more stable, faster process of climbing and descent the stairs and reduces the number of assist. The design is as shown in Figure 7 and Figure 8.

Figure 7: Lin & Xi's Stairs-Climbing Wheelchair Design (2012) (Source: Lin and Xi (2012) An Optimization Design for the Stair-Climbing Wheelchair)



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Framework	
2	1	Walking mechanism	
3	1	Seat and backrest adjusting system	
4	2	Handle	
5	1	Backrest	
6	1	Seatrest	
7	2	Caster	

Figure 8: Lin & Xi's Stairs-Climbing Wheelchair's Assembly Diagram and Exploded View (Source: Lin and Xi (2012) An Optimization Design for the Stair-Climbing Wheelchair)

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY

This project was carried out for two semesters which are Final Year Project I (FYP I) and Final Year Project II (FYP II). The idea of this research is to design curb-climbing mechanism of wheelchair and prove the function ability and to prove it is a workable idea using 3D printed prototype. The software for 3D modelling used in the project is CATIA software.

The design process was divided into first stage (draft design), second stage (error solving of whole mechanism), third stage (error solving of rear wheel), fourth stage (error solving of the rear wheel) and final stage (finalized design).

First, some calculations were made and draft sketch of the wheelchair mechanism was drawn. Then, the mechanism was modified due to some error occurred. Next, the second stage drawings were drawn on CATIA software. There are some errors occurred to the calculations of the mechanism. Thus, the third stage drawings were drawn on CATIA software after some modifications on the calculations of mechanism were made followed by the first 3D printing and testing of rear wheel. However, there are some errors occurred and thus fourth stage drawings was drawn. The second 3D printing and testing was carried out. There were some errors occurred and thus the rear wheel design was modified and followed by third 3D printing of the rear wheel and some other parts of the mechanism. However, there are errors with the tolerance of the ball bearings. After confirm that all the criteria were checked and modified, finalized design of the whole curb climbing mechanism of the wheelchair was drawn followed by last 3D printing of the mechanism. After make sure all the parts printed were no errors in design, all the parts were assembly together.

The processes of the research and design for FYP I and FYP II are as shown in Figure 9.

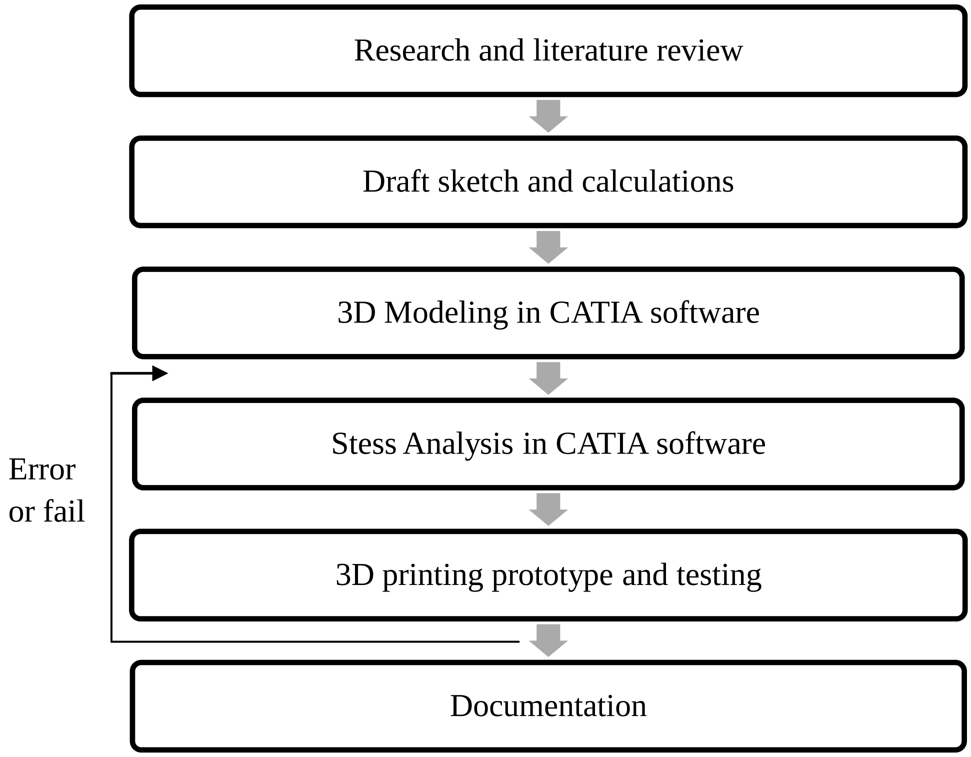


Figure 9: Processes of Research and Design for FYP I and FYP II

3.2 GANTT CHART & KEY MILESTONE

Table 2 and Table 3 show the timeline with the details work involved within 14 weeks for FYP I and FYP II respectively.

Table 2: Timeline for FYP I

No.	Details/ Week	FYP I													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
2	Research and Literature Review		■	■	■	■	■	■	■	■	■				
3	Design of Curb Climbing Mechanism										■	■	■	■	■
4	Sketch of Mechanism in CATIA software													■	■

■ Process

Table 3: Timeline for FYP II

No.	Details/ Week	FYP II													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Stage 1 Design	■	■												
2	Stage 2 Design		■	■											
3	Stage 3 Design				■	■									
4	1st 3D Printing						■								
5	Stage 4 Design							■	■						
6	2nd 3D Printing								■						
7	Finalized Design								■	■	■				
8	Stress Analysis								■	■	■				
9	Final 3D Printing										■	■ ●			

■ Process ● Milestones

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FIRST STAGE DESIGN

The following are the drawings and the dimensions of the first draft design of the curb-climbing mechanism where the handle is located at outside of the wheelchair for the ease of wheelchair users while the climbing wheel is located at inner part the wheelchair.

4.1.1 Drawings of design using CATIA software

Figure 10 and Figure 11 as shown below are the isometric front and back view of first draft design.

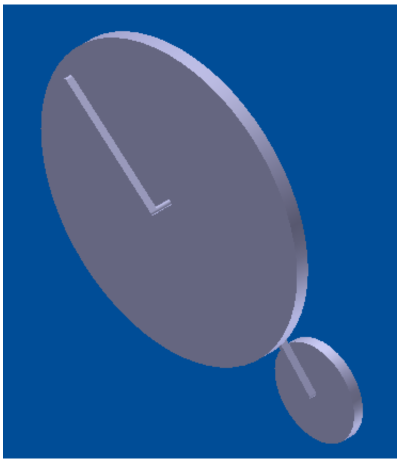


Figure 10: Isometric Front View

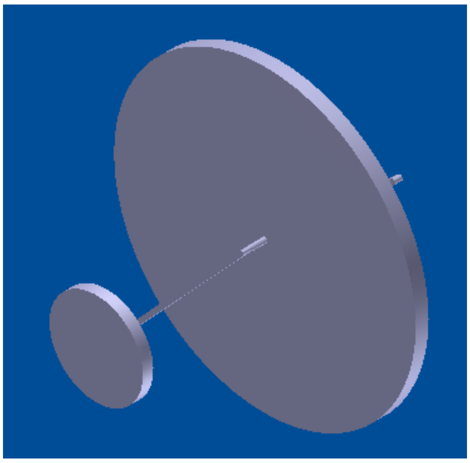


Figure 11: Isometric Back View

Figure 12 shows the side view of handle while Figure 13 shows the front view of handle.

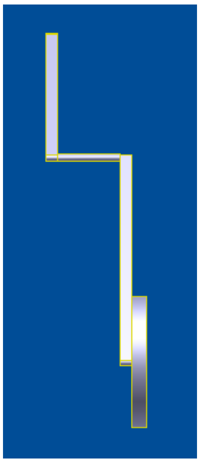


Figure 12: Side View of Handle

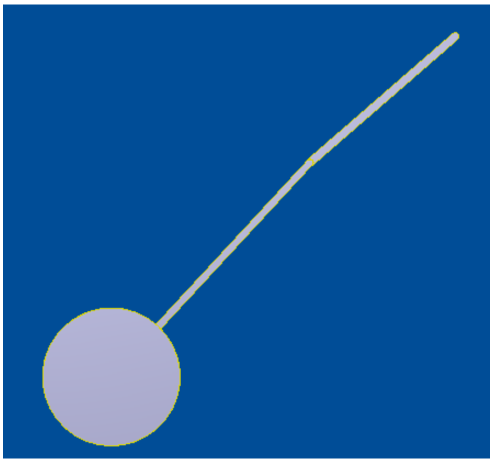


Figure 13: Front View of Handle

4.1.2 Dimensions of design

The normal dimension of a curb is as shown in Figure 14 below.

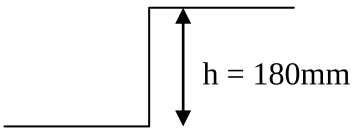


Figure 14: Curb Dimension

The dimensions of curb-climbing mechanism are as shown below.

Radius of rear wheel = 290mm

Radius of hole of rear wheel = 12mm

Thickness of rear wheel = 25mm

Length of upper part of handle = 250mm

Length of lower part of handle = 380mm

Radius of middle part of handle = 10mm

Thickness of handle = 20mm

Radius of climbing wheel = 90mm

Thickness of climbing wheel = 25mm

4.2 SECOND STAGE DESIGN

The following is the drawings and the dimensions of the second draft design of the curb-climbing mechanism where the handle and climbing wheel are combined into one and it is located at outside of the wheelchair. The changes are made in second stage due a few reasons. In the first design, the climbing wheel which is located at inner part of the wheelchair cause a problem where the climbing wheel cannot return back to the original position after climbing a curb and its moving and climbing motion will be block by the frame of the wheelchair when returning back to the original position. Thus, the handle was modified to be located at outside of the wheelchair and it can be turn all over around the big wheel to return to original position ready for next climbing. Threads also were added to the climbing wheel to add more friction when climbing up a curb to make sure safety and stability of the wheelchair.

4.2.1 Drawings of design using CATIA software

Figure 15 below shows the isometric view of second stage design. Figure 16 below shows the side view of mechanism.

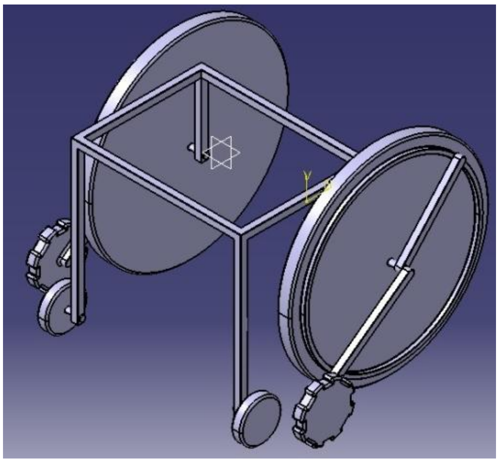


Figure 15: Isometric View

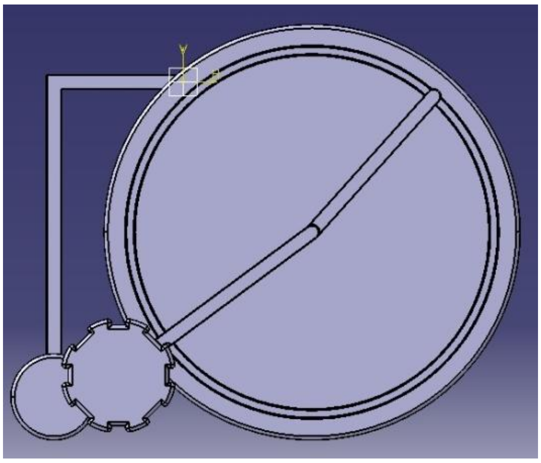


Figure 16: Side View

4.2.2 Dimensions of design

The dimensions of curb-climbing mechanism are as shown below.

Radius of rear wheel = 290mm

Radius of hole of rear wheel = 9mm

Thickness of rear wheel = 40mm

Length of upper part of handle = 250mm

Length of lower part of handle = 380mm

Radius of middle part of handle = 10mm

Thickness of handle = 20mm

Radius of climbing wheel = 60mm

Thickness of climbing wheel = 30mm

Frame dimension = 380mm (width) x 495mm (length)

Length of long frame legs = 445mm

Length of short frame legs = 215mm

The dimensions of small wheel and rear wheel are as shown as Figure 17 below.

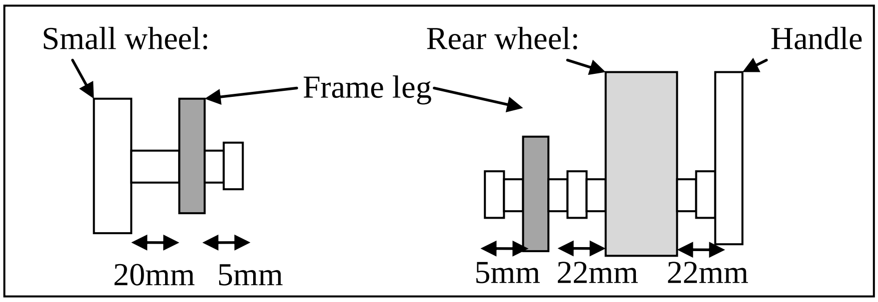


Figure 17: Small Wheel and Rear Wheel Dimensions

4.3 THIRD STAGE DESIGN

The following is the drawings and the dimensions of the third draft design of the curb-climbing mechanism where the handle and climbing wheel are combined into one and it is located at outside of the wheelchair. Some changes are made as compared to second stage design. First, threads were added to the rear wheel to increase the friction of the rear wheel for smoother movement of wheelchair and to prevent slipping occurs. Second, the design of handles was changed to a slider mechanism where the handles are now retractable that they can return to original position after climbing a curb and ready for next climbing. The handles were fixed with inner locks to prevent them from slip out of the slider holes. Third, the rear wheels were designed to be a bearing-like mechanism where the inner wheels are fixed on the frame using bolts and nuts where only the outer wheels will be rotating by the movement of ball bearings located between the inner wheel and outer wheel. Forth, sliding tolerance was added in between the moving parts to enable the movement of wheelchair to be more smooth where in between ball bearings and the cover of outer wheel and groove of inner wheel so that every ball bearing can assist and perform in the best condition and lead to smooth movement of wheelchair.

4.3.1 Drawings of design using CATIA software

Figure 18 as shown below shows the isometric view of the complete design of wheelchair with handles, climbing wheels, rear wheels, small wheels and frame.

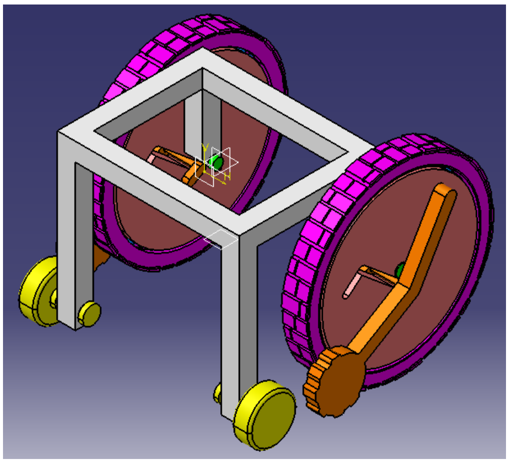


Figure 18: Isometric View

Ball bearings are located in the groove of the inner wheel of the rear wheel. The slider hole also located at the part of inner wheel. Figure 19 shows the outer wheel of the rear wheel with ball bearings located in the cover of the outer wheel to prevent the ball bearings from sliding to the bottom of the outer wheel and this will cause problem on the movement of the wheelchair. Tolerance of 1mm is given in between the ball bearings and the cover and the groove to enable smooth motion.

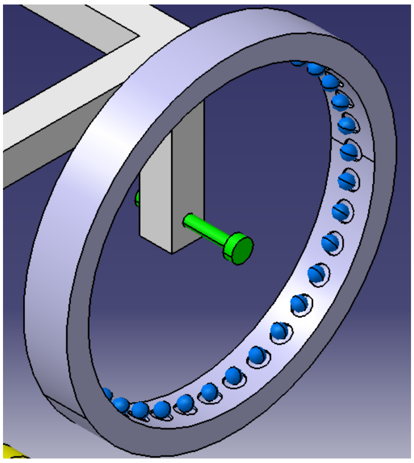


Figure 19: Outer Wheel

Figure 20 shows the holes of the slider on the inner wheel which is offset from the center of the inner wheel for 10mm. Figure 21 shows the lock to lock the handles to prevent handle from fall out of inner wheel whatever direction of the handle turns.

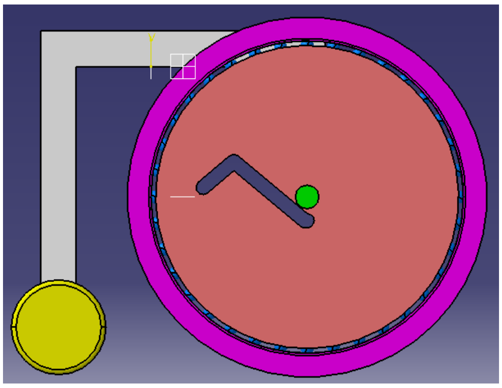


Figure 20: Fixed Slider

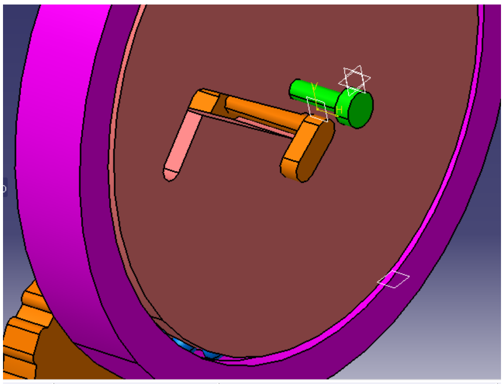


Figure 21: Handle Inner Lock

4.3.2 Dimensions of design

Dimension of frame: Thickness = 15mm

Length = 120mm x Width = 150mm

Length of long legs = 120mm

Length of short legs = 65mm

Dimension of rear wheel: Outer wheel outside diameter = 150mm

Outer wheel inner diameter = 130mm

Inner wheel diameter = 126mm

Hole of bolt fixing diameter = 5mm

Ball bearing diameter = 6mm

The location of ball bearing is as shown in Figure 22 below.

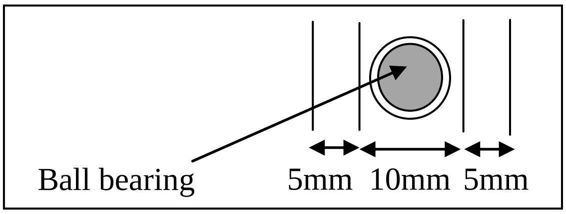


Figure 22: Ball Bearing Location

Dimension of small front wheel: Diameter = 40mm

Thickness = 15mm

Fillet = 2mm

Dimension of handle: Thickness = 10mm

Upper length = 60mm

Lower length = 70mm

Diameter of climbing wheel = 40mm

4.4 FIRST PROTOTYPE 3D PRINTING

First 3D printing of prototype for third design was carried out on 16 February 2015 for the first testing of the ability to work of the rear wheel. The rear wheel was printed successfully. Figure 23 as shown below shows the prototype.

Figure 23: First Prototype Printing

However, there were some errors occurred. The ball bearings were too small in dimension and causing them to fall out of the outer wheel of the rear wheel. Hence, the outer wheel was broken off to check the inner view of outer wheel printing condition and it showed that the inner part of outer wheel was wrongly design that the ball bearings will wear out very fast if using the individual cover as shown in Figure 24 below.

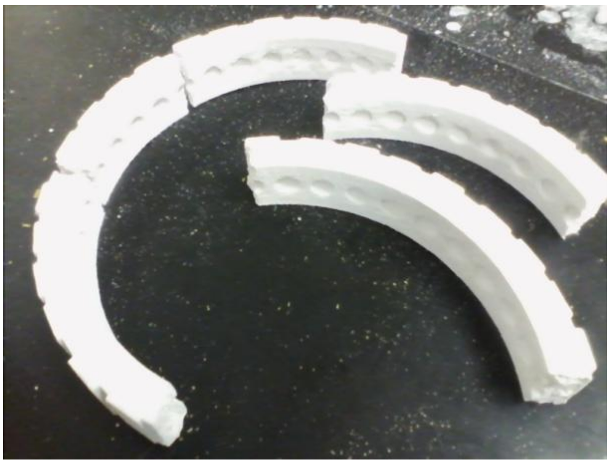


Figure 24: Inner View of Outer Wheel

Another faulty was the wheel was too heavy. The wheel need to have modification wherein to cut off some unnecessary parts in the inner wheel to reduce the weight of the rear wheel. Figure 25 as shown below shows that some lines were drew on the inner wheel which needs to be cut off in the design and reprint next time.

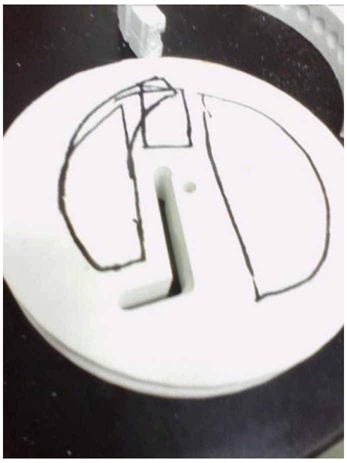


Figure 25: Modifications Needed

4.5 FOURTH STAGE DESIGN

The following is the drawings and the dimensions of the fourth stage design of the curb-climbing mechanism where some changes were made as compared to third stage design. First, the inner part of the outer wheel was changed to groove which ensures the smooth movement of ball bearings and reduce the rate of wear out of the ball bearings. Secondly, size of ball bearings was increased from diameter of 6mm to diameter of 10mm to ensure the ball bearings will not fell off the outer wheel from the gap between inner wheel and outer wheel. Third, the tolerance gap in between inner wheel and outer wheel was reduced from 2mm to 1mm to prevent the ball bearings from fell off. Fourth, the part of the inner wheel was modified to reduce the weight of the rear wheel but still maintain the strength of the wheel. The design of other parts of the mechanism was remained.

4.5.1 Drawings of design using CATIA software

Figure 26 as shown below shows the isometric view of the rear wheel included outer wheel, ball bearings and inner wheel after modification while Figure 27 shows the side view of rear wheel. As shown in the figures, the ball bearings are now modified to be unable to fell off from gap between inner wheel and outer wheel. The inner wheel was modified to reduce the weight of the wheel and thus reduce the materials to be using, reduce the cost of production and can increase efficiency.

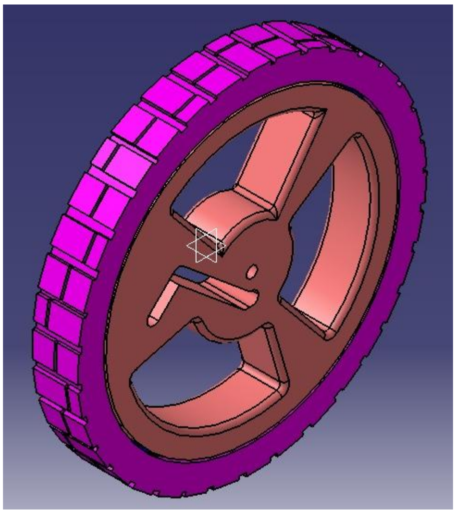


Figure 26: Isometric View

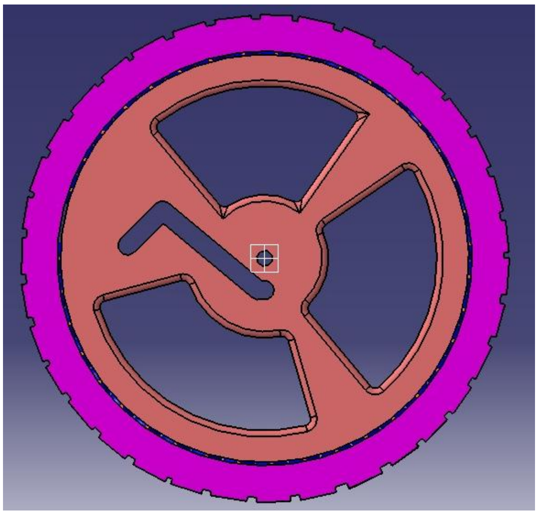


Figure 27: Side View

Figure 28 below shows the ball bearings where total number of the ball bearing is 38 and the angle between the ball bearings is 9.5°. The ball bearings are designed to be got some space in between is to ensure that the ball bearings can more freely without too packed to each other and to avoid wear out of ball bearings. Figure 29 shows the side view of inner wheel with ball bearings.

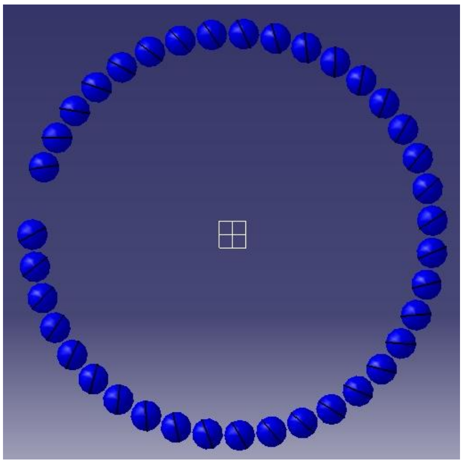


Figure 28: Ball Bearings

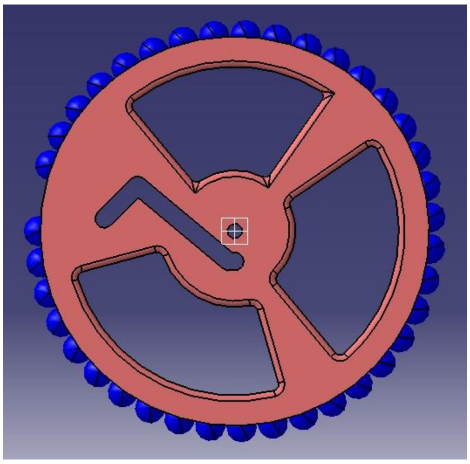


Figure 29: Side View of Inner Wheel

4.5.2 Dimensions of design

Dimension of rear wheel: Outer wheel outside diameter = 150mm

Outer wheel inner diameter = 130mm

Inner wheel diameter = 128mm

Hole of bolt fixing diameter = 5mm

Ball bearing diameter = 10mm

Dimensions and location of ball bearing is as shown in Figure 30 below.

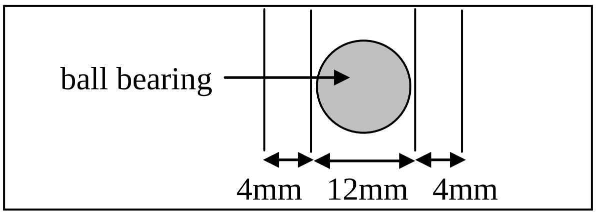


Figure 30: Location of Ball Bearing

4.6 SECOND PROTOTYPE 3D PRINTING

Second 3D printing of prototype for fourth design was carried out on 2 March 2015 for the second testing of the ability to work of the rear wheel. The rear wheel was printed successfully. However, there were some errors occurred where the gap between the inner wheel and outer wheel was too small that the material powders between the ball bearings and gap of inner wheel and outer wheel were unable to clear out. This had lead to the rear wheel was stuck and cannot be rotated as it supposed to be. Figure 31 as shown below shows the broken prototype whereas Figure 32 as shown below shows the outer wheel which was stuck with the ball bearings and material powders. As shown in the pictures, there are powders that were stuck in the groove of the outer wheel.

Figure 31: Second Prototype Printing

Figure 32: Outer Wheel with Ball Bearings

Besides, it was also noticed that the gap between the middle hole of rear wheel and the slider gap of handle was too close and this may lead to failure of the body of the rear wheel where it might be broken when load is apply to the wheelchair mechanism. The material powders also stuck in the groove of the inner wheel. On the other hand, the resolution of the 3D printing file was too low that caused the whole mechanism to be very rough in appearance especially ball bearings which can lead to not smooth movement of the ball bearings while rotating. Figure 33 shows the rough surface of the mechanism printed.

Figure 33: Rough Surface Printing

The powders were successfully removed when sprayed with the Epsom Salt Solution. However, it was impossible to carry out this process when the mechanism is not broken because the gap between inner wheel and outer wheel was too small.

4.7 FINALIZED DESIGN

Below are the drawings and calculations of finalized designs of each component.

4.7.1 Assembly Drawing

The isometric view of assembly of the curb climbing mechanism of wheelchair is as shown in Figure 34 below while side view as shown in Figure 35.

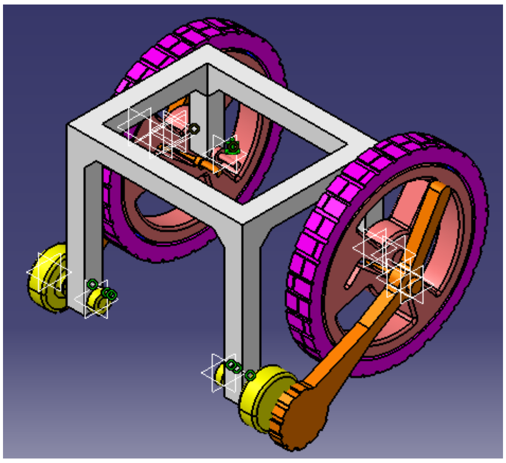


Figure 34: Isometric View of Assembly

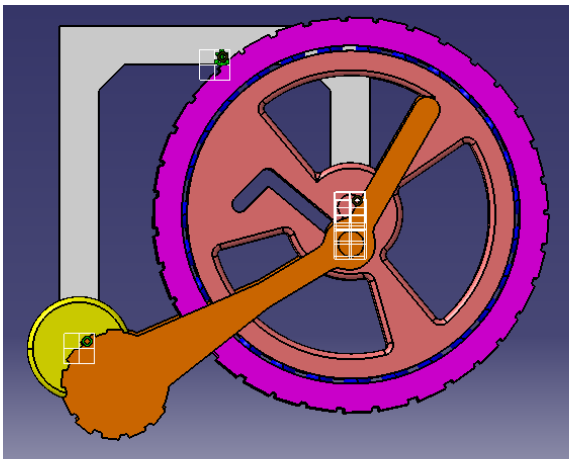


Figure 35: Side View of Assembly

4.7.2 Rear Wheel

The main component that was being modified is the rear wheel where the rear wheel was modified into a bearing-like mechanism so that the middle part of the rear wheel is fixed and only the outer part of the wheel is able to rotate during movement. The diameter and the thickness of the rear wheel was designed to be one third of the size of the original ordinary wheelchair rear wheel as this is the prototype for testing the workability of the idea of design of curb climbing mechanism.

The groove of the outer wheel and inner wheel was designed to be not exactly round shape but to be oval shape and it is 1mm away from each distance from the ball bearing to prevent the ball bearings from playing too much move during rotational movement and thus prevent the ball bearings from fell off from the gap of the wheel. This also ensures that the wheel can be function properly. Isometric view of rear wheel in different view condition is as shown in Figure 36 below.

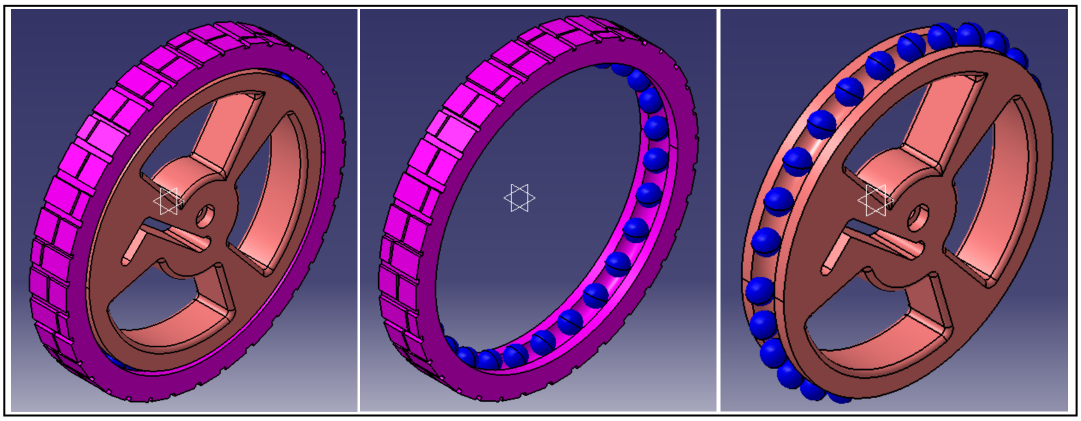


Figure 36: Isometric View of Rear Wheel in Different View Condition

The slider for the handle are designed to have a rest point at the upper left end and to be function when handle is put at the middle of the wheel where climbing is needed. The empty columns in the inner wheel are to ensure the wheel is light weight but strong enough to carry the weight when climbing or normal usage. There are total 27 ball bearings with 13.2 ° apart from each other. The number of ball bearings ensures that the ball bearings will not interfere with each other during the rotational movement of the rear wheel and prevent the ball bearings from wear out very soon. Side view of the rear wheel is as shown in Figure 37.

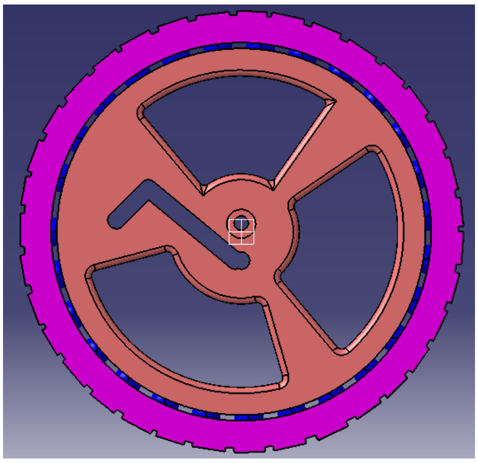


Figure 37: Side View

4.7.3 Small Wheel

Small wheel was designed according to dimensions of ordinary wheel chair but the joint of the wheel with the middle part was modified to have fillet where more materials at the joint can ensure that the small wheel will not break off easily. The end part are having smaller diameter for the purpose of fixing the nuts. Isometric view and front view of small wheel are as shown in Figure 38.

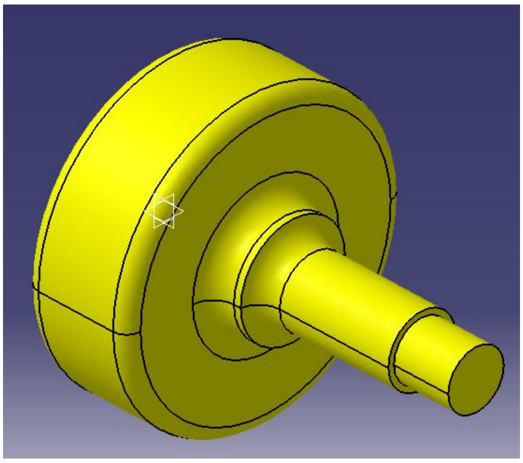


Figure 38: Isometric View

4.7.4 Handle

The handle is modified to be as shown in Figure 39. There are threads at the end part of the handle to ensure more grips on the surface to ensure stable and prevent from slipping. The middle parts of the handle were modified to be thicker to prevent break off when forces are applied on the handle during climbing. The handle was designed to be thick to ensure better grip of users on the handle. The length of the handle was modified to be longer so that when it is put in the climbing position it is ensured that the whole mechanism is able to climb a height of curb.

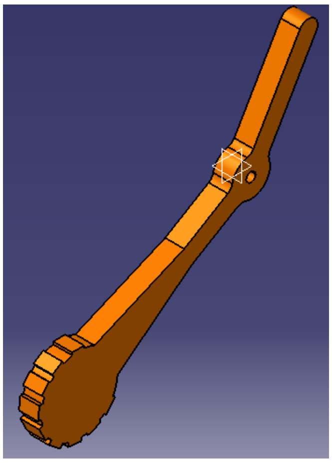


Figure 39: Isometric View

4.7.5 Frame

The frame was as shown in Figure 40 where there are two shorter legs for rear wheels and two longer legs for small front wheels. Reinforcements at the joint of the frame prevent from bending and break off of the legs. The two cutting edges at the shorter legs prevent blocking the movement of the handle when the handle is rotating.

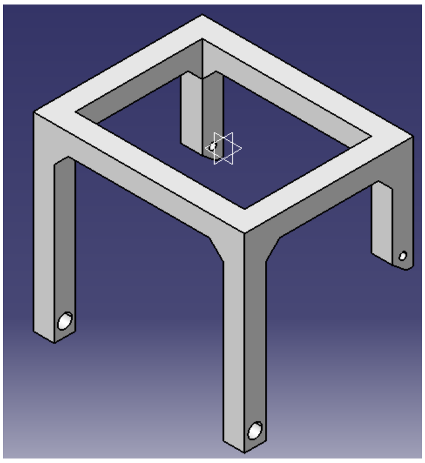


Figure 40: Isometric View

4.7.6 Engineering Drawings of Each Components and Assembly

The engineering drawing of assembly of the curb-climbing mechanism is as shown in APPENDIX A. The engineering drawings of each component are as shown in APPENDIX B to APPENDIX H. Rear wheel drawings were drawn into a group of drawings where the drawings are detailed on the inner wheel, outer wheel and ball bearings. All the detailed dimensions are as shown in the drawings. Each of the engineering drawings was drawn using CATIA software. All the drawings were labeled with dimensions and parts number. The drawings of the bolts and nuts were not included in the project due to availability of bolts and nuts in the market. The drawings show the isometric view, top view, front view, left view and detailed view of the components.

4.8 FINALIZED 3D PRINTING AND ASSEMBLY

The final 3D printing was carried out on 27 March 2015 and the assembly of the mechanism was carried out on 30 and 31 March 2015. The mechanism prototype was printed using material zp150 using ZPrinter ® 450 3D printer available in Universiti Teknologi Petronas. The assembly of the curb climbing mechanism is as shown in Figure 41 below.

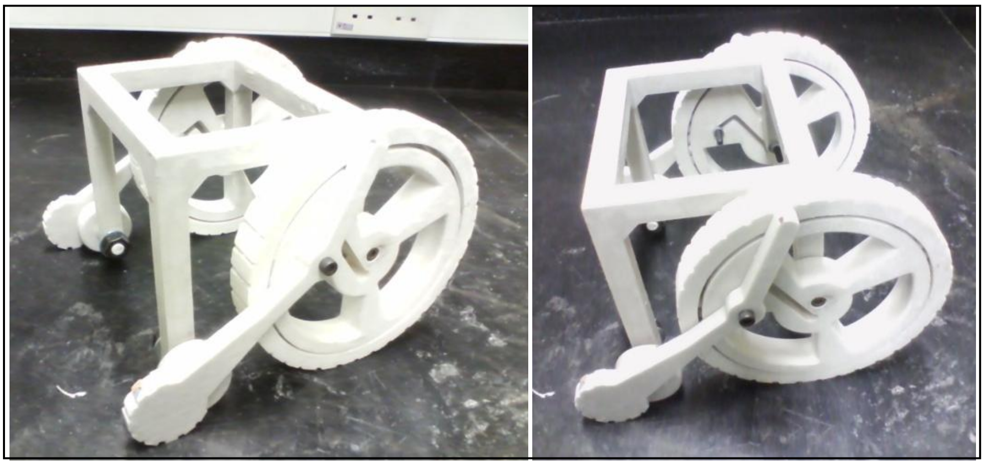


Figure 41: Assembly of Curb Climbing Mechanism

4.9 STRESS ANALYSIS

Material for the components for simulation was chosen to be Aluminium due to strength of Aluminium is higher than the strength of the material used for 3D printing which is ceramic. Besides, Aluminium has the lowest yield strength among the variety of metals. If Aluminium can withstand the weight in simulation, then the other metals which are stronger and tougher can withstand the weight applied on the mechanism too. For deformation analysis, force of 170N was applied on frame, handle and small front wheel due to the scaled down one third of average human weight of 50kg. The properties of Aluminium are as shown in Figure 42 below. The mesh properties of each component are as shown in Figure 43 below.

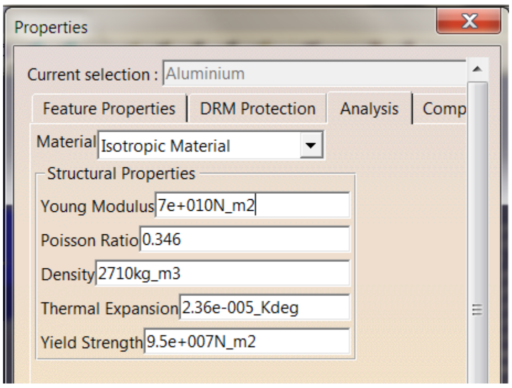


Figure 42: Properties of Aluminium

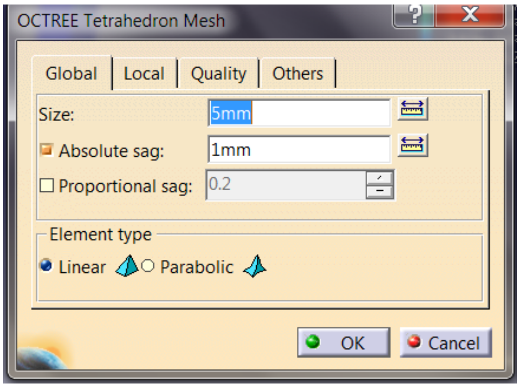


Figure 43: Mesh Properties

4.9.1 Deformation Analysis

Frame deformation analysis is as shown in Figure 44 below.

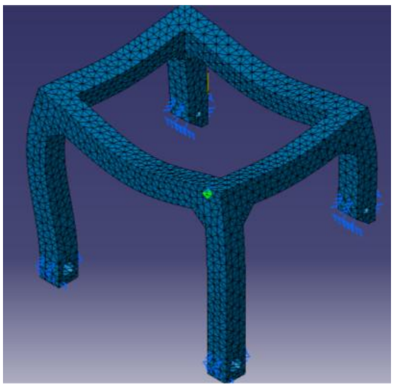


Figure 44: Frame Deformation Analysis

Handle deformation analysis is as shown in Figure 45 while small front wheel deformation analysis is as shown in Figure 46.

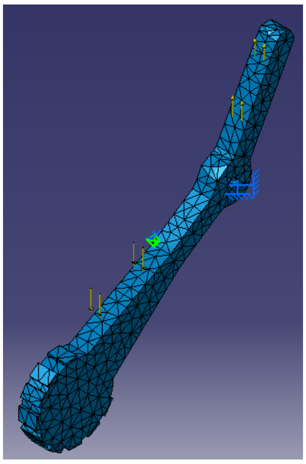


Figure 45: Handle Deformation Analysis

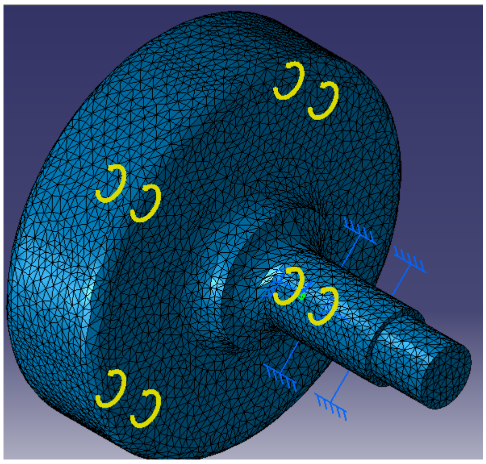


Figure 46: Small Wheel Deformation Analysis

4.9.2 Von Mises Stress Analysis

The color of the Von Mises Stress analysis means the degree of deformation when forces are applied on the component. As the color nearer to red color, the more critical point it is and as the color nearer to blue color, the less critical point it is.

Von Mises Stress analysis of frame is as shown in Figure 47 below. As shown in the figure, the most critical points that might deform when forces are applied are the joint of the legs of the frame.

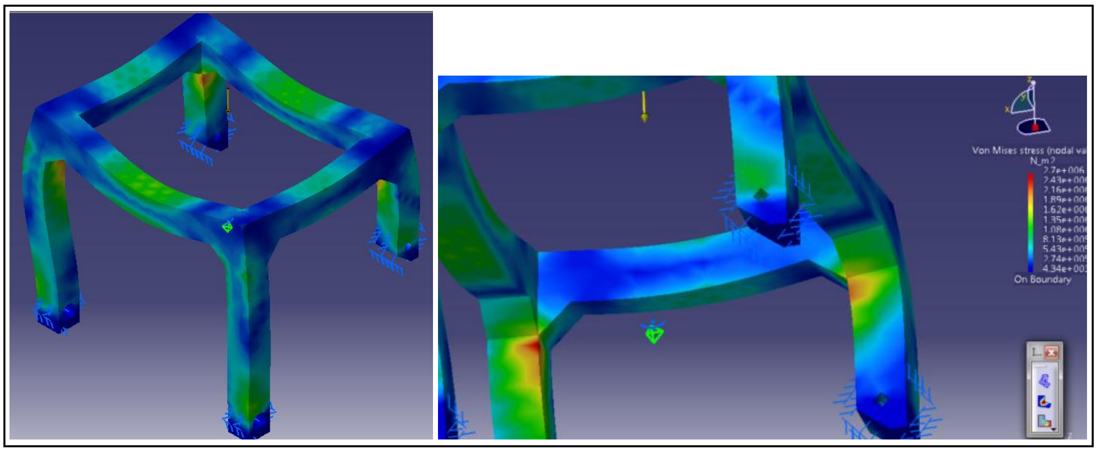


Figure 47: Von Mises Stress Analysis of Frame

Von Mises Stress analysis of handle is as shown in Figure 48 below. As shown in the figure, the most critical point of deform when the forces are applied is near the middle part of the handle where bolt is attached with because the handle is given force that cause rotational moment on the handle.

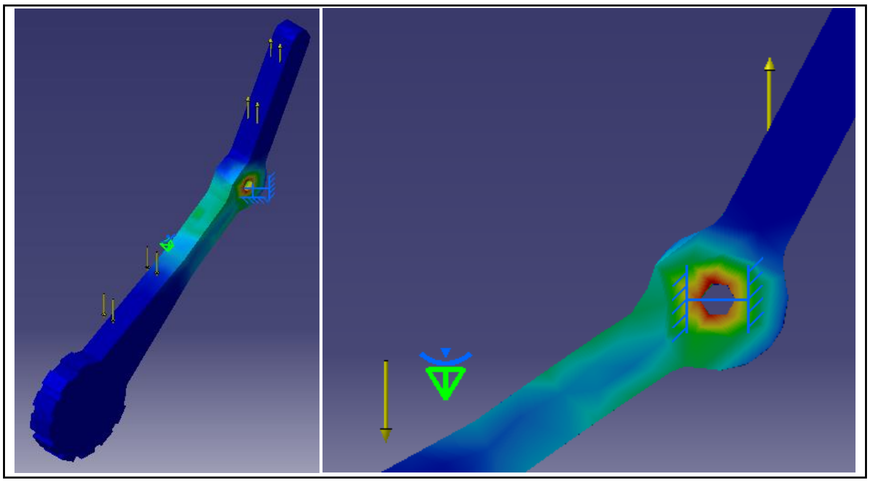


Figure 48: Von Mises Stress Analysis of Handle

Von Mises Stress analysis of handle is as shown in Figure 49 below. As shown in the figure, the most critical point of deform when the forces are applied is at the joint of the wheel where rotational movement of the small wheel can cause rotational moment force on the joint and cause deformation.

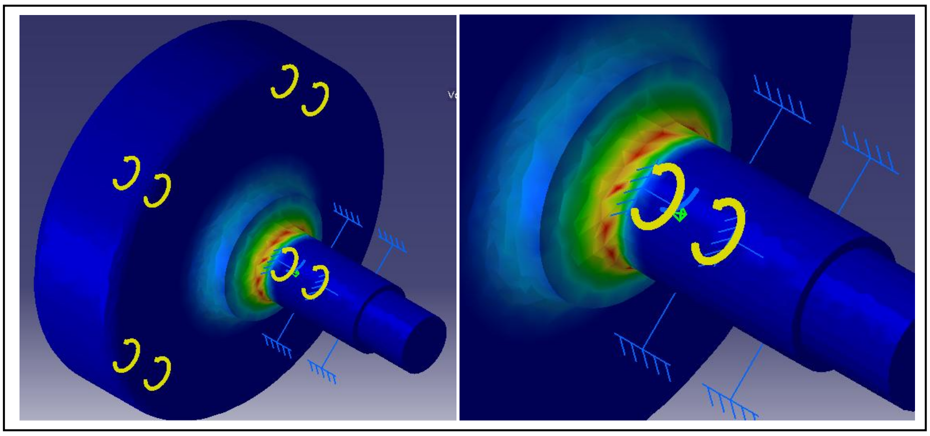


Figure 49: Von Mises Stress Analysis of Small Wheel

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The project had done research and literature review on the curb climbing mechanism of wheelchair based on some other researcher's designs, considerations and testing results and finally came out with a few concept ideas to work with. The project had come out with detailed drawing of the mechanisms on CATIA. After the several printing of the mechanism using 3D printing, testing of the movement of the mechanism components were done on the prototype and hence one best alternative was chosen. The curb-climbing mechanism was tested work smoothly and also stable as compared to the already-have mechanism on the markets nowadays. This project successfully complied with the main purpose which is to design a manually curb climbing mechanism of wheelchair via functional prototype by 3D printing technology. The project realized the concept model for curb-climbing mechanism.

It is recommended that the future project should do simulation and detailed calculations of the forces to be applied according to real environment such as real forces of weight and real materials to be using for each part of the components to increase the reliability of the project and to reduce the cost of repeated 3D printing. It is also recommended to 3D print the mechanism using smoother surface finishing materials such as polymers to increase the efficiency of the mechanism.

REFERENCE

3D Printing Industry. (February 12, 2014). The Free Beginner's Guide to 3D Printing. Retrieved 24 September 2014, from http://3dprintingindustry.com/wp-content/uploads/2014/07/3D-Printing-Guide.pdf

Armstrong, W., Borg, J., Krizack, M., Lindsley, A., Mines, K., Pearlman, J., Reisinger, K. & Sheldon, S. (2008). Guidelines on the Provision of Manual Wheelchairs in Less Resourced Settings. World Health Organization. Retrieved 28 October 2014, from http://www.ncbi.nlm.nih.gov/books/NBK143778/pdf/TOC.pdf

Roland Berger Strategy Consultants GmbH. (November, 2013). Additive manufacturing: A game changer for the manufacturing industry? Retrieved 29 October 2014, from http://www.rolandberger.com/media/pdf/Roland_Berger_Additive_Manufacturing_20131129.pdf

Brubaker, C.E. (1989). "Wheelchair IV" in *Report of a conference on the state-of-the-art of Powered Wheelchair Mobility, December 7-9, 1988*.

Cross, D. J. (May, 2012). "The End of the Common Wheelchair: Service & Policy Implications of the New USDOT ADA Regulations" in *APTA 2012 Bus & Paratransit Conference*.

Ekachai, C. & Teerapol, P. (October, 2011). A Prototype of a Stair-Climbing System for a Wheelchair. Retrieved 23 December 2014, from http://rcme.engr.tu.ac.th/TSME-ICoME%20Web/full_paper_file/AMM/AMM17.pdf

Leo, D. M., Alex, F., Gennaro, A. M. (2011). Curb Climbing Wheelchair. Retrieved 23 December 2014, from http://me.eng.sunysb.edu/~senior-design/project%202011/5%20Curb%20Climbing%20Wheelchair.pdf

Lin, Z. & Xi, F. H. (2012). An Optimization Design for the Stair-Climbing Wheelchair. Retrieved 23 December 2014, from http://www.bth.se/fou/cuppsats.nsf/all/3668abf1d5e2a00ec1257b240036655c/$file/BTH%202013%20Zhang.pdf

McMath, I. (2006). "Getting real [rapid manufacturing]" in *Engineering & Technology,* Volume 1, issue 4, p. 40 – 43.

Murray J. L, & Takakazu, I. (2003). Modeling of a Stair-Climbing Wheelchair Mechanism with High Single-Step Capability. *Neural Systems and Rehabilitation Engineering, IEEE Transactions,* Volume 11, Issue 3.

Srinivasan, V. & Bassan, J. (2012). 3D Printing and the Future of Manufacturing. Retrieved 29 October 2014, from http://lef.csc.com/assets/3705

T. Rowe Price Connections. (2011). A Brief History of 3D Printing. Retrieved 29 October 2014, from http://individual.troweprice.com/staticFiles/Retail/Shared/PDFs/3D_Printing_Infographic_FINAL.pdf

Tyagi, G. (2012). 3D Printing Technology. Retrieved 29 October 2014, from http://nicsu.up.nic.in/knowdesk/3D-Printing-Technology.pdf

Waugh, K. (December, 2013). Glossary of Wheelchair Terms and Definitions Version 1.0. Universiti of Colorado Anschutz Medical Campus. Retrieved 30 October 2014, from http://www.ncart.us/uploads/userfiles/files/glossary-of-wheelchair-terms.pdf

Weinberg, J. & Mignolo. (September 7, 2012). 35 Wildly Wonderful Wheelchair Design Concepts. Retrieved 28 October 2014, from http://www.lovethesepics.com/2012/09/35-wildly-wonderful-wheelchair-design-concepts/

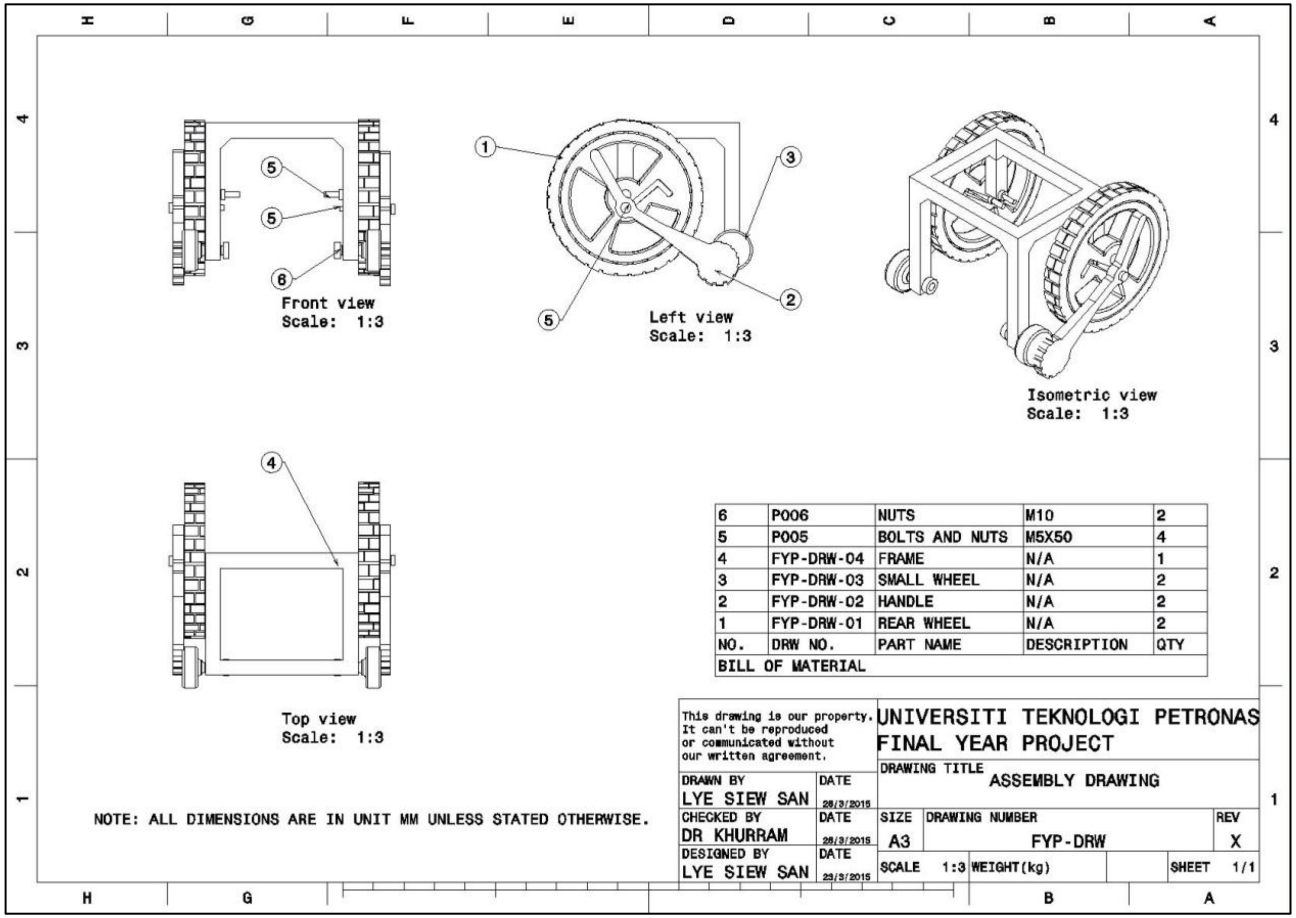
Z Corporation. (2007). 3DP Consumables Catalog. Retrieved 31 October 2014, from http://sldtech.com/wp-content/uploads/2008/10/consumables_catalog_.pdf

Z Corporation. (2008). Presenting the Presenting the ZPrinter® 450 World's Most Automated and Affordable Color 3D Printer. Retrieved 8 October 2014, from http://www.zcorp.com/documents/105_Z%20Corp%20ZPrinter%20450%20Intro.pdf

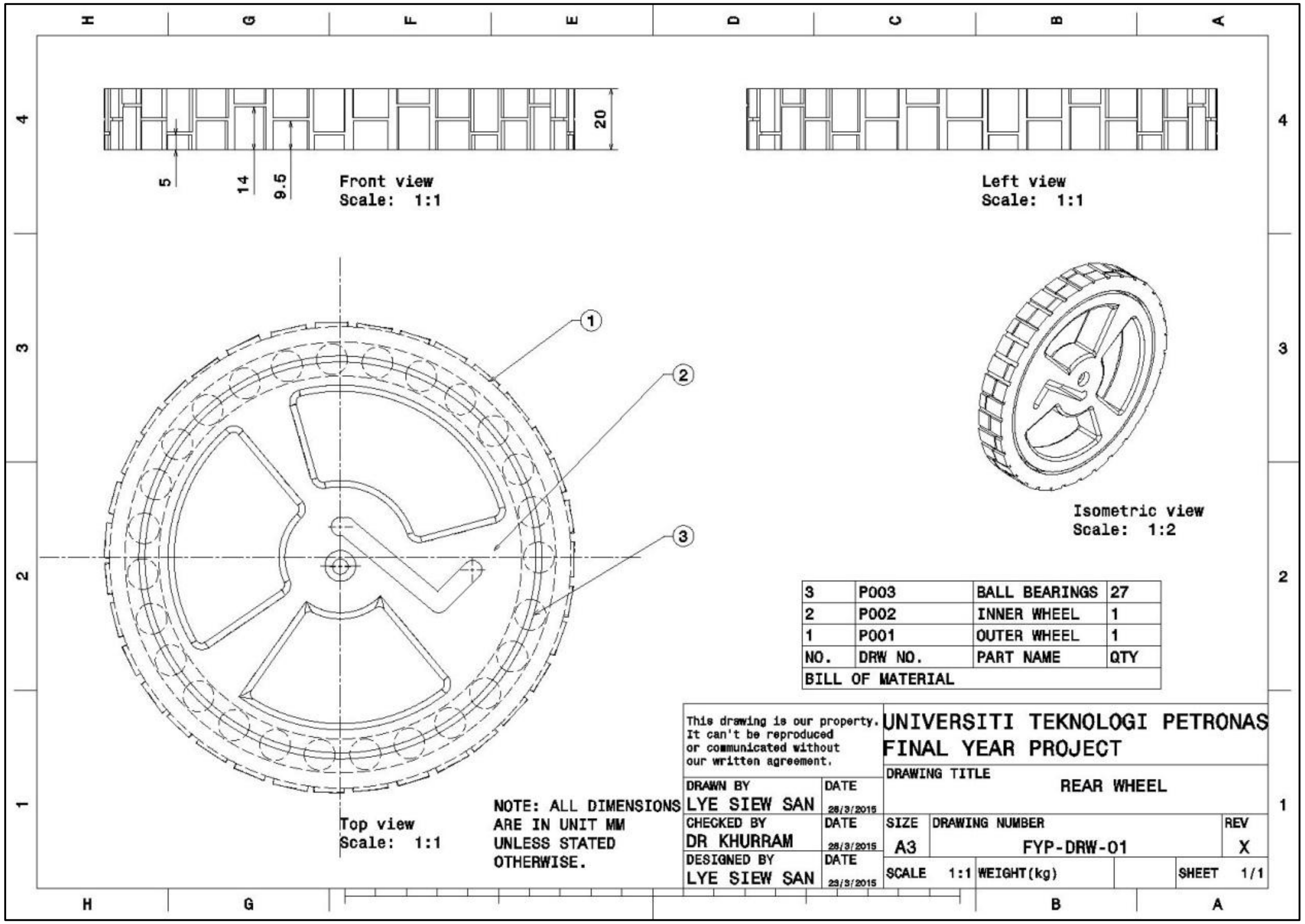
Z Corporation. (2010). ZPrinter Materials and Accuracy: Functional Performance and Accuracy of 3D Printed Models. Retrieved 31 October 2014, from http://prototype-nv.ru/Z450-Material-Properties.pdf

APPENDICES

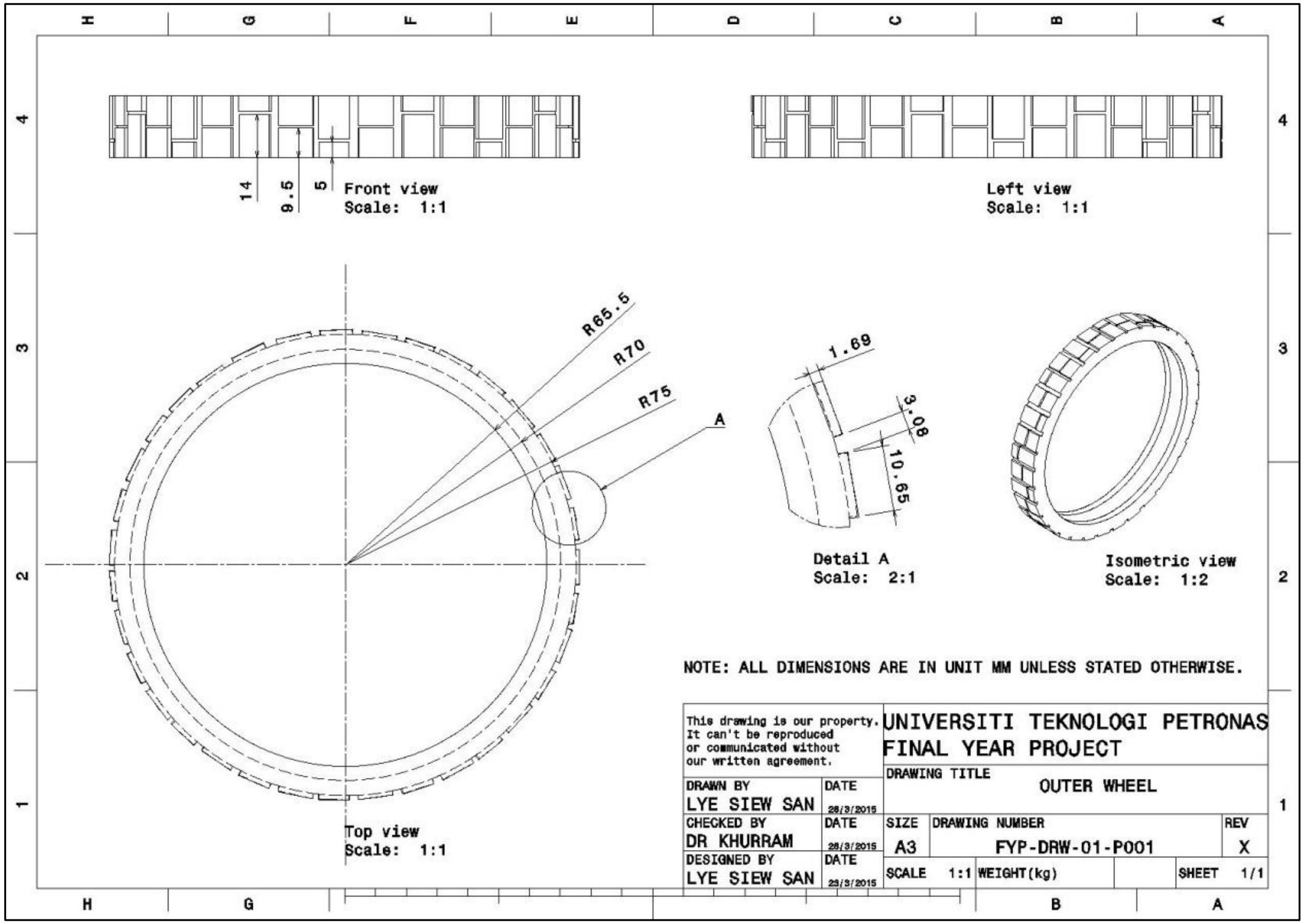
APPENDIX A. Assembly Engineering Drawing



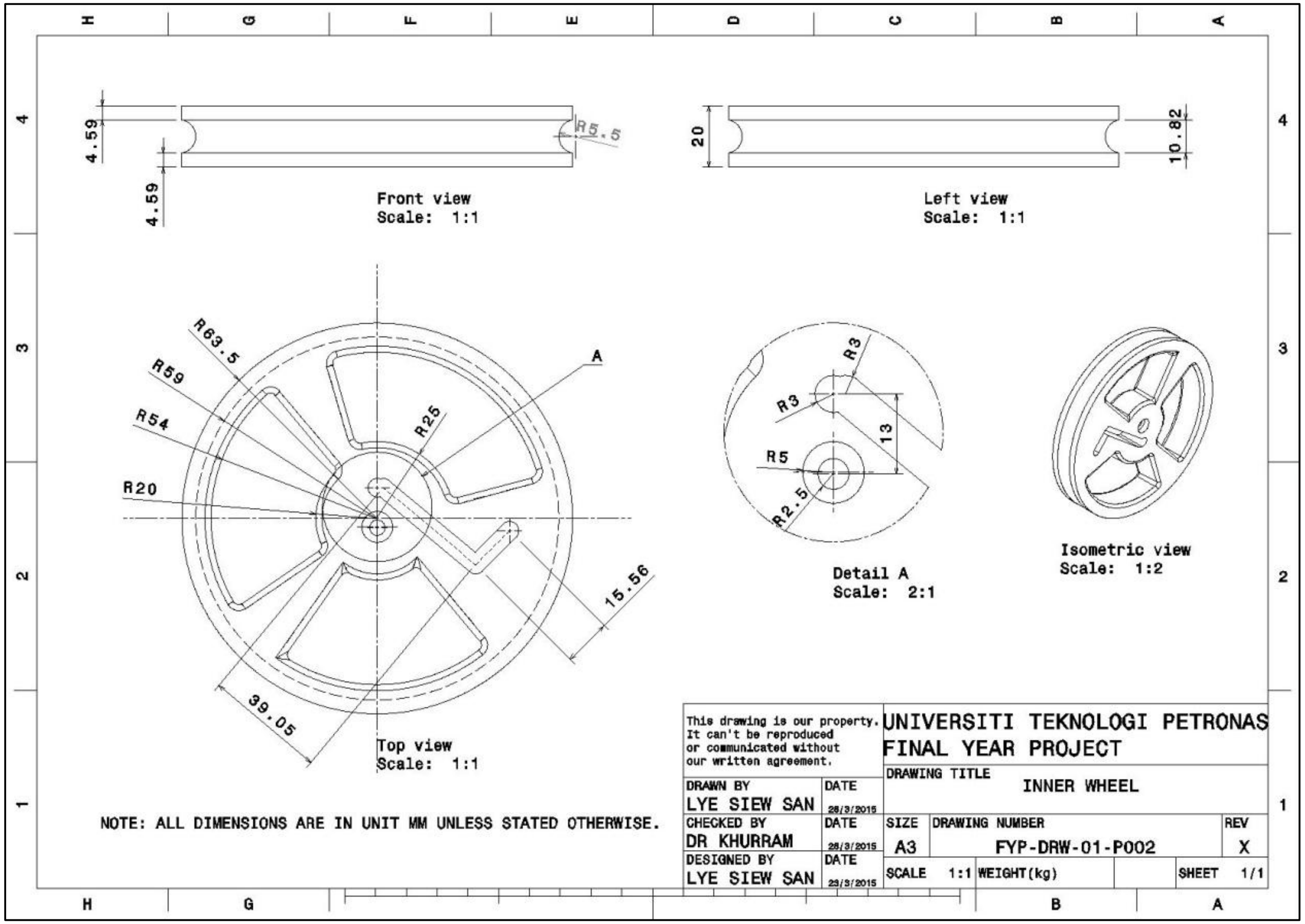
APPENDIX B. Rear Wheel Assembly Engineering Drawing



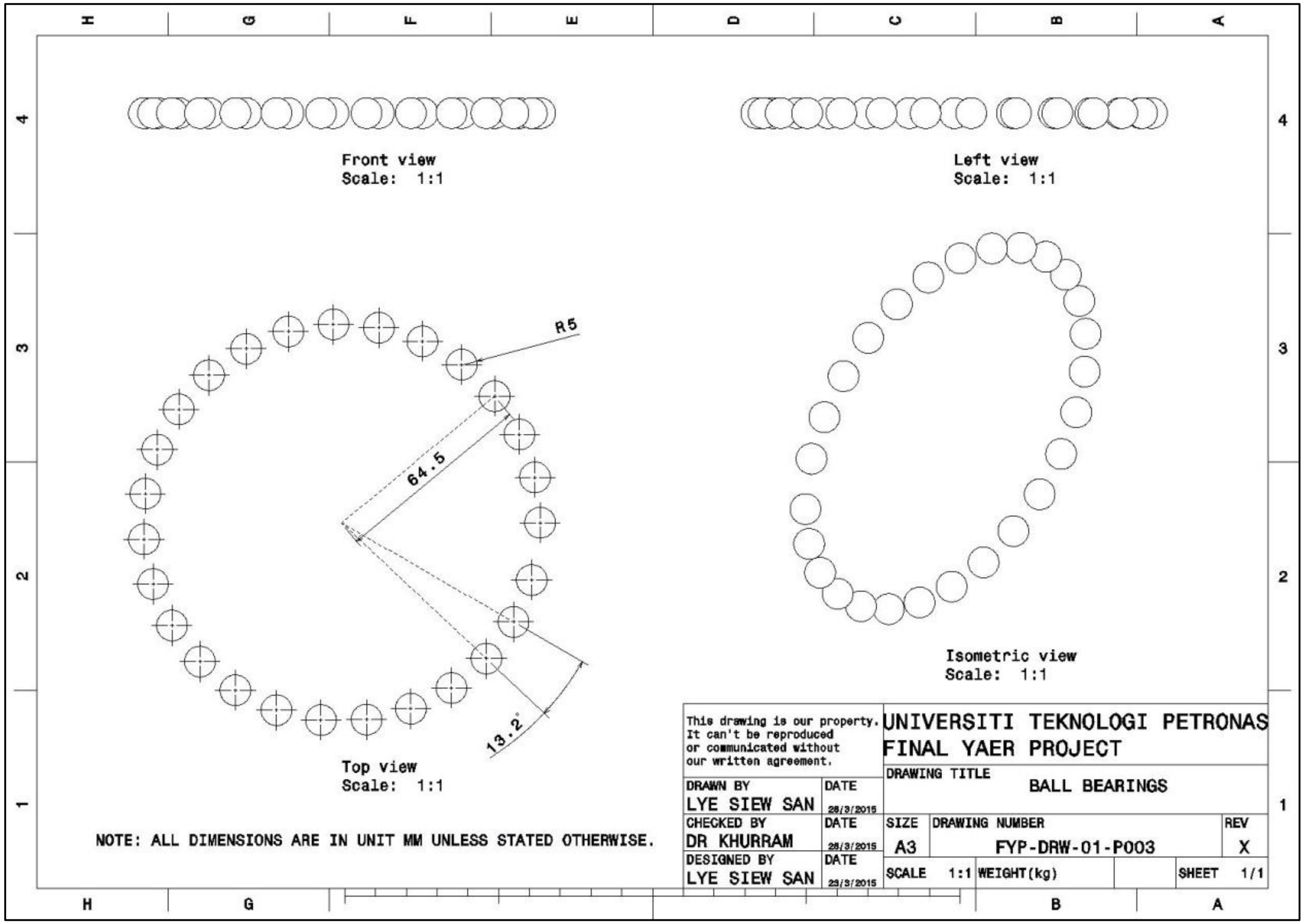
APPENDIX C. Outer Wheel Engineering Drawing



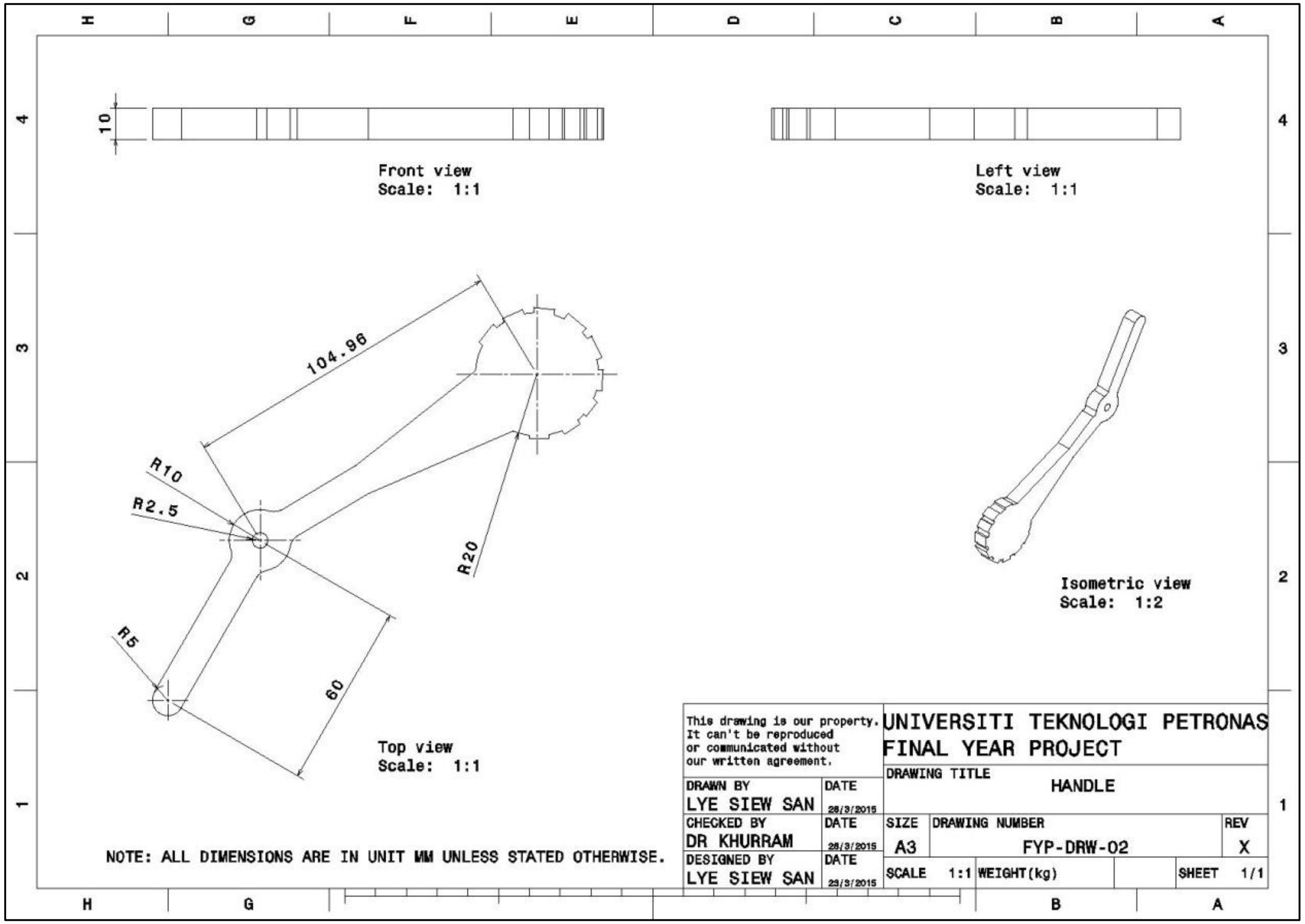
APPENDIX D. Inner Wheel Engineering Drawing



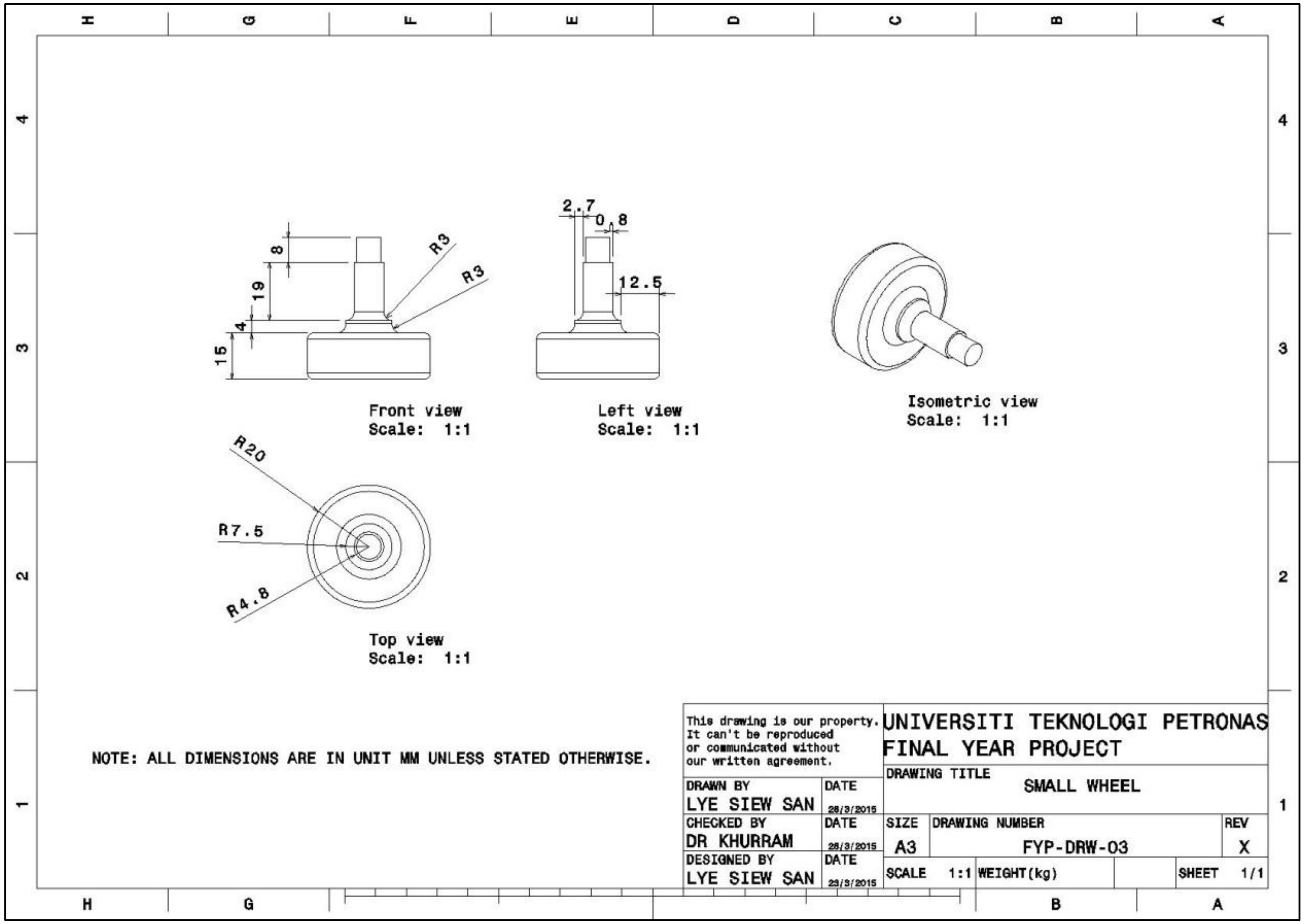
APPENDIX E. Ball Bearings Engineering Drawing



APPENDIX F. Handle Engineering Drawing



APPENDIX G. Small Wheel Engineering Drawing



APPENDIX H. Frame Engineering Drawing