

Preliminary Design of the Wheelchair Elevation Support Unit (WES)

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Abstract

The Wheelchair Elevation Support Unit (WES) has been designed to be an additional mechanism that can be installed into a standard wheelchair to extend its function. This mechanical device helps rehabilitation patients gain the ability to stand, which common wheelchairs are unable to offer. In this research, the Engineering Design Process (EDP) was used to design the product. The design and finite element analysis (FEA) simulation were performed using Catia V5 to verify the reliability and safety of the product. As a result, a sub-assembly with an overall weight of 8 kg was achieved, capable of supporting users with up to 90 kg of weight. The maximum von Mises stress of 62.5 MPa with a total deformation of 2.23 mm was simulated when using the aluminum alloy (6061 T6) material. With a 4.96 safety factor, the selection of this material was considered safe and reliable, as it is lightweight and suitable for engineering applications, especially when combined with the frame structure of the wheelchair. With a fast and easy disassembly process, it is beneficial for the users to return the wheelchair to its standard type. In the future, further improvements will be made to optimize the design. With this additional mechanism featured in the wheelchair, hopefully it will be able to support the rehabilitation process of patients by allowing them to stand with less effort.

1. Introduction

The wheelchair is widely used in hospitals and public places, especially to transport patients. It is a practical method to move a person with a walking disability, from one place to another. Worldwide, it has been estimated that there are around 75 million global wheelchair users, with a daily increment of 3500. As of today, more than one million units of wheelchairs have been distributed in over 150 countries around the world [1]-[3].

Unfortunately, the wheelchair also has limits. A standard wheelchair only offers limited actions and is incapable of performing complex actions, such as reaching high places. Thus, an upgraded version of the wheelchair is needed. Unfortunately, the cost factor is the main issue. Most common users cannot afford a high-tech wheelchair. Good functions normally come at a higher price. Advanced wheelchairs with standing functions, with compact and foldable designs, powered by electric or hydraulic, usually cost thousands of dollars. At the same time, normal users are more reluctant to procure a new system and would rather use the available wheelchair instead. For this reason, this project focuses on designing an additional mechanism that can be installed on a common wheelchair. Instead of creating a new system, a modular design is more cost-effective. It can help rehabilitation patients or wheelchair users stand and allow them to control the wheelchair up to a desired height.

It not only aims for lower costs but also supports users in utilizing the available wheelchair rather than buying a new one. The new design should be compatible with a standard wheelchair, whether for home or hospital usage. The overall design and finite element analysis was performed using Catia V5 software. The expected outcome was to be a design that could withstand heavy loads, while at the same time offering good stability. With this additional mechanism featured in the wheelchair, it was hoped that it would be able to support the rehabilitation process of patients by allowing them to stand with less effort. The concept of an assembly-friendly product would help users fully utilize the available wheelchair by adding a new function at a lower cost compared to a new fully standing wheelchair. With a quick assembly procedure, it would be easy for the users to return the wheelchair to a standard version at any time.

2. Literature Review

2.1 Overview of the Wheelchair

The wheelchair is a commonly used assistive device that promotes mobility for disabled people who have difficulties walking, such as those with a spinal cord injury. It is very helpful in enhancing the quality of life as well as preventing health deterioration among individuals with spinal cord injuries. In hospitals, wheelchairs are used to transport in-patients and out-patients around the hospital. The transportation of patients is usually undertaken by an employee of the trust or associated body. The patients would usually be given a wheelchair prescription if they need help moving or, most often, because they are unable to walk on their own. There are many types of wheelchairs. Manual and standard wheelchairs are operated by pushing solely with the arms. Also, patients can operate power wheelchairs electronically on a certain type of wheelchair.

Wheelchair users usually have a hard time because they are forced to spend long periods in the sitting position. This situation can result in pain, deformities and decubitus ulcers. To have an ergonomic design, the four main criteria should be dealt with: force, duration, posture and repetition factor [4].

2.2 The Human Factor

The posture of standing and sitting needs to be appropriate in order to design a wheelchair that has the ability to support rehabilitation patients. This is vital to ensure that the patient or wheelchair user does not get hurt during the transition from sitting to standing posture. During the position transition from sitting into stand-up posture, the joints at the knee, ankle and hip would be exerted by force. At this point, the angles of the hip, knee and ankle play big roles in adjusting and reducing the force applied to them. The force exerted during this posture should be distributed and reduced by the change in the angle of the hip, knee and ankle. When the angle of the hip is reduced, it eventually distributes the force to the lower part of the body to ease the motion.

Good posture plays a role in producing a good design. For example, a study shows that a minus 45° shoulder extension combined with a 45° elbow flexion angle is the most uncomfortable posture. This is the effect of extension and flexion of the shoulder [5]. Also, having a seat at an appropriate height for visibility is necessary. On average, the standing eye height for the largest person (95th percentile) is around 1.8 m, whereas, for the smallest person, it is around 1.35 m. Wheelchair users often have eye heights as low as 1.15 m [6].

2.3 Market Study

In the current market, there are various companies that have developed special wheelchairs with new abilities and beneficial features. Some of the products are manual and some of them are electric-powered. Overall, there are no products with added-in features. The number of users is also limited. Table 1 shows three examples of stand-up wheelchairs used as benchmarks.




3. Methodology

The Engineering Design Process (EDP) had been utilized to come up with the design. Fig. 1 shows the flowchart of the design process, from the conceptual stage until the preliminary stage. Several concept designs were developed and studied during the conceptual stage. At the same time, the previous mechanical lifter and scissor lift design concepts were also referred to [8], [9]. Overall, three standing wheelchairs were chosen as the initial benchmark. The EDP methods, such as the morphological chart and functional decomposition chart, were used to come up with the best concept idea for the product. The best concept idea was developed and improved until it met the desired targets or goals. The Pugh Matrix was used to compare and decide on the best concept that met the desired goals. Next, the design process proceeded to the preliminary stage by considering design factors such as the ergonomic function [5], [10], [11] and the anthropometric data [12], [13].

The FEA shall be performed to analyze the reliability of the product, especially on two critical components, which are the roller wheel connector and the seat frame. The different loads shall be applied depending on the

parts, based on the actual operation of the product. These criteria are important to ensure the FEA result is reliable and accurate. Fig. 2 shows the parameters that have been set up for the analysis.

Table 1 Product benchmarking [7]

Product	Description
<p data-bbox="165 376 596 405">Leo II (Lightest Standing Wheelchair)</p> 	<ul data-bbox="743 376 1394 591" style="list-style-type: none"> • Manually operated. • Suitable for paraplegia with good strength on arms, palm and fingers. • The lightest standing wheelchair with total weight at only 27kg (59lbs) • Price = RM13,500.00
<p data-bbox="165 739 576 801">Pegasus II (Semi-Powered Standing Wheelchair)</p> 	<ul data-bbox="743 739 1423 913" style="list-style-type: none"> • Roll manually with power stand-up/sit-down function. • Excellent for the user who works with only one hand or one finger because of the controller. • Total weight at only 35kg • Price = RM19,500.00
<p data-bbox="165 1160 580 1189">Draco (Power Standing Wheelchair)</p> 	<ul data-bbox="743 1160 1423 1375" style="list-style-type: none"> • Fully powered for lying down, stand, sit and recline positions. • Equipped with Dynamic LED graphic display Controller (DX2) for precise user control. • Total weight is 135KG (298lbs) • Price = RM39,500.00

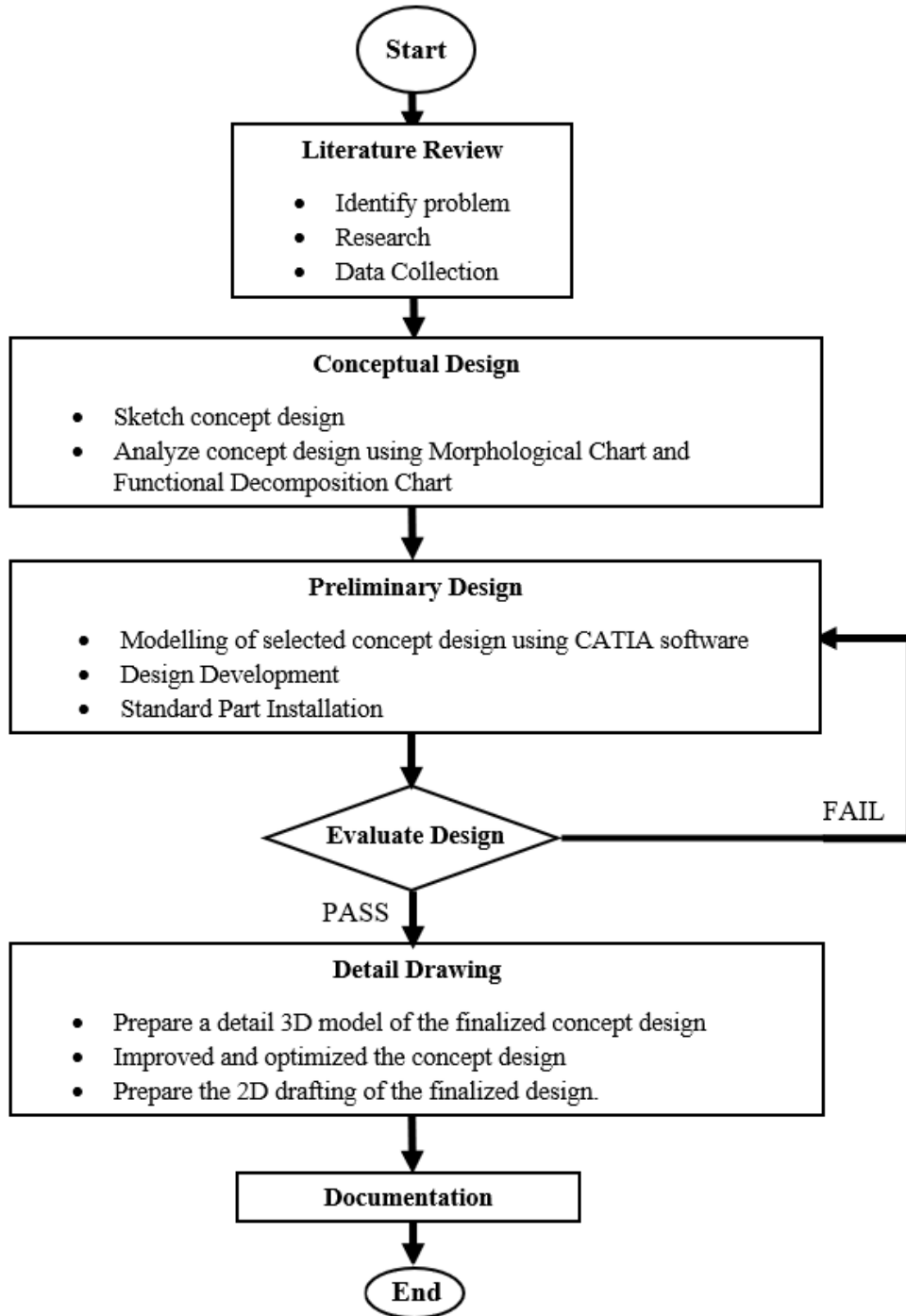


Fig. 1 Flowchart for the WES

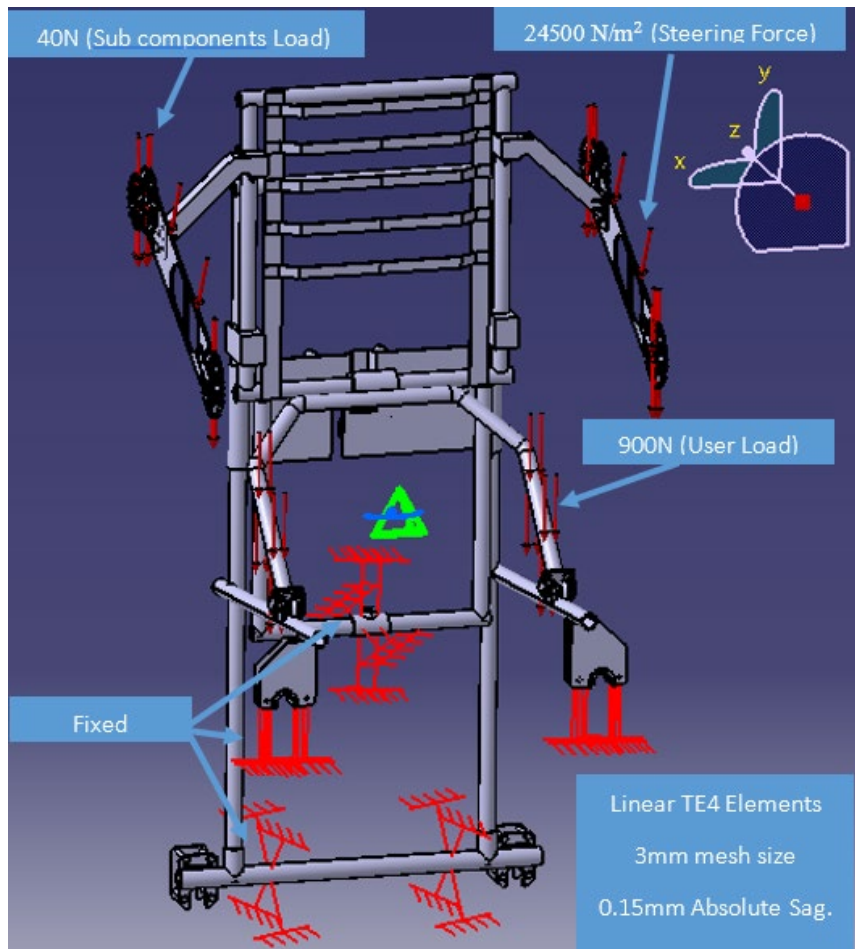


Fig. 2 Finite Element Analysis (FEA) Parameters

4. Result

4.1 Conceptual Design Stage

The morphological chart was used as a method to generate ideas using the combination of important parts identified using the functional decomposition method with certain options (refer Table 2). All ideas for the design were summarized based on the chart. Based on selected options, such as the type of seats, type of supports, and power source, three design sketches were produced (refer Fig. 3).








The Pugh matrix is a method that allows for the comparison of multiple concepts for a product or process, which ultimately leads to one which is the best and meets most of the criteria. The number of alternate solutions to concepts should attempt to satisfy the need. This matrix is usually used to finalize the concept before proceeding to preliminary design.

The evaluation of the concept using the Pugh matrix started with the listing of criteria. Product size, weight, comfort, stability, force used by the user, cost estimation and maintenance of the product were the criteria that were considered important in design evaluation. A +1 value was given if the concept had the advantage for a particular criterion, while a -1 was given when the concept design did not meet the criteria. 0 was given as a neutral point.

Based on the score obtained from the Pugh matrix in Table 3 above, Concept B was selected to be the best due to the highest net score. As highlighted, the seat designed for Concept B was able to support a proper standing posture compared to Concept A, which only offered a rigid elevating seat to the user. The standing mechanism in Concept B involved the movement of muscle during the standing process due to the change of angle of the hip and knee, which is good for rehabilitation patients.

In terms of force used, the chain hoist was able to multiply the force applied by the user using the concept of block and tackle. This means that it would be easier for the user to operate the mechanism compared to others. The application of the power screw in Concept A had poor power efficiency due to high friction and would also be at a disadvantage in terms of maintenance. In Concept C, the device could be limited to a limited range of rehabilitated patients because users would need to be strong enough or would need other human support to use this support device.

Table 2 The morphological chart

OPTION	ASPECT		
	POWER SOURCE	TYPE OF SUPPORT	TYPE OF JOINT
1	Power Screw 	Act as additional mechanism A	Weld (Fixed) 
2	Modified Chain Block 	Act as external mechanism B	Bolt and Nut (Fastener) 
3	Manual lifting by human power C		
INDICATOR			
CONCEPT A	Additional mechanism powered by power screw		
CONCEPT B	Additional mechanism powered by modified chain block		
CONCEPT C	Human powered external mechanism		

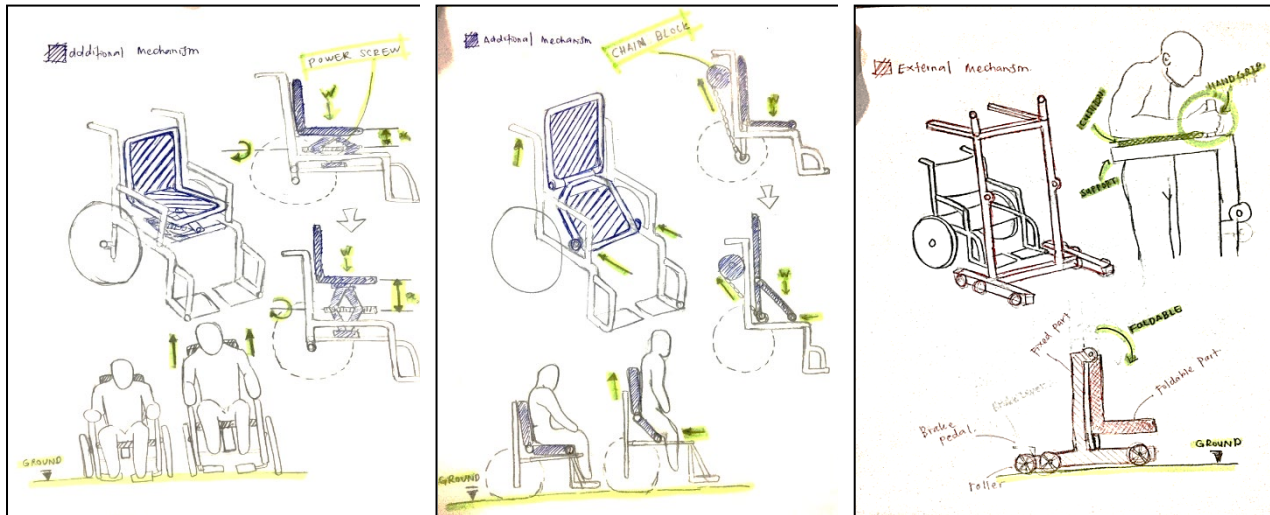


Fig. 3 Sketches for Concept A (left); Concept B (center); and Concept C (right)

Table 3 The Pugh chart

Description		Concept		
Criteria	Weightage	A	B	C
Size	2	+1	0	-1
Weight	4	+1	0	-1
Comfort	3	+1	+1	0
Stability	4	+1	+1	+1
Force used	5	0	+1	-1
Rehabilitation	5	0	+1	-1
Maintenance	4	-1	0	-1
	Net score	9	17	2

4.2 Preliminary Design Stage

The preliminary stage was where the selected concept was converted into a 3D model using CATIA V5 for detailed observation. It was where all important aspects such as technical specification, integration with standard parts, and material availability should be considered in detail during the design process. With a clear view of the product, its output could be maximized based on design improvement or modification. Fig. 4 shows the isometric view of the product in single mode and in assembly mode. Using the Ergonomic Design and Analysis function in CATIA, an anthropometry visual of a Chinese-Taiwan man was added using the Human Measurement Editor module (refer Fig. 5). The main objective was to simulate the WES's user in action while using the ATM machine in full standing mode.

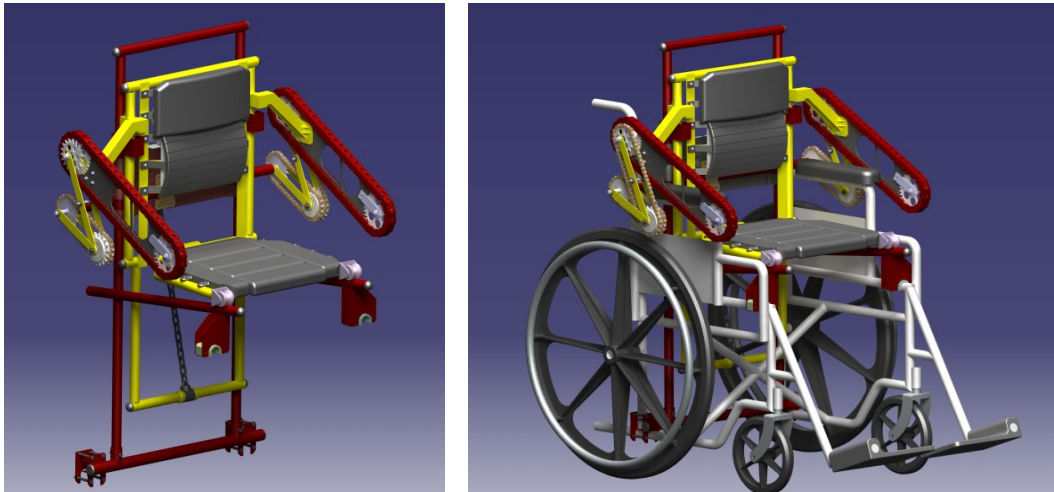


Fig. 4 Isometric view of the WES in single mode (left) versus the assembly mode (right)



Fig. 5 Simulation of the WES in action during standing position

The finite element analysis (FEA) simulation focused on the static analysis of the assembly product. In finite element analysis (FEA), only parts that influence overall strength and reliability will be assembled into one assembly product. The maximum value of Von Mises stress is 62.5 MPa. A visual of the simulation result is shown in Fig. 6.

Next is the safety factor, which is the ratio between material strength and the maximum stress applied (or maximum von Mises stress) used to assess the reliability of the product. Two types of material were selected, mild steel (AISI 1018) and aluminum alloy (6061 T6). As a result, the safety factor for mild steel was 6.27, whereas the aluminum alloy 6061 T6 was around 4.96. Other details are shown in Table 4. The higher safety factor of mild steel indicates that this material offers better strength and safety for the product. Although the safety factor of aluminum was lower, it was still within a good range. Considering the strength and weight properties, selecting aluminum was a better option compared to mild steel.

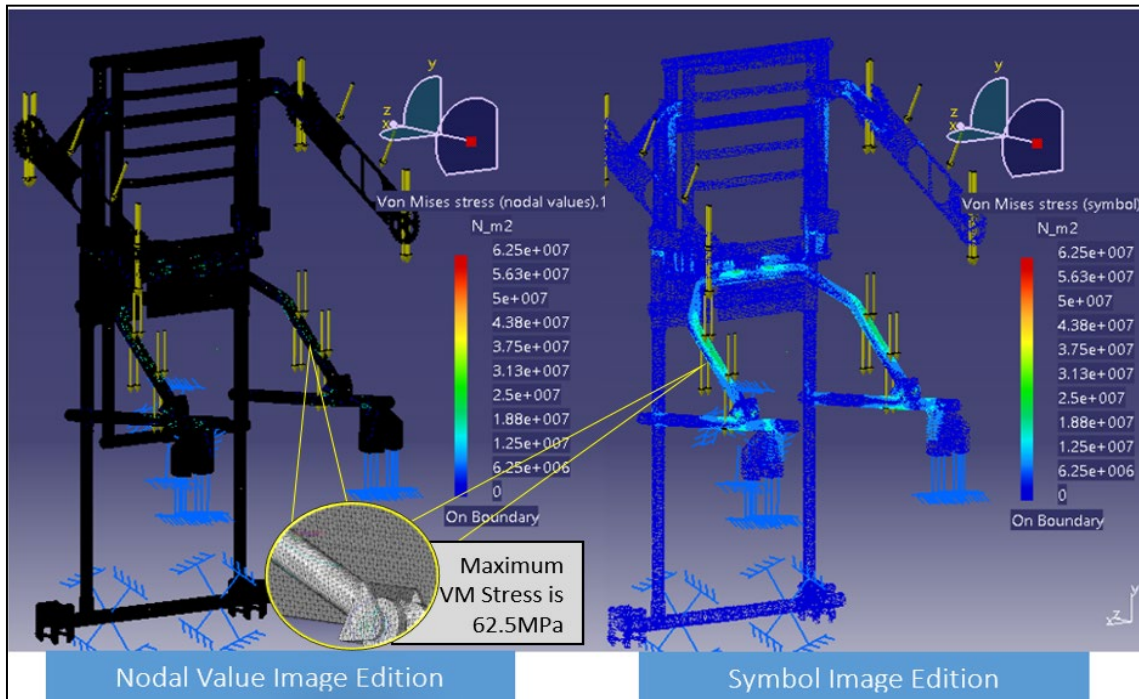


Fig 6 Von Mises (VM) stress result of FEA simulation

Table 4 Summary of simulation result

Material	Mild Steel	Aluminum Alloy
	A36	6061 T6
Density (kg/ m ³)	7860	2700
Ultimate Tensile Strength (MPa)	400	310
Modulus of Elasticity (GPa)	200	68.9
Von Mises stress (MPa)	63.8	62.5
Total deformation (mm)	0.77	2.23
Safety Factor	6.27	4.96

Table 5 Product design specification of the WES

Contents	Details
Product Name:	Wheelchair Elevation Support Unit (WES) Aluminium Alloy 6061-T6
Material:	<ul style="list-style-type: none"> Lightweight High strength Corrosion resistant finishing Maximum overall size 0.68m x 1.08m x 1.2m (W x L x H)
Size:	<ul style="list-style-type: none"> Seat maximum height from ground is 0.57m (sitting position) Seat maximum height from ground is 0.78m (standing position)
Product Weight:	Overall product weight is below 8kg (17.64lbs) excluding weight of wheelchair.
Max. Load:	Applicable to user with weight up to 90kg
Maintenance:	Minimal (e.g. oiling)
Safety:	<ul style="list-style-type: none"> Free from sharp edges. Rotating parts are protected with plastic covers.

Performance:

- Performance of the product varies under specified conditions.
- It is recommended to use the product in less severe conditions.

The Product Design Specification (PDS) was an important aspect of the preliminary design to ensure that the product design would address the project’s objective. It was an important document in the design process as it was where all the information about the product’s detailing, standards and performance was provided. From the PDS, an overall size of 0.68 m x 1.08 m x 1.2 m (W x L x H) with an overall weight of 8 kg (excluding the weight of a wheelchair) was achieved. The product was expected to support users with up to 90 kg of weight. Details of the PDS can be viewed in Table 5. Finally, for manufacturing purposes, part drawings and assembly drawings needed to be generated. Fig. 7 below shows the final assembly drawing for the product.

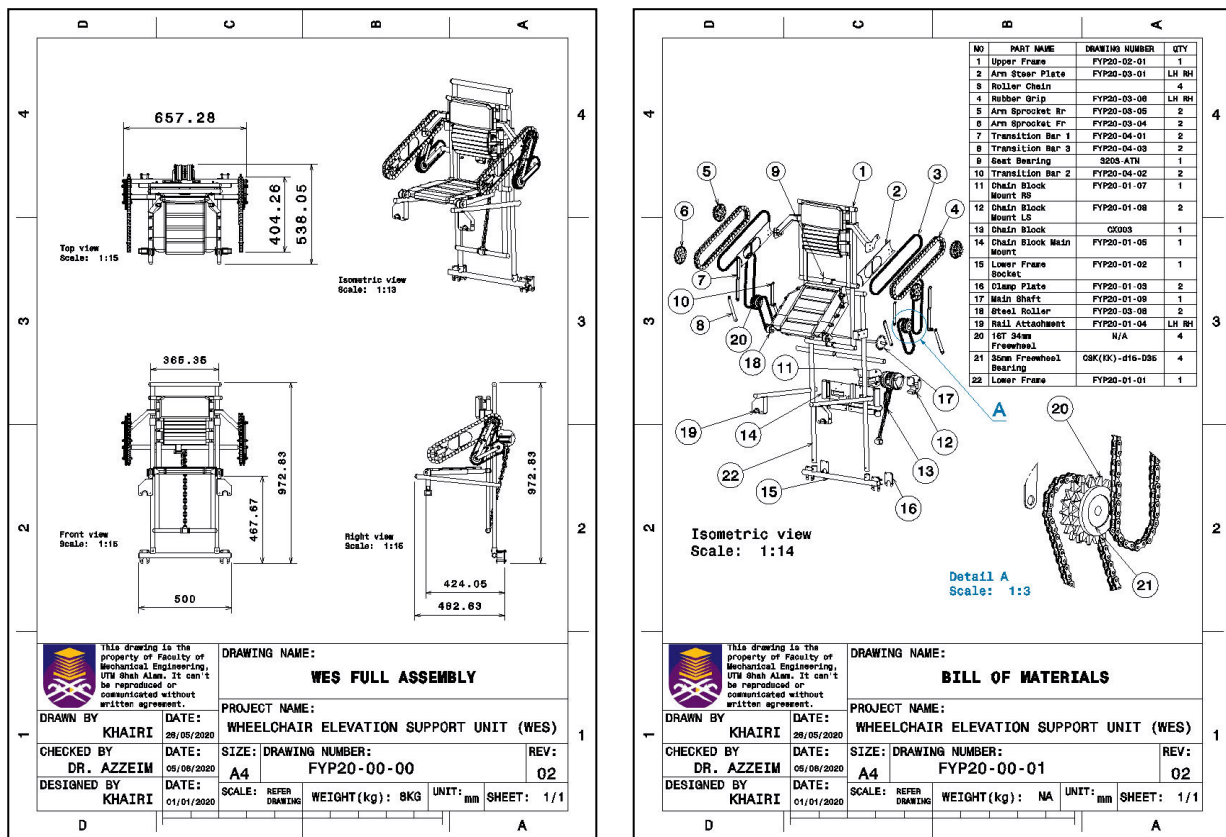


Fig. 7 Assembly drawing (left) and bill of material (right) of the WES

5. Discussion and Conclusions

In conclusion, the project’s objective was achieved successfully. The conceptual and preliminary designs of the standing support device for rehabilitation patients were produced throughout the project.

There were also some recommendations and improvements that could be made to ensure a better wheelchair elevation support (WES) unit design. One of them was to change or redesign the subcomponents of the product into something smaller, thinner, or less complex for ease of manufacturing and assembly. Redesigning the product through famous engineering methods such as Design for Assembly (DFA) and Design for Manufacturing (DFM) may be helpful to come out with a better result.

Further study on product material could be very useful to source a material with better properties, such as a lightweight yet strong material. Additionally, a combination of materials in design is also recommended. The application of different materials with different mechanical properties may vary; for example, strong materials may be used for structural and frame components, while soft and smooth finishing materials may be used for direct contact components.

In the case of an articulated structure, the transition from sitting to standing position may cause the position of the centre of gravity (CG) to change. The higher the CG from the base, the more likely the product would be to topple over if tilted. Hence, it would be vital for future design work to widen the safety margin between lifting and overturning of the product to maintain the stability of the overall product. Based on the simulation results, mild

steel showed the highest safety factor. However, the decision to select aluminum material with a 4.96 safety factor is seen as a wiser option, considering its lightweight and robust use in structural engineering applications. Overall, the objective of the project had been achieved. Finally, it is highly suggested for future work to introduce several analyses for further design evaluation, especially in the dynamic study of the product. Further study on the vibration effect and moment of inertia would be very useful to solve stability and racking motion problems to enhance product safety.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Khairi Azri & M. Azzeim; **data collection:** Khairi Azri; **analysis and interpretation of results:** Khairi Azri & M. Azzeim; **draft manuscript preparation:** Khairi Azri, M. Azzeim, Sukarnur & Helmi. All authors reviewed the results and approved the final version of the manuscript.*

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