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The Design of a Compact and Lightweight Wheelchair for Disabled Children

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Abstract – *This paper describes the process of designing a wheelchair with the main aim of making it compact and lightweight. A wheelchair is a common device used to assist in terms of mobility for those with difficulty to walk. Most conventional manual wheelchairs are heavy and bulky, even after they are folded. The designed wheelchair in this research is able to reduce the weight approximately by 30%. The wheelchair volume after folding is also reduced significantly. Besides, the designed wheelchair was evaluated by using 3D CAD software to analyse the strength and possible material failure. Moreover, a virtual mannequin was used to evaluate the geometry and the comfort of the design. On top of that, a scale down prototype was produced by using a 3D printer to evaluate the fold-ability function of the wheelchair.*

Keywords: Wheelchair, Disable, Compact, Lightweight

1.0 INTRODUCTION

The wheelchair is one of the common assistive devices used all around the world for more mobility and accessibility [1]. A recent report has suggested that over one billion people in the world are suffering from some kind of disabilities [2]. Besides, another study showed that in the United States of America alone, 21.2 million people have at least a disability that limits their basic physical activities, such as walking, lifting, reaching, and so on [3]. Most of them are forced to use a wheelchair for easier mobility.

The conventional manually propelled wheelchair is the most common wheelchair around as it is easily available and relatively low in cost. The common manually propelled wheelchairs may be the obvious choice, but due to its heavy framework and importable design, they do require larger space to be stored. Another variant that is commonly used is an electric-powered wheelchair, in which may sound promising but the key features, such as portable and weight issues, are compromised [4]. Electric wheelchair also tends to be very bulky, heavy, and more costly.

The work in this research focused on designing a lightweight and compact manually propelled wheelchair for disabled people, especially children, to ease their daily commute and also to help them to perform their daily life activities. The designed wheelchair should be easy to operate, and to be carried around, if necessary, as well as easy to be stored away if not used. It was also aimed that the design could be produced at the lowest cost possible.

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Manually propelled wheelchairs are designed in two ways; rigid and folding. Folding wheelchairs, as the name may suggest, are designed to be easily stored away. This folding type wheelchair is commonly used for temporary use like in the hospitals to move patients around and so on. This folding wheelchair also lacks postural support, pressure relief, and usually cannot be customized based on the needs of the users. Rigid wheelchairs, on the other hand, have permanently welded parts and lesser moving parts than a folding wheelchair [5]. Rigid wheelchairs are usually used for long term purpose, where the seat and the back support can be easily customized based on users' needs [6]. This rigid wheelchair can also be built by using lighter materials, such as aluminium and titanium, because most of the joints would be welded together. This welding process and the use of lighter material make the wheelchair lighter, but it cannot be easily stored as portability is an issue here.

Other than manually propelled wheelchair, electric wheelchair is another popular option among users in the market today. In contrast to a manually propelled wheelchair, electric wheelchairs are propelled by an electric motor [5]. Electric wheelchairs are commonly used by people who cannot push with their own arm strength, or in other words, have low upper body strength [7]. These wheelchairs are powered by batteries, depending on the model, as some have on board charger that can be plugged into wall sockets. Electrically-powered wheelchairs come in several basic types. Old-fashioned electric wheelchairs are just beefed up standard manually propelled wheelchairs with extra batteries, motor, and a control system. The platform model electric wheelchairs, on the other hand, have a more civilized design with a proper seat and back support [7]. This type of wheelchair is commonly used for long term purpose rather short term [5]. It is also typically highly customizable according to the users' needs. Electric wheelchairs may sound promising, but the drawbacks are as in the following; it is heavy and cannot be easily stored away. It is also very expensive compared to common manual wheelchair.

2.0 DESIGN CONSIDERATIONS

The design of a wheelchair should be kept as minimal and as simple as possible. Wheelchairs should be designed to enable the user to conduct their daily life activities with ease and without difficulties.

A survey was carried out to understand the customers' needs. A total of 25 respondents answered the survey question that was posted online and this survey was also targeted to those with a close family member, or friend who used wheelchair, as well as the wheelchair users themselves. Figure 1 shows the response for the preferred features of a wheelchair.

This survey question clearly stated the features on the wheelchair that the respondents preferred. Nearly all preferred a light-weighted with a reasonable price tag. Lightweight materials, such as aluminium, which could be used to build wheelchairs, is relatively less expensive compared to titanium. Users also tend to prefer a wheelchair with an affordable price range. Portability and durability were also features that the respondents had opted for.

From the survey responses and discussions with several parties, the design requirements were established, as shown in Table 1.

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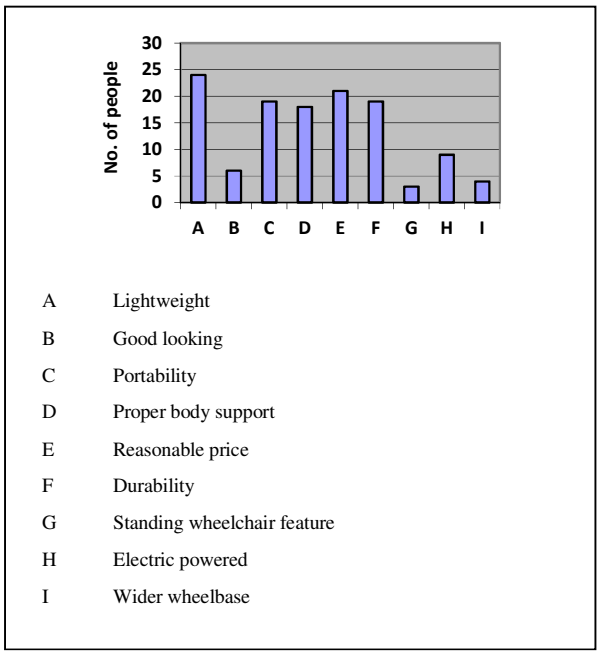

Figure 1: Survey response on preferred features for a wheelchair.

Table 1: Design requirements

Requirement	Description
Weight	Standard manual wheelchair that weighed about 15 kg minimum. The weight of the wheelchair would be kept lower than 15kg.
Price range	The price range was around RM500 – RM1000, which is about the same for the cost of a normal wheelchair.
Dimension	A common manually propelled wheelchair is 70cm wide and around 1.3m tall. The width would be around the same as any longer would be harder for the user to use the wheelchair in confined space and any shorter width could compromise the stability of the wheelchair.
Comfort	The wheelchair should be well-cushioned with proper back rest to avoid the users from getting a backache after using the wheelchair for a longer period of time.
Portability	The wheelchair designed needs to be portable, for example, folding features are welcomed to safe more storage when storing the wheelchair in cars and others.
Safety	The wheelchair designed has to avoid any sharp edges or any dangerous components/ design that may hurt the user.

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3.0 DESIGN AND ANALYSIS

This wheelchair design, on the whole, was aimed at being light weight and compact at the same time. This wheelchair is targeted to be around or less than 15 kg. From the image below, one could say that a conventional wheelchair stretches at about 1.2 meters in length and 0.7 meters across. The design of the wheelchair would be more compact as it can be folded and kept under the range of only 30 to 40 cm of span across once it is folded.

Meanwhile, Figure 2 shows the 3D model of the wheelchair in fully opened configuration. It was designed to be similar to the conventional wheelchair in terms of the frame and structure. Design optimization was carried out to reduce the weight of the wheelchair, while maintaining the strength and the robustness.

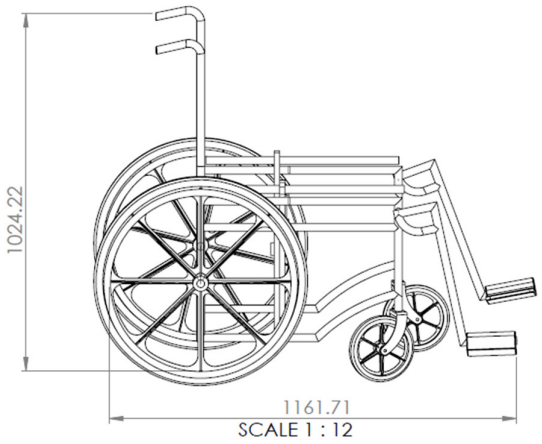

Figure 2: 3D model of the wheelchair in open configuration

Figure 3 shows the wheelchair in folded configuration. Apart from normal folding, the push handles and leg rests can be folded as well. This will reduce the overall volume of the wheelchair when folded.

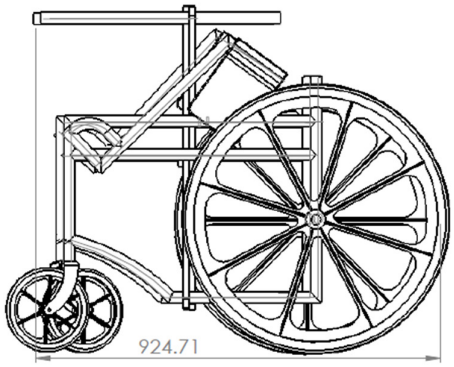

Figure 3: The wheelchair in folded configuration

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Stress analysis is one of the crucial analyses for the design. It shows the rigidity of the wheelchair once a load is applied to it. It is noted that every part of the wheelchair should be tested with a maximum weight of 240kg or approximately 2400N, which is the double of its recommended weight of 120kg for safety reasons. Even the smallest components must be tested, especially the crucial points where failure may occur. The critical parts of this wheelchair include the folding mechanism that supports the wheelchair and the weight of the user, screws that connect the wheelchair parts together, the wheelchair frame, and a small connector that helps in the folding of the wheelchair.

In this study, the SolidWorks software was employed for stress analysis. The material used in these components was T6 aluminium, which had 215 Mpa of yield strength. Moreover, all the parts were analysed accordingly, and the results showed that the wheelchair was able to support the expected load without any failure. Figure 4 shows the screenshot for one of the stress analysis results.

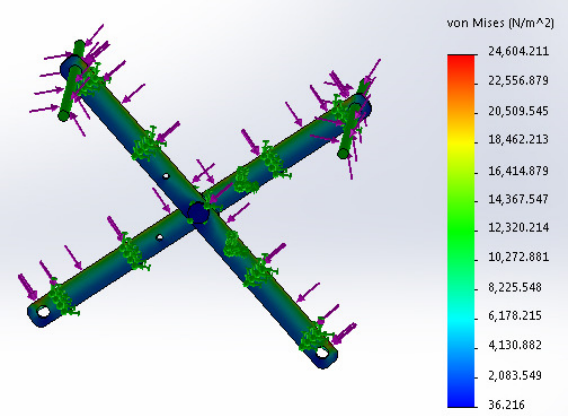

Figure 4: Screenshot of stress analysis on frame support

4.0 RESULTS AND DISCUSSION

The target weight of the wheelchair, which was lower than 15kg, is the average weight of a foldable wheelchair. The designed wheelchair weighed at 11.7kg. It is 20% lighter from the target of 15kg. The main reason for the weight reduction is mainly on the frame of each sides of the wheelchair. The weight of the frames was only 0.7 kg each, yet they were strong and durable due to the material they were are made out of, which was aluminium. The frame structure had been rigid and hollow on the inside to save weight.

The wheelchair could have been made lighter and stronger at the same time with the use of titanium, but due to pricing concerns, it was not applied to this wheelchair. Titanium is another type of alloy that is very light in weight compared to aluminium, but it is far more expensive.

The design was also more compact and achieved higher fold-ability ratio. The approximate volume before and after folding had been 0.89m3 and 0.25m3 respectively. Table 2 shows the comparison in dimensions and volume of a common wheelchair and the design proposed in the study.

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Table 2: Comparison of dimension and volume

Standard Manual Wheelchair	Our Wheelchair
Dimensions	Dimensions
When wheelchair is fully opened	When wheelchair is fully opened
Height: 1200mm	Height: 1024mm
Width: 700mm	Width: 750mm
Length: 1200mm	Length: 1161mm
Approximate volume: 1.008m3	Approximate volume: 0.89m3
When wheelchair if folded	When wheelchair if folded
Height: 1200mm	Height: 751mm
Width: 350mm	Width: 358 mm
Length: 1200mm	Length: 924mm
Approximate volume: 0.504m3	Approximate volume: 0.25m3
Change in volume : 0.504m3	Change in volume: 0.64m3
This wheelchair is only able to fold sideways, which only reduces in width. Once folded, the change of volume is just about half of the original opened wheelchair.	This design allowed for more compatibility as it could be folded sideways to reduce width, as well as to handle, and the footrest can also be folded to reduce the height and the length of the wheelchair.
Approximate weight:	Approximate weight:
15 kg	11.8 kg

Figure 5: Virtual mannequin sitting on the wheelchair

In terms of comfort, a virtual mannequin was obtained from the internet [8], to be used in evaluating the geometry of the wheelchair. Figure 5 shows the sitting position of the virtual

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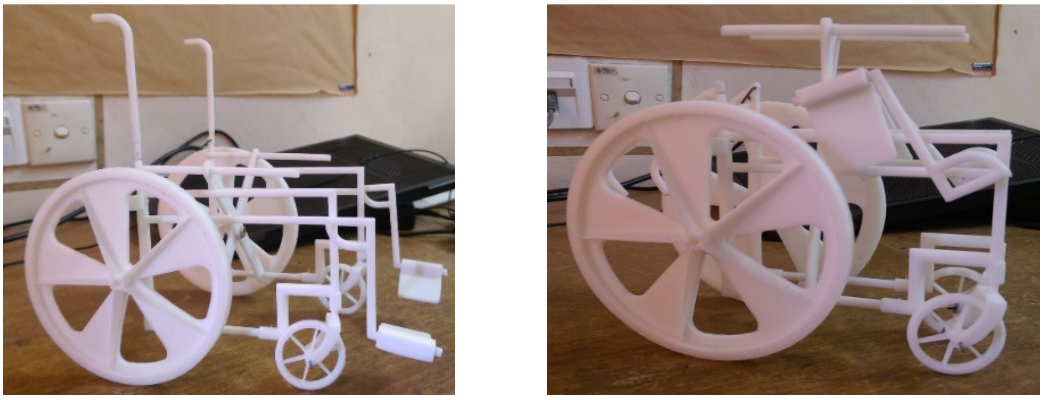
mannequin on the designed wheelchair. From this evaluation, the dimension of the seat width, backrest, and leg rest had been deemed suitable.

A scale down prototype was also fabricated to evaluate the fold-ability function of the designed wheelchair. This prototype was produced by using a 3D printer, as shown in Figure 6. Besides, folding test was conducted to ensure nil interference or overlapping between the parts.



(a) (b)

Figure 6: The scale down prototype of the wheelchair (a) Open (b) Folded

5.0 CONCLUSION

The objective of this research was to design a light weight and a compact wheelchair. A common manually propelled wheelchair has an average weight of 15 kg. The goal was to stay under the 15 kg mark by removing unnecessary parts and properly designing the frame, as well as the body of the wheelchair. After simulating by using 3D modelling software, it was found that the designed wheelchair was only 11.8 kg, which was around 30% lighter than the benchmarked wheelchairs. The material used in designing the wheelchair played a big role in saving the weight of the wheelchair, where aluminium was chosen instead of traditional steel.

The change of volume in the normal conventional wheelchair was 0.504m3, while the designed wheelchair had a change in volume of 0.64m3. The designed wheelchair had a larger change in volume, thus making it more compact than the conventional wheelchair. A scale down prototype was created by using a 3D printer to show the portability of the designed wheelchair.

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