

ORIGINAL ARTICLE

THE PROCESS OF DESIGNING SPECIAL WHEEL CHAIR FOR PEOPLE WITH PHYSICAL DISABILITIES

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ABSTRACT

There is a need to design and develop an affordable motorized vehicle for better mobility among physical disabilities. This study aimed is to initiate appropriate and affordable materials to develop an accessible motorized wheelchair. It includes the feasibility study of the existing used wheelchair, the system used and the characteristic of the physical disabilities symptom. Through the observation, an existing motorized wheelchair uses stainless steel as the main structure, manipulating the shelves heavy-duty accessories, electrical component, heavy-duty battery and car pulley system in which the weight accumulates approximately 100 kg. The heavyweight wheelchair cannot be folded and put inside the car. It also needs to have a special carrier to carry the wheelchair. The field research has also been conducted to evaluate the existing wheelchair system in the market with various systems used, components, and motors material used in the area of technical, usability and comfort before start to redesigning the wheelchair. The results of the study would include the background needs of the characteristic of physical disabilities. The available high-grade aluminium materials will be used to support the mobility and their relevant properties. The design will be done all the way and the specification will be used as an instrument data for the motorized vehicle. The selection of design features, documentation of design procedures and results will be used to create a P.O.C (Prove of Concept) prototype for the meant vehicle. The user will use the preliminary prototyping test and the data (result) will be used to improvise the wheelchair prototype. The second improvised prototype will undergo the second user testing in the area of reliability, stabilization of system, and ease of usage. The results expected will be observed and tested by the user to lead towards the recommendation of the motorized wheelchair design.

Keywords: Physical disabilities, wheelchair, motorized vehicle, mobility

INTRODUCTION

Universiti Sultan Zainal Abidin (UniSZA) is among the leading higher learning institutions in Malaysia that offers broad professional studies faculties. Among the faculties is the Faculty of Innovative Design and Technology where the Department of Industrial Design is one of the programs offered by this faculty. Industrial design is the integration of aesthetics, technology, ergonomic and marketing - know-how into new products, in which the needs of people are transformed into potentially commercially products (Ibrahim, 1999). Through the creative design process, students will come out with a tangible product that will benefit people and society. Students will also be exposed to many different approaches to design thinking and design awareness. Universal design is one of the design approaches that related to buildings, variety design products, or environments to make them accessible and open-minded mind-sets to all people, regardless of age, capability or other factors. For young student designers, their hope and desire through this project will gain an in-depth understanding of problems faced by the disabled people and able to produce a quality and useful product for the disabled. For this design exercise, the design policy adopted was to strive for a simple design that has many

functions and safety features as well as producible. The design should be specific at catering to the needs of the disabled group. This effort is in line with the Malaysian government's commitment to upgrade disabled people's welfare and to ensure they have a meaningful life similar to ordinary people (Marzuki Ibrahim et al, 2019).

METHODS

Case Study 1 - Designing the wheelchair for a child with Tetraphochomelia with PPFd symptom - Nor Damia binti Dr. Daeng Malis, a 12-year-old female child.



Figure 1. People suffering from tetraphochomelia symptom

Tetraphochomelia is a scarce case found in the world. According to the user’s father, Dr. Daeng Malis bin Hj Abd Kahar Senior Medical Officer, UMT, there are only 20 cases of registered patients in the world, including Nick Vudicic-the Australian motivator, who is born without hands and legs. Many authors had mentioned that “Amelia’s complete absence of a limb, which may occur in isolation or as part of multiple congenital malformations” (Shonubi et al., 2006).

Several authors had stated that “fatal limb defects are known to occur although these defects are included within the rare category”. Amelia is a condition in which one arm or leg is absent. Such condition is also known as Phocomelia - a term which was first used in 1836 by Etienne Geoffroy Saint Hilaire. When all the four limbs affected are known as “Tetra-Phocomelia”. Here, “Tetra” is four and “Photo” means Seal while “Melos” is Limb. In this condition hands and feet are only parts of limbs from shoulder or pelvis like seal flippers” (Shukla et al., 2015).

According to Subbarao (2015), “Proximal femoral focal deficiency (PFFD) is a rare congenital disorder affecting the hip bones”. The images of a baby with Tetraphochomelia are shown below.



Figure 2. Tetraphochomelia symptom

The Existing Wheelchair Designs

DiGiovine (2006) had stated that Electric wheelchair, also called electric-powered wheelchair, motorized wheelchair, or power chair, is any seating surface with wheels affixed to it that is propelled by an electrically based power source, typically motors and batteries. In another definition, a wheelchair is as a chair with wheels that is used by a person who is unable to walk for moving around. He also defined a wheelchair as any seating surface (e.g., a chair) that has wheels attached to it to support movement an individual to move anywhere and anytime.

According to Iqbal (2015), a motorized wheelchair is a DC Electric base motor which moves the wheelchair through the navigational control (joystick) which is mounted onto the armrest. Therefore, it can be concluded that the

existing manual wheelchair is human-powered while the motorised wheelchair is equipped with accessories that are customized to user conformability.

An early wheelchair was designed and fabricated by Zol Design Company where its nature of the business was producing customized products and prototypes. This mechanical engineering prototype builder company is located in Rawang, Selangor, Malaysia. Based on their track record, many products have been invented, including those based on electronic and mechanical approaches.

The wheelchair design outcomes are workable but not very user-friendly, not reliable and lack safety consideration and do not portray any aesthetic value within the wheelchair design according to the user and her family. Few improvements to the prototype were made but still failed to both, gain system stability and meet the user’s satisfaction. Lastly, Zol Design recommended Dr. Daeng Malis bin Hj Abd Kahar Senior Medical Office, UMT, the father of Nur Damia to approach UniSZA; the project has been awarded to the Department of Industrial Design, located in FRIT. A team was formed and the project started in 2016 to 2017 with a special grant from the V.C under RMIC. The team began its work by carrying out a feasibility study on the existing wheelchair designed by Zol Design. Based on the evaluation of the existing design, we have a shortlisted the findings on the existing wheelchair design as below:



Figure 3. Existing wheelchair parts and systems

Research and Feasibility Study

In the research phase, instead of evaluating the existing wheelchair design and listing its defects, the team also underwent a brainstorming process which trashed out any possible solutions and work plan. There are two things that the team has achieved were:

a. Mind Mapping

This process as a guide to explore the possible area and have a clear direction to achieve the target set. The outcome of the mind map will be illustrated into a design statement which includes the design process as below:

Table 1. List of work

The current research focuses on developing motorized wheelchair for "DISABLED PERSON" with Tetraphocoameila with girdl synthon.

The mission is to innovate and improve existing wheelchair :

- 1. HUMAN FACTOR & ERGONOMIC OF THE "DISABLED PERSON" TO :**
 - a. Record and study the DISABLED PERSON percentages and Anthropometric data.
 - b. To study daily activity of the disable people
 - c. To enable the DISABLED PERSON to self crawling up and down independently.
- 2. GENERATING DESIGN PROCESS :**
 - a. Generating Industrial Design Concept Ideation base on Research and Problem arise.
 - b. Generate 3d model base on CAD data
 - c. To fabricate full size prototype for testing and evaluation purposes.
 - d. To integrate Control panel, manoeuvre, Toggle Switches for lifting seats and platforms onto prototype come with 2 unit of external 12V battery.
 - e. To perform user testing from preliminary version up to refine version.
- 3. MANUFACTURING METHOD & PROCESS**
 - a. To perform stress analysis simulation onto the moving parts such as seat and filter by the adding load onto the reinforcement parts

b. Theoretical Framework

It is a simple diagram of the scope of work about things needed to be done based on the mind mapping process.

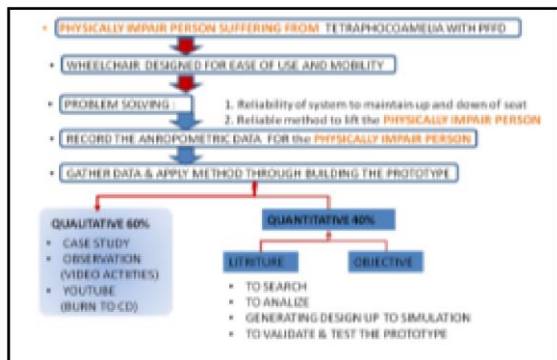


Figure 4. Theoretical framework

c. Design Direction and Target User

In industrial design practice, it is scarce that the product designed caters for an individual or one area. The design needed to go further to certain phases to gain zero defects as close as possible and the design was required to produce a particular volume to achieve reasonable pricing and product reliability. According to Drislane (2015), "It might seem that after all of the hard work of product development and introduction of the product design to the factory, that mass production should be simple and straightforward, but in reality, it can be quite challenging. Forecasting, planning, and committing to the levels of production needed to satisfy the demand for the product can be complex given the key constraints". Therefore, the focus on the target group is increased. This can clearly be seen as below:

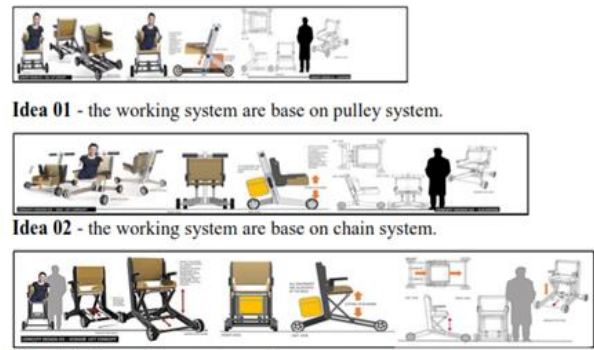


Figure 5. Range of disabled group and target user

The Design Process

a. Conceptual Design Idea Generation

Preliminary conceptual ideation was made based on the research output. Each design showed the different approaches to the working system. In this ideation stage, the aim was to select the most suitable concept to be further developed. A team of 10 which comprised of designers and engineers, participated in the idea selection. The designer presented the idea to the team for selection. The concept illustration is as Figure below:



Idea 03 - the working system are base on cross arm system.

Figure 6. Illustration of concept

The advantages and disadvantages of the conceptual system will be stated in the column. The design which received the highest score was further developed. The diagrams are illustrated in the table below:

Table 2. Concept analysis outcome

CONCEPT ANALYSIS	CONSENSUS TOWARDS DESIGN SELECTION BY WHEELCHAIR TEAM					
TYPE OF CONCEPT DESIGN	SYSTEM 25	ERGONOMIC 25	DESIGN 30	SAFETY 20	SCORE 100%	REMARKS
CHAIN CONCEPT	13	15	23	15	66	DISADVANTAGE : Long layout foot print when the wheelchair fold to ground.
HYDROLIC CONCEPT	20	23	25	17	85	ADVANTAGE : Short layout foot print when the wheelchair fold to the ground. Handle can be pull up and push down.
SWING ARM CONCEPT	14	18	20	13	65	DISADVANTAGE : Unable to balance up the weight of seat and will lead to slippery of the user.

The data was then transformed into Pie Chart concept analysis to illustrate the percentage of the design selection based on three concept ideations.

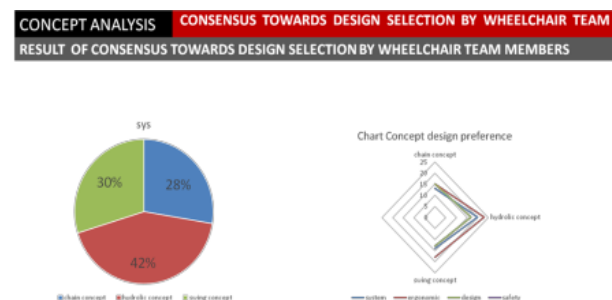


Figure 7. Pie chart concept analysis

b. Idea Refinement to Detail Design

As for concept refinement, there are two requirements needed to be added on which are:

- i. Easy for seat to be lifted up and down
- ii. Foldable for ease of transport.

The concept design refinement was then returned to the drafting board to be added to the new requirement that has been mentioned. The refined concept design that adopted the two required criteria was set as a target criterion. The second level of design was to initiate the Prove of Concept (P.O.C) for the working system for both new criteria.

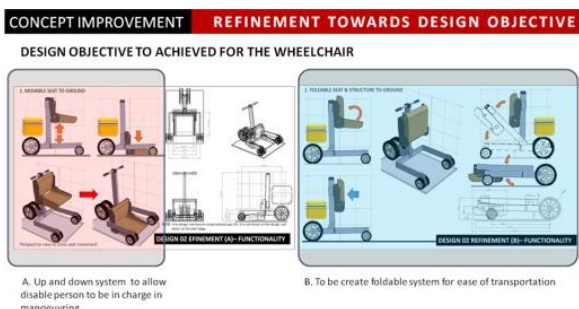


Figure 8. Refinement concept ideation

c. Prove of Concept (P.O.C) on System Design

In designing the wheelchair, the most important thing is to establish a reliable system for the ease of the user to self-manoeuvre either in mechanical or electrical solutions. In this case, the researchers needed to consider the two new criteria to be embedded into the wheelchair design; the first P.O.C component on the system will be:

- i. Electrical auto car jack lifter attached to the wheelchair to lift and down movement of the bucket seat
- ii. Wheelchair ergonomic for user comfort.



Figure 9. Dismantle of existing wheel

d. Building Wheelchair Prototype

As for wheelchair structure, the team agreed to reuse the self-model that is very similar to the final design and, at the same time, would have shortened the cycle of building the prototype. The existing structure was torn off, leaving

behind only the main frame for both sides (left and right). Other configuration followed the concept design by using the electrical auto car jack lifter system attach at the back of the mainframe to enable the bucket chair to be lifted up and down. The Figure below shows the attachment of the electrical car jack lifter to the wheelchair structure.



Figure 10. Reconstruct wheelchair frame

The seating frame which has been welded with lifting mechanism as shown in Figure below was tested a few times together with the holder on both sides. Unfortunately, it did not work well. The failure will be shown in the Results section.



Figure 11. Assembly of lifting system on Prototype 01

The prototype of P.O.C was completed but the result showed failure in many areas that showed in the Results section. The team had to go back to the CAD modelling and source for a more reliable system. The post-mortem and the process continued to the 2nd version of the prototype.

In this stage, the existing structure was taken off and reassembled according to the new design with a new configuration. Dimension of the prototype was done in-house using UniSA facilities such as welding, mate joining and painting. After the repositioning of the lifter and the supporting body structure, the second thing to be built which was the bucket seat support that will be mounted onto the lifting mechanism therefore, when the mechanism is pushed up or down, it will carry along the seat accordingly. It was tested a few times together with the holder on both sides.

e. Building Process of Prototype 02

i. Prototype System Equipment



Figure 12. Electric actuator

The actuator device was eventually stabilized, used for home automation and testing equipment. It can be found in the testing equipment lab. There were two types of actuators which were meant for AC and DC. The DC type actuator was the one that was used for electric gates. The below Figure shows Actuator was the DC standalone version which can directly be connected to the power supply.

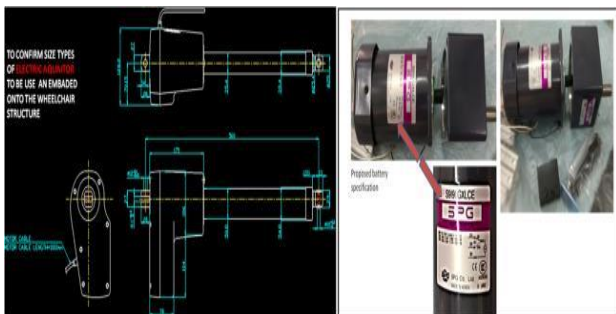


Figure 13. Actuator physical dimensions and DC motor specification

The external battery connected to DC was proposed to be used to power up the wheelchair. The design for the second version was completed as per below wheelchair design and was separated into two sections which were upper frame and lower frame. In this stage, both of the frames were assembled and accessories such as battery, wiring, and actuator system for testing purposes were installed.

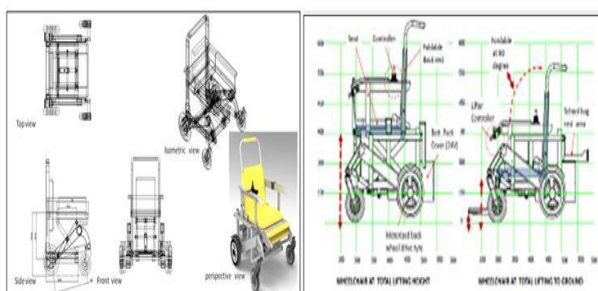


Figure 14. Final wheelchair refinement design and design dimension

ii. Raw Material Selection

The material selection was of a high-grade Aluminium that complied with building aircraft parts (Alloy 2024: One of the most commonly used high strength aluminium alloys) with its combination of high strength and excellent fatigue resistance; it is commonly used where a good strength-to-weight ratio is desired - source: (www.metalsupermarkets.com). The cutting and welding processes were included in this building process.



Figure 15. Aluminium



Figure 16. Main frame construction

The frame construction was divided into two sections, which were upper frame including both left and right arm and seat while the lower frame which included the system actuator adjuster.



Figure 17. Aluminium frame welding

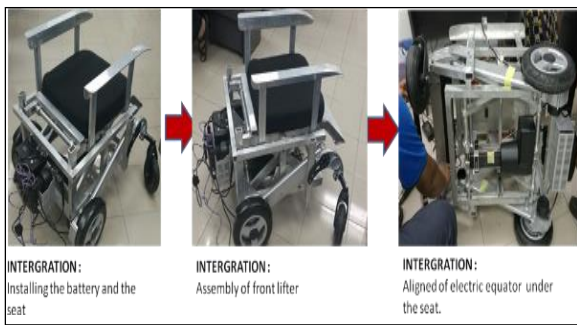


Figure 18. Finished framework construction

The wheelchair design undergone the final stage of the sub-assembly. After this stage, the focus was on the functionality test. The testing was done in-house. After the completion of wiring, the performance was tested and the lifting system was installed, followed by undergoing the user evaluation test. In this test, the user trial-ran the product by operating the wheelchair by herself as part of the evaluation and validation assessment.

f. Validation Assessment

The evaluation of the prototype validation assessment considered these three key points as shown below:

- Ability to operate
- Transportable and foldable
- Comfort and aesthetic

The result will be discussed in the Results section for product validation.



Figure 19. Prototype 02 Ready for Testing



Figure 20. Ongoing validation testing

RESULTS

a. Result on Prototype 01

The seating frame which was welded with lifting mechanism as per shown below was tested few times together with the holder on both sides. Unfortunately, it did not work well. The result shows failure as Figure below.

The completion of P.O.C prototype of P.O.C showed failure resulted in many areas. The post-mortem was done and the process were continued to the 2nd version of the prototype.



Figure 21. Post-mortem and observation result on the prototype 01

As mentioned before, all the dimension and designing process was done in-house using UniZA facilities and workshops such as welding, jointing and painting. After the repositioning of the lifter and supporting the body structure, the bucket seat support had to be mounted onto the lifting mechanism.

Table 3. Result Analysis on Prototype 01

FINISHED PROTOTYPE 01 MODEL		CONCLUSION	
STAGE	DETAILS	ISSUES	REMARKS
FABRICATION STAGE	SEAT FRAME & PREPARED SEAT ASSEMBLY	• SEAT FRAME • SEAT ASSEMBLY	• The welded seat frame have been attached together with the motorized car jack which located at the back of the wheelchair.
ANALYSIS FACTOR	THE SUPPORT LIFTER	• THE SUPPORT LIFTER	• The support lifting at 3 area not only need to withstand the weight of the seat (5kg), but also user weight (70 kg). This observation shows that there will be a big failure if we further proceed the prototype 01. The prediction will be: • Too many heavy load be allocated at each tension point. • The car jack device cannot withstand both weight due to low power consumption and slow movement of up and down. • The welding point will break and twisted after conducting free testing (straight material used). • The seat will be attached on the seat frame by bolt and nut screw which is not testing.
CONCEPTUAL	WHEEL CHAIR SYSTEM AND STRUCTURE	• WHEEL CHAIR SYSTEM AND STRUCTURE	• The concept fail due to many unreliable factors: a. not using the right material b. not using the right lifting system c. not using the right holding mechanism for balancing d. in correct center of gravity to balance up the wheelchair e. too small seat size to cater the user f. unbalanced controller position to allocate the controller joystick g. All back design solution
RECOMMENDATION			To redesign the second version

Therefore, when the mechanism is pushed up or down, it will carry along the seat accordingly. This was tested a few times together with the holder on both sides. Unfortunately, it did not work well. The result showed failure as described below:

- The broken shaft tube at the jointing parts between the lifter mechanism mounting.
- Hole and the seat support back frame. As for the car jack lifter, the motor and the shaft cannot withstand the frequent use of the up and down lifter which was attached to the seat

b. Result on Prototype 02

This Figure below showed the result of critical findings items that were certified by professionals from academics and specialists in their particular field. Experts consisted of two mechanical and electrical engineers, two industrial designers and wheelchair users themselves. The Likert scale tools have been used to validate the product by the subject matter expert. The evaluation of the prototype considered three key points as described below:

- Ability to operate
- Transportable and foldable
- Comfort and aesthetic

The expert results were based on their evaluation during the user testing process. From these findings, the researchers had to develop a prototype to be tested by the user. Based on the result, the adult user experienced hang twisted and the problem of lifespan on the new wheelchair design.

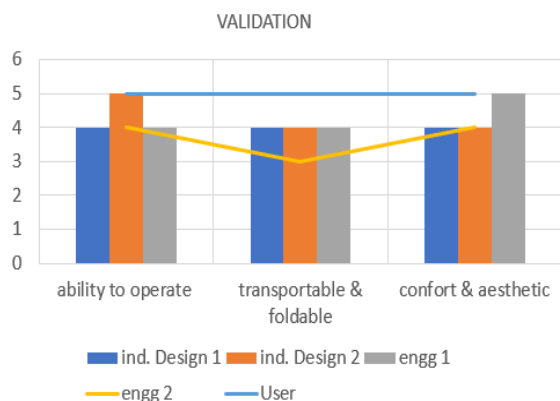


Figure 22. Pre-testing electrical function system



Figure 23. Outcome of validation testing

As per the dateline, the user has come to perform the first evaluation test. Based on the Figure above, it showed that there are still some area needed to be improved, especially in the self-lifting area.

DISCUSSION

The design aims are to enable the user to self-operate the wheelchair and to manoeuvre freely without any assistance. Based on the test, the area that needed to be refined is to change the stairs to the platform lifter to lift the user to an eating position, where she can then push herself back to a proper seating posture. The refinement work is still ongoing until the second user testing.



Figure 24. Evaluation findings

Based on the above Table, the result shows that all the respondents agreed that the wheelchair prototype feature proposed based on all the reading achieved 4.0 and above. In the area of ability to operate, two experts highlighted that it is very easy to use while the other three experts expressed that it is modularly easy to operate. In term of transportability and foldable aspect, of the experts agreed on modularly easy, one expert agreed on easy while the owner agreed at 5.0 score.

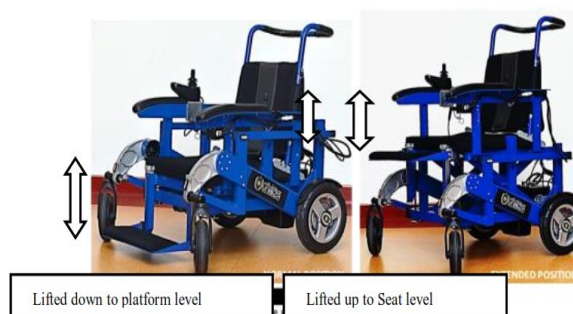


Figure 25. Wheelchair functional

As for comfort and aesthetics, two of the experts gave a high score of 5.0 while three other experts agreed on modularly easy. In conclusion, this data collection showed that the design approached for the wheelchair design is suitable for the user with Tetraphochomelia symptom and

can be produced in a large quantity. The 2nd user evaluation took place at FRIT, UniSZA. The user had total control to manoeuvre the wheelchair. As usual, minor improvement needed to be done, especially on the platform that has to be extended for the comfort of seating and lifting.

Another target user proposed to use this wheelchair is one experiencing abnormal growth as Figure below:



Figure 26. Abnormal growth people

The adult user experiences hang twisted and growth problem but has two distorted legs but remain able to walk or crawl.



Figure 27. Woman suffering from nerve system

There is also the case that an adult lady from Terengganu suffering from a nerve system unable to walk properly. According to her family, she experiences the symptom from an early age around 12 years of age.

CONCLUSION

Generally, the designs that were developed by the students of the Industrial Design Department are solution base and needed by the disabled people. These products are also adequately designed in terms of safety, usability of material, ergonomic factor, form and aesthetic. The faculty was aware that many of the potential designs' solutions produced in this project cannot be commercialized and put into full practical use as yet because of the lack of centre research and development. A lot of work and funds are needed before the design is ready for commercial production. As a result, the

Industrial Design Department is proposing the setting up of The Centre of Design for Disability within the Faculty. The department firmly believed that with the establishment of this centre, most of the problems related to the development of products and equipment for the disabled be researched and resolved.

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COMPETING INTERESTS

There is no conflict of interest.

REFERENCES

1. D. Jayasooria, G. Ooi. 1994, Disabled people's movement in Malaysia, Disability & Society Journal. Vol.9 Issue 17.
2. Department of Statistic Malaysia <https://www.dosm.gov.my>
3. DiGiovine, C. P. 2006, Wheelchair. Encyclopedia of Disability, 1629-1631.
4. Drislane, B. 2015, What is the Product Manufacturing Lifecycle? Retrieved from <https://blog.dragoninnovation.com/blog/2015/10/08/product-manufacturing-lifecycle-overview>
5. Ibrahim, M. 1999, The Role of the Industrial Designer in Malaysian Small and Medium Industries, PhD Thesis, University of Northumbria at Newcastle, UK.
6. Iqbal, A. K. 2015, Motorized Wheel Chair for Physically Challenged Person. International Conference on Humanizing Work and Work Environment 2015
7. JKM. Pelan tindakan OKU 2016 - 2022 Kementerian Pembangunan Wanita, Keluarga dan Masyarakat, Malaysia. http://www.jkm.gov.my/jkm/uploads/files/POKU/PelanTindakan_OKU.2019
8. Marzuki Ibrahim et al 2019, UniSZA as National Centre of Design for Disability in Malaysia. IOP Conference Series Materials Science and Engineering. 697:012030
9. Shonubi, A. M., Akiode, O., Salami, B. A., Musa, A. A., Sotimehin, S. A., & Sule, G. A. 2006, Asymmetrical Tetraphocomelia with Radiohumeral Synostosis. Annals of Saudi Medicine, 26(4), 318-320.

10. Shukla, A. K., Sanjay, S. C., Krishna, L., & Krishnappa, N. 2015, Tetra-Phocomelia: A Rarest of Rare Case. Journal of Clinical and Diagnostic Research : JCDR.
11. Subbarao, K. 2015, Proximal femoral focal deficiency (PFFD) imaging spectrum. Journal of Research in Medical Sciences, 3(2), 90-93.
12. UNISEF. (n.d.) https://www.unicef.org/Malaysia/sowcsowc_13-situation_in_malaysia.html.