# CONCEPTUAL DESIGN OF THE CRUTCHES USING TRIZ-BIOMIMETICS METHOD

TAN JIA WEI

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# CONCEPTUAL DESIGN OF THE CRUTCHES USING TRIZ-BIOMIMETICS METHOD

**TAN JIA WEI**

**A report submitted**
**in fulfillment of the requirements for the degree of**
**Bachelor of Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2020**

**DECLARATION**

I declare that this project report entitled “Conceptual design of the crutches using TRIZ-Biomimetics method” is the result of my own work except as cited in the references.

Signature : .....
Name : .....
Date : .....

## APPROVAL

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

| | | |
|---|---|---|
| Signature | : | ..... |
| Supervisor's Name | : | ..... |
| Date | : | ..... |

**DEDICATION**

To my beloved mother and father

## ABSTRACT

Crutch is a medical device that give assistance to disabled people in walking. Most of the crutches are made of hollow tube that consists low resistance of local buckling and ovalization. This study explained the conceptual design processes of the crutches using Theory of Inventive Problem Solving (TRIZ) with the integration of Biomimetics method. There are still many constraints in order to implement the nature technology into engineering designs discipline. Biomimetics known as a method in mimicking the technology of the nature were used in this study to be the bridge of the technology transfer. The objectives of this study are to generate the design concepts of crutch based on TRIZ Function Oriented Search (FOS) with Biomimetics method and selecting the best design concepts using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. This study has been carried out through eight processes namely problem identification, function analysis, TRIZ (FOS) – Biomimetics method, biological strategies, design concept generation, performance analysis, results/data gathering and final design concept selection. The preliminary result shows that the design concept 1 (DC1) using carbon fiber reinforced polymer (CFRP) composites material is the ideal solution among the 20 design variables. Then, the design of the DC1 was optimized to achieved the optimum results. The final result shows that the optimized design concept 1 (DC1-new) with CFRP material is the most ideal solution among 6 design variables (CFRP material). The weight of the DC1-new has been reduced by 28% (from 0.540 kg to 0.385 kg) and the safety factor has been improved from 10.31 to 4.52. As a conclusion, TRIZ (FOS) – Biomimetics method succesfully shows that

it can be the medium in transferring the nature technology into engineering design to generate the design concepts while TOPSIS method can evaluate multiple alternatives (design concepts) with multiple criteria to select the ideal solution of the design for the crutches. The integrated method of TRIZ (FOS) – Biomimetics and TOPSIS can assists designers, engineers and researchers in transferring the biological technology into engineering designs to solve the engineering problems.

## ABSTRAK

Topang adalah alat perubatan yang membantu orang kurang upaya untuk berjalan. Kebanyakan topang diperbuat daripada tiub berongga yang mempunyai rintangan yang rendah ke atas lengkungan dan perubahan bentuk bujur. Kajian ini menerangkan tentang proses konsep rekabentuk bagi topang menggunakan kaedah Teori Penyelesaian Masalah Inventif (TRIZ) dengan integrasi kaedah Biomimetik. Masih terdapat banyak kekangan dalam melaksanakan pemindahan teknologi alam semula jadi ke dalam disiplin rekabentuk kejuruteraan. Biomimetik dikenali sebagai kaedah dalam meniru teknologi alam semula jadi akan digunakan dalam kajian ini untuk menjadi pengantara pemindahan teknologi. Objektif kajian ini adalah untuk menjana konsep rekabentuk topang berdasarkan keadah TRIZ – Carian Berorientasikan Fungsi (FOS) dengan kaedah Biomimetik dan memilih konsep rekabentuk yang terbaik dengan menggunakan Teknik Pilihan Urutan Mengikut Kesamaan dengan Penyelesaian Ideal (TOPSIS). Kajian ini telah dilaksanakan melalui lapan proses iaitu pengenalpastian masalah, analisis fungsi, kaedah TRIZ (FOS) – Biomimetik, strategi biologi, penghasilan rekabentuk konsep, analisis prestasi, pengumpulan keputusan/data dan pemilihan akhir rekabentuk konsep. Keputusan awal menunjukkan bahawa rekabentuk konsep 1 (DC1) yang menggunakan polimer gentian karbon (CFRP) adalah penyelesaian yang ideal antara 20 pembolehubah rekabentuk. Kemudian, rekabentuk DC1 telah dioptimumkan untuk mencapai hasil yang lebih memberangsangkan. Keputusan akhir kali ini menunjukkan bahawa konsep reka bentuk yang dioptimumkan 1 (DC1-baru) dengan bahan CFRP adalah penyelesaian yang paling ideal di antara 6 pembolehubah rekabentuk

(bahan CFRP). Berat DC1-baru ini berkurang sebanyak 28% (dari 0.540 kg kepada 0.385 kg) dan faktor keselamatan telah bertambah baik daripada 10.31 kepada 4.52. Kesimpulannya, keadah TRIZ (FOS) – Biomimetik menunjukkan bahawa ia boleh menjadi medium dalam pemindahan teknologi alam semulajadi ke dalam rekabentuk kejuruteraan untuk menjana rekabentuk konsep manakala kaedah TOPSIS boleh menilai pelbagai alternatif (rekabentuk konsep) dengan pelbagai kriteria dalam memilih penyelesaian yang ideal bagi rekabentuk topang. Kaedah bersepadu TRIZ (FOS) – Biomimetik dan TOPSIS dapat membantu pereka, jurutera dan penyelidik dalam memindahkan teknologi biologi ke dalam rekabentuk kejuruteraan bagi menyelesaikan masalah kejuruteraan.

## ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Mohd Adrinata bin Shaharuzaman from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for his essential supervision, support and encouragement towards the completion of this project report.

I would also like to express my greatest gratitude to Dr. Nidzamuddin bin Md. Yusof from Faculty of Mechanical Engineering UTeM, second examiner or reviewer of this project for his advice and suggestions in this project.

Special thanks to all my friends, my beloved mother, father and siblings for their moral support in completing this degree. Finally, thank you to everyone who has been at the critical parts of realization of this project.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBEREVATIONS

| | |
|---|---|
| AD | Axiomatic Design |
| AHP | Analytic Hierarchy Process |
| CFRP | Carbon Fiber Reinforced Polymer |
| DFMA | Design for Manufacture and Assembly |
| FMEA | Failure Mode and Effect Analysis |
| FOS | Function Oriented Search |
| GFRP | Glass Fiber Reinforced Polymer |
| MCDM | Multiple Criteria Decision Making |
| NLP | Neuro-Linguistic Programming |
| QFD | Quality Function Deployment |
| SCAMPER | Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse |
| TOC | Theory of Constraints |
| TOPSIS | Technique for Order of Preference by Similarity to Ideal Solution |
| TRIZ | Teoriya Resheniya Izobreatatelskikh Zadatch |
| U.S.S.R. | Union of Soviet Socialist Republics |
| VIKOR | VlseKriterijumska Optimizacija I Kompromisno Resenje |
| 6σ | Six Sigma |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Crutch is a medical tool or walking aids that used by people who were unable to use their legs due to short-term injuries or lifelong disabilities and crutch able to assist them to move (Physiopedia Contributors, 2019). There are three types of crutches which are underarm or axillary crutches, forearm crutches and platform crutches. Most of the crutches available in the market are made of hollow cylindrical aluminium tube. The advantages of aluminium are their strength, high rigidity and low density that can provides comfortability to the users when they move (Stojanovic, Bukvic and Epler, 2018). Nevertheless, in order to enhance the crutches design and performance, design optimization process is required. Therefore, implementation of problem-solving tools is required in order to assist the designers or researchers in the process of design optimization and one of the most familiar and famous problem-solving tools is the Theory of Inventive Problem Solving (TRIZ).

TRIZ is a collection of tools and techniques which founded by Genrich S. Altshuller and his colleagues during the former Union of Soviet Socialist Republics (U.S.S.R.). TRIZ able to define the problem at a functional level precisely and provides highly effective and innovative solutions. Besides that, TRIZ has integrated with different types of problem-solving tools, techniques and philosophies such as Quality Function Deployment (QFD), Six Sigma (6σ) and one of the well-known problem-solving tool is the contradiction matrix with 40 inventive principles. A new TRIZ-based tool which is Function Oriented Search (FOS) has developed by S. S. Litvin (2004) where it requires less time and effort to prove the potency of the new solution due to the method that can adapts the existing technology, product or process to solve problem. Nonetheless, Bogatyrev (2000) and Vincent and Mann

(2002) as cited in Vincent et al. (2006) stated that TRIZ is well-known in transferring of functionality and integration of knowledge from one field to another as well as biomimetics. Therefore, TRIZ seems as an ideal point of departure and as an important linkage for nature-engineering problem solving.

Biomimetics or biomimicry define as a subject that imitate nature or biological characteristics and it was implemented in product design to solve engineering problems (Biomimicry Institute, 2015; Pathak, 2019). In other words, biomimetics also known as technology transfer method as its copy the nature strategies to solve the engineering problems. Wahab, Rose and Osman (2011) defined that technology transfer is closely link to the transfer of information, know-how, technical knowledge embodied in products, processes and management. Pathak (2019) stated that biomimicry claims that nature is the most prominent and assured source of inspiration for the designers by imitate the design features from nature due to nature's 3.8 billion years of evolution, as it has adapted and transformed based on the experience of solving limitation of the environment to meet their needs.

The purpose of this project is to create a new design concept of the crutches based on biological strategies by implementation of TRIZ (FOS) – Biomimetics method that able to reduce the weight and enhancing the performance and quality of crutches at the same time. In addition, it can create a breakthrough in design process and manufacturing process therefore change the perspective for the combination of biological and engineering. Besides that, it also allows user breakthrough in material selection. User can choose composite materials rather than just apply the conventional materials (mainly metals). Daniel *et al.* (1994) stated that composite materials consist a lot of advantages compare to conventional materials. For instance, high strength, high stiffness, low density and etc.

## 1.2 Problem Statement

There are still many drawbacks in conducting and practicing the technology transfer discipline, which varies from biological cases to engineering cases. Bogatyrev and Bogatyreva (2015) mentioned that there are variations in methodologies and societies between biological and engineering. Therefore, it is very difficult to develop a strong bridge between nature and engineering. In addition, Baldussu and Cascini (2015) also stated that engineers and designers lack knowledge and guidance to adopt the principle of technology transfer through the integration of biological and nature with engineering, and this is the barrier for engineers and designers to find a suitable biological strategy to solve engineering problems and the widespread application of biomimetics in industrial research and development activities.

Other than that, most of the crutches are made of hollow tube due to hollow tube are lightweight. Nevertheless, Karam and Gibson (1994) and Vincent (2002) stated the weakness of the hollow tube or cylindrical shell structures that hollow tube is usually unable to resist of local buckling and ovalization. From the previous statement, it can make the assumptions that it may cause injury again to the user due to failure design of crutches. In order to overcome the local buckling and ovalization issue, the stiffener will be adding in the hollow tube but most of the crutches are made in aluminium material with around 2700kg/$m^3$ of density and this will increase the weight of the crutches. Therefore, different materials need to be applied in order to achieve lightweight target.

## 1.3 Objective

The objectives of this project are as follows:

1. To develop the design concepts for the crutches using TRIZ (FOS) -Biomimetics method.
2. To study the performance of the design concepts through finite element analysis (FEA) using Autodesk Fusion 360 software.
3. To select the best design concept of the crutch using Multiple Criteria Decision Making (MCDM) method.

## 1.4 Scope of Project

The scopes of this project are:

1. This project will focus on the axillary (underarm) crutches.
2. The performance criteria of the design concepts which is stress, displacement, weight and safety factor are simulated in this project.
3. The Multiple Criteria Decision Making (MCDM) method used in this project is Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method to select of the final design concept of the crutch.

# CHAPTER 2

# LITERATURE REVIEW

Morphology of design demonstrate detailed description of the design process shows in Figure 1 was introduced by Asimow (1962) (Dieter and Schmidt, 2013). The design process was divided into three phases namely, conceptual design, embodiment design and detail design. Conceptual design refers the problem statement that have been analyzed based on the needs and generates various of ideas and preliminary solutions (French, 1985). Problem definition is the first and the most important stages in the product design process to create a statement explains about what the requirements that product must meet. A thorough understanding of problems are essential in order to find an excellent solution. Besides that, gather information can be made through various of sources such as internet, journal and technical article. However, designers and engineers are required to validate the gathered information to ensure that the information is reliable. In order to generate innovative concept design solution, the gather information step is placed between the problem definition and concept generation steps as shown. Dieter and Schmidt (2013) also stated that gather information is an important step in product design process because it brings great influences for the embodiment and detail design phases. In addition, concept generation includes creating a wide range of design concepts that might meet the product needs and satisfy the problem statement. In order to generate extraordinary and reliable design concept, designers and engineers required to think creatively and critically with fully utilization of gathered information by using problem-solving tool such as brainstorming, mind mapping and Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse (SCAMPER). Finally, Multiple Criteria Decision Making (MCDM) method is used in this project for evaluation of design concepts that function as selection the final ideal design concept among

various of design concepts with contradiction of multiple design criteria before proceeds to embodiment design phase. Hsu and Liu (2000) and Wang *et al.* (2002) identified that conceptual design is the most important phases in product design because it gives a vast impact to the product such as total cost, performance, quality and others. Therefore, this project focus on conceptual design phase which requires the problem identification, information gathering, design concept development and design concept evaluation for the crutches.

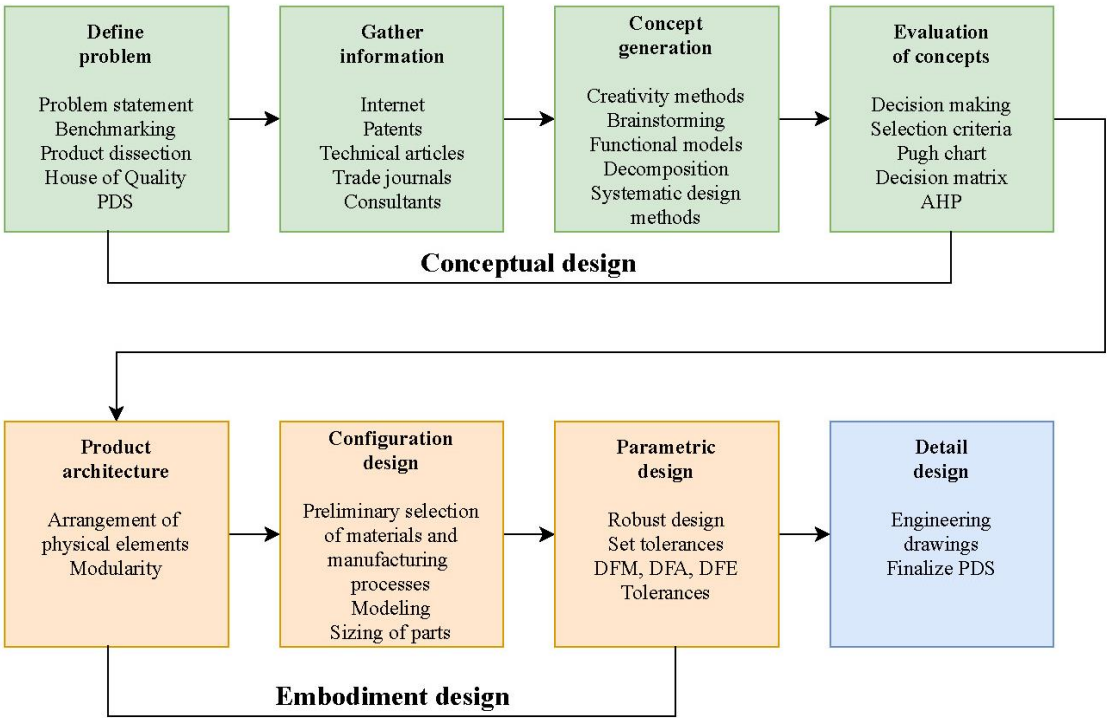


Figure 1: Morphology of design (From Dieter and Schmidt, 2013)

Crutch is a mobility device and walking support used by those who are unable to use their limbs because of short-term accidents and permanent disabilities (Edelstein, 2019; Physiopedia Contributors, 2019). Figure 2 shows three main types of crutches which are axillary (underarm) crutches, forearm crutches and gutter (platform) crutches. Axillary (underarm) crutches are the most common crutches and used by positioning the pad against the ribcage below the armpit and holding the grip. Forearm crutches has a forearm cuff that

allows user inserts the arm into the forearm cuff and hold the handgrip. Gutter (platform) crutches are suitable used by people with poor hand or grip strength due to arthritis, cerebral palsy, or other disabilities. The forearm sits on a horizontal platform and is typically attached with Velcro straps.


Figure 2: Types of crutches

At present, most of the crutches are made from hollow tube of aluminium or magnesium. Karam and Gibson (1994) and Vincent (2002) stated that hollow tube or cylindrical shell structures usually fail to resist of local buckling and ovalization. Therefore, additional of stiffener or foam core in the tube is added in order to overcome the ovalization and local buckling issue. Nevertheless, the weight of the hollow tube will increase by adding the stiffener or foam core. Alternatively, composite material indicates as an ideal solution in order to produce the product with high strength and low weight of properties. Composite material is a material that compound of two or more different materials and present extraordinary of material properties with high strength-to-weight ratio (Alberto, 2013). In this project, the composite materials that studied are carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP). CFRP and GFRP are the composite material made of polymer such as polyester thermosetting plastic, epoxy, vinyl ester or nylon and reinforced with carbon and glass fiber (Alberto, 2013; Che *et al.*, 2014). Besides of material

properties, generating adequate ideas are also important in order to develop several of adequate design concepts.

Nowadays, there are many tools to generate good idea to solve the problems such as Ishikawa diagram (or fishbone diagram), failure mode and effect analysis (FMEA), morphology chart, brainstorming and the Theory of Inventive Problem Solving (TRIZ) (Mansor *et al.*, 2017). Recently, TRIZ is getting familiar and popular within engineering field. It helps designers or researchers to determine the keyword or main problem and generating ideas or solutions that gives the positive output in design process.

TRIZ, the acronym of 'Teoriya Resheniya Izobreatatelskikh Zadatch' in Russian term which means the Theory of Inventive Problem Solving. TRIZ was developed by Genrich S. Altshuller and his colleagues in the former Union of Soviet Socialist Republics (U.S.S.R.) between 1946 and 1985. TRIZ is a collection of tools and techniques that ensures an accurate definition of a problem at a functional level and then provides strong indicators towards successful and often highly innovative solutions. In addition, Hua *et al.* (2006) listed the problem-solving tools, techniques and philosophies that have been integrated or compared with TRIZ such as Quality Function Deployment (QFD), Six Sigma (6σ), Design for Manufacture and Assembly (DFMA), Robust Design, Axiomatic Design (AD), Theory of Constraints (TOC), Brainstorming, De Bono's theories, Mind Mapping, Neuro-Linguistic Programming (NLP) and others. Abramov *et al.* (2015) and Li *et al.* (2015) also constructed a TRIZ based innovation roadmap as shown in Figure 3. The roadmap consists of four stages namely target definition, problem identification, problem solving and solution evaluation. Target definition stage is to identify and select the products which target specifically on the product parameters and features to be improved and optimized. Next, problem identification stage is to identify the specific problems of the product that should be solved from different perspective by using system analysis tools and there are several of tools such as function