BIOPATTERN: A BIOMIMETIC DESIGN FRAMEWORK FOR GENERATING
BIO-INSPIRED DESIGN (BIOMIMICRY)

FOO CHIN TOONG

A thesis submitted in
fulfillment of the requirement for the award of the
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Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

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To the Creator of the heavens and the earth.
ALL GLORY BE TO THE LORD OF HOST, THE INTELLIGENT DESIGNER OF THIS WORLD, FOR FROM HIM, THROUGH HIM, AND TO HIM ARE ALL THINGS. THIS THESIS WILL NOT BE COMPLETED WITHOUT THE GRACE OF MY LORD JESUS CHRIST. HE HAD BEEN FAITHFUL TO ME FOR HE DID NOT LEAVE NOR FORSAKE ME THROUGHOUT THIS JOURNEY. AS A LOVING FATHER, HIS GRACE SUSTAINS ME.

I am grateful for my parents for giving me the opportunity to pursue my own dreams and support me in all areas. They had helped me to be a better person by standing on top of their shoulder to reach greater heights which was impossible for them to reach in the past. Though they were not perfect, they are beautifully imperfect to me.

I’m grateful for Jong Oi Ka for being my supporter, cheerleader, helper, and friend. She’s been there with me all the time, despite the distances between us. She has always been supportive with my decisions and cheers me on in everything I do.

I wanted to express my gratitude to my supervisor, Prof. Ts. Dr. Badrul Bin Omar for being more of a friend and a father instead of a supervisor when he is guiding me throughout this research, giving me valuable advices, and directing me to proper sources of help.

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Last but not least, I wanted to thank my family-in-Christ for keeping me in their prayer, especially when I am lost and didn’t know how to continue on. They have been giving me love, care, and encouragement all the time to help sustain me until the end.
ABSTRACT

Some of the best inventions are inspired by nature because nature had been adapting to environmental changes as an algorithm improving itself to solve engineering problems in the most efficient ways. However, there is a huge knowledge gap between engineering and biology where engineers are unable to crossover. The objective of this research is to develop a biomimetic design framework, BioPattern, which bridges this knowledge gap. BioPattern constitutes of TRIZ, SAPPhIRE, and pattern language. It has a pattern-based ontology and a sustainability evaluation, known as Ideal Chart. The method to assess BioPattern is by case study where two different groups of students (controlled group and experimental group) are asked to generate inventive ideas where the experimental group employed BioPattern as the ideation tool. BioPattern is then applied in two industrial problems; centrifugal blower and plastic extruder, conceptually. BioPattern is found to be better in generating ideas with higher novelty. 71% of the ideas generated by the controlled group are of no novelty, 11% low novelty, 7% medium novelty, 11% high novelty, and no new invention. While there are only 8% of the ideas generated the controlled group are of no novelty, 33.5% low novelty, 33.5% medium novelty, 25% high novelty, and no new invention. BioPattern is also able to generate strategies that are practical as the experimental groups are able to fabricate functional machines that are suggested by BioPattern. As for industrial applications, BioPattern suggested the strategy of composite layer to reduce the weight of the impeller of the centrifugal blower, while the strategy of insulation with ceramic for extruder insulation. It can be concluded that BioPattern is able to bridge the biology-engineering gap and it is holistic model which will ease ideation by providing sustainable inspiration from nature.
ABSTRAK

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<th>Description</th>
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<tbody>
<tr>
<td>°C</td>
<td>Degree Celsius</td>
</tr>
<tr>
<td>ARIZ</td>
<td>Algorithm for Solving Inventive Problems</td>
</tr>
<tr>
<td>BDA10602</td>
<td>Course code of C&amp;I</td>
</tr>
<tr>
<td>BDA40804</td>
<td>Course code of IED</td>
</tr>
<tr>
<td>BID</td>
<td>Bio-Inspired Design</td>
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<tr>
<td>BMO</td>
<td>BioMimetic Ontology</td>
</tr>
<tr>
<td>C&amp;I</td>
<td>Creative and Innovation</td>
</tr>
<tr>
<td>CaCO$_3$</td>
<td>Calcium Carbonate</td>
</tr>
<tr>
<td>CFRP</td>
<td>Carbon fibre reinforced polymer</td>
</tr>
<tr>
<td>DANE</td>
<td>Design by Analogy to Nature Engine</td>
</tr>
<tr>
<td>E2B</td>
<td>Engineering-to-Biology Thesaurus</td>
</tr>
<tr>
<td>E2BMO</td>
<td>Hybrid tool of E2B and BMO</td>
</tr>
<tr>
<td>F</td>
<td>Field</td>
</tr>
<tr>
<td>$F_E$</td>
<td>Electrical field</td>
</tr>
<tr>
<td>$F_{GR}$</td>
<td>Gravitational field</td>
</tr>
<tr>
<td>$F_M$</td>
<td>Mechanical field</td>
</tr>
<tr>
<td>$F_{MG}$</td>
<td>Magnetic field</td>
</tr>
<tr>
<td>$F_{NS}$</td>
<td>Nuclear field of strong interaction</td>
</tr>
<tr>
<td>$F_{NW}$</td>
<td>Nuclear field of weak interaction</td>
</tr>
<tr>
<td>$F_T$</td>
<td>Thermal field</td>
</tr>
<tr>
<td>FBS</td>
<td>Function-Behaviour-Structure</td>
</tr>
<tr>
<td>FM</td>
<td>Flowthing Model</td>
</tr>
<tr>
<td>FR</td>
<td>Functional Representation</td>
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<tr>
<td>GF</td>
<td>Generic function</td>
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<tr>
<td>HDPE</td>
<td>High density polyethylene</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>I/O</td>
<td>Input/output</td>
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<tr>
<td>IED</td>
<td>Integrated Engineering Design</td>
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<tr>
<td>IFR</td>
<td>Ideal final result</td>
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<td>J</td>
<td>Joule</td>
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<tr>
<td>K</td>
<td>Kelvin</td>
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<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre</td>
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<tr>
<td>MMD</td>
<td>Model with Miniature Dwarfs</td>
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<tr>
<td>N/A</td>
<td>Not applicable</td>
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<tr>
<td>PE</td>
<td>Polyethylene</td>
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<td>Polyethylene terephthalate</td>
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<td>PP</td>
<td>Polypropylene</td>
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<tr>
<td>RFBS</td>
<td>Requirement-Function-Behaviour-Structure</td>
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<tr>
<td>rpm</td>
<td>Revolution per minute</td>
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<tr>
<td>s</td>
<td>Seconds</td>
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<td>Substance</td>
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<td>Substance 2</td>
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<td>SAPPhIRE</td>
<td>State-Action-Part-Phenomenon-Input-oRgan-Effect</td>
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<td>SEM</td>
<td>Scanning electron microscope</td>
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<td>SFM</td>
<td>S-Field model</td>
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<tr>
<td>SME</td>
<td>Small and medium enterprise</td>
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<tr>
<td>SSBID</td>
<td>Scalable systematic biologically-inspired design</td>
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<tr>
<td>STC</td>
<td>Size, time, cost</td>
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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter will discuss about engineering design, specifically bio-inspired design (BID), where technologies are inspired by nature. The problem statement, research objectives, and research scope will also be discussed in detailed in the following subchapters.

1.2 Research background

Engineering design is an algorithm used by engineers to create functional products and processes. It is something that affects all areas in our daily lives where scientific laws are used to realize physical solution to address technical problems, especially product development. In just 11 years, from 2008 until 2019, the number of world human population had increased by 1 billion. To date, the world population is 7.7 billion (Worldometers, 2019). As the demand of human’s basic need increases with the global human population, technology advancement for higher rate of goods supplies and bringing new products to market is required to catch up with the pace of the growing human population (Kennedy, 2017). This is what Stuart Pugh called ‘market-pull’ and ‘technology-push’ (Pugh, 1990). In the modern product development, engineering design are faced with challenges of attracting and retaining consumers, competing with other competitors, and satisfying the diverse requirements within global supply chains. This is
why research on engineering design had been done extensively over the past decades (Liu & Boyle, 2009). As a result various engineering design approaches were developed, such as user centred design (Norman & Draper, 1986), total design (Pugh, 1990), kansei engineering (Nagamachi, 1995), axiomatic design (Suh, 1998), decision-based engineering design (Hazelrigg, 1998), robust design method or Taguchi methods (Taguchi, Chowdhury, & Taguchi, 2000), systematic engineering design (Pahl & Beitz, 2003), TRIZ (Altshuller, 2007), and bio-inspired design.

Bio-inspired designs, or biomimicry, are functional innovative technologies, products, and processes inspired by nature, through a process called biomimetic. The term “bio” means life and “mimicry” means an aptitude of copying. Biomimetic is used specifically to assist the conceptual design stage where the main problems are identified via abstraction, searching for appropriate working principles, and so determines the principle of a solution (Pahl & Beitz, 2003). Biomimicry is not a new design concept because the term “biomimetic” was first introduced by Otto Herbert Schmitt in 1969 (Schmitt, 1969). However, only in recent years that it is gaining popularity. According to Figure 1.1, the Da Vinci Index shows that the number of scholarly articles, number of patents, number of grants, and dollar value of grants for biomimicry had increased exponentially.

![Figure 1.1: Da Vinci index 2.0 of biomimicry growth (PLNU, 2019).](image)
Nature has been on an ongoing research and development process in finding solutions to counter challenges be it with the principles of physics, mechanics, chemistry, material science, transportation, or sensors, from the range of nano to macro, a single cell to an entire ecosystem. It is a rich source of knowledge and inspiration of inventions as nature itself is an enormous collection of inventions that overcame the test of practicality and durability (Bar-Cohen, 2006; Nkandu & Alibaba, 2018). For example, before the first heat exchanger is being invented, the penguins, and tunas already had counter-current heat exchanger built in them to adapt in sub-zero environment (Stevens, Kanwisher, & Carey, 2000; Stevens & Kendall, 1974; Thomas, Ksepka, & Fordyce, 2011). Before Daniel Bernoulli introduces the Bernoulli’s principle, nature had already been applying this principle for air ventilation in ant nests, termite mounds, and prairie dog’s tunnels (Kleineidam, Ernst, & Roces, 2001; Ocko et al., 2017; Vogel, Ellington, & Kilgore, 1973). However, unless the gap between biology and engineering is bridged, the strategies from nature will not flow over into the engineering world. There are actually eight common errors that Helms identified that most designers made in practicing biomimicry, which are vaguely defined problems, poor problem-solution pairing, oversimplification of complex functions, using the biological solutions literally without proper understanding, simplification of optimization problems, solution fixation, misapplied analogy, and improper analogical transfer (Helms, Vattam, & Goel, 2009). Even so, various strategies from nature had been successfully transferred yielding bio-inspired designs such as Velcro® (Pugno, 2007), autonomous self-healing concrete (Elia, Eslava, Miranda, Georgiou, & Saiz, 2016), self-reinforced composites (Mencattelli, Tang, Swolfs, Gorbatikh, & Pinho, 2019), oil repellent coating (Y. Chen et al., 2018), acid resistance surface (Wu et al., 2019), water distribution and power grid networks (Dave & Layton, 2019; Panyam, Huang, Davis, & Layton, 2019), and underwater adhesive (Zhao et al., 2017).

Biomimicry is expected to be able to overcome major global challenges, which are sustainable development, water, population and resources, democratization, long-term perspectives, information technology, the rich–poor gap, health, capacity to decide, peace and conflict, status of women, transnational crime, energy, science and technology, and global ethics (Gebeshuber, Gruber, & Drack, 2009). According to Elena Lurie-Luke’s


Benford, P. (2017). Infrared image of a cactus shows the rib with different temperatures.


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