UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF BIOMIMICRY APPLICATION FRAMEWORK FOR SUSTAINABLE DESIGN

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By

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Biomimicry is a design in the field of science which studies nature as a model and draws inspiration from it. In this light, nature's design and processes are mimicked to solve problems facing humans and the world around them. This field presents enormous capabilities and potential for exciting future technologies. However, out of the three levels of biomimicry, only the organism level biomimicry has been widely applied as a tool to achieve a design solution. Thus, understanding biomimicry application and levels of mimicking are also crucial in promoting it. Developing a framework that connects the three levels of biomimicry is necessary to produce a sustainable design. Hence, this research proposes a framework that can guide the application of biomimicry to achieve sustainable design. This study adopted the KJ method, where the qualitative method is supported by a quantitative component, to identify the design elements has been inspired by or applied in biomimicry. The study also distributed a survey questionnaire involving 134 respondents. This method was employed to gauge the participant's understanding and knowledge of biomimicry. The third method involved focus group discussions in conducting an expert validation of the proposed framework. The findings showed that the knowledge and understanding of biomimicry at the educational level are important in applying biomimicry in designs. Therefore, it is crucial to have a framework that guides designers in promoting and implementing biomimicry for a sustainable environment. Other than that, as more designs are inspired by nature, it may help facilitate the sustainable growth of towns and cities, sustain and enhance people's well-being, and improve their quality of life.

Keywords: Biomimicry, Biomimicry approaches, Sustainable Design, Design Method

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN RANGKA KERJA YANG MENGAPLIKASI BIOMIMIK UNTUK PENGHASILAN REKA BENTUK YANG LESTARI

Oleh

NURUL IZZATI BINTI OTHMANI

April 2022

Pengerusi	:	**Profesor Madya Mohd Yazid bin Mohd Yunos, PhD**
Fakulti	:	**Rekabentuk dan Senibina**

Biomimikri adalah salah satu rekaan baru dalam bidang sains yang mengkaji alam semulajadi. Di sini, rekabentuk serta proses alam semulajadi dijadikan model dan inspirasi untuk menyelesaikan masalah yang dihadapi oleh manusia dan alam. Bidang ini berpotensi besar untuk menghasilkan rekaan baharu yang berteknologi tinggi untuk masa hadapan. Walaubagaimanapun , dari tiga tahap mimikan dalam biomimikri, hanya tahap organisma sahaja yang sering digunakan sebagai rujukan bagi membantu pereka untuk menyelesaikan masalah. Oleh itu, ,pemahaman mengenai penggunaan biomimikri dan tahap mimikan adalah penting untuk mengaplikasikannya di dalam rekaan. Tujuan penyelidikan ini adalah untuk menghasilkan rangka kerja yang boleh membimbing pereka untuk mengaplikasikan biomimikri dalam rekaan untuk mencapai reka bentuk yang mampan. Kaedah yang digunakan adalah kaedah kualitatif dan disokong oleh kuantitatif; Kaedah KJ digunakan untuk mengenal pasti elemen reka bentuk dari alam semulajadi yang telah digunakan atau diterapkan dalam rekaan biomimikri, kaedah kedua merangkumi tinjauan soal selidik melibatkan 134 orang responden. Kaedah ini digunakan untuk menganalisis tahap kefahaman dan pengetahuan pereka terhadap biomimikri. Kaedah ketiga adalah perbincangan kumpulan fokus untuk mendapatkan pengesahan pakar bidang mengenai rangka kerja yang dicadangkan. Dapatan kajian menunjukkan pengetahuan dan pemahaman biomimikri peringkat pendidikan adalah penting dalam mengaplikasikan biomimikri di dalam reka bentuk. Pembinaan rangka kerja yang boleh membimbing pereka bentuk dalam menggunakan biomimikri dan mempromosi pelaksanakan biomimikri bagi menjamin persekitaran yang mampan adalah sangat penting Selain itu, kepelbagai rekaan yang diinspirasikan oleh alam semula jadi dapat membantu pertumbuhan mampan di kawasan bandar, menjamin kesejahteraan penduduk, dan meningkatkan kualiti hidup penduduk di Malaysia.

Kata Kunci : Biomimikri, Pendekatan Biomimikri , Rekaan Mampan, Kaedah rekaan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy .The members of the Supervisory Committee were as follows:

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Declaration by Members of Supervisory Committee

This is to confirm that:
- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

SDG	Sustainable Development Goals
I.R 4.0	Industrial Revolution 4.0
KJ Method	Jiro Kawakita Method
FGD	Focus Group Discussion
BADF	Biomimicry Application in Design Framework

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter begins by studying the background by identifying issues that can be addressed from the built environment. Background and issues will produce research problems, research questions, aims and objectives for this study. This chapter ends by showing the entire framework of this thesis by showing the research process to achieve the aims and objectives of this study.

1.2 Background Study

Biomimicry is one of the approaches to achieve harmony between human and nature. Biomimicry claims nature as an alternative method by inspiring designers to develop intelligent and innovative designs to reduce the negative impact to the environment while achieving sustainability. The widespread research that has been done on biomimicry reveals why biomimicry is still unknown by most designers. One of the reasons is there is no clear approach that designers can implement into their design (Radwan & Osama, 2016). Although mimicking the form of nature can be considered as biomimicry, however, mimicking only the form or shape misses the point of biomimicry design (Benyus, 2011). There are at least three levels of mimicry that are required in design to achieve a complete emulation of nature, which are organism level, behaviour level, and ecosystem level (Benyus, 2011).

Malaysia is in the process of applying sustainable design for the environment. The Prime Minister of Malaysia, Tan Sri Muhyiddin Yasin, declared that a particular focus on sustainability will be included in Budget 2021 Malaysia and described the COVID-19 pandemic as a wake-up call for Malaysia and other countries. Muhyiddin said Malaysia, just like any other country, needed to rethink its development agenda, particularly regarding sustainability and green technology, which played a vital role in driving the economy. The Twelfth Malaysia Plan (12MP) announced by the prime minister encompassed three dimensions: Economic empowerment and environmental sustainability.

The first dimension, economic empowerment, will include new plans to increase economic growth, which are the Industrial Revolution 4.0, digital economy, green economy, blue economy, aerospace industry, regional development, sustainable energy sources, and infrastructure connectivity. Biomimicry and green economy have the same purpose which is to produce and use products that can achieve sustainability for a long-term. New technologies and practices

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are one of the aims of biomimicry, while green technologies promote the importance of new technology inventions that can be used to improve the country's economy. Biomimicry technology may help businesses become more competitive, and it can also be used to the same economic sectors that have the greatest export potential: primary and secondary industry, as well as the energy sector. Form and function of design will be emphasised in the industrial and energy sectors, with core industry mirroring ecosystems. Simulating natural ecosystems, on the other hand, can be used practically anywhere.

The environmental sustainability dimension encompasses, among other things, includes green technology, renewable energy, adaptation, and mitigation of climate change. The built environment field for most of the world's global environmental and social problems with vast proportions of waste, material, energy use, and greenhouse gas emissions (Mazria, 2003, Doughty and Hammond, 2004). There is an increase of demand for a practical ecological sustainable design approach without compromising the needs of society. Although there are numerous approaches to sustainable design in architecture, very few have proven effective macro scale. Biomimicry offers a relatively new solution to the issues of sustainability. It demands integrating multiple disciplines to produce more beneficial systems for its users and give back to nature. Imitating, when it is implemented correctly, may be beneficial to the environment and human existence in general.

Malaysia has applied Industry revolution 4.0 (IR 4.0) by creating smart factories to produce products that are more efficient and also productively. IR4.0 operates holistically involving manufacturing and this allows collaboration between departments, products, vendors and partners.IR 4.0 can ensure food manufacturing, food production is safe, nutritious food, affordable, and sufficient agricultural resources for all people. In line with the concept of IR4.0, the production and processing of food in large quantities can be done by all factories. the use of the concept of biomimicry in the field of agriculture is to learn how prairies grow food in resilient ways.

By using Biomimicry design could increase the country's economy while also conserving the environment. Biomimicry is rapidly gaining prominence as a global environmental conscious sustainable development design approach that frequently inspires new inventions and solutions (Goss, 2019). According to Taleb and Al Amin (2017) believes that biomimicry as a method can address human problems because other animals in nature confront or have solved many of the same obstacles that humans do and have overcome to all those problems.

The built environment accounts for a majority of the world's global environmental and social problems with vast proportions of waste, material, energy use, and greenhouse gas emissions (Mazria, 2003, Doughty and Hammond, 2004). There is a rapidly growing demand for an effective ecological sustainable design

approach without compromising the needs of society. Although there are currently numerous approaches to sustainable design in architecture, very few have proven effective at a macro scale. Biomimicry offers a relatively new solution for issues of sustainability. It demands the integration of multiple disciplines working together to produce buildings and systems that are not only more beneficial to their users but also give back to nature. Once implemented well, imitating could prove advantageous in the field of architecture and human life as a whole.

Biomimicry is explained to be different from other bio-inspired designs, because of its focus on learning from nature how to be sustainable. Designs following biomimicry are thought to be more efficient, resilient, and sustainable if they emulated biological lessons on form, process, and ecosystem. The outcome is superior to that developed through any artificial means. Biomimicry's ability to drive environmentally sustainable innovation, is a finding worth highlighting given the challenges currently faced by the industry with regard to sustainability. A relationship between the thoughtful practice of biomimicry and the generation of green product concepts makes intuitive sense, given that natural selection favors biological strategies fit for life on earth over the long haul.

The natural world has been existing for around 3.8 billion years with models that manufacture without heat, beat, and treat; ecosystems powered by sunlight and create design solutions rather than waste. As observed and discovered, the activities, processes, strategies, and systems displayed in nature are found to be sustainable, effective, efficient, and aesthetically pleasing too. These, among other attributes, have made biomimicry to be outstanding among the sustainability trends.

Biomimicry has already instituted the realization of some appropriate and exceptional innovations in different sectors and specific areas of global interest such as energy engineering and waste re-use, where multiple-scale efficiency improvements are much needed. Examples include the noiseless Shinkansen Bullet Train (inspired by the splashes of water entry of kingfishers and silent flight of owls), the smart windows and walls called Raven Brick (inspired by passive pigmentation in cephalopods and many species of lizards), wind energy harvesting Vibro-Wind without turbine (inspired by the movement of leaves in windy condition), and Green infrastructure stormwater control (inspired by the filtering mechanism provided by the vegetation in an ecosystem) amongst others.

Without question, biomimicry is one of approach towards a more resilient and sustainable future for humanity. It attempts to address the challenges posed by unrestrained global industrialisation and natural resource exploitation (Hwang, 2017). In their pursuit of sustainability, efficiency, and effectiveness, many global corporations and organisations are turning to biomimicry. As previously said,

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Malaysia is making a concerted effort to create a sustainable environment, and the development of Biomimicry design will help to support this effort. Malaysia will also try to improve and be on par with other industrialised nations by 2025.

1.3   Problem Statement

Nowadays, most of biomimicry design focuses on the physical features and lacks a deep understanding of biology whereas biomimicry design should be based on its levels (Faludi, 2014). There is limited study or research show the application ecology and nature principles in green design. The challenge in biomimicry is to elucidate nature's physical and chemical strategies to apply them, with suitable modifications, to the chosen application (Borgh, 2006). Other than that, Biomimicry as design method remains largely unrealised where biology shapes or decorations have always become an inspiration for interior designers in designing a product or space (i.e., Art Nouveau, Jugendstil, and the like). However, simply replicating or being inspired by natural-looking forms, textures, and colours is not biomimicry; it must have some biology. This indicates that in order to be really biomimicry, a design should be informed by nature's science, not merely its appearance (El-Zeiny, 2012).

Most of the designers used or mimicked biology as shape of the buildings or as decorations. But, Biomimicry is not about mimicking or inspired by textures of floral or fauna, colours , pattern or nature forms and it should have biology in that design and means that , to achieve full biomimicry concept , a design should in some way be informed by nature's science, not just its look. (El-Zeiny, 2012). Despite the fact that researchers and experts in sustainable architecture have discussed many kinds of biomimicry or bio-inspired design, the actual implementation of biomimicry as a design process remains mostly unrealised, because there is only a few built case studies have been done (Faludi, 2014) .The design of buildings, gardens or pools shaped like a leaf is not a biomimicry design; this is only mimicking natures shapes and patterns and the designers should study the biology on how does the biology used to solve problems or achieve a function (Kulper, 2003).

In biomimicry design, designers need to think about how nature does in solving problems. Biomimicry entails more than just mimicking nature or systems. It begins by studying in detail about the organism or ecosystem and then followed by the application of design principles found from nature where learning about nature is one thing but learning from nature is another. mimicking shape is one of the components of biomimicry, but according to Benyus and other researchers, mimicking only natural shapes misses the goal of Biomimicry where there needs to be biology in it.Another issue related to biomimicry is there is limited elements used in Biomimicry design. Exploration of the abilities of nature elements is very limited because designers assume that they need a deeper knowledge of biology. Among the obstacles to the use of biomimicry elements in design is the lack of understanding of the biomimicry approach

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where the use of biomimicry can be beyond just the form of nature. Thus, many of the elements used are just forms of nature.

Understanding and knowledge barrier towards Biomimicry. A biomimicry design could simply be design following any biological shape, but it does not have to be. As a result, designers and architects must understand that biomimicry does not always affect appearance and style. The designers should engage with nature in ways that go beyond simply copying natural form. They must move beyond nature's formalistic characteristics and urge people to develop a deeper and more responsive awareness of nature (El-Zeiny, 2012).

A growing body of international research on biomimicry in relation to the built environment identified various obstacles to the employment of such a methodology. One barrier of particular note is the lack of a clearly defined approach to biomimicry that architectural designers can initially employ (Alaa ElDin Sarhan, 2019). According to Oluguna (2016), from his research, there are seven barriers in applying biomimicry into design, among which are limited availability of biomimicry materials, lack of incentives for adopting biomimicry, and lack of database and information on biomimicry.

Lack of information on defining the biomimicry approach is one of obstacles where there is no clear information on biomimicry approaches, where it can guide designer in applying biomimicry into their design. (Alaa ElDin Sarhan, 2019). According to Oluguna (2016), from his research, limited availability of biomimicry materials, lack of incentives for adopting biomimicry, and lack of database and information on biomimicry is a challenge for applying biomimicry into design.

Lastly, there is no well-defined of biomimicry approach or framework guiding using biomimicry in design. According to Benyus (1997), to have a full emulation of nature, the process of mimicry should at least engage three levels of biomimicry which are organism, behaviour and ecosystem level. Biomimicry is more than just inspired natural object or system. It is not simply designing something looks like a natural form and considered as green or sustainable. This means that a design should in some way be informed by nature's science, not just its look to be truly biomimicry. Lack of requisite knowledge and understand and guidelines or framework needed to implement biomimicry practices in design (Piestrosemoli and Monroy, 2013). By having a design guidelines application of Biomimicry to achieve a sustainable design will have a potential to promote Biomimicry (Al Sanad, 2015).

According to Alawad, A. and Mahgoub, Y., (2014), the impact of teaching biomimicry as a tool for enhancing thinking skills for students in art education. Their research findings showed that biomimicry has a number of major benefits.

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It offers spiritual development as it gives them the opportunity to mediate and appreciate God's creation. It awakens students' perception of nature realizing that everything in nature has a purpose and function. Moreover, biomimicry can positively impact early years' education. The results also showed that biomimicry has long-lasting effect skills. They develop their self-reflection, critical and creative thinking, and problem-solving techniques. However, there are no guidelines or frameworks related to applying biomimicry in design, resulting in the lack of use of the biomimicry concept. As well as information related to biomimicry is quite limited to be found causing designers not to use this concept. Table 1.1 shows the problems encountered in using biomimicry, namely most of biomimicry design only emphasize on the physical features. Researchers have identified that most designs with the concept of biomimicry only mimic the organism level, that is, mimic in terms of shape, color and form nature. This is because there are no guidelines or frameworks that show how and what level of mimicry in biomimicry. This is a research gap that has been identified by the researcher.There appears to be a limited understanding of available biomimicry options by design professionals.

This includes insufficient knowledge to produce specifications; a lack of available high-performance materials; difficulties in gaining approval of new technologies for building codes; uncertainty about approvals; regulatory barriers to adoption of technologies and labors due to potential lab labor-saving asures; all providing further challenges to sustainable design .This is cause current design are not sustainable. In order for sustainable design techniques and materials to be adopted, they must be specified by the designer. However, there is no standard assessment criterion for products that allows them to be directly evaluated, and therefore design professionals must invest a lot of time in assessing potential materials and technology (Hayles, 2008).

1.4　　　The KJ Method (Jiro Kawakita)

Jiro Kawatika or also known as KJ Method is one of the methods used in this research were to identify most of the elements used in designing by using the Biomimicry concept. The KJ-Method or KJ Technique is an idea-generating and prioritizing technique named after its inventor, Jiro Kawakita. This technique is one of the most popular brainstorming variations for design, team, retrospective, and project meetings.

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1.5   Research Question

This research posited several research questions to guide its research aim and objectives.

> **RQ 1**   What are the elements, characteristic and sustainability approach applied/used in currently biomimicry design?
>
> **RQ2**   How does designer understand about biomimicry and its application towards sustainability in design?
>
> **RQ3**   How will the biomimicry framework guide designers in applying biomimicry as holistic and towards sustainable?

1.6   Research Aim

The aim of this research is to develop a Biomimicry framework that will guiding the designers to achieve sustainable design. In order to achieve the aim of the research, the following objectives are formulated:

1.7   Research Objectives

> **RO1**   To form the conceptual framework and execution through the KJ Method process.
>
> **RO2**   To analyse the level understanding and knowledge of biomimicry towards sustainability in design.
>
> **RO3**   To develop a design framework of Biomimicry application that will guide designers applying Biomimicry as a holistic in design towards sustainable.

1.8   The Scope of Study

Research focuses on designers with built environment backgrounds using Biomimicry or bio-inspired design as concept in their design. The designers or respondents in this research belong to Malaysian citizens who are taken from experienced designers and design students. Meanwhile, in terms of the location of the research study, the researchers selected several local universities such as Universiti Putra Malaysia, Universiti Teknologi Mara and Universiti Teknologi Malaysia. Location selection is based on universities that offer design courses especially in architecture, landscape architecture and industrial design and some related courses.

1.9 Significance Study

This research focuses on the development of new design processes that use biomimicry as an approach. At the same time, it encourages designers to understand the terminology and principles in various scopes in studies that are inspired by nature as a guide.

1.9.1 Improving Knowledge and Understanding of Biomimicry

The study's findings can add to the body of knowledge by developing a new Biomimicry Application framework in a Malaysia setting and fulfil universal and future research needs. This study provides a complete reference to address a gap in the existing literature on biomimicry design in Malaysia.

1.9.2 Biomimicry Application in Industrial Revolution 4.0

Malaysia is currently in the fourth industrial revolution, often known as Industry 4.0, which is characterised by increased automation and the use of smart factories informed by data to manufacture items more efficiently and productively. The first food revolution was mostly focused on farming. Industry 4.0 can ensure that food and agricultural resources are plentiful and sustainable, as well as that food is safely manufactured, healthy, and economical. The processes and bulk production of foods, as well as their information have advanced significantly in conjunction with the industrial revolution. To revolutionize modern agriculture, designers have produced models inspired by natural prairies where they demonstrate the use of deep-rooted plants that live as perennials in agricultural systems that can mimic stable natural ecosystems compared to weed crops that are often used in most agricultural systems. modern.

1.9.3 Enhancing the Economy by using Biomimicry Concept

There are similarities between Biomimicry and green economy in terms of goals and principles. Among them is aiming to achieve sustainability for a long time and also related to the production and use of products. Biomimicry is about the production of new and practical technologies while the green economy is about technology transfer to developing countries. using biomimicry technology can encourage high investment and production of prototypes in rich countries. This will give benefits to those countries once biomimicry has been established. Apart from that, the invention of biomimicry can help to compete with other companies and can even be applied to other economic sectors that have export potential in the primary and secondary industry and even in the energy sector. with this change of mindset will provide an opportunity for sustainable design to continue

to grow for example the invention for resilience which can be realized by using biomimicry.

1.9.4 Enhance Sustainable Design Development in Malaysia

The 2030 Agenda for Sustainable Development is a global blueprint for creating a healthier living and becoming a more sustainable future for the environment and humankind. The new goals concern all groups, whether rich, middle-income or poor, in all countries. This is an initiative to end poverty and at the same time protect the environment. The Sustainable Development Goals (SDGs) must collaborate with initiatives that promote economic growth and provide job opportunities to people, provide education to every part of the country, social welfare, and health services and also fulfill other social needs, and at the same time concerned for environmental conservation and protection and climate change. From the total of seventeen goals, there are twelve goals that can be achieved using the biomimicry concept which are: Zero hunger, clean water and sanitation, responsible consumption and production, climate change action, affordable and clean energy and Sustainable cities and communities.

Biomimicry is explained to be different from other bio-inspired designs, because of its focus on learning from nature how to be sustainable. Designs following biomimicry are thought to be more efficient, resilient, and sustainable if they emulated biological lessons on form, process, and ecosystem. The outcome is superior to that developed through any artificial means. Biomimicry's ability to drive environmentally sustainable innovation, is a finding worth highlighting given the challenges currently faced by the industry with regard to sustainability. A relationship between the thoughtful practice of biomimicry and the generation of green product concepts makes intuitive sense, given that natural selection favors biological strategies fit for life on earth over the long haul.

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Biomimicry has already instituted the realization of some appropriate and exceptional innovations in different sectors and specific areas of global interest such as energy engineering and waste re-use, where multiple-scale efficiency improvements are much needed. Examples include the noiseless Shinkansen Bullet Train (inspired by the splashes of water entry of kingfishers and silent flight of owls), the smart windows and walls called Raven Brick (inspired by passive pigmentation in cephalopods and many species of lizards), wind energy

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harvesting Vibro-Wind without turbine (inspired by the movement of leaves in windy condition), and Green infrastructure stormwater control (inspired by the filtering mechanism provided by the vegetation in an ecosystem) amongst others.

1.10　　　Thesis Structure

This thesis is organized into several chapters as follow:

Chapter One This chapter briefly presents about Biomimicry. This chapter was divided into nine sections. Section 1.1 brief of the introduction about this study, Section 1.2 explain the research background, Section 1.3 highlights problems statements regarding biomimicry as a design method still unrealised by the designers. Section 1.4 to Section 1.6 formulates research questions, research objectives and research aim. Section 1.8 explained the significance of biomimicry study in knowledge field, economy, Industrial Revolution and also enhancing Sustainable environment. Lastly Section 1.9 will summarize the whole thesis structure.

Chapter Two Content analysis approach is used in this chapter to identify the application of biomimicry from articles, reports, case studies, journals, books and also internet sources. This search is not limited to Biomimicry only, it also involves sustainable design, this chapter divided into 26 Sections. Provides an overview of the meaning of biomimicry, biomimicry approaches, biomimicry levels, principles and theories of biomimicry as design, and other studies related to this research. It provides an information about biomimicry which are biomimicry meaning, the beginning of biomimicry, approaches and principles, and three levels of mimicking; organism level, behaviour level and ecosystem level as the guide of using biomimicry concept in design. It further examines the understanding of Biomimicry concept and biomimicry level in design. Section 2.21 highlights Sustainable Development Goals where some of Biomimicry approaches is in line with 17 SDGs.

Chapter Three This Chapter presents the methodology that used in this research. It was divided into eight sections. Section 3.1 introduce the methods used in this research followed by section 3,2 shows the research design flow. The beginning of this methods is by studying and identify the keywords from journal, books, articles. Section 3.4 is formation of Conceptual framework by using KJ Method. Kj Method was divided into three stages. Section 3.5 is preparation of Questionnaires. Section 3,6 is Focus Group Discussion where six experts were chosen to validate the propose framework. Section 3.7 is data analysis where this section are using descriptive analysis and Kruskal-Wallis Test Section 3.8 concludes all the method that been used in this research.

Chapter Four Presents the results and findings of the study based on critical analyses of the archival literature, questionnaire survey and focus group discussions. Section 4.2 obtained to fulfil first research question is through keywords search using KJ method. Section 4.3 presents data were gathered through questionnaire survey where to identify to what extent of designer knowledge and understanding towards biomimicry. Section 4.5 presents the result form Kruskal-Wallis Test and Section 4.6 analysed data that were obtained from validation form where the selected experts in Landscape architecture, architecture and industrial design in Malaysia. This data will be analysed based on their comments and suggestions regarding Biomimicry. This chapter also examines their knowledge about Biomimicry concept and analyses their comments and recommendations regarding the suggested conceptual framework as described. Section 4.8 presents second framework validation by experts.

Chapter Five Chapter 5 begin with the introduction to this chapter. This chapter was divided into six sections. Section 5.2 is answering the second research question followed by Section 5.3 presents the results from third research question. This section presents the result of three domain which are application, design approach and sustainable design. Section 5.4 discussed the result of Kruskal-Wallis Test where the result is not significant. Section 5.5 presents the outline of proposed Biomimicry Application in design framework and section 5.6 conclude the result of the discussion.

Chapter Six This chapter which concludes this research divided into six sections. Section 6.1 presents answered research question. Section 6.2 presents research contributions implications to practical, economy and knowledge. Section 6.3 explained the limitation of this research, Section 6.5 presents the recommendation for future research of using Biomimicry in design and lastly, Section 6.6 concludes this research by highlighting the importance of Biomimicry as a design method to achieve sustainable design that can improve the environment and improve the quality of life of the people.

1.11 Summary

In sum, this chapter has briefly described the problem of limited of exposure to biomimicry makes this method unknown and widely used while biomimicry is one of the ways that allows the design to achieve sustainability. By introducing definition of biomimicry, approaches, principles and levels can minimize the gap of knowledge and understanding regarding biomimicry. Eventually, the outcome of this study can yield guidelines to encourage designers to use biomimicry into their designs.

11

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