Analysis of Mercedes-Benz Concept Car Using Biomimicry Design Spiral and Template Analysis – An Exploratory Study

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Abstract

As industry and technology continues to develop, the incidence of technical bottlenecks and damage to the environment likewise grows. In response, product designers have started to look to nature for inspiration. However, the means of drawing on principles in nature and integrating them into product design and development are a considerable challenge. With the use of a form of qualitative research methods - template analysis, this study used the Biomimicry Design Spiral, proposed by the Biomimicry Institute, as predetermined themes to examine the Bionic Concept Car – Boxfish, developed by Mercedes-Benz and inspired by the aerodynamic qualities of the species 'boxfish'. This paper interprets how the designers and engineers at Mercedes-Benz used the operational mechanisms of a living being to achieve innovative product design; we also examine the influence of this approach on the design and development process. We further demonstrate how to apply the Biomimicry Design Spiral in assisting with the biologically inspired product design in question.

Keywords: Biomimicry, biomimicry design spiral, bio-inspiration, innovative product design

1. Introduction

During the lengthy process of natural evolution, the ecosystem has gradually formed a benign circle. Through the transfer of matter and energy, life endures and is sustained (Elton, 1936). Margulis and Sagan (1997) emphasize the importance of symbiosis and cooperation in biological evolution, advocating that symbiosis exists among all living beings. In contrast, humankind, a part of this natural ecosystem, constantly imposes burdens and inflicts damage on the natural environment through the rapid development of industry and technology, thereby upsetting the ecological balance (Collado Ruano, 2017; Hawken et al., 2013; Russell et al., 2013; Spier, 2015).

In pursuit of a sustainable existence, humans must reflect on how to coexist in harmony with nature (Collado Ruano, 2017; Hawken et al., 2013; Russell et al., 2013; Spier, 2015). The idea of going "back to nature" is central to this reflection process. Biomimicry, or bio-inspiration, seeks innovative solutions that do not disrupt the balance of the natural environment (Benyus, 1997; 2009; Bhushan, 2009; Collado Ruano, 2017; Hawken et al., 2013). Bio-inspiration does not signify blind and senseless imitation but the complete immersing of oneself in nature (Bhushan, 2009; Forbes, 2005) to observe the lifestyles, appearances, and structures of living beings and listening to and conversing with them directly, allowing one to understand their composition, functions, structure, and characteristics before applying that understanding as inspiration in product design and in the solving of relevant issues (Bar-Cohen, 2012; 2016; Benyus, 1997; 2009; Bhushan, 2009; Bhushan, 2009; Vogel, 1998).

A number of cases have demonstrated that designs inspired by nature not only provide effective solutions to design problems but also induce breakthroughs in innovation and invention (Bar-Cohen, 2012; 2016; Benyus, 1997; 2009; Bhushan, 2009; Biomimicry Institute, 2015; 2018; Hawken et al., 2013; Macnab, 2011; Vincent et al., 2006; Vogel, 1998). Moreover, bio-inspiration achieves the objectives of harmonic existence with nature and sustainable development (Bhushan, 2009; Dickinson, 1999; Hawken et al., 2013; Macnab, 2011; Ramzy, 2015).

This study focuses on the Mercedes-Benz's Bionic Concept Car, introduced in 2005 and inspired after the boxfish (Daimler Chrysler, 2005; 2018). Using the Biomimicry Design Spiral (Biomimicry Institute, 2015; 2018) as a predetermined theme and template analysis, we analyze the available on-line documents about the Bionic Concept Car – Boxfish developed by Mercedes-Benz with the application of biological inspirations from the nature. We also explore how to apply this approach to the design and development process. This case study demonstrates that the systematic nature of the Biomimicry Design Spiral approach forms a useful tool to help solve design issues holistically and comprehensively.

2. Literature Review

2.1 Introduction to Bio-inspiration

Since the beginning of our evolution, humans have used mimicry to solve everyday problems; our observations of the movements and appearances of plants and animals and their subsequent imitation formed the beginning of bio-inspiration. Modern bio-inspiration originated from Otto Schmitt's introduction of the concept - biomimetics in 1950. Biomimetics is now an interdisciplinary field that spans over materials science, engineering and biology, and generally involves the study of principles in living beings to synthesize or manufacture biomimetic materials (Bhushan, 2009; Schmitt, 1963; Vincent, et al., 2006). In 1958, Jack E. Steele coined the term 'bionics', which implies the imitation of the natural skills of living beings to develop various human engineering techniques (Bhushan, 2009; Vincent, et al., 2006). Biologist Janine Benyus suggested the term 'biomimicry', in which 'bio' has the meaning of 'ecological' and 'mimicry' is a technical term taken from ethology, indicating the simulation of a living being of its environment in color, appearance, or behavior for the sake of camouflage or protection (Benyus, 1997; 2009). In comparison with biomimetics and bionics, biomimicry is a wider concept that encompasses a larger domain, including argronomy, ethnic integration, energetics, ecology, plant physiology, biochemistry, materials science, physics, medicine, ethology, information technology and engineering, molecular biology, genetics, evolution, industrial planning, and industrial ecology (Benyus, 1997; 2009). Other related terms include bio-inspiration design, biognosis, and bionical creativity engineering.

2.2 Research Associated with Bio-inspiration

2.2.1 Biologically inspired cases

One of the most famous biologically inspired examples is Velcro®, which was developed by Swiss engineer George de Mestral (Bhushan, 2009; Velcro Industries N.V., 2018; Vincent, et al., 2006). The idea first occurred to him when he saw burrs stuck to his clothes during an outdoor activity. Using a microscope he discovered that the burrs had rows of hooks that would adhere to that with which it came into contact, such as cloth or animal fur. From the original inspiration of the conformation of burrs, de Mestral carried out extensive research and experimentation to produce a practical fastener – the now ubiquitous Velcro®. In addition to clothes, shoes, straps, and backpacks, Velcro® is also used in cars, airplanes, parachutes, space suits, and space ships (Vogel, 1998). Another well-known application of bio-inspiration is the Lotus Effect® (Bhushan, 2009; Solga et al., 2007; Vincent, et al., 2006). Lotus flowers are known for their ability to remain unstained and unsoiled. This phenomenon is owing to the unique nanostructures on the lotus' leaf surfaces that lead to high water repellence. This unique characteristic was discovered by Wilhelm Barthlott, who trademarked the term Lotus Effect® in 1992. He applied this structure from the surfaces of lotus flowers to coating materials. Objects coated with such paint left no traces of water; the self-cleaning effect reduced the use of cleaning agents, thus becoming environmentally friendly (Bhushan, 2009; Forbes, 2005; Solga, et al., 2007).

Biomimicry, a book by Janine Benyus published in 1997, mentions a number of successful biologically inspired cases. Benyus (1997; 2009) also indicates that the industrialization of human development has pushed the environment to its limits, and that by copying nature's inventions, such as automatic composition and photosynthesis which have endured natural se-lection, humans can produce sustainable solutions. Mattheck (1998) was inspired by the coping mechanisms of trees to develop an optimization method. Dickinson (1999) similarly asserted that humans should learn from and follow nature, demonstrating this point with several successful examples of biologically inspired cases. Many researches outline the innovative solutions inspired by nature (Bar-Cohen, 2016; Bhushan, 2009; Chen & Liu, 2001; 2002; 2003; Vincent, et al., 2006), and Bar-Cohen (2005; 2006; 2012; 2016) and Macnab (2011) advocates the use of nature to stimulate human innovation and problem solving.

2.2.2 Biomimicry design spiral

The majority of human activities and behaviors are based on accumulated experience or learned from superior examples that is/are inspired by our Mother Nature. These lack of a standard or systematic procedure for biologically inspired design. In her book, Benyus (1997; 2009) proposes four steps for implementing the process of biomimicry: quieting, listening, echoing, and stewarding. This process involves using nature as the model, completely immersing oneself in nature, communicating with living beings, encouraging biologists and engineers to collaborate, and preserving the diversity and ingenuity of life to achieve the final goal of sustainability (Benyus, 1997; 2009). In recent years, the Biomimicry Institute (2015; 2018) has been actively promoting the Biomimicry Design Spiral. This systematic bio-inspired design approach combines guidelines summarized from the knowledge of experts including designer Carl Hastrich and biologists Janine Benyus and Dayna Baumeister. The approach provides distinct directions for design tasks that facilitate the implementation of bio-inspiration. The design scheme is divided into seven stages that form a closed loop, as shown in Figure 1 and briefing in the following (Biomimicry Institute, 2015; 2018). The first stage – Identity – is to "*develop a Design Brief of the* *human need*". The second stage – Translate – is to "*biologize the question; ask the Design Brief from Nature's perspective*". The third stage – Observe – is to "*look for the champions in nature who answer/resolve your challenges*". The forth stage - Abstract – is to "*find the repeating patterns and processes within nature that achieve success*". The fifth stage – Apply – is to "*develop ideas and solutions based on the natural models*". The sixth stage – Evaluate – is to "*how do your ideas compare to the successful principles of nature". The* last stage – Identify – is to "*develop and refine design briefs based on lessons learned from the evaluation*".

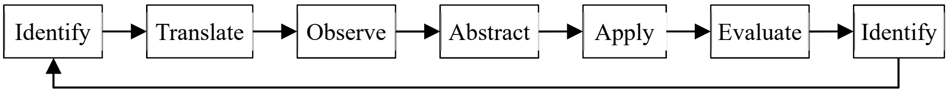

Figure 1: Biomimicry Design Spiral

3. Analysis of the Mercedes-Benz's Bio-inspired Concept Car

3.1 The Boxfish Inspired Concept Car

In 2005, the design team at Mercedes-Benz cooperated with biologists in analyzing and applying the biological characteristics of boxfish (Figure 2) to automobile design (Daimler Chrysler, 2005; 2018). They successfully derived a boxfish concept car that they called the Bionic (Butt, 2005). The design features practicality in passenger seating (for four people) and ideal aero-dynamics (the ideal tear-drop shape has a drag coefficient (cd) of 0.04 whereas the drag coefficient of the Bionic tested at 0.095, which is 35% less than the drag of general passenger cars) (Daimler Chrysler, 2005; 2018). The innovative approach and technical breakthroughs of the Bionic Concept Car have consequently provided significant inspiration in automotive technology. Therefore, the Bionic Concept Car was chosen as the case to be studied.

Figure 2: Boxfish
Source: DaimlerChrysler, 2005; 2108

3.2 Qualitative Data Collection and Analysis

The relevant information and literature in the official release on the Mercedes-Benz's Bionic Concept Car and the reports published in the public domain were collected through comprehensively searching on-line. As a form of qualitative research method, template analysis was selected to analyze the textural data collected, because it is a useful data analysis method when using the pre-defined themes or the existing framework identified and investigated by the researcher(s) in advance of the analysis process (Au, 2007; Brooks & King, 2012; 2014; Minnaar, 2013; Ray, 2009). In this study, the Biomimicry Design Spiral was selected as a priori coding template. The qualitative data collected were organized and coded into the categories according to the seven stages of the Biomimicry Design Spiral, which are predetermined themes.

With the analysis of the Bionic Concept Car, we uncovered the practical applicability of bio-inspiration in this study and further reviewed the inspiration provided by the boxfish concept car for reference in related designs. Based on specific design strategies and needs, the systematic structure of the cyclical Biomimicry Design Spiral can help assist design and relevant personnel in deriving clear guidelines and selecting suitable biomimicry principles to direct conception, determine the level of mimicry, and check design results.

3.3 Analysis Results

Using the Biomimicry Design Spiral and template analysis to analyze the textural data on the Mercedes-Benz's Bionic Concept Car, we derived the following results:

(1) Identify

The design team at Mercedes-Benz searched for a design concept in nature that featured efficiency, economic principles, aerodynamic performance, four-passenger seating comfort, and good environmental compatibility (Car body design: automotive design & engineering, 2005; Conceptcarz, 2006; Hell, 2006). According to general wind-tunnel tests, approximately 60% of automotive power is used to overcome aerodynamic drag (cd) while the vehicle is motion (Daimler Chrysler, 2005; 2018). For this reason, good aerodynamics is crucial to fuel efficiency. After due consideration, two major conditions were established in initial developments: suitability for everyday use while maintaining comfortable seating space (Hell, 2006).

The design team then confirmed the core concept, setting the objective as increased driving efficiency as well as the reduction of fuel consumption and the enhancement of performance. In accordance with the Biomimicry Design Spiral, this step conforms to the mandate of formulating a specific design outline and ascertaining the problems to be solved, thereby establishing clear and distinct design goals. Analysis of the design concepts above showed that the core issues could be resolved by considering the weight of the vehicle, its aerodynamics, comfort, safety, seating space, and environmental compatibility.

(2) Translate

The designers then looked to nature to seek a model that would translate into the technological goals they had set. They began by examining marine animals (Hanlon, 2005). During this process, the design team considered dolphins, sharks, penguins, and boxfish, all of which possess excellent hydrodynamics. From a biological point of view, the interdisciplinary team of engineers, designers, and biologists summarized specific keywords to redefine their problem, including highly efficient aerodynamic design, sturdy structure, and crash worthiness (Butt, 2005; Hanlon, 2005; Conceptcarz, 2006).

Once again in accordance with the Biomimicry Design Spiral, the interdisciplinary design team cooperated in using a biological perspective to combine engineering and design to translate and redefine the initial design guidelines. The marine candidates were screened for practicality and efficiency, resulting in a final choice of the boxfish as their bio-inspired index (Daimler Chrysler, 2005; 2018). The data published by Mercedes-Benz indicated that this result of translating design needs to conditions such as biological characteristics and living environments. Whether it was in coral reefs, lagoons, or tropical oceans, the boxfish provided the best model for the selected design specifications (Daimler Chrysler, 2005; 2018; Conceptcarz, 2006). The primary reasons are as follows: (a) To increase survival rates, the boxfish has evolved to conserve its energy. It possesses a streamline shape and powerful muscle structure that enable it to flee instantly when threatened. (b) The boxfish possesses a rigid outer skin and skeleton that are able to withstand high pressure and protect it from collisions that may occur while swimming among coral reefs. (c) The boxfish has good maneuverability that assists it in searching for food in confined spaces.

(3) Observe

The cubic structure of the boxfish meets the spatial needs of passenger cars, providing a comfortable seating space. Furthermore, its good structural safety and high maneuverability in confined spaces comprehensively satisfied the requirements of the design. The characteristics mentioned above are typical examples of biological evolution (Car body design: Automotive design & engineering, 2005). Observation showed that the unique bone structure of hexagonal bony plates and rigid outer skin tissue are the origins of these biological characteristics. In addition to the high-strength structural conditions of the dendritic bones, protecting the boxfish from harm, the bone structure also substantially reduces body weight, granting increased speed and maneuverability (Daimler Chrysler, 2005; 2018). Furthermore, the angular structure of the fish's appearance creates micro-vortexes that form a stable fluid space around the body. Fluid performance tests conducted with a 1:4 scale model found that the drag coefficient (cd value) was a mere 0.06, which is extremely close to the 0.04 of the ideal teardrop shape (Figure 3) (Car Body Design: Automotive Design & Engineering, 2005; Daimler Chrysler, 2018). For this reason, the boxfish maintains good navigational capabilities even in fluctuating ocean currents. With fewer fin movements, the boxfish is able to conserve energy that can otherwise be used to flee in emergencies (Conceptcarz, 2006; Hanlon, 2005).

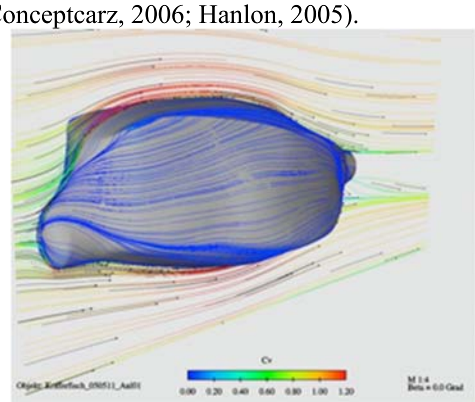

Figure 3: Fluid Measurements of Boxfish
Source: Car body design: automotive design & engineering, 2005

(4) Abstract

In summarizing the translatable characteristics between the boxfish and the design specifications, such as shape, structure, and performance, suitable elements were extracted, resulting in the following applicable conditions (Daimler Chrysler, 2005; 2018): (a) The solid and crashworthy structure is suitable for vehicle design. (b) The cubic structure and angular contours create surprisingly good aerodynamic effects that can be applied to reduce air resistance while the car is in motion and, at the same time, maintain a comfortable seating space, thus serving both physics and practicality. (c) By enhancing overall effectiveness, the car has good environmental compatibility, which provides additional value to the product.

(5) Apply

The design team translated the results of observation and analysis into suitable concepts before applying them to the form and structure of the design. Based on the dendritic and hexagonal bony plate structures, the designers used the Soft Kill Option method (SKO) to calculate an appropriate body frame structure (Daimler Chrysler, 2018). In contrast with conventional car structure, the Bionic Concept Car features enhanced strength and reduced car weight. While performance is increased, vehicle safety is still guaranteed (Figure 4) (Daimler Chrysler, 2005; 2018; Ultimatecarpage.com, 2005).

The cubic structure allows the Bionic Concept Car to conform to the usual features of two-door four-seater sedans manufactured by Mercedes-Benz (safety, comfort, designer feel, and everyday practicality). At 4.24 m (length) by 1.82 m (width) by 1.59 (height), the wide and fully equipped seating space also enables a number of other practical features, including a panoramic windscreen, a panoramic glass roof, four comfortable individual seats, and a large-size tailgate (Conceptcarz, 2006). The angular contour was applied to the roof and side skirts, and in conjunction with other aerodynamic components (egrear wheel covers, flat door handles, and rearview cameras in place of conventional exterior mirrors), they created a combined effect that enabled the 1:1 scale prototype to maintain a drag coefficient of 0.19, thus retaining the good hydrodynamics of the boxfish (Hell, 2006).

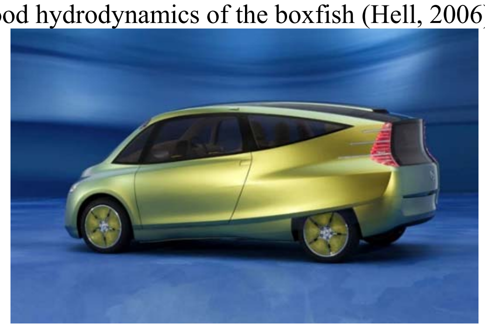

Figure 4: Body of the Boxfish Concept Car. Source: DaimlerChrysler, 2005; 2018

(6) Evaluate

Results simulated by the SKO computer-aided software system showed that through the appropriate bio-inspiration, the body frame of the Bionic Concept Car provides 40% more rigidity and yet reduces overall weight by 30% (Daimler Chrysler, 2018; Piquepaille, 2006). Wind tunnel tests and water tunnel fluid experiments indicated that the drag coefficient was 0.19 (which is 35% less than that of general compact cars on the market), making the Bionic Concept Car the most aerodynamic sedan ever made. The design meets all of the objectives for four-passenger box sedans, providing a comfortable, spacious, and safe seating space (Conceptcarz, 2006; Daimler Chrysler, 2018). In terms of driving performance, the car has a net weight of 1,100 kg (which is half that of common minivans and small cargo trucks) and fuel efficiency of 70 miles per gallon on average, guaranteeing a comprehensive balanced performance (Conceptcarz, 2006).

(7) Identify

The Mercedes-Benz Technology Center (MTC) stated that in this project, ‘complete transfer of nature to technology’ was achieved. The interdisciplinary design team cooperated to find a specific model designed from multiple perspectives, including biology, biologically inspired design, and engineering (Daimler Chrysler, 2005; 2018). A wide diversity of technical and scientific possibilities was explored, demonstrating that innovation has no bounds. This experience also illustrates how free and interdisciplinary thinking leads to exceptional achievements (Daimler Chrysler, 2005; 2018). The incorporation of a systematic analysis tool assisted the design and development process in efficiently obtaining a suitable solution. Reviewing the experience gained during the development process, the initial needs and objectives, and biological principles can also facilitate the development and extraction of better innovative design concepts and products.

4. Discussions

Nature, resulting from a long process of evolution, is a precious and valuable system that contains a great amount of wisdom and knowledge for us to be learned and inspired in order to address the problems we are facing. Besides, those famous bio-inspired examples introduced in the literature review section, the Mercedes-Benz’s “Bionic Concept Car: Boxfish” case selected for this paper further confirms that using bio-inspiration to devise artificial systems that mimic nature with current technology can reach the innovative product design. For example, bio-inspiration was found, when the team was conducting the observations in aquariums (Hanlon, 2005). And the ideas inspired by the boxfish help interdisciplinary team solved the tradeoff issues that generally occur between vehicle weight and safety, and between aerodynamics and seating space (Conceptcarz, 2006; Hell, 2006; Ultimatecarpage.com, 2005).

However, not all companies have such a wealth of teamwork opportunities and resources like the Mercedes-Benz’s Bionic Concept Car case described here, without the assistance of a systematic tool, designers and engineers can be easily influenced by past experience and functional fixation. Even with the existence of many biological effects, blind spots can still occur, thereby lessening the chance of deriving optimal designs. As suggested by the case analysis of using the Biomimicry Design Spiral and template analysis, it shows that how the team at Mercedes-Benz defined and translated the problem at hand, and then continually re-evaluated and redefined the problem and its potential solutions as the problem-solving process unfolded. The methodical examination procedure outlined by the Biomimicry Design Spiral can certainly help guide the team from other companies in applying bio-inspiration thinking step-by-step. In general, we found out that this approach can help clarify needs and objectives, assist in the formulation of reasonable design specifications, direct design concepts, and maximize the application of biological characteristics.

5. Conclusion

Since the beginnings of humankind, we have learned from nature. We went on to further extract natural elements and apply them to tool design and production with the goal of enhancing quality of life. The means of extending such wisdom in the face of ecological degradation and forming a symbiotic coexistence with the natural world are crucial issues that designers and engineers need to take into consideration. This paper selected a case study - Mercedes-Benz's Bionic Concept Car to examine under the systematic guideline provided by the Biomimicry Design Spiral. Using a problem-solving model conforming to the conception process, we broke down the problem and clarified each link, including status, objectives, the object (including the resources), rules, and limitations. Through the analysis process, it demonstrated that how we can apply the Biomimicry Design Spiral to help assist design and engineering team in learning from nature through a systematic procedure, deriving design solutions, and developing an innovative product that takes environmental conservation into consideration.

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