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SWOT Analysis of Biomimicry for Sustainable Buildings – A Literature Review of the Importance of Kinetic Architecture Applications in Sustainable Construction Projects

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Abstract. Biomimicry is a term to explain the use of genius in nature. It basically aims to use of resources in the most effective manner while satisfying human needs. Likewise, kinetic architecture implementations and biomimicry both tend to imitate the excellent mobility of nature and kinetic architecture implementations are somehow investigated in biomimicry studies. These two inspirational concepts of nature nested each other and were integrated over time contributing to the development of sustainable building system design. However, integration of biomimicry and kinetic architecture is essential to explain sustainable buildings and their certification systems. There is still lack of knowledge in the construction industry in terms of kinetic architecture and biomimicry practices since the concepts are dynamic and perceived to be complex by the industry practitioners. Moreover, traditional structure of the construction industry considering short term profits and project-based nature makes these concepts even more challenging for the projects. Hence, it is essential to apply strength, weakness, opportunity and threat (SWOT) analysis in biomimicry and kinetic architecture implementation so that construction industry practitioners might conduct projects more effectively and satisfy project requirements in sustainable building projects. Therefore, this study adopts SWOT as the research methodology and aims to guide construction professionals to better understand these concepts. Within this perspective, this study proposes five major strengths, namely the effective use of energy, higher prestige level, climate adaptation ability, enhancing comfort and higher value and rental costs, where weaknesses are higher initial or maintenance costs, lack of systems expertise, the need for coordination of different professions, special production requirements and complexity in design. Moreover, five major opportunities and threats are suggested as top management support, sustainability focused development strategy, technological improvements, the demand increase to the environmentally responsible buildings, incentives from the governmental bodies are opportunities; unfamiliar systems, system failures, difficulties in project financing, materials do not comply with standards, and market conditions, respectively. The study is expected to reinforce the link between the design and construction processes to apply the above-mentioned concepts in sustainable buildings.

1. Introduction

Not only scientists but engineers and designers have involved to the process of tracing solutions to provide balance between the conflict of nature and human. It is essential to implement effective design and maintenance strategies in construction industry to reduce the amount of waste for the sake of future generations. Lately, the concept of sustainability came to the fore as a measure to conserve natural resources. It is a widely-accepted fact that nature is highly influential to create solutions for

sustainability-related problems. Therefore, industry leaders seek for effective solutions inspired by the nature itself in order to maintain sustainability goals. It is possible to take lessons from unique characteristics of every living creature. From insects living at the desert to the mammals in tundra, nature has a variety of probing solutions could be translated into sustainability in construction industry. However, this diversity creates confusion. It is first necessary to understand the problem and operation thoroughly to be able to imitate nature. This study is aimed to give insight about the terms of biomimicry and kinetic architecture. Moreover, it aims to guide professionals to comprehend biomimicry with internal and external environmental analysis for the industry by - strength, weakness, opportunity and threat (SWOT) analysis.

2. Biomimicry Concept and Kinetic Architecture

Biomimicry is of Greek origin that consists two terms - bio (life) and mimicri (imitation) [1]. The concept of biomimicry aims to design by imitating nature's genius [2]. These designs, inspired by nature, aim to solve the problems that arise in current designs. From first ever humans, humankind have been inspired from the nature, imitating nature conscious or subconsciously. By examining the anatomy and flying techniques of birds, Leonardo Da Vinci was a biomimicry pioneer who after inspired Da Vinci Index. This index aimed to increase the effectiveness of biomimicry applications [3]. For centuries, imitation of the nature has not been identified properly until "biomimicry" term is coined by Otto Schmitt in 1950 [4]. In 1997, Benyus described three stages of biomimicry [5]:

- Organism Stage (natural form): Very simple characteristics of the creature to be transferred from the nature, appearance, etc. explored and transferred. (For example: visual transfer of a bird's feather shapes),
- Behavioural stage (natural production): Behaviour and specific characteristics of the creature to be transferred from the nature are researched and transmitted. (For example: transmission of a bird's feathers to keep its body temperature constant),
- Ecosystem Stage: The location, posture, positive and negative aspects of the organism to be transferred from the nature are investigated and transmitted into the ecosystem.

He also made different biomimicry definitions that guide the understanding of the term in a comprehensive way [5]:

- Nature as model: Biomimicry is a new scientific discipline that works on models of nature to solve human problems and imitates or uses them as inspiration.
- Nature as mentor: It is a new way of seeing and evaluating nature. It is a new insight that tells us what we have failed so far and what we can learn from it.
- Nature as measure: Using nature's 3.8 billion years of evolution, quality control and ecological standards to determine the sustainability of innovations. Nature has already learnt what works sustainably. Biomimicry uses an ecological standard to judge "rightness" of our innovations.

Architects have benefited from nature's structures and forms for centuries. It is possible to encounter this inspiration on the façade systems of the structures, carrier systems, installation and energy systems or at the outer ceilings. Nevertheless, the development of technology at such rapid pace has been another important boost in the design variety at construction industry. The concept of movement and dynamism entered the industry so fast has also affected the discipline of architecture in the sustainable manner. Kinetic architecture could be defined as a concept through which buildings are designed to allow parts of the structure to move, without reducing overall structural integrity. There are many approaches in which architecture can be said to be kinetic, through structural innovation, material properties, mechanical and dynamic elements, robotic systems etc. [6]. Kinetic architecture inspired structures are more-likely to be complex and in need of various contributions from different professions. Therefore, design, production, installing and maintenance processes need to be more carefully planned than traditional architecture examples [7]. The first kinetic structure, Villa Grasole, was designed by Angelo Invernizzi in 1935 could be seen in Fig 1.a. This structure moves according to the sunlight and the view

that completes one turn in 9 hours and 20 minutes. The V-shaped structure is connected to a circular central tower with a diameter of 44 m which is controlled by a three-button panel [8]. Montreal Olympic Stadium was designed by Roger Taillibert in 1976. This structure has a movable roof cover has been suspended by 26 steel cables [9]. Suite Vollard, is the building designed by Bruno de Franko was built in 2004 in the Brazilian city of Curitiba and lays claim to be the world's first tower to have independently rotating apartments [10].

Figure 1. a) Villa Grasole [8], b) Montreal Olympic Stadium [9], c) Suite Vollard [10]

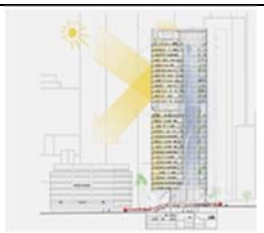
Advances in biomimicry and kinetic architecture have facilitated the proliferation of sustainable structures. Sustainability is one of the most frequently mentioned concept nowadays seems to be branding to every field. As concerns increase about the consumption rates of natural resources where evidences of global warming became apparent, the importance of maintaining a healthy relationship between production and consumption become crucial. Today, it is not a choice but a necessity from minor to major organizations to be able to adapt their decisions with adjusting their strategy according to sustainable strategies that would benefit the environment. Main goals of sustainable architecture can be defined as to provide effective energy usage in buildings, to minimize environmental damage, and to provide healthy environments to its users [11]. The concept of sustainable construction came to the fore in 1972, at the United Nations Conference on the Human Environment in Stockholm. In 1980s, examples of passive-energy structures were designed which contributed the concept of biomimicry in natural lighting, heating and ventilation. Brundtland report defined sustainable development in the most apprehensible way - development that meets the needs of the present without compromising the ability of future generations to meet their own needs - in 1987. By 1990s, rapid advancements in technology let the concept of kinetic architecture became more widespread and the structures in which intelligent systems were used emerged [12]. Additionally, kinetic architecture and biomimicry concept used together helped designers to understand and imitate the nature in a more realistic way resulted with sustainable solutions. The basic principles of sustainability could be defined as; resource consumption should be at a minimum-level, renewable (energy) resources must be used, waste can be converted to 100%, energy conservation is to be considered "must" and toxic substances must be removed [13]. In the light of technological developments, buildings today have natural lighting, ventilation, water, power supply etc. systems. These advancements, led the transfer of the auxiliary features from the nature to the sustainability-related solutions for the buildings. Some of the biomimicry inspired kinetic architecture examples and their sustainability outcomes are given in Table 1.

3. SWOT Analysis

SWOT is one of the oldest and commonly-used organizing frameworks in management related studies. It's organizing frameworks is developed in the early 1960s by Harvard Business School faculty [18, 19, 20]. Method's matrix model was officially presented by in the famous study of "The concept of corporate strategy" [21]. SWOT analysis was utilized in many researches, moreover its content changed depending on the purpose of its utilization [22]. This adaptation ability is one of the reasons that this concept is widely-used. SWOT analysis is applicable with the concepts as well as company or market

evaluations. Strength and weaknesses are to measure the existing internal environment, while opportunities and threats are for external environment [23]. It is an essential method to implement while initiating new concepts to the industry. Hence in this study, the concept of biomimicry and kinetic architecture implementations are evaluated within this framework by literature review and interviews with twelve different industries professional. Six of the interviewees are architects, three of them are civil engineers, two of them are mechanical engineers and the remaining one is a software-engineer. Those interviews helped authors to better understand different perspectives from the industry and shape a common framework of SWOT analysis.

Table 1. Biomimicry – Kinetic Architecture – Sustainability Matrix

Biomi-micry examples from nature	Picture	Features	Architect. example of biomimicry	Use in Kinetic Architecture	Picture of Kinetic Architecture Example	Sustaina-bility Impact
Termite Nest		Optimum air temperature Natural ventilation	Buildings constructed using ventilation with a chimney system.	The Blight Street structure has a natural ventilation system which represents a kinetic architecture example [14].		It provides energy conservation It provides fresh air It helps protect the heat level
White Butterfly		Sunlight reflection Energy storage	The wings of white butterflies have shaped the design of photovoltaic panels.	Peter Koch (project manager) say that the shutters open and close like butterfly wings in response to heat and light levels inside the building [15].		It takes advantage of daylight. It provides energy conservation.
Cuttlefish		Camou-flage properties Communication with colour change	It can be led on facades without energy.	The Galleria Centercity has a single reflective surface during the day, and the nights radiate different light waves [16].		Passive energy is obtained from sunlight absorption with the colour changes
Hippopotamus Skin		UV light absorption	UV-absorbing material has been developed for a building in Italy.	Brisbane Domestic Terminal Car Park absorb energy like water bath skin [17].		It provides energy conservation. Natural protect from the UV lights

3.1 Strengths

Today, the importance given to concepts such as energy efficiency and sustainability highlighted the design in nature. Benyus (1997) refers to biomimicry as a new science that examines, imitates and inspires models of nature in order to find solutions to the problems of people ([5], [24]) with describing nine basic features of biomimicry. Features of using the energy only that is needed, creating the appropriate form according to its function, providing recycling of everything, benefitting from local elements and avoiding redundancies could be associated with the effective use of energy and climate adaptation ability. El-Zeiny (2012) referred these benefits in an interior design perspective [25]. Those buildings affected by the biomimicry design have gained popularity due to their unusual but natural shapes. Primlani (2013) contributed new design principles of biomimicry [26] which includes to adapt to changing conditions, to create awareness and responsibility in local needs, to use nature-friendly

chemistry and to be productive in resources. Taylor Buck (2015) who interviewed with biomimicry consultants stated that most of the clients are profit driven and see biomimicry as one route to creating a unique product that results in market differentiation and higher rental income [27]. This paper also investigated real cases and revealed that biomimicry approaches can help to reduce infrastructure maintenance costs and help in reducing liability to environmental fines, taxes and levies. Kellert (2016), identified further converge in the emphasis of biomimicry on the practice that seeks to enhance the human condition through better understanding and connection with the natural world [28]. Oguntona and Aigbavboa (2017) elicited the perceived likelihood of the adopted twenty-three biomimicry principles to optimize sustainability based on a five-point likert scale [29]. According to results, harnessing freely available energy, using readily available materials and recycling all materials are ranked as the most important strengths of biomimicry. Daphne and Pravin (2017) proposed biomimetic design inspired by the adaptive strategies of the African reed frog and the Hercules beetle that incorporates a hydrogel chamber, embedded phase changing material, and the use of adaptive thermal comfort. Results show a potential of up to 66% reduction in the space conditioning energy use intensity thanks to a decrease in cooling energy needs [30]. Biomimicry combined with kinetic architecture lets architects to construct dynamic modular pieces which enables different benefits for buildings i.e. from sunflowers – house systems harnessing solar energy more accurately tracking the sun with solar sensors and from desert animals - moving shadings in order to control sunlight.

3.2 Weaknesses

One of the basic features of biomimicry is that concept supports the award of cooperation [5]. However, combining different professions including new design and technology is challenging. Knowledge transfer between stakeholders in design and implementation is effective when stakeholders have the same aims for the project [31]. The issue of the different language and approaches used by designers, engineers and biologists constitutes an important barrier to adoption [27]. It is also harder to find experienced personnel in combining the professional knowledge and to shape intended system. Kenny et al. (2013) explored biomimicry as an alternative and sustainable design approach to traditional water infrastructure systems. They summarized the key barriers to innovations, indicating that regulatory and economic grounds are some of the major hindrances to integrating alternative design approaches in the water sector in developed countries [32]. Lurie-Luke (2014) found out that the use of biomimicry is widespread in the material development industry. These newly developed materials have features like reacting to external stimuli and surface modifications involving surface topography [33]. The challenges faced during the complex design, special production requirements according to material, install and maintenance of these materials is highly concerning for the investors as construction projects are aimed to finish in a desired budget and time. Initial costs of these systems are closer to require additional resources as R&D activities are frequently used. Grigorian (2016) studied that an understanding of the structural performance of trees can enhance the structural design of moment frames [34]. According to study, biomimicry and performance control are evaluated and resulted with that they need time and exposure before gaining consensus as mainstream methods of advancing structural design strategies. Lack of experienced workforce about behavioural modelling of dynamic systems constitutes another weakness that decelerate the proliferation. Also, imitating nature is not an easy task. The production of similar motion is only possible with appropriate software and engineering design.

3.3 Opportunities

Kenny et al. (2013) indicated that expectations surrounding infrastructure development are shifting with governments and communities increasingly demanding the integration of efficient, sustainable solutions for innovative urban designs which will trigger incentives in the future [32]. Sustainable development has become a motto for greater number of countries. Universal acts related with sustainability oblige governments. So, they started to seek for more sustainable ways than today which triggers the technologic development. These developments are given as great opportunities to spread biomimicry. New technologies and design approaches have the opportunity to be cheaper than traditional approaches or provide additional quality. Advanced technology is able to produce new materials or methods to

mimic the nature and produce newer ways to leave sufficient resources for upcoming generations. Kellert (2016) remarked importance of environmental conservation and sustainability with giving insight about the biophilia and biomimicry convergence [28]. Daphne and Pravin (2017)'s work encourages the use of new design and technology according to sustainable focused design. According to system that has been inspired from two different biological examples, calculated energy saving resulted up to 66% decrease in the HVAC-related energy use [30]. Zhang et al. (2018) built a model to analyze the relationship between external pressures and firms' energy-saving behaviour found out that top management support positively influences firms' energy-saving behaviour [35]. Likewise, it is important for a biomimicry project to took back the support from the top management in order to fulfil desired goals.

3.4 Threats

The project-based nature of the construction sector combined with the desire for short project delivery periods, can create a situation that favours proven technologies over new improvements. It is harder to find financing alternatives for newly developed technologies according to their uncertain results especially in the traditional environments like construction industry [36]. Also, newly developed materials have the higher possibility to have inconvenience and system failures [33]. Market conditions are one of the other major threats for the construction industry as financial fluctuations is frequently confronted [37]. Kenny et al. (2013) argued that regulations are one of the foremost barriers to innovation [32]. Grigorian (2016) showed that new concepts like biomimicry and bioinspiration need more time to develop and accord with the market needs [34]. Dynamic systems are newly developing for construction sector accommodating unknown risks. Testing standards for these movable systems could be challenging as they manufactured uniquely.

Table 2. SWOT Analysis

STRENGTHS	**OPPORTUNITIES**
Effective use of energy [1, 5, 25, 26, 29, 30, 39, 40]	Top management support [35]
Higher prestige level [25]	Sustainability focused development policy [28, 29]
Climate adaptation ability [1, 5, 25, 26, 29, 30, 38]	Technological developments [30, 32]
Enhancing comfort [25, 28, 30, 38, 40]	The demand increase to the environmentally responsible buildings [28, 30, 32]
Higher value and rental costs [25, 27]	Incentives from the governmental bodies [32]
WEAKNESSES	**THREATS**
Higher initial or maintenance costs [32, 33, 34]	Unfamiliar systems [32, 33, 34]
Lack of systems expertise [33, 34, 38]	System failures [33, 34]
The need for coordination of different professions [5, 27, 34]	Difficulties in project financing [32, 36, 37]
Special production requirements [33, 34]	Materials do not comply with the standards [32, 33, 34, 37]
Complexity in design [33, 34, 38]	Market conditions [32, 34, 37]

4. Conclusion

Imitating nature has been a powerful solution for decades. Lately, sustainability related concerns have attracted more attention which guided architects and engineers to imitate nature in their designs. Moreover, not only the shape but also the motion imitation started to be applied that correlated the concepts of biomimicry and kinetic architecture. According to interviews, these newly-emerging concepts carry the potential to shape the future of construction industry. So, after a diligent literature review and interviews with industry practitioners from different professions, study conducted a SWOT analysis as the research method in order to identify internal and external environmental situation for the

better understanding of both terms. In this study five major strengths, weaknesses, opportunities and threats are identified for biomimicry and kinetic architecture in construction industry. The study is expected to compose literature related to biomimicry studies and give greater insight to professionals in order to apply the above-mentioned concepts into the pathway of sustainable buildings.

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