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Procedia Environmental Sciences 34 (2016) 178 – 189

Procedia Environmental Sciences

Improving Sustainability Concept in Developing Countries

BIOMIMICRY,

AN APPROACH, FOR ENERGY EFFECIENT BUILDING SKIN DESIGN.

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Abstract

Since 1970, a major problem worldwide is energy shortage along with the high consumption of energy in buildings. Architects are attempting to find solutions for managing buildings energy consumption. One innovative approach is Biomimicry ,Which is defined as the applied science that derives inspiration for solutions to human problems through the study of natural designs, systems, and process[2]. A subcategory of biomimicry is building skin which forms the entire exterior of the building. It is the boundary through which the buildings interaction with the environment occurs. Proper management of the building skin can significantly reduce the building's energy demand. The main objective of this paper is to investigate the ability of reducing energy consumption by applying the biomimicry approach on buildings skin design. In order To achieve this aim, a research methodology has been designed to accomplish four objectives**.** First, it will carry out an in depth research on biomimicry, skin, and biomimicry in building skin through the study of existing literature. Second, international case studies will be presented and analyzed in terms of usage of biomimicry, in addition to, the impact it had on reducing the buildings energy consumption. Finally it will conclude with guidelines for building skin biomimicry design for more efficient energy consumption in buildings.

Peer-review under responsibility of IEREK, International experts for Research Enrichment and Knowledge Exchange

Keywords: Biomimicry, building skin, energy efficiency, architecture, investigation

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Peer-review under responsibility of IEREK, International experts for Research Enrichment and Knowledge Exchange
doi:10.1016/j.proenv.2016.04.017

1. Introduction

Concerns about a dependable future for energy is only natural since energy provides 'essential services' for human life - heat for warmth, cooking, and manufacturing, or power for transport and mechanical work. Currently, in the 21st century all over the globe, enormous amount of primary energy is wasted due to the inefficient design of buildings. In addition to the running of the equipment used to convert energy into required services. As a result, an encouraging growth in awareness of energy conservation and efficiency has been rapidly growing, forcing, a number of design approaches and solutions have been researched and applied in order to overcome energy problems. One of those approaches is Biomimicry which is defined by as" the applied science that derives inspiration for solutions to human problems through the study of natural designs, systems, and process"[2]. The following paper discusses the principals of Biomimicry as an approach for sustainable and efficient design. . The aim of this study is to provide guidelines for applying Biomimicry principals on building skin design concepts and process for efficient energy management.

1.1Research Problem:

Since energy efficiency is a major problem worldwide a further steps relating to efficient buildings have to be applied in order to reduce energy consumption in buildings.

1-2 Research hypnotises:

Biomimicry principals could provide guide lines for improving energy efficiency of buildings through applying those principals on building skin.

1-3 Research aim:

Providing a design matrix for energy efficient building skin according to biomimicry principals.

1-4 Research methodology:

A research methodology has been carried out to accomplish research objectives**.** First, a literature review about Biomimicry. Approaches and Biomimicry in building skin through the study of existing literature. Second, an analytical study for international case studies will be presented and analyzed in terms of usage of biomimicry, and the impact it had on reducing the buildings energy consumption. Finally and guidelines a building skin must follow to be efficient and regulate energy.

2. Historical background of Biomimicry

The history of Biomimicry goes back to 500 B.C where, the Greek philosophers have seen natural organisms as models for a harmonious balance and proportion between the parts of a design that is synonymous to classical ideal of beauty. Later, in 1482 Leonardo Da Vinci was inspired by birds flying to invent a flying machine as an early example of Biomimicry. It helped in the development of the wright's brother first prototype to an airplane in 1948. In 1958, Jack E. Steele introduced the term Bionics and he defined it as the science of natural systems or their analogues. However, the term Biomimicry, it first appeared in 1982. In 1997, scientist and author Janine Benyus popularized the term more in her book;" Biomimicry: Innovation inspired by Nature[13]". In 2005, Bryony Schwan and Janine Benyus co- founded the Biomimicry institute. , in 2007 Chris Allen joined Beynus and Schwan to help launch "AskNature" which is the world's very first digital library that contains a list of natural solutions, Where designers are able to search through this collection of natural system that are classified on their design and engineering.

3. Biomimicry Definitions:

There have been many researchers who have defined Biomimicry. For example, Benyus, defined Biomimicry as "a new discipline that studies natures best ideas and then imitates the designs and process to solve human problems."[2].While Pederson Zari noted that an obstacle faced by architects is the lack of a clear definition from the diverse options that architects can apply in their project. That's why it's important to analyze the appropriate approach to fully apply the best method of Biomimicry to fully utilize the advantages[16]. On the other hand, Guber defined Biomimicry as "the study of overlapping fields of biology and architects that show innovative potential for architectural problems[4]".

4. Different approaches for applying Biomimicry in design

Biomimicry, is a growing research field in architecture and engineering as, it offers new and inspirational solutions while creating the possibility of sustainability in the built environment. Researchers have introduced two main approaches to the design process in Biomimicry such as the problem based approach and the solution based approach.

4-1The problem based approach (Design to biology):

This approach is driven through inspiration from biology through progression of steps that are either non linear or dynamic in the out of steps. This provides feedback as well as refinement in the loops[15]. In this approach, the designers search for solutions through identification of the of the problem. This prompts the biologists to match the problem to an organism that has solved a similar problem. The problem based approach relies on identification of goals and design limitations[9].

4-2 The solution based approach Biology to design:

This approach has different names known as the biology influence design, bottom up approach and the solution driven biological inspired design. This approach is used when the design process is originally depended on the scientific knowledge of biologists and scientists instead of human design problems. For instance, the scientific analysis of the lotus flowers surfacing clean from the swamp water resulted in many new designs. This consists of the STO Lotusan which allows a building to self clean itself[16].

5. Levels of Biomimicry

There are three main levels of Biomimicry that can be applied when a design problem is tackled. These include form, process, and ecosystem[13]. Through analyzing the organism or ecosystem, form and process, a solution can be brought through nature. In order for this application, it is important to determine which aspect in biology is mimicked[14]. This is known as level.

6. Application of Biomimicry in different fields

Biomimicry has been applied in many fields ranging from transportation, the car industry, electronics and clothing. Through research in biology Biomimicry can offer new technological and contribute to advances in several different fields[10].

6.1 Biomimicry in Architecture:

There are many examples of Biomimicry in architecture. One example can be dated to 1851 when James Paxton designed the structural system of the crystal palace from his observation of giant water lilies. in These lilies also inspired him in the lily house in Stratsbourg. In the mid 20th century, Robert Le Ricolais, a French professor at the University of Pennsylvania also developed structural models by mimicking biological structure models that were drawn by Haeckel, a German biologist, in the 19th century[15]. During the same century; many designers such as Le Corbusier and Frank Lloyd Wright were inspired by nature. Frank Lloyd Wright incorporated organic architecture into his designs, but at the same time did not have nature as an overpowering element. [In figure 1], it shows how he used the natural element of water in the falling water. His whole philosophy was that architecture welcomes nature and nature welcomes architecture. As Le Corbusier affirmed as biology to be "the great new word in architecture and planning" [12] .

Fig. 1. (a) James Paxston Crystal palace ; (b) Frank loyed Falling water .

Name of building	Inspiration	Application in design	Problem solved	Level of biomimicry

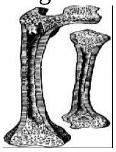
Eiffel tower 	Thighbone 	-The outward flare resembles that of a femur bone. -The lattice is built from metal studs and braces.	-Withstands bending and shearing effects due to wind -Ventilation problem solved	Organism Level
National Aquatics Center, Bejing 	Water bubbles 	-The surface is covered with membrane of lit blue bubbles of pneumatic cushion created from ETFE allowing for the bubble effect.	-The bubbles collect solar energy that heats swimming pools. -Allows for temperature regulation.	Organism level
Bejing National Stadium 	Birds Nest 	-Contains ETFE panels that insulate by stuffing small pieces of materials in the twigs. -Panels protect and provide sunlight filtration.	-Facade openings allow for natural ventilation -panels reduce the dead load supported by the roof. -cost reduction, durable, and recyclable.	Behavior Level
Eastgate Center, Harare 	Termite Mound 	The center opens and draws more air to help fans and is pushed up through ducts that are located in the center of the building.	Temperature is regulated throughout the year with no need for HVAC systems.	Behavior Level
HOK, Lavasa, India 	Fig Leaf 	-Foundation stores water. -Drip tip system water to clean its surface.	-Responds to the seasonal flooding. -Moves excess water.	Ecosystem level

Table 1. Applications of Biomimicry in architecture

7. Building skin as a tool for energy management :

There are many researchers who have defined building skin. For example, according to Rankouhi, it is the "*boundary through which the buildings interaction with the environment occurs*" [9]. It forms layers and filters that react to light. air, moisture, sound and heat. "The most common feature is the ability to maintain the optimal internal conditions that respond to the functions they carry." While, Hoeven, defined the building envelope as the building shell, fabric or enclosure as, it is the boundary between the interior of a building and the outdoor[6]. On the other hand, Kieran defined the building skin as where most energy and material exchange occurs[8]. It is the perception of a building identity. The building skin consists of the facade and roof. It includes the external walls, floors, roofs, ceilings, windows and doors .

8. Biomimmicry and building skin

In order to be able to draw the analogues of building skin and biomimicry it is important to analyze the commonalities of each. This includes evaluating the main similarities and the driving forces that affect nature and the architectural design process[9]. The building skin is a thin membrane that covers the skeleton (structure), regulates the organs (mechanical, plumbing and electrical) and defines its interior spaces. The building skin is similar to natural skin as it consists of different layers and filters that react to light, air, moisture, sound and heat. The frequent quality among natural skin is for its capability to maintain internal conditions while be responsive to its function. The building skin similar to natural skin is the boundary the controlled and uncontrolled environment. It is the configuration of the results of both internal and external forces. They both act as a filtration in the process of allowing what is allowed to enter and exit[15].

9. Analytical study:

This part of the paper will introduce an analytical study for 2 international examples that have applied the Biomimicry approaches on Building skin for reducing energy consumption focusing on techniques and strategies applied, aiming to obtain a Biomimicry design matrix which abstracts characteristics from different natural organism to fulfil the needed objectives .

9.1 The Council House 2, Melbourne CH2

(CH2) is a 10 stories sustainable building currently residing in Melbourne, Australia. It was built 2004:2006; it is designed by City of Melbourne with association of Mick Pearce in design Inc. The design of the building was very innovative as it challenged traditional approaches to sustainability and building design as it emulated a trees bark. The biomimic approach was Design to biology[14]. The building Green rating is 6.The CH2 is a representation between art and science. In order to achieve the objectives, it was based on linking the building to its external environment and living organisms surrounding it. As a result it responds holistically to its environment[14]

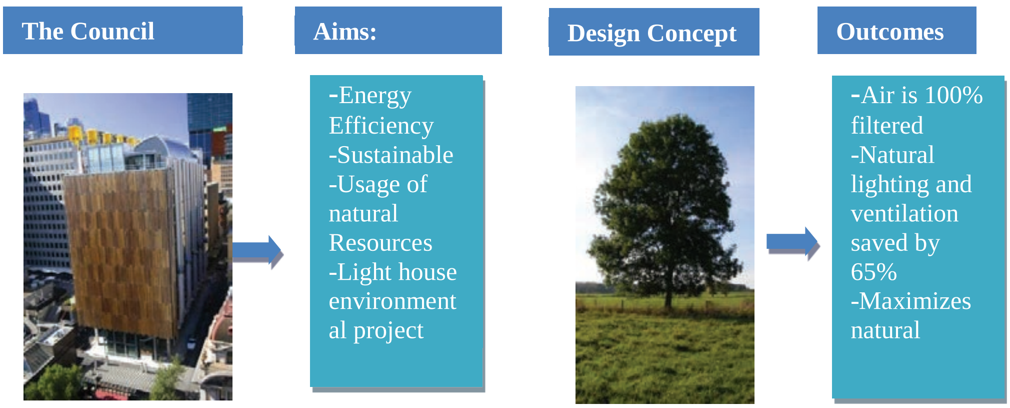


Fig. 2. illustrates the overview of the entire project of the Council House,

The usage of biomimicry appeared throughout the entire building. For instance, the west facade is the epidermis of the tree. It was inspired in how the facade would moderate the external climate. While the north and south facades were inspired from the bronchi of the tree. These were implemented as wind pipes and allowed for air ducts on the exterior of the CH2 as shown in [figure 3a].The eastern core and the facade, consisting of the service core and the toilets, emulated the tree skin (bark) as shown in [figure 3b]. The skin acted as a protective layer which filters light and air in the ventilated wet area spaces behind. Finally, the overlapping layers of the facade are constructed with perforated metal with polycrabonate walling in order to fix the louvers[14].

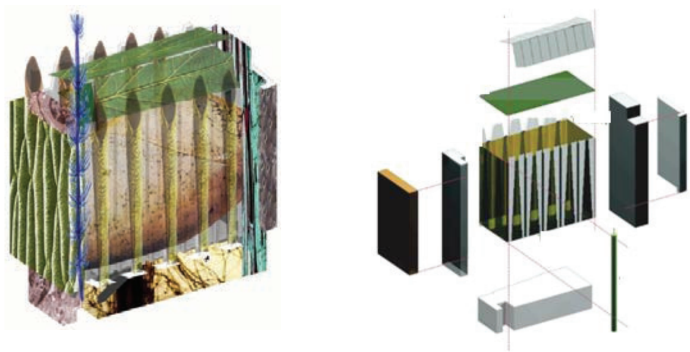


Fig. 3. (a) wind pipes on the north façade (b) overlapping layers of the façade

The design process was valuable as it led to the breakage between traditional industry solutions. Even though the buildings of the future may not resemble the CH2, but the CH2 represents a living type of architecture[14]. As a result it was reached the future buildings should contain the following:

- Interact with environment.
- Express climate and culture.
- Facades should express orientation.

9.2 Water cube, Beijing

The water cube, also known as the Beijing National Aquatic centre, was built between 2004 and 2007 mainly for the 2008 Olympics. The 4 storey high was designed by Chriss Boss, Tristam Carfrae, PTW Architects, CSCEC, CCDL and Arup. The Biomimic was exemplified in the building by mimicking the form of soup bubbles which also represented the main ideal for swimming. The Biomimic approach is also Design to biology[11].

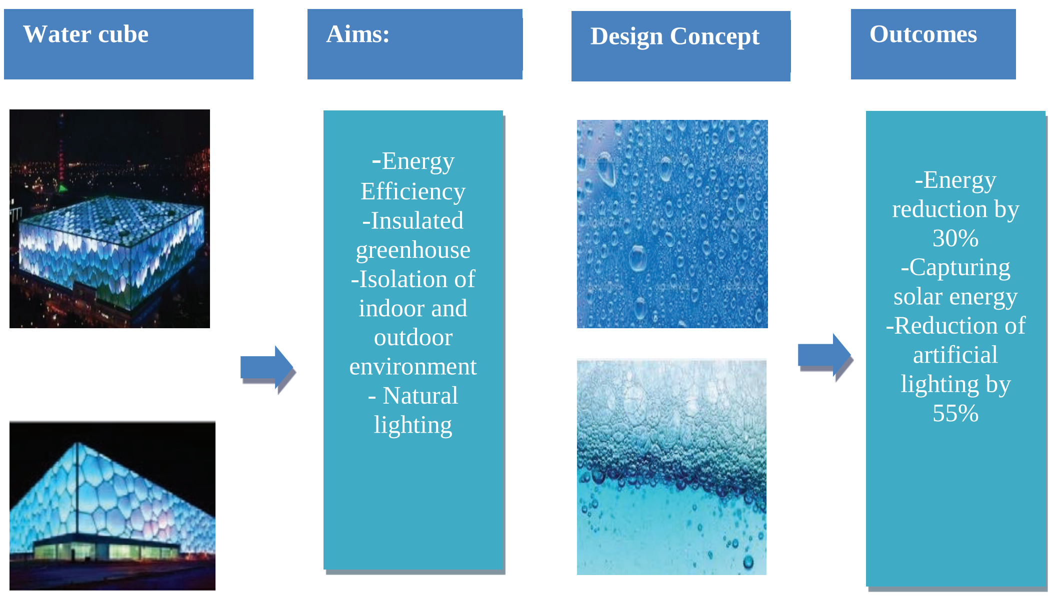


Fig. 4. illustrates the overview of the entire project of the Water Cube.

The building skin needed to be able to divide the spaces into cells of equal sizes and contain minimal surface area. At the same time, the building skin needed to absorb solar energy in order to be energy efficient. Tristan Carfrae, the designer of the water cube, found out that previous scientist such as lord Kelvin discovered during the 19th century that the tetrakaidechedron allow as a space to be divided into cells of equal sizes with the least surface area between them. Belgian scientist, Plateau, had researched soap bubbles and the rules of how they join within the three faces together forming a line. The soap films in the bubbles have the ability to reduce the surface area and surface energy. This coincidently answered Kelvin's question since the surface tension of the partitions reduces surface area of the bubbles. The geometry proved to be the most efficient way to subdivide a space. Therefore, the approach was to visualize the array of foam in a certain orientation and then to remove the foam block in order to obtain the geometry of the structure. It is based on a repeating unit that is tiled in a 3D space, rotated then sliced through the axes to obtain the geometric form as illustrated in [figure 5]. Even though the geometric structure is purely regular, when viewed from a certain angle it appears completely random and organic. The building skin offers the transparency of water with the mystery of the bubble system. As a result, it engages the people both inside and outside experience water throughout[11].

Fig. 5. illustrates the Water Cube's geometric form.

9.2.2 Environmental outcomes

The Water Cube achieved many environmental outcomes that led it to achieve an energy efficient design and overcome all the challenges and objectives through applying a biomimic approach. The outcomes include:

- Energy costs reduced by 30%
- Artificial lighting reduced by 55%
- Green house project
- Experience of water transparency to the visitors
- Rainwater is collected and recycled through efficient filtration and backwash systems
- ETFE energy savings are equivalent to covering the entire roof with solar panels.
- 20% of solar energy is trapped and used for heating

The Water Cube utilized biomimicry in search for a geometric form that maximized surface area in a 3 dimensional space while allowing for energy efficiency. There were many lessons learned from biomimicry in this project including[11]:

- Experience of nature within the environment
- Facades should express orientation
- Creation of a responsive and comfortable environment
- Importance of geometry and formation of natural form

9.3 The Esplanade Theatre, Marina bay

The building is a 2 storey high building which was designed by DP architects, Micheal Wilford. The Esplanade theatre is located at the Marina bay near the historic Singapore River. The decision to use Biomimic approach was taken after the initial design was criticized for containing too much glass and the design pertained to Western design. The design was also criticized for being insensitive to the tropical climate of Singapore. Therefore, the new design aimed to create a building that responds to its environment and culture without being too traditional. The building skin, based on biology analogy of the tropical durian fruit, is unique as provides for shading and repetition against its hot climate drawings inspiration from nature. The building was completed in 2007 and its biomimic approach is also design to biology[11].

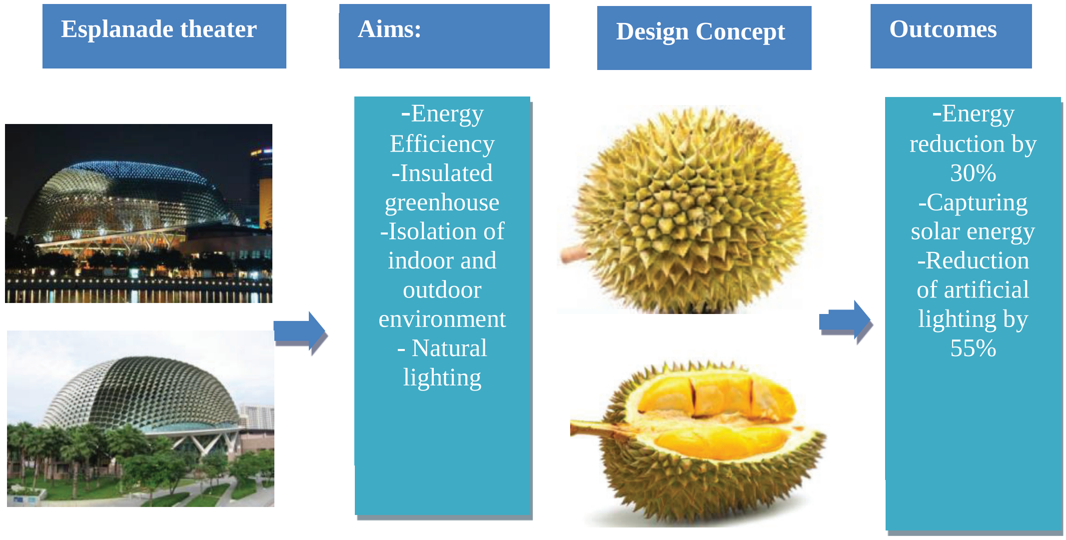


Fig. 6. illustrates the overview of the entire project of the Esplanade Theater ,

9.3.1 Design concept

In order to solve the problems of the public, the sun shades were inspired from spikes on the durian fruit to prevent overexposure of The spikes act as a protective layer to the fruit as do the sunshields of the Esplanade theatre[4]. Each shell contains the sunshields created from aluminium. The shape allows for a sense of tranquillity and is typical in some traditional Asian culture. The East and west facades with the greatest sun and heat contains the longest sunshades. While the North and south facades were much smaller[4]. The theatre is a steel structure. It contains an internal grid and bracing system that connects both the internal and external layers. In many areas of the theatre, natural materials were used such as timber and stone. Majority of the floors are paved with stones. The internal walls use sandstone cladding as well. The triangular shades are made from insulating glass with aluminium fixtures cornering the intermediate points.

9.3.2 Environmental outcomes

There were many environmental outcomes that resulted from the theatre. The dynamic sun shield allowed the building to be a landmark and contains a Singaporean personality from its biomimic inspiration. At the same time, the biomimic approach solved the issues that the public had raised concerns[1]. The outcomes include the following:

- Comfortable environment for the users
- Protection against the heat of Singapore
- Allows natural light to enter but protects the interior from over heating
- Lowered HVAC usage The lessons learned from where many as the usage of biomimicry solved the main issues that were presented in the first phases of the design. The usage of biomimicry allowed the following:
- Brought a sense of culture to the building
- Usage of geometry and patterns
- Usage of sun path to provide protection in needed areas

Case Study	Concept and biomimic level	Objectives	Reasons for choosing the analogy	Building Skin Material	Building skin outcomes
The Council House 2, Melbourne 	**Concept**: Tree **Level:** Organism and behavior 	Lighthouse environmental project Green house neutral -Energy efficient -Improve well being -Respond to environment -Sustainable.	-Usage of integral solutions -Functional model for complex problems -Protective skin and it creates louver system -Trees are very energy efficient - Moderates the external climate	All recycled -Timber -Steel Concrete	-Air is 100% filtered -Natural lighting and ventilation saved by 65% -Maximizes natural ventilation -Works with natural environment -Shading for visual comfort
The Water Cube, Beijing 	**Concept**: Water bubbles **Level:** Organism 	-Create insulated green house -Energy efficiency -Entrance of natural light -Isolation of indoor and outdoor environment	-Usage of geometric shapes and form -Surface tension of bubbles reduced surface area -Created experience of water transparency	-Steel -ETFE sheets	-Energy reduction 30% -Artificial lighting reduction 55% -ETFE saved energy 1.
The Esplanade Theatre, Singapore 	**Concept**: The Durian Fruit **Level:** Organism and behavior 	Consideration of climate -Follow sun path diagram -Creating a shading system -Energy Efficiency -Importance of location	-Usage of geometric shapes and form -Protection of spikes against heat -Durians form allow for optimum view of the bay	-Aluminum -Insulated glass Steel	-Comfort for users -Protection against heat -Natural lighting -Lowered HVAC levels

Table 2. Case study comparison (Author, 2015)

10. Objective Matrix

The next step in order to obtain a building skins design guidelines is to compare the case studies and their objectives. As illustrated in [table 3] an analysis was conducted of the different criteria met throughout the three case studies in order to determine the level of energy efficiency and the strength of each case study.

Case study 1: CH2 **Case Study 2**: Water Cube **Case Study 3**: Esplanade theatre

Key: ✸Fulfilled ❋Partially fulfilled ○Not fulfilled

Criteria	Case 1	Case 2	Case 3

Efficiency	Energy savings	82%	30%	30%
	Natural ventilation and lighting	65%	55%	45%
	Air filtration	✸	○	○
	Working with natural environment	✸	✸	✸
	Heat protection	✸	✸	✸
	Visual comfort	✸	✸	✸
	Following sun path diagram	✸	✸	✸
	Usage Photovoltaic panels and solar panels	✸	✸	○
	HVAC level lowered	20%	30%	15%
Materials	Recyclable	✸	❊	❊
	Renewable	✸	❊	❊
Approach	Biology to design	○	○	○
	Design to biology	✸	✸	✸
Biomimic Level	Organism	✸	✸	✸
	Behavior	✸	○	○
	Ecosystem	○	○	○

Table 3. Case Study Comparison Table. (Author, 2015)

The outcome of the total savings is a direct resultant of the different criteria that were met throughout the project. For instance, the usage of solar panels, usage of the sun path diagram, and visual comfort all contributed the end product of the total energy savings, HVAC savings and natural lighting and ventilation. [Figure 7] illustrates the percentage of savings for each case study.

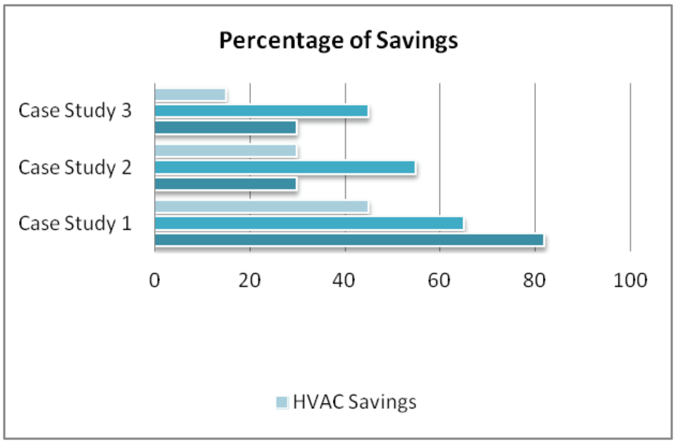


Fig. 7. illustrates a comparison of the percentage of savings for each case study. (Author, 2015)

As shown in [figure 7] the most efficient and strongest case study was the Council House 2 as its total savings were the greatest compared to the other 2 case studies. Case study one used the most recyclable and renewable material. It filtered its air completely and used the main characteristics of a tree in terms of energy efficiency. It also maximized the usage of its biomimic analogy.

11. Design Matrix

Afterwards, a design matrix needs to be created in order to determine the main building skin design requirements. The design matrix includes the main criteria needed in order for the skin design to be energy efficient for each category. This will serve as a guide to design energy efficient envelopes [table 4].

Mechanism			Thermal regulation behaviors	Water efficiency and sustainable properties	Insulation and conserving heat	Dynamic behavior and response to the environment	Communicati -on and attraction of colors	Water collection and skin protection
Site Context		Tropical		●	●		●	
		Polar			●		●	
		Arid/desert	●	●	●	●	●	●
Criteria to meet	Communication	Color change				●		
		Communication with external environment	●	●		●	●	
		Colors for attraction				●		
		Creating enthusiasm for the user				●		
		Attracting users	●	●		●		
	Heat Conservation	Heat storage		●	●			
		Light harvesting		●	●			
		Heating of interior			●			
		Insulation			●			
	Water efficiency	Water use reduction		●				●
		Recycling of water		●				●
		Water collection		●				●
		Air filtration		●				
		Self cleaning facade		●				
	Thermal Regulation	Regulation of internal temperature	●		●			
		Creation of sun shields varying in size	●					
		Follow sun path diagram	●			●	●	
		Responsive facade	●			●	●	
		Skin protection	●	●	●			●
		Responsive to external environment	●	●	●	●	●	●
Possible inspiration			Reptiles (Lizards, snakes)	Plants/Flowers	Polar bears, penguins, sea otters	Violet tailed hummingbird, chameleon	Geometric Patterns (water foams, cells etc)	Namibian desert beetle or thorny devil

Table 4. Design Matrix. (Author, 2015)

12. Conclusion

Nature has been sustainable and energy efficient for billions of years. Natural organisms have evolved and developed strategies in order to be energy efficient. Through applying these characteristics into architecture, human problems can be solved. Mimicking nature has significant potential in order to accomplish a new approach for energy efficient building envelopes. The building envelope contains a significant amount of energy usage. Through discovering and emulating nature's strategies the energy consumption level can be decreased by applying the biomimicry approach.

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