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Energy Efficient Buildings in Smart Cities: Biomimicry Approach

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1 ABSTRACT

Smart cities are those using technologies to make life easier for their citizens and enhancing the quality of life and urban service in order to reduce consumption, especially of energy. Biomimicry is one of the tools of the 21st century toachieve an emotional smart city that has its own spirit and identity. Biomimicryhas three main levels: organism, behaviour and ecosystem level, in terms of form generation, material selection, construction process, and function establishing.A subcategory of biomimicry is building skin which forms the entire exterior envelope of the building. It is the boundary through which buildings interact with the environment and the whole city. The aim of this paper isto discussbiomimicry as a tool to reduce energy consumption in cities through buildingskins. It also discusses concepts of smart cities. It provides an overviewof biomimicry as a tool of achieving a perfect biomimetic skin of buildings in smart cities. In addition it analysescase studies of energy conservationusing concepts of biomimicry. Finally it would conclude guidelines for biomimicry design of building skinsas a tool for reducing energy consumption in smart cities.

Keywords:Smart cities, Energy consumption, Biomimicry,Building skin

2 INTRODUCTION

Concern about the use of energy is increasing yearly to be used in many areas, whether cooking or operating electrical appliances and various machinery. In the 21st century electricity consumption is increasing because of the use of electricity ofmany buildings, so people must be aware of the importance of electricity.There are a lot of solutions and designswhich are applied to overcome the increasing use of electricity. Architects have begun to deal with other fields to create living spaces with minimal impact on nature in terms of energy use to create smart emotional cities. Hence they sought to return to nature to create living buildings that adapt to it without playing with the equations of life created by Allah. One of the most important solutions is Biomimicry which means inspiring nature to reach a solution. This paper discusses the principles of Biomimicry, its approaches, potentials and constraints. Biomimicry is not only related to energy, but also to form and structural systems, and so on. It is also related to fields other than engineering, such as medicine, transport and business. This paper also discusses Biomimicry as an environmental solution for smart cities, as well as giving some examples that use Biomimicry to save energy to create smart cities by how they mimic nature and how far they were successful. Also there will be guidelines to apply Biomimicrywhen we design a building skin to reduce the use of energy in the whole city in order to achieve a perfect smart city.

3 THEORETICAL BACKGROUND

3.1 Evolution of Biomimicry: Inspired by nature

The evolution of the concept of biomimicry began to emerge in the early 1980s but it spread by Janine Benyus1, a scientist and an author, who introduced an innovative way into design by taking nature as an important source to solve any design problem. In her book “Biomimicry: Innovation inspired by nature” published in 1997, she defined Biomimicry idea as ”a new science which studies nature as a model and an inspiration from which one can imitate its design and process to solve human problems”. The idea behind the concept is emphasising sustainability as a major objective of biomimicry which when applied to building design in order to increase the strength of materials through self-healing and self- assembling properties, could offer better solutions to increase the performance of buildings, saving energy and cutting down material costs by eliminating wastes.

Biomimicry is often termed as an evolutionary process taking inspiration from nature to generate systems and processes infinitely seeking a close fit to the ever changing environment.

By understanding biomimicry, we can say that many problem related to the built environment can be solved through the biomimicry approach and it proves successful with the surrounding environment.

3.2 Levels of Biomimicry

There are three main levels of Biomimicry that can be applied in a design process: organism, process and ecosystem level4. The organism level refers to an organism which may include a part or whole which can be mimicked. The behavioural level interprets the behaviour or response of an organism to a specific context. The eco-system level explains the mimicking of the function of a full eco-system 4. Three case studies with different levels of Biomimicry will be reviewed in order to demonstrate how each of them dealt with the environment to reduce energy in order to have a perfect building in an emotional smart city.

3.3 Approaches to Biomimicry

There are essentially two approaches to Biomimicry, which play a pivotal role in design3. The First approach identifies human problems and searches for ways through which a human or any living organism can solve the problem through it. This approach is called'Design to Biology' (Top-Down Approach).2

The idea is to identify similar cases in nature and how they have been resolved or dealt with, which in turn helps designers to effectively identify our goals and factors that help us design to reach the most suitable solution. This type of approach is a result of the designer's knowledge and ideas that comes from design principles to finally arrive at a solution to any design challenge.The second approach determines a specific function or property of any organism or ecosystem and turns it into a design which is called 'Biology to Design' (Bottom-Top Approach).2

Within these two approaches of Biomimicry, architectural design can also be classified into three main levels, i.e. form (organism), process (behaviour) and function (eco-system).The application of all these levels are based on thedesign programmeand the current context where the design is going to be carried out.

4 A BUILDING SKIN AS A TOOL OF REDUCING ENERGY USE IN THE BUILDING

There are many definitions of the building skin. According toRankouhi, it is the "boundary through which the buildings interaction with the environment occurs" 5. It consists of layers and filters that interact with the whole world and external factors like sound, heat, light and moisture. The most common feature is the ability to maintain the optimal internal conditions that respond to the functions they carry. While Hoeven defined it as the building shell, fabric or enclosure as it is the boundary between the interior of the building and the outdoor7. The building skin also acts as the identification of the building. It includes façades, roofs, external walls, ceilings and floors, as well as doors and windows.

5 BUILDING SKIN AND HUMAN SKIN (BIOMIMICRY INSPIRATION)

There are many similarities betweenhuman skin and building skin. For instance, the building skin covers the entire building as the human skin covers the entire body. Each of them regulates the organs (mechanical, electrical, plumbing in the building and heart and lungs in the human body). Both define their inner spaces. They are like the boundary that defend and control the external environment. Building skin also looks like a filter that controls what to enter like light, air, moisture, sound and heat and what comes out to reduce energy consumption of the building and perfect biomimetic skin to achieve our smart emotional city.

6 ANALYSIS OFCASESTUDIES OF ENERGY CONSERVING BUILDINGS UTILISING BIOMIMICRY CONCEPTS

In order to understand the role of building skin in reducing energy consumption through biomimetic approach, an analytical study of different case studies will be done in which the Biomimicry approach hasbeen applied on different levels to understand and analyse the different techniques and strategiesapplied in building skin and how they have successfully responded to realise an efficient building designin an emotional smart city that has its own spirit and character.

7 CRITERIA OF SELECTION OF CASE STUDIES

There are many case studies mimicking nature and applying the principle of Biomimicry. So case studies will be chosen according tothe largest number of buildings that reduce energy considerably and where theBiomimicry approach has been applied withvarious inspirationsfrom nature (plant - animal - nature). In addition it is shown how different levels of biomimicry and their distinctive designare challenging traditional approaches.

The parameters, which will be used in the comparative analysis between case studies, as obtained from literature review are: elements inspired, design concept, energy efficiency technique, and level of biomimicry.

7.1 Eco system level: Minister of Municipal Affairs & Agriculture building in Doha, Qatar

An office building that was designed for the ministry of municipal affairs in Doha which is known for its extremely hot weather and the intense desert sun. The building is designed by an architectural firm known as Aesthetics Architects Go Group.10

7.1.1 Elements Inspired

Due to the desert environment the entire building form and function was inspired from the cactus plant as shown in Figure 1. The shading system of the building is inspired by the cactus'capability to shade itself to prevent losing water in the dry weather. One of the strategies of cactus plants is to avoid losing moisture by using its spines or thorn like structures to prevent air exit near the surface skin so it will keep it cool and also they act like shades to protect it from the sun.

Fig. 1 The protection of Cactus plants by its spines

7.1.2 Design Concept

The building is covered from its top to its bottomwith shades that resemble the spines in the cactus plant. They actsas the same function of shading the surface of the building as shown in Figure 2. The opening and closing of shading devices occurs according to the sun intensity inspired by the interpretation of the cactus transpiration. Also the building uses different ecological systems to clean dirty water. Each ecological system breaks up pollutants in water according to the nutrients it feeds and what it needs to thrive from the water. Those ecological systems rely on “the use of helpful bacteria, fungi, plants, snails, clams and fish that thrive by breaking down and digesting pollutants”8. If this building is implemented it won’t be only thebuilding that using biomimetic techniques but an ecological system that disposes its wastes naturally.

Fig.2 The concept of the building is the form of Cactus plant

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7.1.3 Energy efficiency technique

The building skin is covered overall with shades which look like spines in cactus.These shades control the amount of sunlight that is entering the building and keeping it cool. In addition, it helps flooding the rooms with natural light so as to create a building that is highly energy efficient.

7.2 Behaviour level: Council House Building (CH2), Australia

CH2 is an extension for an existing office building in Australia, designed by an architectural firm called designinc. It is a ten-storey building, as shown in Figure 3 and it is a “six star rating from the Green Building Council of Australia.” 11. The building was designed to be one of the most energy efficient buildings “to create an effective building for the staff and a building that would be a lighthouse project locally, nationally and internationally for environmental innovation” 6. Part of the sustainability of the building lies on Biomimicry to solve some of the design problems.

Fig.3 The difference between the two elevations according to building’s orientation

7.2.1 Elements Inspired

The building is inspired by Termite moundsfor itsheating and cooling system. One of the termites’ features within the built environment is regulating the temperature of its mound. There are two processes in which termites regulate inner mound temperature according to the opening on top of the mound. If the top of the mound is closed then a process known as the thermo-siphon flow which is “warm buoyant air, driven by metabolic heat transfer, is removed from the nest via a network of tunnels and expelled through the porous surface of the mound. Here it is replaced with cooler, denser air that descends back into the nest". If the top is opened then the passive system used is known as Induced flow and also known as venturi effect “they are dependent on wind velocity to remove warm air, which in turn draws in cool, dense air in through the base of the mound”. These strategies help the termites to stabilise the temperature inside the mound regardless of the temperature of the mound. The soil stores the cold and the vents and pores in the mound get rid of the warm air if it is not needed. The termites constantly create and open new vents while closing old ones in order to regulate the temperature as shown in Figure 4.

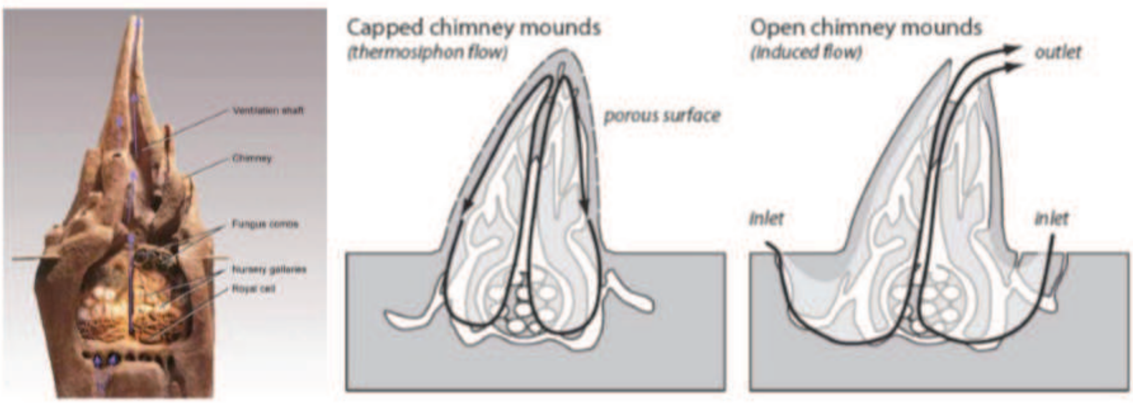

Fig. 4 How the termite mound works and regulates heat

7.2.2 Design Concept

The same concept was applied in the building to apply passive cooling and heating to minimise the use of HVAC systems that consume energy and contribute to the emission of Green House Gases. This system was interpreted in the CH2 building via a series of ventilation stacks in the north and south facades (vents), controlled window openings (pores) and precast wavy concrete ceiling (soil)as shown in Figure 5.

The ventilation stacks were strategically placed on the northern façade because it is the most exposed to the sun and the southern façade because it is façade least exposed to the sun and this is due to its location in Australia. The warmer the air gets in the northern vents the easier it rises out and gets replaced by cool air from the southern vents. To further enhance this process the vents on the northern façade are painted black to absorb more heat, a sort of a tomb like wall effect and the vents on the southern façade are painted with a light colour to reflect heat.

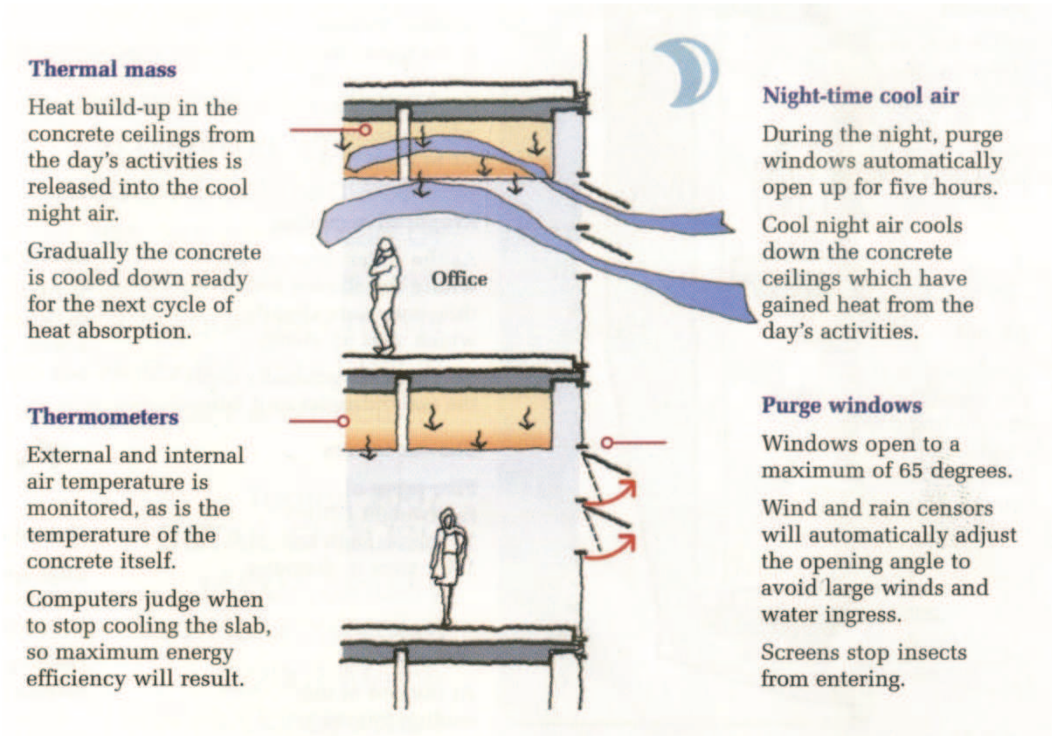

Fig. 5: The section show how the passive cool system works in the building, acting like the termite mounds

The concrete wavy ceiling has a similar function to that of soil in termite mounds which is storing thermal mass. The ceiling is wavy to "increases the surface area and the thermal mass capacity." At night the concrete replaces the hot thermal mass stored in it throughout the day by the cool night air; moreover there are channels that collect the heated air and remove it out through the ventilation stack as shown in Figure 6.

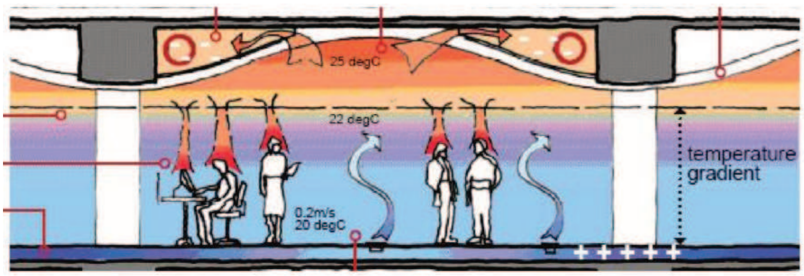

Fig. 6: The wavy ceiling that looks like the termite mound

7.2.3 Energy efficiency technique

The epidermis provides sun and glare control while creating a semi-closed micro environment. This form of imitation of nature is not relied on completely. There are more techniques and systems used in the CH2 building to enhance the outcome and it is still not one hundred percent without human intervention. However, it is inspired from the behaviour of termites and how they use available natural resources to make

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their surrounding environment comfortable and it is a way to tackle passive heating and cooling to minimise energy usage and damaging the environment.

7.3 Organism level:The Sino steel International Plaza

Sino steel plaza is high-rise commercial building which is totally made of glass. It is located besides Grayston drive and Rivonia Road. Construction is underway on the Sino steel International Plaza in Tinajin, China designed by Beijing-based architects MAD 9. The development consists of a 358 metre-high office tower and adjacent hotel at 88 metres height as shown in Figure 7.

Fig. 7: The Two Building of Sino Steel and The international plaza

7.3.1 Elements Inspired

The inspiration of the outer structure of the building is from thebee hive(honey comb). The external structure consists of hexagonal honeycomb windows in five different sizes. They were arranged according to wind and sun direction inits contextin order to regulate the temperature insidethe towers as shown in Figure 8.

Fig. 8: The external structure of the building looks like a bee hive

7.3.2 Design Concept

The form of the two buildings is simple, it looks like a rounded box. The façade consists of five different sizes of hexagonal windows which look like a honeycomb. These windows are spread over the building in a random and in a pattern occurring in a natural way: like cells multiplying as shown in Figure 9. This pattern gives the building a life and changes the way people look at it. The towers rise from a green hill that acts as the hotel's podium.

Fig. 9: the windows spreads in a random way to allow sun and wind to enter the building

7.3.3 Energy efficiency technique

The pattern which is inspiredby the honeycomb lets the building be efficient for energy as it responds to the patterns of sun and wind direction on the building. By mapping the different air flows and solar direction across the site, different sized windows are positioned accordingly, to minimise heat loss in the winter and heat gain in the summer.

7.4 Organism and Behaviour level: Esplanade art centre Singapore

It is a cultural center composed of two giant theatre buildings, outdoor stages, offices and apartments. It is designed by architects Michael Wilford and engineers Atelier one13.

Fig. 10: Esplanade Art Centre in Singapore

7.4.1 Elements Inspired

The shading system of the building was inspired by two elements: the durian fruit, which is a local fruit in Singapore, and the polar bear which is not belong to this place.

Fig. 11: The durian fruit and its thorns and the polar bear and its fur

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The durian plant has a thorn such as protrusions all over its skin to protect the seeds inside it from heat and direct sun light. These thorns acts as the shading devices that are mimicked from the durian plant.

The polar bear has a white fur which actually consists of transparent hair follicles and black skin. When this transparent hair be upright,it allows the light to enter and to be absorbed by the black skin whenever there is sun and return to normal position otherwise. This what was mimicked from the polar bear because unlike the polar bear in this building the heat is not wanted14.

7.4.2 Design Concept

The aluminium shading devicesin the double curved building envelopelooks like the durian fruits thorns which protrude to provide shade and move like the polar bears hair according to sun location and light intensity through photovoltaic sensors thus protecting the inner space of the art center15.

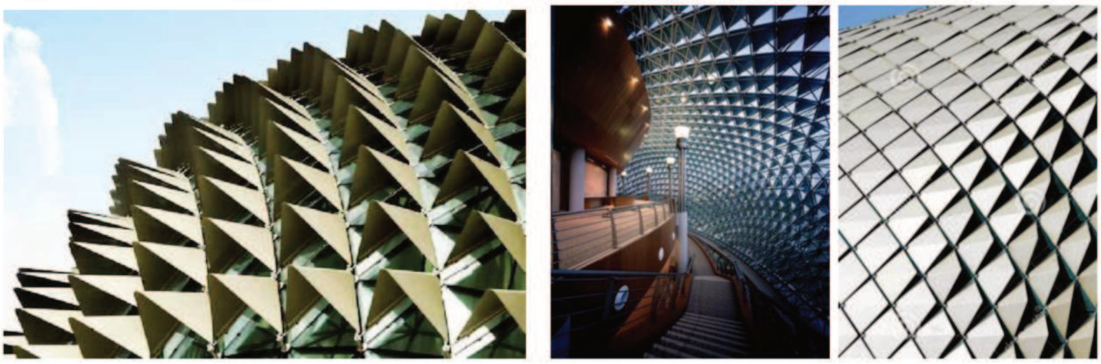

Fig. 12: The protrusions which resembles thorns in durian fruit and their move via sensors like the polar bear hair

7.4.3 Energy efficiency technique

The external shading system (The aluminium shading devices) provides the interior spaces with shade throughout the day allowing natural daylight and minimal heat and it lowered HVAC level.

A summary table of our case studies is made to show how different inspirations from nature is applied to buildings skins are contributing to energy efficiency, as shown in Table 1.

No.	Name of the building	Inspiration	Design Concept	Saving Energy Technique	Level of Biomimicry
1	Minister of Municipal Affairs & Agriculture building	Cactus plant	The building is covered from top to bottom with shades that imitate the spines of the cactus and perform the same function of shading the surface of the building	Controlling the amount of sunlight entering the building, keeping it cool and flooding room with natural light.	Ecosystem Level.
2	Council House 2 Building	Termite mound	CH2 uses ventilation strategy similar to termite mound using natural convention ventilations stacks	The epidermis provides sun and glare control while creating a semi-closed micro environment	Behaviour Level
3	Sino Steel international plaza	Bee Hive	The design of the windows is about five different hexagonal shapes in size to save energy	The form of Hexagonal shapes uses minimum energy	Organism level
4	Esplanade art centre	Durian fruit and polar bear	The use of aluminium shading system resembles thorns to provide shade and its move according to sun location and light intensity.	The shading system provide the interior spaces with shade all the day and minimal heat	Organism and behaviour level

Table 1 Application of Biomimicry in Building Design

8 OBJECTIVE MATRIX:

In order to get building skin design guidelines, a comparison of case studies and their objectives has been made. Table 2 illustrates the different criteria that have been achieved in the study of the three cases in order to determine the strength of each case study.

Criteria	**Council House 2 Building**	**Minister of Municipal Affairs & Agriculture building**	**Sino Steel international plaza**	**Esplanade art centre**
Energy savings	82%	62%	75%	30%
Natural ventilation and lighting	⁂	⁂	⁂	⁂
Heat Protection	⁂	⁂	□	⁂
Visual Comfort	⁂	⁂	⁂	□
Reducing the use of HVAC system	⁂	□	□	□

Table 2 the Comparison between Case Studies: ⁂ Fully Achieved, • Relatively Achieved

9 DESIGN MATRIX

After an intensive study of case studies applying Biomimicry in different ways, a design matrix is created. It containsthe main criteria that are needed to reduce energy efficiency in smart cities, through getting a perfect building skin design. This matrixrepresents a guide for building envelopedesign, as shown in Table3.The table shows different species and its different features in different contexts. Various examples are mentioned to help designers to get an overview of the capability of biomimicry as applied to building skins to reduce energy consumption.

Species		**Weather**				**Feature**													
		Tropical	Polar	Desert	Water	Thermo Regulation	Water management	Insulation and conserving heat	Illumination system	Sound or Noise Control	Structure Shading	Structure Stability and Strength	Color change	Self-Protection	Self-cleaning	Self-Healing	Produce Energy	Produce Oxygen	Purify Water
Animals	Butter- Fly	•		•					•				•						
	Octopus				•				•				•	•	•	•			
	Iridescent-Bird weather	•							•				•	•		•			
	Sea- tinkle				•				•				•						
	Hippopotamus	•				•		•						•					
	Owl	•		•						•									
	Jelly- Fish				•							•		•		•			
	Moth’s eyes	•		•											•	•			
	Alkaliphilic Bacteria				•									•	•	•			
	Flying Beetle (elytra)	•		•							•								
	Hummingbird	•										•	•						

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Reptiles	Tortoise beetle	•		•		•			•		•							
	Devil lizard			•		•	•											
	Blotched Lizard			•		•	•											
	Spiders								•									
Plants	Lotus leaf	•		•			•							•	•			
	Cactus plant			•		•	•					•						•
	Durian Fruit	•				•				•	•		•					
	Algae	•		•												•	•	•
	Water lily leaf				•						•							
	Coconut palms	•									•							
	Cilantro	•					•											•
Nature	Human Skin	•	•	•		•							•		•			
	Termite Mound	•				•		•										
	Muscles (Homeo-stasis)	•		•						•	•							
	Human thigh bone	•	•	•							•				•			
	Bird Nest	•		•							•							
	Honey Comb	•									•							

Table 3 Design Matrix, by Researcher

10 DISCUSSION

Just as the survival of any living organism in this nature depends on its adaption to the environment, the survival of the building depends on its adaptation to those around it and thus the city as well. Solving any problem depends on creating a set of ideas, converting them into a group of experiments and then reaching the suitable solutions to solve the problem that is facing us. One of most important problems are energy issues. This paper focuses on reducing the use of energy in buildings, which is reflected in the city as a whole, through applying the biomimicry approach to buildings skins. It discusses the building skin, its importance as it covers the entire building and how it can be a tool for reducing energy. Case studies have been analysed showing their techniques for saving energy and their inspiration from nature. Also a matrix consists of various species (animals, reptiles, nature or plants),their features (thermal regulation, colour change... etc.) that could contribute to energy efficiency in buildings. In addition, the weather which is suitable for their applicationwas illustrated. This matrix will be such a guide for designing a biomimetic building skin. When a skin for building is needed to be designed, the suitable species is chosen according to its context to achieve a biomimetic building skin in a perfect smart city.

11 CONCLUSION

Man has developed lots of solutions to satisfy his demands and to adapt to nature. These properties have been applied in architecture and other fields to solve problems. With the collaboration of biologists and architects, they are able to access new technologies and strategies to solve the energy problem.One of these solutions is the biomimetic approach. It is difficult to be fully inspired by nature, be it by a living organism or an ecological system, due to highly articulate design of it. This paper has tried to refer to the biomimetic approach as an important solution, although it is still unfulfilled towards design due to its modernity. But it has a distinctive potential to accomplish a new entrance into energy efficiency of the building envelope. Itis a vast area that deserves extensive study and research to obtain ideal buildings in a perfect smart city that has itsown spirit and character. Finally a matrix has been constructedwhich represents a guide to be used in designing energy efficient building skins inspired from nature, plant or any other organism.

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