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Improving Sustainability Concept in Developing Countries

Biomimetic Potentials for Building Envelope Adaptation in Egypt

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Abstract

Biomimicry is a science that seeks sustainable solutions by emulating nature's time-tested 3.8 billion years of patterns and strategies. The paper is concerned with embodying the biomimetic strategies to building envelopes which shall offer a high potential to reduce the energy demand, save material and thus improve the sustainability of buildings, through accessing current practices process of natural ventilation biomimicry in buildings for a potential application in building envelope for environmental adaptation which could help for the emergence of a new generation of biomimetic building envelopes aiming at promoting biomimicry in Egypt by showing the benefits that could be harvested.

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Keywords: Biomimicry; Natural ventilation; Adaptation; Building envelope

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1. Introduction

One of the key considerations in designing energy-efficient buildings is their skin. This element has the capability of improving the building's performance in natural ventilation, managing heating transfer, redirecting and filtering daylight and enhancing occupant well-being among several other functions. Therefore it could play an important role in reducing the energy consumed in cooling loads.

In the current context of climate change, insecurity of energy supply, rising prices of traditional energy sources, and economic crisis, the search for solutions to improve the energy performance of buildings, particularly of the

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envelopes, as responsible of the exchange of energy and other flows with the environment, sets out, in order to reduce energy consumption and achieve greater efficiency in the use of materials, by the use of adaptive building skins.

In Egypt the envelope of the building is responsible for a major part in controlling the climate and energy consumption. The paper elaborates distinct approaches to biomimetic design that have evolved through discussing theoretical fundamentals about the importance of the issue of biomimicry in architecture and the position of nature inspiration in building envelope adaptation using the historical and current examples based on natural organisms ,then discussing biomimetic ventilation solutions in building envelopes in international and local case studies.

The aim is to further the implementation of biomimetic principles and adaptive strategies to enhance adaptive behavior, take advantage of the evolutionary knowledge that nature provides, derive applying principles to achieve best architectural solutions, serve as a driver of innovation in architecture and promote efficiency and sustainability in building skins, using principles such as optimality in resource management, resilience behavior, exchange of information and energy with the environment, complexity by organization of simple elements, or multi functionality, which could help putting Egypt back on the road to sustainable architecture .

2. Biomimicry overview

All Biomimicry and biomimetics originates from the Greek words bios, meaning life, and mimesis, also meaning to imitate, it is the examination of nature, its models, systems, processes and elements that can provide solutions to human problems. Although various forms of biomimicry or bio-inspired design are discussed by researchers and professionals in the field of sustainable architecture, the widespread and practical application of biomimicry as an architectural design method remains largely un realized, as demonstrated by the small number of built case studies (Faludi, 2005).

One of the impressive biological processes is the ability of adaptation found in natural organisms. Flora and fauna offer numerous examples of adaptation methods to hot climate by means of physical characteristics, behavioral reactions.

2.1. Nature as Mentor, Mode l, Measure

- Nature as mentor: A new way of seeing and valuing nature as a resource that we can learn from and that we should preserve instead of uncontrollably extracting its resources. Biomimicry is a new way of viewing and valuing nature
- Nature as Model: Studies nature’s Form, process, systems and strategies and then imitates or takes inspiration from these designs and processes to solve the problems of humanity in a sustainable manner.
- 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.

2.2. Historical background

Our problem solving has been inspired by nature since the Stone Age, but this activity has been established only recently as a formal method of inquiry. Below are a few historical examples:

Leonardo da Vinci considered it essential to observe the anatomy and flying techniques of birds to create a flying machine, see Fig 1.Although his machine was never completed, the mere principle of being inspired by nature introduces da Vinci as a biomimicry pioneer along with the Wright Brothers, who derived their inspiration from flying pigeons to construct the first airplane.

Fig. 1. Leonardo Da Vinci's drawings for the flying machine; one of earliest Biomimetic designs in the 13th century..

As well as the design of the crystal palace by Sir Joseph Paxton designed a greenhouse at Chatsworth in England in, its structure based on the study of the giant Amazonian laves of water lily was inspired by the leaves of the water lily, see Fig 2.

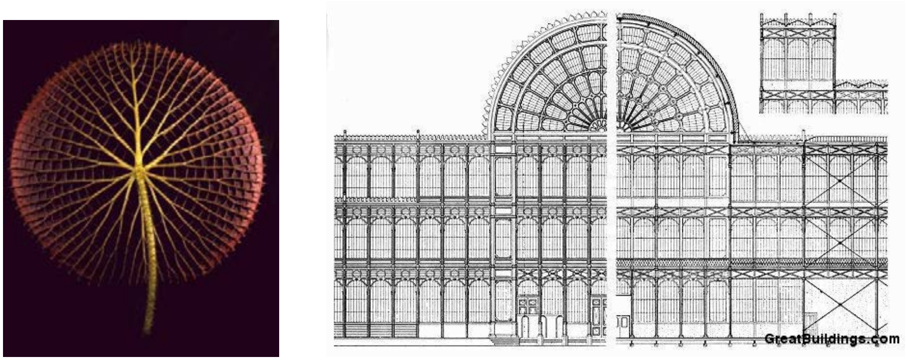

Fig.2. On the left water Lilly; on the right crystal palace ;(The secret was in the rigidity provided by the radiating ribs connecting with flexible cross-ribs. Constant experimentation over a number of years led him to devise his glasshouse design that inspired the crystal palace).

2.3. Biomimetic approaches

Our There are generally two main approaches to biomimetic design; a “Problem-Based”and a “Solution Based” approach. The two approaches have been addressed in literature such as Zari (2007), Knippers (2009), Helms et al. (2009), and Biomimicry 3.8 (2012).The Biomimicry Institute [19] (founded by Janine Benyus) created a Design Spiral methodology to help people learn and practice biomimicry.

Approaches to biomimicry as a design process typically fall into two categories: Defining a human need or design problem and looking to the ways other organisms or ecosystems solve this, termed here design looking to biology, or identifying a particular characteristic, behavior or function in an organism or ecosystem and translating that into human designs, referred to as biology influencing design (Biomimicry Guild, 2007).

2.3.1. Design to biology (problem –Based approach)

The approach where designers observe nature for solutions, which requires designers to identify problems and biologists to then match these to organisms that have solved similar issues. This approach is commonly used by designers.

2.3.2. Biology to Design (solution –Based approach)

Design process is initially dependant on people having previous knowledge of relevant biological research rather than on determined human design problems, see Fig 3.

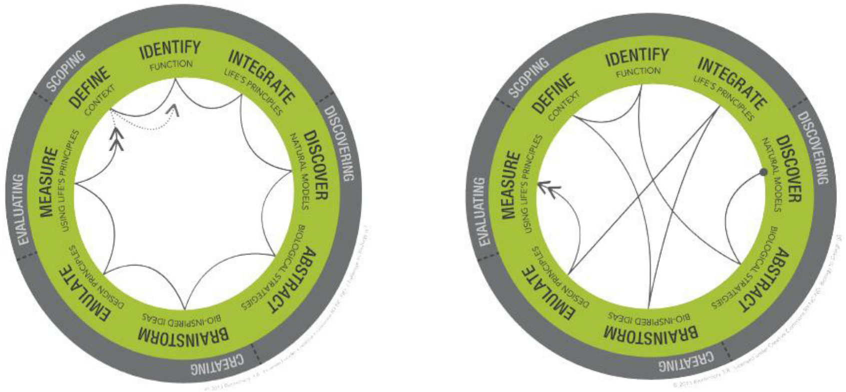

Fig.3. Representing biomimicry approaches; on the left problem based; on the right solution based.

2.4. Levels of biomimicry

According to Pedersen Zari (2007), There are three levels of mimicry ; the organism, behavior and ecosystem. The organism level refers to a specific organism like a plant or animal and may involve mimicking part of or the whole organism. The second level refers to mimicking behavior, and may include translating an aspect of how an organism behaves, or relates to a larger context. The third level is the mimicking of whole ecosystems and the common principles that allow them to successfully function. Within each of these levels, a further five possible dimensions to the mimicry exist. The design may be biomimetic for example in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function). The differences between each kind of biomimicry are described in Table 1 and are exemplified by looking at how different aspects of a termite, or ecosystem a termite is part of could be mimicked.

Table 1. A Framework for the Application of Biomimicry – adapted from (Pedersen Zari & Storey, 2007)

	Organism Level	Behavior Level	Ecosystem Level
	(Mimicry of a specific organism)	(Mimicry of how an organism behaves or relates to its larger context)	(Mimicry of an ecosystem)

Form	The building looks like a termite.	The building looks like it was made by a termite; a replica of a mound.	The building looks like an ecosystem (a termite would live in).
Material	The building is made from the same material as a termite; a material the mimics termite exoskeleton skin for example.	The building is made from the same material as a termite builds with; using digested fine soil as the primary material for example.	The building is made from the same kind of materials that (a termite) ecosystem is made of; it uses naturally occurring common compounds, and water as the primary chemical medium for example.
Construction	The building is made in the same way as a termite; it goes through various growth cycles for example.	The building is made in the same way that a termite would build i.e. piling earth in certain places at certain times for example.	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used.
process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.	The building works in the same way that a termite; by careful orientation, shape, material selection and natural ventilation for example or it mimics how termites work together.	The building works in the same way as a (termite) ecosystem; it captures and converts energy from the sun, and stores water for example.
Function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.	The building functions in the same way it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example. It may also function in the same way that a termite mound does in a larger context.	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilizing the relationships between processes; it is able to participate in the hydrological, carbon and nitrogen cycles in a similar way to an ecosystem.

3. Biomimetic building envelope adaptation

When applying adaptive concept into building envelopes, it means that building envelope should have the ability to deal with the exterior surroundings, in order to act as an adaptive layer capable of achieving internal thermal comfort and minimized energy consumption. This approach introduces the potential of the biomimetic concept to be used in building envelopes.

A couple of general examples to plants and animals that have a diversity of ways and use a multitude of strategies to keep adapted could be mentioned in order to put some of these ideas within an architectural context is shown in the Table 2.

Table 2. Representing examples to flaura and fauna adaptation to nature.

Means of Adaptation	Plants	Animals
Cooling	Plants loss heat through the process of the transpiration, in which the plant carries water from the soil around its root to the leaves, then evaporates water through specialized openings called stomata's (Gibson, 1996) ,(Batanouny, 2001)	The sweat glands of many mammals aid thermoregulation through evaporative cooling (BI, 2008).
Insulation skins	Insulation skins Thick external layers and waxy covering, which reduce heat gain (Earlham Collage, 2006).	- Some animals have thick coat with dense hair, it does not only protect animals from cold winter, but it insulates them from summer heat (Shenbrot et al, 1999) ,(Costa, 1995).
Insulation skins	Leaves cells that can absorb moisture and store it, creating an insulation layer (Batanouny, 2001).	Coloration is an important factor in reducing of heat absorption, so lighter colored coat is more familiar in desert animals (Earlham Collage, 2006).
Avoiding heat gain	Dense small leaves, spines and hairs instead of large leaves to decrease surface exposed to direct sunlight and insulate the plants against heat gain, while allowing the fresh air to pass between them (Gibson, 1996),(Springuel, 2006), (Batanouny, 2001).	
Retaining water	Shallow, radial roots, those which extended horizontally, which maximize water absorption at the surface (Springuel, 2006).	Different animals adopt different mechanisms to produce enough water such as sand lizard. It has hygroscopic skin to absorb moisture from the air.

4. Case studies

Addressing the problem of increasing cooling loads in hot climates, this paper represents an investigation into nature to learn from it how to adapt to the surrounding hot climates. The following examples the biomimetic approach in building envelope which can be incorporated in new buildings designs to function like living organisms, and to meet current requirements to make them adaptable to surrounding climate and able to provide all of their needs for energy from the surrounding nature.

4.1. International case study “Eastgate centre” (Harare) by Mick Pearce1996:

Architectural example of process and function biomimicry at the behaviour level are demonstrated by the Eastgate Building in Harare, Zimbabwe, see Fig 4. A breathing skin for building based on principles and methods abstracted from termites and termite mound is presented.

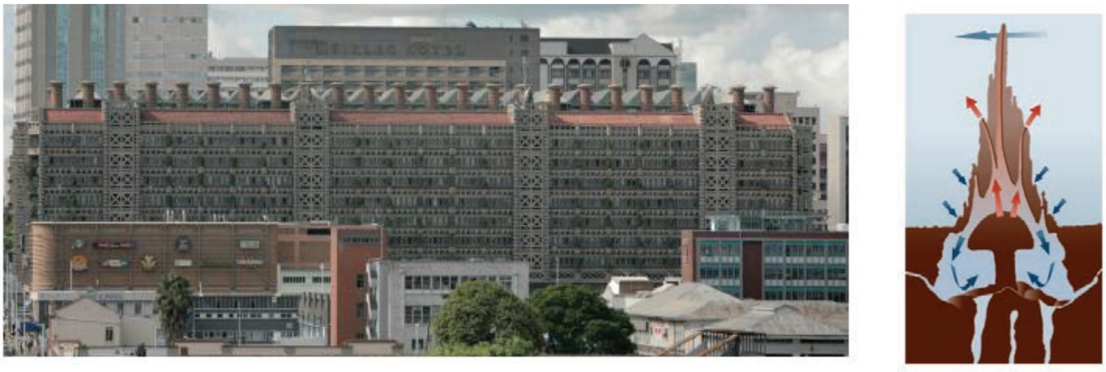

Fig.4. On left (Eastgate Building in Harare, Zimbabwe); on right (schematic of termite mound).

Impressed by the local African mounds was the climate control, Despite a daily fluctuation from 40 degrees C to less than 0 degrees C°, the termites are able to maintain a constant inside temperature of 30 degrees C° .Within thick, insulating walls they accomplish this by creating and constantly maintaining a draft of air from low openings to top holes. They make use of the so-called stack effect, convective airflow from cool to warm. The termites are constantly tweaking these openings for optimum performance, sometimes adding wet mud that aids cooling with its evaporative effects. The building is partly based on passive ventilation techniques and temperature regulation as observed in termite mounds.

Pearce employed some of these principles, see Fig 5. The complex is actually two buildings that shelter an interior atrium (right). Heat gain is reduced by limited glazing, deep overhangs, and building mass, and the architect took advantage of night cooling, thermal storage and convective air currents to moderate temperatures.

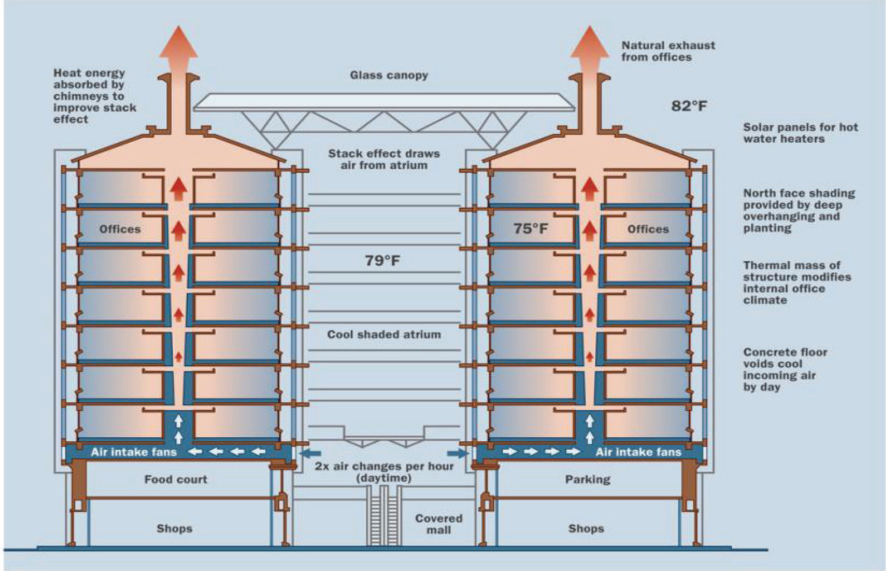

Fig 5. Eastgate sectional diagram, central cavity

During the day the heavy building mass and rock storage in the basement absorb the heat of the environment and human activity. At night, cool air is allowed into the bottom of the building and starts the convective flow that vents the hot daytime air through roof vents. This cool air is also stored and then distributed the next day into offices via hollow floors and baseboard vents.

These passive techniques, although not able to supply all of the climate control for the building, contributed to some impressive building conservation statistics. The approximately 32,000 square meter building was built with 10 percent of the typical ventilation costs for the area, 35 percent less energy costs, and 10 percent fewer typical capital costs, translating to a savings of $3.5 million for a $36 million building.

4.2. Local case study “Breathing Wall Model” by Mahmoud ElGhawaby, 2006

El Ghawabi was inspired by the concept of creating adaptive layer that can breathe that is applied in biological skins (plants, animals and human), Bedouin’s tents and traditional cloths and could be considered as an evidence of the importance of applying the same concept in recent façades in order to enhance ventilation systems towards decreasing energy needed for cooling process.

This research project is an attempt to link architecture with biology, and is an important example for the problem-based approach, as the designer asks a biologist to identify the flaura and fauna in which a certain function is available. The problem here was the desire to enhance natural ventilation that improves the energy efficiency of building envelope through biomimetic adaptation .This design is based on strategies, principles, methods, and techniques abstracted from natural organisms that regulate ventilation within the building envelope . Several organisms were studied and design case was been proposed and tested .This system, therefore, provides a conceptual and practical framework for an adaptive building envelope that response to their environment.

He describes his conceptual model of “breathing wall” that it is capable of controlling air flow through the entire surface, while cooling it and that the model works as an adaptive layer suitable for buildings located in hot climate such as in Sinai, Egypt. According to El Ghawabi, the model consists of three layers which aim at minimizing direct sunlight, allowing airflow to pass and thus cooling it he continues that each layer has specific features and tasks, see Fig 6.

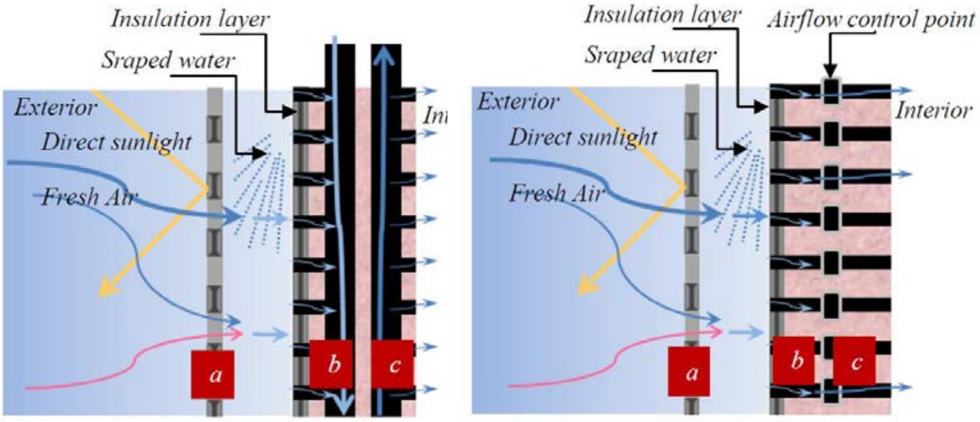

Fig. 6. Conceptual model of breathing wall; (a) exterior layer capable of preventing or filtering direct sunlight while allowing airflow to pass; (b)Middle layer acts as thermal insulation layer, then it cools air temperature by evaporative cooling and receives air flow; (c)Internal layer aims at controlling airflow.

- External layer is capable of preventing or minimizing direct sun light. It can be simple layer made of material that has the ability to absorb the moisture such as natural textile, clay, wood or reeds. This layer can be more sophisticated layer consisting of openable slots capable of controlling the intensity of sunlight according to pre programmed needed orders or according to the occupancy desire.
- Middle layer resembles the “epidermis” layer in human skin, it contains controlled airflow entrances, water sprayed system and airflow duct network. This layer aims at achieving three tasks; thermal insulation, cooling airflow by evaporative cooling then receiving and controlling airflow by duct network. Controlled airflow can be re-cooled by convection with earth deepness or other natural resources like underground water or sea water.
- Internal layer contains controlled ventilation outlets managed by both building management system and occupancy desire. This phase could contain a condensation process for obtaining potable water. This process can mimic camel’s nose which is capable of extract water vapor from exhaust air. He suggested that this concept could be applied whether with traditional simple elements or with advanced technologies.

By developing this system we are not dealing with a separate ventilation system, but with an integral part of the building envelope, which functions as a protective layer too. In this way we save material and energy and thus improve the sustainability of buildings. In order to prove the efficiency of breathing wall concept, a field experiment has been realized and lasted for 2 days during the summer of 2010 in Ismailia-East city, Sinai .Two minor models were constructed and compared with each other, see Fig 7. the first model was constructed with solid traditional bricks , while the second was constructed with the proposed breathing walls concept.

Fig. 7. Representing field experiment to the breathing model

The results showed that the differences between temperatures at the same time inside the two models varied from 1.2% to 16.23% and arrived at maximum till 5.6 c° lower inside the breathing model than the solid model without using water for evaporative cooling, see Fig 8.

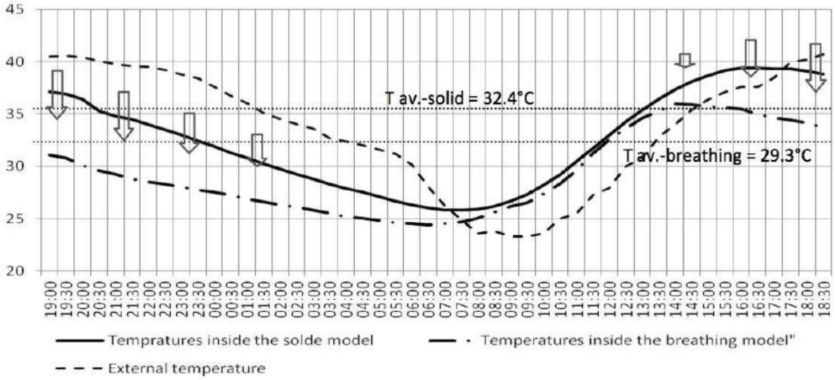

Fig.8. Representing temperatures measured during the experiment without the usage of evaporative cooling ; (by ElGhawabi).

In order to approve this hypothesis , a further step was a simulation on the same breathing model was carried by an aerodynamic simulation software called “Vaseri 2.5”created by “Autodesk inc”. A digital climate data of Sinai was used for wind speed and direction. see Fig 9

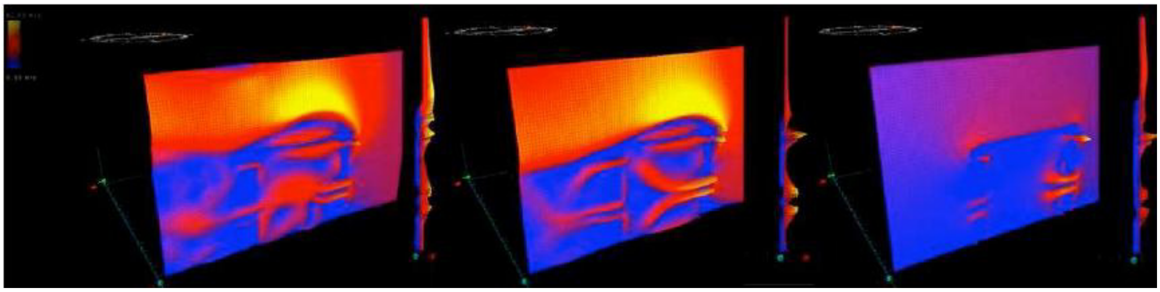

Fig.9 Representing the aerodynamic simulation for breathing model to simulate air flow inside and around the breathing model; (by ElGhawabi).

The results showed different types of air fountains according to wind speed and direction and a reduction of internal temperatures from about 5C° to 8 C°. It is such a worth using this concept for achieving comfort particularly during thermal peak hours.

5. Observations

Current work followed the approach which mimicked the nature by looking to its systems and process in order to learn how natural systems can overcome the same design problem. There could be a variety of applications and potentials which might turn out to have different viabilities dependent on criteria on which we should base the selection could be shown in Table 3.

Table 3. Analysis

Point of study	Points of strength	Points of weakness
Available technology and materials.	√	
Construction and maintenance costs.	√	
Suitable to the context (hot arid climate).	√	
Responding to environmental changed manually or previously programmed.	√	
Maintain inside temperature throughout the day.	√	
Limit the use of external additional cooling devices to the façade.	√	
Multi-functionality of the idea; whether it has simultaneous benefits such as structural, environmental, or aesthetic advantages		√
Integration with local character		√
Site to building relationship		√
Formal flexibility		√
Managing structural forces and loads		√

It is clear that further research would offer us opportunity to explore techniques used in construction directly within the context of sustainability and that the project was only a short fact finding exercise. Funding is needed so that the work will be able to extend the knowledge gained from this project into further work. Overall the case studies emphasize that integrating biomimicry within building envelope requires introducing the approach at the primary stages of the design process, ideally before any preliminary ideas have even been formed. It also involves inviting a biologist to the design table as a full team member.

6. Conclusion

Biomimetics has nothing to do with appearance and though it is still in its infancy in the field of architecture, however by using biomimicry as problem solving methodology could help creating a new adaptive building envelope, as the principles of biomimicry will help in providing design smarter, and connect the work with the natural environment and in the future, Biomimetic design is becoming more and more popular across many fields of study due to its potential benefits, and the field of architecture is no exception. More study needs to be carried out on the effect of biomimicry on building envelope and thermal comfort. On the other hand, it would be interesting to analyze a more biomimetic examples of buildings, and nature ,possibly with the additional information and suggestions.

The paper identified that using biomimicry as a problem solving methodology would help us discover sustainable and effective solutions to the most important issues in the building envelope and shown how the application of biomimetic principles and adaptive strategies of natural organisms, could improve the adaptive behaviour of building skins since the adaptive strategies from organisms could be applied in the design of building skins, also serving as a tool for development and as innovation engine. The application of these principles in the design of adaptive building skins, far from being a theoretical disquisition, is a practical necessity.

Finally, we expect the way a biomimetic building envelope is used to be a major determinant of energy efficiency as biomimicry promises to transform the way we envision, appreciate, and act with nature. It is about re-making who we are, how we see, and what we do to make our industrial lives possible.

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