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# Bio-inspired Built Environments for Climate Change: Developing Strategies for Adaptation and Mitigation

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**ABSTRACT: Climate change, whether solely driven by human activities or influenced by natural processes, has been widely accepted as a reality of our times. The effect of Climate change varies from region to region across the globe, but it is evident that many closed loop systems across the world such as the carbon and water cycles have been affected by it. These in turn have a devastating effect on many physical, biological and chemical systems on the planet. Extreme weather and climate events such as temperature extremes, heat waves, heavy precipitation, cyclones and tornadoes at high latitudes are getting more frequent and intense while subtropical land regions are being affected by severe droughts. The construction industry is accountable for more than half of the energy expenditure globally, drastically causative to climate change, along with the colossal carbon emissions they generate. The awareness gap that exists with respect to how emissions from built environments can be mitigated and, concurrently, how built environments and their occupants can acclimatize to shifts in micro and macro climate must be filled, linking assimilation of recognized knowledge, advanced design strategies, application of pioneering technologies and multidisciplinary investigations.**

**In pursuit of solutions, significant lessons can be derived by looking at adaptive natural systems. Almost all living organisms develop to endure varying circumstances without depleting their resources and changing the equilibrium of their bionetwork. Considering the global climate alterations we are now facing and the impetus of these shifts, an 'adaptive' approach inspired from nature could provide a framework for built environments in the future. We can draw an enormous lesson from nature where very form of life develops within a particular bio-system, through evolution, receptive mechanisms to endure altering circumstances without depleting their resources and altering the balance of their ecosystem.**

**Adaptations in nature range from structural, to behavioural, to survival. Various organisms demonstrate that they thrive over evolutionary time scales within their environments with the least spending of energy. If the human race has to prosper, then it is high time we re-learn how to emulate nature at organism level, behavioural level and ecosystem level and their efficient metabolic systems, integrating chief laws of the natural world with cutting edge technology for the most sustainable building design strategies and policies.**

**This paper demonstrates an analysis of diverse built environments, both urban and rural, which derive inspiration from nature as a means to develop design strategies for built environments, to either mitigate the causes of climate change or adapt to the impacts of climate change.**

**Keywords:** Adaptation, Mitigation, Architecture, Biomimicry, Climate Change, Strategies

'From my designer's perspective, I ask: Why can't one design a building like a tree? A building that makes oxygen, fixes nitrogen, sequesters carbon, distils water, builds soil, accrues solar energy as fuel, makes complex sugars and food, and creates microclimates, changes colours with the seasons and self replicates. This is using nature as a model and a mentor, not as an inconvenience. It's a delightful prospect...'(Mc Donough and Braungart, 1998)

## I. INTRODUCTION

The Fourth Assessment Report of the IPCC states that, "the observed widespread warming of the atmosphere and the oceans, together with ice mass lost, support the conclusion that is extremely unlikely that climate change of the past 50 years can be explained without external forcing, and very likely that it is not due to known natural causes alone." [IPCC (1)].

The multiplicity of responses by various experts across various fields is exceptionally broad ranging from scientific to behavioural, administrative and political resolutions, even though the barriers, confines and expenses to their effectual execution are still to be completely overcome.

It is important to understand that while we address near term impacts, adaptation measures are inevitably needed in several fields of human activity, especially in building design.[Roaf *et al* (2)].

The reason to emphasise adaptation here is due to the awareness that climate change would continue unabated for at least half a century even if the most effective mitigation actions were implemented straight away and green house gases emission drastically reduced (or even totally stopped ), due to the 'momentum' already built up in the climate system [IPCC (1)].

But it is also to be understood that adaptive strategies only cannot be considered as an enduring key to the anticipated impacts of altering climate scenarios, as it is being observed that the effects of these events are increasing in magnitude. Adaptive solutions coupled with measures of mitigation to combat the risks associated with altering climate scenarios would exceed the capacity of natural and human systems to adapt.

More than half of the comprehensive utilization of energy budgets and major contribution of $CO_2$ emissions they generate, to the very causes of climate change are due to the unhealthy building materials (like concrete and steel), detrimental construction techniques and unsustainable expansion of the built environment. To mitigate these impacts and simultaneously maintain tempo with the impetus of global warming, a novel category of building design integrating cost-effective, social and cultural needs with ecological accountability becomes thus obligatory. Hence the question to be asked is whether the architectural design process can be made sustainable at the same time adjusting to the altering climate scenario.

In spite of the prevalent availability of information on energy efficiency and renewable sources, the inclusion of environmental design strategies in the architectural and planning design process is still rather infrequent. It is understood that the built environment is usually designed to last at least well into the current time scale of climate science scenarios, but there does lie a crucial need to fill the knowledge fissure with how existing and new buildings, as well as their occupants can adapt to prospected climate changes.

In the endeavour to fill this gap, a fundamental insight possibly be represented by looking at the very natural scheme that humans are a component of the discipline of evolution proves that organisms have evolved in such a way that their cycle of growth and metabolism is not a burden on other bio-networks. Consumption of food and production of waste balance each other and the energy for various processes are derived from the sun.

This paper studies and analyses various case studies with respect to their advanced design methodologies, technologies and tools developed from the 'learning' from nature rather than merely extracting from it, an approach to innovation that can produce more advanced forms of building 'life' able to adjust to the evident shift in the climatic equilibrium of the planet, while also ensuring our long term sustainability within the context of the fragile ecosystem that houses and sustains us.

## II. BIO-INSPIRED DESIGN

Although various forms of bio-inspired design are discussed by researchers and professionals in the field of sustainable architecture (Reed, 2006, Berkebile, 2007), the widespread and practical application of bio-inspiration as an architectural design method remains largely unrealised, as demonstrated by merely a small number of built case studies (Faludi, 2005).

Various examples of built environments inspired from nature are typically based on the products and materials used, rather than the entire building or the building system as a whole. Several historic and contemporary examples are detailed by Vincent et al (2006) and Vogel (1998).

After a comparative literature review and analysis of various built environments inspired from nature, it is evident that various distinct approaches to biomimetic design exist with various inherent advantages and disadvantages. In terms of overall sustainability, all of these examples have diverse approaches. While some designers and scientists employ bio-inspiration specifically as a method to increase the sustainability of what they have created, bio-inspiration is also used in some cases simply as a source of novel innovation (Baumeister, 2007b).

## III. BIOMIMETIC APPROACHES

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, behaviour or function in an organism or ecosystem and translating that into human designs, referred to as *biology influencing design* (Biomimicry Guild, 2007).

## IV. DESIGN INSPIRED FROM NATURE

Designers have been identifying problems to contest them to organisms or natural systems that have solved similar issues, to get inspired by these solutions and apply them to man made solutions. This approach helps designers to identify various parameters for the design.

Daimler Chryslers prototype Bionic Car based on the boxfish (ostracionmeleagris), an aerodynamic fish given its box like shape is an example of such an approach.

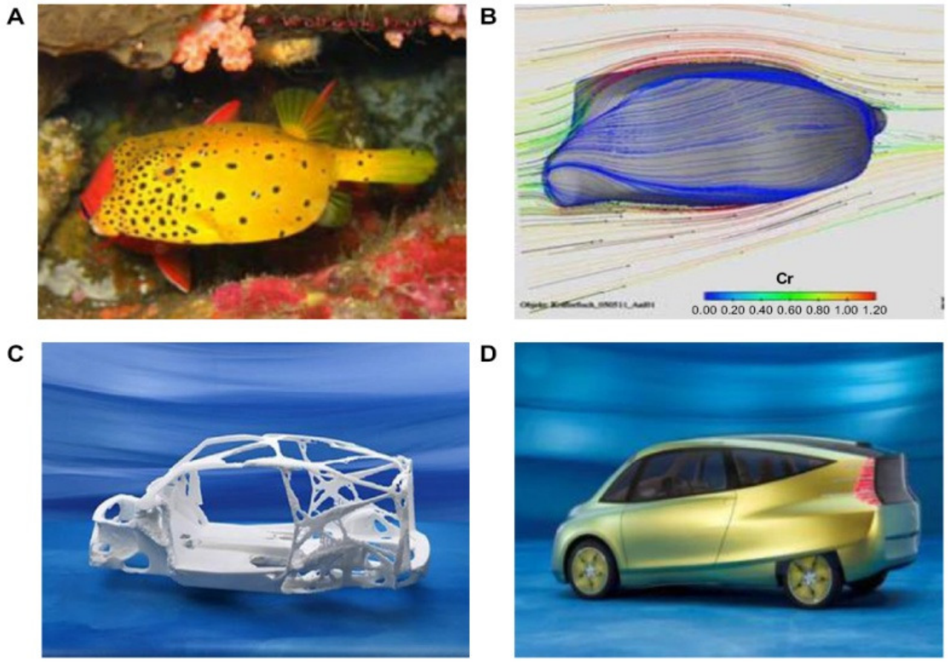


**Figure 3** DaimlerChrysler's prototype bionic car (**D**), inspired by the box fish (**A**), skeleton structure of blowfish adapted for designing of vehicles (**C**), and tree growth patterns (**B**).
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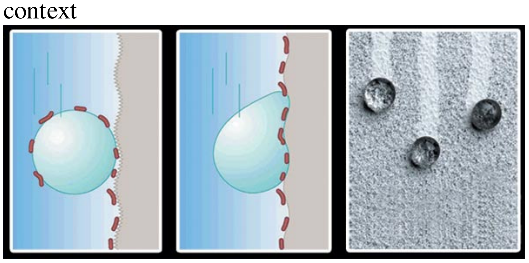
The fundamental approach to solving a given problem and the issue of how buildings relate to each other and the surrounding environment is a must when biological analogues are matched with human identified design problems.

When designers tend to have knowledge of relevant biological or ecological research, then it starts having an influence over the design process.

For example one of the many design innovations as detailed by Baumeister (2007a), show the scientific analysis of the lotus flower, emerging clean from swampy waters seen in Sto's Lotusan paint which enables buildings to be self cleaning.

Hawken(2007) points out that humans as a species have been around for longer than the oldest living forest and are undoubtedly a learning and adaptable species, similarities between human design solutions and tactics used by other species, have a surprisingly small overlap considering they exist in the same context



and with the same available resources (Vincent *et al.,* 2006, Vogel 1998). Hence this approach illustrates that novel ideas, technologies or systems or even approaches to design solutions can be inspired from biology especially to combat the changing environment around it.

## V. FRAMEWORK FOR APPLICATION OF BIOMIMETICS IN ARCHITECTURAL DESIGN

Within the various approaches discussed above, three levels of Biomimicry that may be applied to a design problem are typically given as form, process and ecosystem (Biomimicry Guild, 2007). As stated by Pedersen Zari (2010), in studying an organism or ecosystem, form and process are aspects of an organism or ecosystem that could be mimicked. To clarify biomimetics as a tool to increase the regenerative capacity of the built environment to its surrounding environment, a framework for understanding the application of Bioinspiration is represented **by** Pedersen Zari (2007). This framework could allow designers to employ biomimetics in the design methodology and identify an effective approach to take. Through an examination of existing biomimetics technologies it is apparent that there are three levels of mimicry: organism, behaviour and ecosystem. (Pedersen Zari, 2010).

The framework in which a specific plant or animal is being mimicked in part or whole refers to organism level. The framework that translates the behaviour of an organism in a micro or macro context refers to Behavioural level. A framework that mimicks whole ecosystems and common principles that allow them to successfully function refers to Ecosystem level.

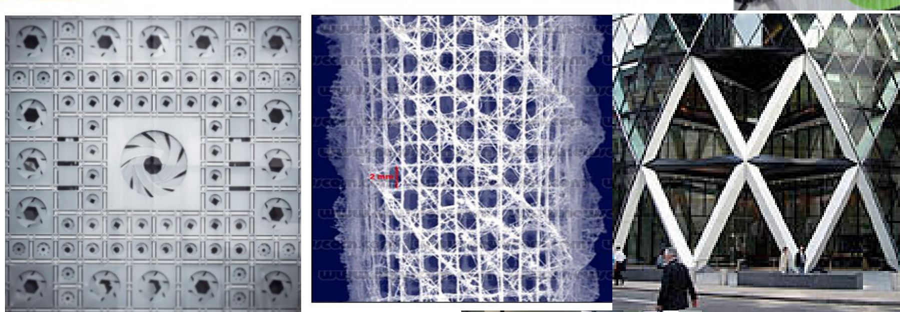
Further five possible dimensions such as form, material, construction, process and function can be the parameters in each of these levels.

*A. Organism Level*

Living organisms have been evolving for millions of years. Nature provides us with extensive research and development that has already been done. We can solve various problems that might already be addressed by living organisms in effective and efficient ways.

*B. Behaviour Level*

Many organisms and humans share similar environmental conditions and need to solve various challenges that humans face.



They tend to function within a certain environmental carrying capacity and within limits of energy and material availability. These limits as well as pressures that create ecological niche adaptations in ecosystems mean not only well adapted organisms continue to evolve, but also well adapted organism behaviours and relationship patterns between organisms or species (Reap *et al*, 2005).

*C. Ecosystem Level*

Benyus (1997) and Vincent (2007) described various examples of biomimcry at ecosystem levels.

The term eco mimicry has been used to describe the mimicry of ecosystems in design (Louvenci *et al,* 2004, Russell, 2004) and Marshall (2007) uses the term to mean a sustainable form of Biomimicry where the objective is the well being of ecosystems and people. Proponents of industrial, construction and building ecology advocate mimicking of ecosystems (Graham,2003, Kibert *et al*., 2002, Korhonen, 2001) and the importance of architectural design based on an understanding of ecology is also discussed by researchers advocating a shift to regenerative design. (Reed, 2005).

## VI. ARCHITECTURAL BUILT EXAMPLES THAT DEMONSTRATE COMPREHENSIVE BIOMIMICRY AT ORGANISM, BEHAVIOURAL OR ECOSYSTEM LEVEL

The table below shows examples of application of Biomimicry in Architectural Design to achieve more sustainable and regenerative built environment. These approaches could be adopted to develop a built environment to adapt to the altering climate scenario. The following examples draw principles from nature and develop adaptation strategies that could address climate change.

| Name of Building (Case Study) | Bio Inspiration | Materials Used | Application in Design | Climate Change Adaptation Strategy | Level of Biomimetics |
|---|---|---|---|---|---|
| **Eiffel Tower** | Thigh bone | Exposed iron | The outward flares at base resemble the upper curved portion of femur.<br><br>The internal wrought iron braces closely follow design of original trabeculae within femur. | Can withstand bending and shearing effects due to wind.<br><br>Ventilation problem solved | Organism level |
| **L'institute Du Monte Arab** | Iris of eye | Steel, glass & Aluminium | Cladding with screens with automated lens to control light | Controls the amount of sunlight entering the building, keeping it cool and flooding room with natural light. | Organism level |
| **Waterloo International Terminal** | Pangolin | Steel & glass | The glass panel fixing that makes up the structure mimic the flexible scale arrangement of Pangolin. | Ability to move in response to the imposed air pressure forces when trains enter and depart. | Organism level |
| **Eastgate Centre, Harare** | Termite mound | Concrete | The building is designed with a unique ventilation system, which draws outside air and cools or warms it depending on temperature.<br>The central open space draws more air with help of fans and is pushed up through ducts located in the central spine of the buildings | Temperature remains regulated all year around without using conventional air-conditioning or heating systems. | Behaviour level |
| **Beijing National Stadium** | Bird's nest | Steel, ETFE | "Cushion system" adopted where façade is in-filled with translucent ETFE panels just like a nest is insulated by small pieces of material. | Protects spectators from elements<br>Provides acoustic insulation,<br>Reduces maintenance cost<br>Reduces dead load,<br>Filters sun rays | Behaviour Level |

| Name of Building (Case Study) | Bio Inspiration | Materials Used | Application in Design | Climate Change Adaptation Strategy | Level of Biomimetics |
|---|---|---|---|---|---|
| **Council House, Melbourne** | Termite mound | Concrete, recycled timber | $CH_2$ uses ventilation strategy similar to termite mould using natural convention, ventilation stacks, thermal mass, phase change material and water for cooling<br>The façade is composed of dermis and epidermis, which provides microclimate<br>Ventilation stacks are implemented on the north and south facades of the building<br>The ceilings are wavy shaped to optimise surface area to increase thermal mass capacity<br>The west façade is covered with system of timber louvers to optimize the penetration of natural light and views. | The epidermis provides primary sun and glare control while creating a semi-closed micro-environment.<br>The wavy design helps it efficient collection and channelling out of heated air.<br>The vaulted ceiling also allows more filtration of natural light to the deeper parts of the space.<br>Shower towers provide a reduction of 4-13 degrees C from the top of the tower to the bottom. | Behaviour level |
| **Sinosteel International Plaza** | Bee hive | Concrete, steel and glass | The windows are designed in five different sizes of hexagon, placed in an energy-efficient configuration. | Minimum possible energy used in the form of conventional energy.<br>The skin removes the need for internal structures | Organism level |
| **Habitat 2020** | Stomata of leaves | Designed as living skin | The exterior designs as living skin which serves connection between exterior and interior, like stomata on leaf surface.<br>The surface automatically positions itself according to the sunlight and let it in<br>Surface absorbs water and converts waste to biogas energy | Electricity not required during day<br>Air and wind filtered to provide clean air and natural air conditioned<br>Recycling of water air and waste | Organism level |
| **Rafflesia House** | Rafflesia flower | Tensile environmentally friendly fabric | The building sits on 12 columns to allow other species to develop around it, trying to change traditional definitions of its characteristics.<br>Concave and convex internal walls to regulate flow of air inside. | Effective air conditioning at independent zones | Behaviour level |
| **National Aquatics Centre, Beijing** | Water bubbles | Steel, ETFE | The surface is covered with membrane of lit blue bubbles or pneumatic cushions made of EFTE creating bubble effect | The bubbles collect solar energy to heat swimming pools.<br>Temperature regulation | Organism level |
| **Swiss Re Headquarters, London** | Glass sponge | Steel & glass | Using a series of triangulations on the exterior similar to those of a glass sponge<br>The building ventilates air in a similar fashion just like glass sponge filters nutrients from the water by sucking water from its base and expelling it through the holes at its top | Its aerodynamic, Glazed shape minimizes wind loads and maximizes natural light and ventilation, reducing the building's energy consumption<br>Triangulations on the exterior similar to those of a glass sponge makes the structure stiff enough to resist lateral structural loads without extra reinforcements. | Organism level |

| Name of Building (Case Study) | Bio Inspiration | Materials Used | Application in Design | Climate Change Adaptation Strategy | Level of Biomimetics |
|---|---|---|---|---|---|
| **Treescraper Tower of Tomorrow** | Growing of tree | Steel & glass | The southern façade would be made of photovoltaic panels that convert sunlight into electricity. A combined heat-and-power plant installed, to be fuelled by natural gas, to supply the power that the solar panels cannot. | It uses minimal construction materials, while making maximum use of the enclosed space. All of the water in the building is recycled. All products, from building materials to furnishings, could be recycled or returned safely to the earth | Behaviour level |
| **Ministry of Municipal & Agriculture** | Cactus plant | Steel & glass | Sun shades on the windows can be opened or closed to suit the prevailing temperature, mimicking the activity of the cactus which performs transpiration at night rather than during the day in order to retain water. | Temperature regulated. Absorption and loss of heat controlled. | Behaviour level |
| **Hydrological Centre for the University of Namibia** | Namibian desert beetle, s*tenocara* | Steel & Glass | It is able to capture moisture however from the swift moving fog that moves over the desert by tilting its body into the wind. Droplets form on the alternating hydrophilic – hydrophobic rough surface of the beetle's back and wings and roll down into its mouth | to clear fog from airport runways and improve dehumidification Equipment for example. | Organism Level |

## VII. BIOMIMICRY TO COMBAT CLIMATE CHANGE

Biomimicry is often described as a tool to increase the sustainability of human designed products, materials and the built environment (Berkebile and McLennan, 2004, Baumeister, 2007a). It should be noted however that a lot of biomimetic technologies or materials are not inherently more sustainable than conventional equivalents and may not have been initially designed with such goals in mind (Reap et al, 2006).

## VIII. CONCLUSION

The built environment is increasingly held accountable for global environmental problems, with vast proportions of waste, material and energy use, and GHG emissions attributed to the habitats humans have created for themselves.

It is becoming clear that substantial changes must be made in how the built environment is created, inhabited and maintained in order to avoid further damage to climate and ecosystems. Long-term responses to adapting the built environment to the impacts of climate change are urgently needed.

Mimicking living organisms, as well as the complex interactions between them that make up ecosystems, is both a readily available example for humans to learn from, and is a source of inspiration for creating future built environments that may be able to integrate with ecosystems in a mutually beneficial way.

Such positive integration with ecosystems leading to a regenerative rather than a damaging effect on them will contribute to maintaining biodiversity and the ecosystem services that humans are dependent on for survival, particularly as climate change continues.

The ideas posited through this paper would demonstrate that the greatest potential of biomimicry to assist to adapt to climate change impacts is in the exploration of ecosystems. This is also the least explored aspect of biomimicry in built form, especially for Building Envelopes and Skins.

By devising principles for the application of ecosystem biomimicry to the built environment, it is anticipated that designers can begin to understand how to utilize ecology knowledge beyond the level of metaphor.

It has also been demonstrated that ecosystem biomimicry is a way of giving order and coherence to the myriad of methods used in the creation of sustainable architecture.

The change needed will not come about through new technologies necessarily, but by the adoption of new mindsets and goals for how built environments can and should function.

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