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BIOMIMETIC APPROACHES TO ARCHITECTURAL DESIGN FOR INCREASED SUSTAINABILITY

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ABSTRACT

Biomimicry, where flora, fauna or entire ecosystems are emulated as a basis for design, is a growing area of research in the fields of architecture and engineering. This is due to both the fact that it is an inspirational source of possible new innovation and because of the potential it offers as a way to create a more sustainable and even regenerative built environment. The widespread and practical application of biomimicry as a design method remains however largely unrealised. A growing body of international research identifies various obstacles to the employment of biomimicry as an architectural design method. One barrier of particular note is the lack of a clear definition of the various approaches to biomimicry that designers can initially employ.

Through a comparative literature review, and an examination of existing biomimetic technologies, this paper elaborates on distinct approaches to biomimetic design that have evolved. A framework for understanding the various forms of biomimicry has been developed, and is used to discuss the distinct advantages and disadvantages inherent in each as a design methodology. It is shown that these varied approaches may lead to different outcomes in terms of overall sustainability or regenerative potential.

It is posited that a biomimetic approach to architectural design that incorporates an understanding of ecosystems could become a vehicle for creating a built environment that goes beyond simply sustaining current conditions to a restorative practice where the built environment becomes a vital component in the integration with and regeneration of natural ecosystems.

KEYWORDS

Biomimicry; bio-inspired design; ecology; ecomimicry; industrial ecology.

INTRODUCTION

'From my designer's perspective, I ask: Why can't I 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,
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…'
(McDonough and Braungart, 1998)

Although various forms of biomimicry or 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 biomimicry as an architectural design method remains largely unrealised, as demonstrated by the small number of built case studies (Faludi, 2005). Examples of successful biomimicry that have progressed past the concept and development stage are typically of products or materials, rather than of buildings or building systems, and tend to mimic an aspect of a single organism (fig. 1 and 2). Several historic and contemporary examples are detailed by Vincent et al (2006) and Vogel (1998).

A growing body of international research on biomimicry in relation to the built environment identifies various obstacles to the employment of such a methodology. One barrier of particular note is the lack of a clearly defined approach to biomimicry that architectural designers can initially employ (Vincent et al., 2006).

A comparative literature review and examination of existing biomimetic technologies was conducted. It is apparent that distinct approaches to biomimetic design exist, each with inherent advantages and disadvantages. These diverse approaches may have markedly different outcomes in terms of overall sustainability. While some designers and scientists employ biomimicry specifically as a method to increase the sustainability of what they have created, biomimicry is also used in some cases simply as a source of novel innovation (Baumeister, 2007b). As demonstrated by Reap et al (2005), a biomimetic design approach does not necessarily mean the resulting product or material will be more sustainable than a conventional equivalent when analysed from a life cycle perspective.

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

Design looking to biology

The approach where designers look to the living world for solutions, requires designers to identify problems and biologists to then match these to organisms that have solved similar issues. This approach is effectively led by designers identifying initial goals and parameters for the design.

An example of such an approach is DaimlerChrysler's prototype *Bionic Car* (fig. 1). In looking to create a large volume, small wheel base car, the design for the car was based on the boxfish (*ostracion meleagris*), a surprisingly aerodynamic fish given its box like shape. The chassis and structure of the car are also biomimetic, having been designed using a computer modelling method based upon how trees are able to grow in a way that minimises stress concentrations. The resulting structure looks almost skeletal, as material is allocated only to the places where it is most needed (Vincent et al., 2006).

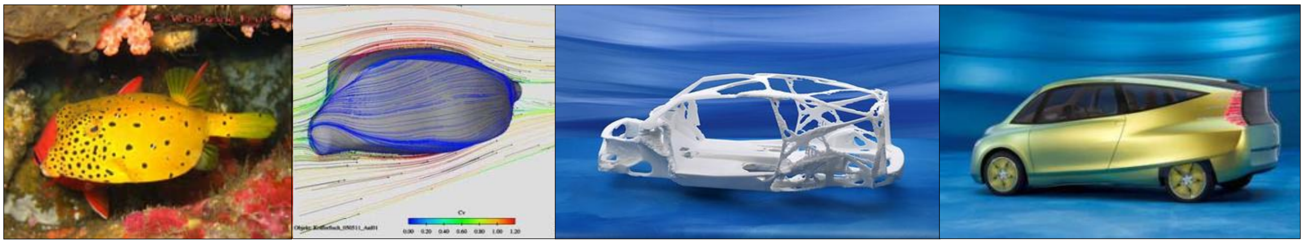

Figure 1: DaimlerCrysler bionic car inspired by the box fish and tree growth patterns.

The possible implications of architectural design where biological analogues are matched with human identified design problems are that the fundamental approach to solving a given problem and the issue of how buildings relate to each other and the ecosystems they are part of is not examined. The underlying causes of a non-sustainable or even degenerative built environment are not therefore necessarily addressed with such an approach.

The *Bionic Car* (fig. 1) illustrates the point. It is more efficient in terms of fuel use because the body is more aerodynamic due to the mimicking of the box fish. It is also more materials efficient due to the mimicking of tree growth patterns to identify the minimum amount of material need in the structure of the car. The car itself is however not a new approach to transport. Instead, small improvements have been made to existing technology without a re-examination of the idea of the car itself as an answer to personal transport.

Designers are able to research potential biomimetic solutions without an in depth scientific understanding or even collaboration with a biologist or ecologist if they are able to observe organisms or ecosystems or are able to access available biological research. With a limited scientific understanding however, translation of such biological knowledge to a human design setting has the potential to remain at a shallow level. It is for example easy to mimic forms and certain mechanical aspects of organisms but difficult to mimic other aspects such as chemical processes without scientific collaboration.

Despite these disadvantages, such an approach might be a way to begin transitioning the built environment from an unsustainable to efficient to effective paradigm (McDonough, 2002). Leading thinkers on regenerative design such as William Reed and Ray Cole argue however that a shift from a built environment that ultimately is degenerating ecosystems to one which regenerates capacity for ecosystems to thrive and restore local environments will not be a gradual process of improvements but will in fact require a fundamental rethinking of how architectural design is approached (Reed, 2006, Cole et al., 2007).

Biology influencing design

When biological knowledge influences human design, the collaborative design process is initially dependant on people having knowledge of relevant biological or ecological research rather than on determined human design problems. An example is the scientific analysis of the lotus flower emerging clean from swampy waters, which led to many design innovations as detailed by Baumeister (2007a), including Sto's *Lotusan* paint which enables buildings to be self cleaning (fig. 2).

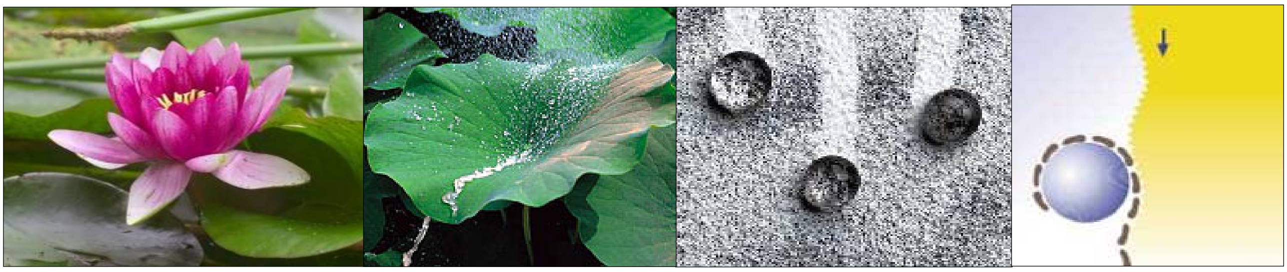

Figure 2: Lotus Inspired Lotusan Paint.

Although 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). An advantage of this approach therefore is that biology may influence humans in ways that might be outside a predetermined design problem, resulting in previously unthought-of technologies or systems or even approaches to design solutions. The potential for true shifts in the way humans design and what is focused on as a solution to a problem, exists with such an approach to biomimetic design. (Vincent et al., 2005).

A disadvantage from a design point of view with this approach is that biological research must be conducted and then identified as relevant to a design context. Biologists and ecologists must therefore be able to recognise the potential of their research in the creation of novel applications.

A FRAMEWORK FOR UNDERSTANDING THE APPLICATION OF BIOMIMICRY

Within the two approaches discussed, three levels of biomimicry that may be applied to a design problem are typically given as *form, process and ecosystem* (Biomimicry Guild, 2007) In studying an organism or ecosystem, *form* and *process* are aspects of an organism or ecosystem that could be mimicked. *Ecosystem* however is what could be studied to look for specific aspects to mimic.

A framework for understanding the application of biomimicry is proposed in this paper that redefines these different levels and also attempts to clarify the potential of biomimicry as a tool to increase regenerative capacity of the built environment. By defining the kinds of biomimicry that have evolved, this framework may allow designers who wish to employ biomimicry as a methodology for improving the sustainability of the built environment to identify an effective approach to take. The framework that will be described here is applicable to both approaches (design looking to biology, and biology influencing design). The first part of the framework determines which aspect of 'bio' has been 'mimicked'. This is referred to here as a *level*.

Through an examination of existing biomimetic technologies it is apparent that there are three levels of mimicry; the organism, behaviour 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 behaviour, 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.

Level of Biomimicry		*Example - A building that mimics termites:*
Organism level (Mimicry of a specific organism)	*form*	The building looks like a termite.
	material	The building is made from the same material as a termite; a material that mimics termite exoskeleton / skin for example.
	construction	The building is made in the same way as a termite; it goes through various growth cycles for example.
	process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.
	function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.
Behaviour level (Mimicry of how an organism behaves or relates to its larger context)	*form*	The building looks like it was made by a termite; a replica of a termite mound for example.
	material	The building is made from the same materials that a termite builds with; using digested fine soil as the primary material for example.
	construction	The building is made in the same way that a termite would build in; piling earth in certain places at certain times for example.
	process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites work together.
	function	The building functions in the same way that it would if made by termites; internal conditions are regulated to be optimal and thermally stable for example (fig. 6). It may also function in the same way that a termite mound does in a larger context.
Ecosystem level (Mimicry of an ecosystem)	*form*	The building looks like an ecosystem (a termite would live in).
	material	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 assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example.
	process	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 is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilising the relationships between processes; it is able to participate in the hydrological, carbon, nitrogen cycles etc in a similar way to an ecosystem for example.

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

It is expected that some overlap between different kinds of biomimicry exists and that each kind of biomimicry is not mutually exclusive. For example, a series of systems that is able to interact like an ecosystem would be functioning at the ecosystem level of biomimicry. The individual details of such a system may be based upon a single organism or behaviour mimicry however, much like a biological ecosystem is made up of the complex relationships between multitudes of single organisms.

Organism Level

Species of living organisms have typically been evolving for millions of years. Those organisms that remain on Earth now have the survival mechanisms that have withstood and adapted to constant changes over time. As Baumeister (2007a) points out *'the research and development has been done'*. Humans therefore have an extensive pool of examples to draw on to solve problems experienced by society that organisms may have already addressed, usually in energy and materials effective ways. This is helpful for humans, particularly as access to resources changes, the climate changes and more is understood about the consequences of the negative environmental impact that current human activities have on many of the world's ecosystems (Alberti et al., 2003).

An example is the mimicking of the Namibian desert beetle, s*tenocara* (Garrod et al., 2007). The beetle lives in a desert with negligible rainfall. 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 (Parker and Lawrence, 2001). Matthew Parkes of KSS Architects demonstrates process biomimicry at the organism level inspired by the beetle, with his proposed fog-catcher design for the Hydrological Center for the University of Namibia (fig. 3) (Killeen, 2002). Ravilious (2007) and Knight (2001) discuss a more specific material biomimicry at the organism level, where the surface of the beetle has been studied and mimicked to be used for other potential applications such as to clear fog from airport runways and improve dehumidification equipment for example.

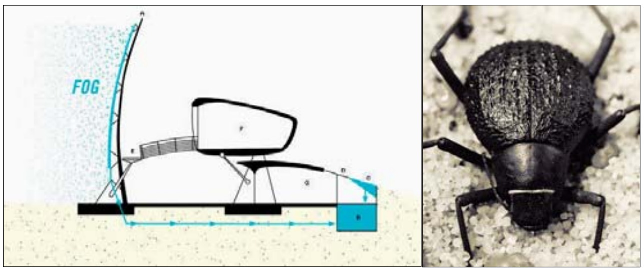

Figure 3. Matthew Parkes' Hydrological Center for the University of Namibia and the stenocara beetle.

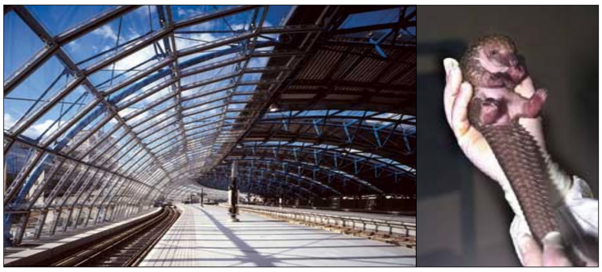

Figure 4. Nicholas Grimshaw & Partners' Waterloo International Terminal and the pangolin.

Nicholas Grimshaw & Partners' design for the Waterloo International Terminal demonstrates an example of form and process biomimicry at the organism level (fig. 4). The terminal needed to be able to respond to changes in air pressure as trains enter and depart the terminal. The glass panel fixings that make up the structure mimic the flexible scale arrangement of the Pangolin so they are able to move in response to the imposed air pressure forces (Aldersey-Williams, 2003).

Mimicking an organism alone however without also mimicking how it is able to participate in and contribute to the larger context of the ecosystem it is in, has the potential to produce designs that remain conventional or even below average in terms of environmental impact (Reap et al., 2005). Because mimicking of organisms tends to be of a specific feature, rather than a whole system, the potential also remains that biomimicry becomes technology that is added onto buildings rather than being integral to them, particularly if designers have little biological knowledge and no not collaborate with biologists or ecologists during the early design stages. While this method may result in new and innovative building technologies or materials, methods to increase sustainability are not necessarily explored.

Behaviour Level

A great number of organisms encounter the same environmental conditions that humans do and need to solve similar issues that humans face. As discussed, these organisms tend to operate within environmental carrying capacity of a specific place 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).

Organisms that are able to directly or indirectly control the flow of resources to other species and who may cause changes in biotic or abiotic (non living) materials or systems and therefore habitats are called e*cosystem engineers* (Jones and Lawton, 1995, Rosemond and Anderson, 2003). Ecosystem engineers alter habitat either through their own structure (such as coral) or by mechanical or other means (such as beavers and woodpeckers). Humans are undoubtedly effective ecosystem engineers, but may gain valuable insights by looking at how other species are able to change their environments while creating more capacity for life in that system. Several authors provide examples and details of organisms altering their own habitats while facilitating the presence of other species, increasing nutrient cycling and creating mutually beneficial relationships between species. The building behaviour of other species is often termed *'animal architecture'* (von Frisch and von Frisch, 1974, Hansell, 2005) and may provide further examples of such ecosystem engineers.

The example of the North American beaver *(castor canadensis)* (fig. 5) demonstrates how through its altering of the landscape, wetlands are created and nutrient retention and plant and animal diversity is increased, helping in part to make the ecosystem more resilient to disturbance (Rosemond and Anderson, 2003).

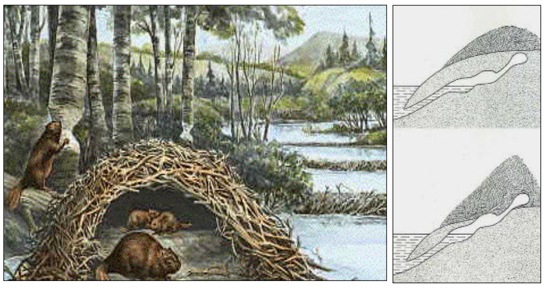

Figure 5: The North American Beaver

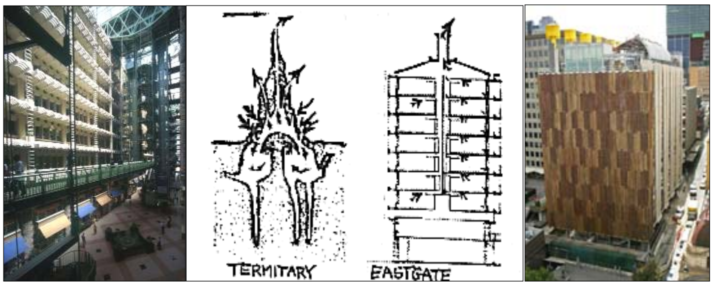

Figure 6: Eastgate Building in Harare, Zimbabwe and CH2 Building in Melbourne, Australia

In behaviour level biomimicry, it is not the organism itself that is mimicked, but its behaviour. It may be possible to mimic the relationships between organisms or species in a similar way. An architectural example of process and function biomimicry at the behaviour level is demonstrated by Mick Pearce's Eastgate Building in Harare, Zimbabwe and the CH2 Building in Melbourne, Australia (fig. 6). Both buildings are based in part on techniques of passive ventilation and temperature regulation observed in termite mounds, in order to create a thermally stable interior environment. Water which is mined (and cleaned) from the sewers beneath the CH2 Building is used in a similar manner to how certain termite species will use the proximity of aquifer water as an evaporative cooling mechanism.

Behaviour level mimicry requires ethical decisions to be made about the suitability of what is being mimicked for the human context. Not all organisms exhibit behaviours that are suitable for humans to mimic and the danger exists that models of consumption or exploitation could be justified on the basis of how another species behaves. For example, mimicking the building behaviour (and outcome of that) of termites might be appropriate for the creation of passively regulated thermally comfortable buildings. Mimicking the social structure of termite colonies would not be suitable however if universal human rights are valued. It may be more appropriate to mimic specific building and survival behaviours that will increase the sustainability and regenerative capacity of human built environments rather than mimicking that could be applied to social or economic spheres without careful consideration. It may be more appropriate to mimic whole systems rather than single organisms in this regard. An example is Benyus' (1997) assertion that we should *'do business like a redwood forest'*.

Ecosystem Level

The mimicking of ecosystems is an integral part of biomimicry as described by Benyus (1997) and Vincent (2007). The term ecomimicry has also been used to describe the mimicking of ecosystems in design (Lourenci et al., 2004, Russell, 2004), while Marshall (2007) uses the term to mean a sustainable form of biomimicry where the objective is the wellbeing of ecosystems and people, rather than *'power, prestige or profit'*. 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, 2006).

While the author is not aware of any architectural examples that demonstrate comprehensive ecosystem based biomimicry at either the process or function level, there are proposed projects that display aspects of such an approach. An example is the Lloyd Crossing Project proposed for Portland, Oregon by a design team including Mithūn Architects and GreenWorks Landscape Architecture Consultants. The project uses estimations of how the ecosystem that existed on the site before development functioned, termed by them *Pre–development Metrics*™ to set goals for the ecological performance of the project over a long time period (fig. 7).

An advantage of designing at this level of biomimicry is that it can be used in conjunction with other levels of biomimicry (organism and behaviour). It is also possible to incorporate existing established sustainable building methods that are not specifically biomimetic such as interfaced or bio-assisted systems, where human and non-human systems are merged to the mutual benefit of both. An example is John and Nancy Todd's Living or Eco Machines where the process of waste water treatment in ecosystems is mimicked and also integrated with plants (Todd, 2004, Todd and Josephson, 1996). The Australian developed Biolytix® system mimics soil based decomposition to treat grey and black water and again integrates actual worms and soil microbes into the process (Allen, 2005, Baumeister, 2007a).

A further advantage of an ecosystem based biomimetic design approach is that it is applicable to a range of temporal and spatial scales (Reap et al., 2005) and can serve as an initial benchmark or goal for what constitutes truly sustainable or even regenerative design for a specific place as demonstrated by the Lloyd Crossing Project (fig. 7).

Figure 7. Lloyd Crossing Project, Portland, USA


Figure 8. Dog Building, Tirau, New Zealand

The most important advantage of such an approach to biomimetic design however may be the potential positive effects on overall environmental performance. Ecosystem based biomimicry can operate at both a metaphoric level and at a practical functional level. At a metaphoric level, general ecosystem principles (based on how most ecosystems work) are able to be applied by designers with little specific ecological knowledge. Several authors have offered such general principles (Benyus, 1997, McDonough and Braungart, 2002, de Groot et al., 2002). A set of ecosystem principles derived from comparing these cross disciplinary understandings of how ecosystems function is detailed by Pedersen Zari and Storey (2007). If the built environment was designed to be a system and was expected to behave like an ecosystem even if only at the level of metaphor, the environmental performance of the built environment may increase (Korhonen, 2001).

On a functional level, ecosystem mimicry could mean that an in-depth understanding of ecology drives the design of a built environment that is able to participate in the major biogeochemical material cycles of the planet (hydrological, carbon, nitrogen etc) in a reinforcing rather than damaging way (Charest, 2007). That a greater understanding of ecology and systems design is required on the part of the design team is implicit. Also required would be increased collaboration between disciplines that traditionally seldom work together such as architecture, biology and ecology. Such an approach challenges conventional architectural design thinking, particularly the typical boundaries of a building site and time scales a design may operate in.

While Kibert (2006) cites a number of authors advocating similar ideas, he criticises this kind of approach to design, because of the difficulty in understanding and modelling ecosystems and asserts that *'…the mimicking of nature in human designs is one dimensional* [and] *non-complex…'* This is true in terms of realised built form, but does not suggest that mimicking what is known about ecosystems is not a worthy goal in terms of increasing sustainability or indeed that it is impossible, particularly when one takes into account that biological knowledge may be doubling every 5 years (Benyus, 1997).

BIOMIMICRY TO INCREASE SUSTAINABILITY

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).

As discussed, most examples of biomimicry are organism biomimetic. While biomimicry at the organism level may be inspirational for its potential to produce novel architectural designs (Aldersey-Williams, 2003, Feuerstein, 2002), the possibility exists that a building as part of a larger system, that is able to mimic natural processes and can function like an ecosystem in its creation, use and eventual end of life, has the potential to contribute to a built environment that goes beyond sustainability and starts to become regenerative (Van der Ryn, 2005; Reed, 2006). This does not prevent organism biomimicry at a detail or material level.

The examples provided in table 1 demonstrate the deepening of the levels of biomimicry in terms of regenerative potential from form biomimicry at the organism level to functional biomimicry at the ecosystem level. A building that is exhibiting form biomimicry, which is stylistically or aesthetically based on an organism, but is made and functions in an otherwise conventional way, is unlikely to be more sustainable than a non-biomimetic building.

An example is New Zealand town Tirau's iconic dog building (form biomimicry at the organism level) (fig. 8). A building that is able to mimic natural processes and can function like an ecosystem in its creation, use and eventual end of life has greater potential to be part of a regenerative built environment. Both buildings could be termed biomimetic, but the potential for increased sustainability would obviously be quite different. It is suggested that if biomimicry is to be conceived as a way to increase sustainability of an architectural project, mimicking of general ecosystem principles should be incorporated into the design at the earliest stage and used as an evaluative tool throughout the design process as described by the Biomimicry Guild (2007), Pedersen Zari and Storey (2007) and Hastrich (2006).

CONCLUSION

The built environment is increasing held accountable for global environmental and social problems with vast proportions of waste, material and energy use and green house gas emissions attributed to the habitats humans have created for themselves (Mazria, 2003, Doughty and Hammond, 2004). It is becoming increasingly clear that a shift must be made in how the built environment is created and maintained. Mimicking life, including the complex interactions between living organisms that make up ecosystems is both a readily available example for humans to learn from and an exciting prospect for future human habitats that may be able to be entwined with the habitats of other species in a mutually beneficial way.

By using a framework as suggested by this paper it is anticipated that distinctions between the different kinds of biomimicry and their regenerative potential can be more easily made. Although this discourse tends to be theoretical at present with many ideas related to ecosystem based biomimicry and architectural biomimicry in general yet to be tested in built form, design that mimics how most ecosystems are able to function in a sustainable and even regenerative way, has the potential to positively transform the environmental performance of the built environment. This may be enhanced if a systems based biomimicry that mimics how mature ecosystems function, is included in initial design parameters and is used as an evaluation benchmark throughout the design process.

REFERENCES

Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C. & Zumbrunnen, C. (2003) Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. *Bioscience,* 53**,** 1169-1179.

Aldersey-Williams, H. (2003) *Zoomorphic - New Animal Architecture,* London, Laurence King Publishing.

Allen, J. (2005) Global Winner, Biolytix is Taking on Effluent Society. *ECOS,* 5**,** 127.

Baumeister, D. (2007a) *Biomimicry Presentation at the University of Washington College of Architecture*. Seattle, USA. 8 May.

Baumeister, D. (2007b) Evolution of the Life's Principles Butterfly Diagram, *personal communication*, April.

Benyus, J. (1997) *Biomimicry - Innovation Inspired by Nature,* New York, Harper Collins Publishers.

Berkebile, B. (2007) Master Speaker Address. *Living Future Conference.* Seattle, WA.

Berkebile, B. & McLennan, J. (2004) The Living Building. Biomimicry in Architecture, Integrating Technology with Nature. *BioInspire 18.*

Biomimicry Guild (2007) *Innovation Inspired by Nature Work Book*, Biomimicry Guild, April.

Charest, S. (2007) Ecosystem Principle Research, *personal communication*, May.

Cole, R., Reed, W. & Du Plessis, C. (2007) Friday Theme Session Panel. *AIA 2007 National Convention and Expo.* San Antonio, Texas.

De Groot, R., Wilson, M. A. & Boumans, R. M. J. (2002) A Typology for the Classification, Description and Valuation of Ecosystem Function, Goods and Services. *Ecological Economics,* 41**,** 393-408.

Doughty, M. & Hammond, G. (2004) Sustainability and the Built Environment at and Beyond the City Scale. *Building and Environment,* 39**,** 1223-1233.

Faludi, J. (2005) Biomimicry for Green Design (A How To). *World Changing*.

Feuerstein, G. (2002) *Biomorphic Architecture - Human and Animal Forms in Architecture,* Stuttgart, Edition Axel Menges.

Garrod, R. P., Harris, L. G., Schofield, W. C. E., McGettrick, J., Ward, L. J., Teare, D. O. H. & Badyal, J. P. S. (2007) Mimicking a Stenocara Beetle's Back for Microcondensation Using Plasmachemical Patterned Superhydrophobic-Superhydrophilic Surfaces. *Langmuir,* 23**,** 689-693.

Graham, P. (2003) *Building Ecology - First Principles for a Sustainable Built Environment,* Oxford, Blackwell Publishing.

Hastrich, C. (2006) The Biomimicry Design Spiral, *Biomimicry Newsletter*, 4.1, 5-6.

Hansell, M. (2005) *Animal Architecture,* New York, Oxford University Press.

Hawken, P. (2007) *Blessed Unrest,* New York, Viking Press.

Jones, C. G. & LAWTON, J. H. (1995) *Linking Species and Ecosystems,* New York, Chapman and Hall.

Kibert, C. J. (2006) Revisiting and Reorienting Ecological Design. *Construction Ecology Symposium.* Massachusetts Institute of Technology, Cambridge, MA.

Kibert, C. J., Sendzimir, J. & Guy, G. B. (2002) *Construction Ecology,* New York, Spon Press.

Killeen, M. (2002) Water Web. *Metropolis Magazine,* May.

Knight, W. (2001) Beetle fog-catcher inspires engineers. *New Scientist,* 13**,** 38.

Korhonen, J. (2001) Four Ecosystem Principles for an Industrial Ecosystem. *Journal of Cleaner Production,* 9**,** 253-259.

Lourenci, A., Zuffo, J. A. & Gualberto, L. (2004) Incipient Emergy Expresses the Self-Organisation Generative Activity of Man-Made Ecomimetic Systems. In Ortega, E. & Ulgiati, S. (Eds.) *IV Biennial International Workshop. Advances in Energy Studies.* Campinas, Brazil.

Marshall, A. (2007) *The Ecomimicry Project*. Accessed May 2007, http://www.geocities.com/ecomimicryproject/

Mazria, E. (2003) It's the Architecture, Stupid! *Solar Today,* May / June.

McDonough, W. & Braungart, M. (1998) The NEXT Industrial Revolution. *The Altantic,* October.

McDonough, W. & Braungart, M. (2002) *Cradle to Cradle - Remaking the Way We Make Things,* New York, North Point Press.

Parker, A. R. & Lawrence, C. R. (2001) Water capture by a desert beetle. *Nature,* 414**,** 33.

Pedersen Zari, M. (2007) Biomimetic Approaches to Architecture (poster). *Toronto Sustainable Building Conference 07.* Toronto, Canada.

Pedersen Zari, M. & Storey, J. B. (2007) An Ecosystem Based Biomimetic Theory for a Regenerative Built Environment. *Lisbon Sustainable Building Conference 07.* Lisbon, Portugal.

Ravilious, K. (2007) Borrowing from Nature's Best Ideas. *The Guardian*, July 31.

Reap, J., Baumeister, D. & Bras, B. (2005) Holism, Biomimicry and Sustainable Engineering. *ASME International Mechanical Engineering Conference and Exposition.* Orlando, FL, USA.

Reed, B. (2006) Shifting our Mental Model - "Sustainability" to Regeneration. *Rethinking Sustainable Construction 2006: Next Generation Green Buildings.* Sarasota, Florida.

Rosemond, A. D. & Anderson, C. B. (2003) Engineering Role Models: Do Non-Human Species have the Answers? *Ecological Engineering,* 20**,** 379-387.

Russell, J. A. (2004) Evaluating the Sustainability of an Ecomimetic Energy System: An Energy Flow Assessment of South Carolina. *Department of Mechanical Engineering.* University of South Carolina.

Todd, J. (2004) Restorer Eco-Machines for the Culture of Aquatic Animals and the Restoration of Polluted Aquatic Environments. *BioInspire 19.*

Todd, J. & Josephson, B. (1996) The Design of Living Technologies for Waste Treatment. *Ecological Engineering,* 6**,** 109 - 136.

Van der Ryn, S. (2005) *Design for Life - the Architecture of Sim Van der Ryn,* Salt Lake City, Gibbs Smith.

Vincent, J. (2007) Re: Designing around existing patents through TRIZ, *personal email communication*, 5 May

Vincent, J. F. V., Bogatyrev, O., Pahl, A.-K., Bogatyrev, N. R. & Bowyer, A. (2005) Putting Biology into TRIZ: A Database of Biological Effects. *Creativity and Innovation Management,* 14**,** 66-72.

Vincent, J. F. V., Bogatyrev, O. A., Bogatyrev, N. R., Bowyer, A. & Pahl, A.-K. (2006) Biomimetics - its practice and theory. *Journal of the Royal Society Interface*, April 2006,

Vogel, S. (1998) *Cat's Paws and Catapults,* New York, Norton and Company.

von Frisch, K. & von Frisch, O. (1974) *Animal Architecture,* New York, Helen and Kurt Wolff Books.