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Biomimicry of Termite Social Cohesion and Design to Inspire and Create Sustainable Systems

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1. Introduction

Biomimicry (from bios, meaning life, and mimesis, meaning to imitate) is a new discipline that studies nature's best ideas and then imitates these designs and processes to solve human problems. The core idea of biomimicry as enunciated by the Biomimicry Institute (Anon 2008) is that nature, imaginative by necessity, has already solved many of the problems we are grappling with. Margulis (1998) considers that the major kinds of life on Earth are bacteria, protocists, fungi, animals and plants. All have become the consummate survivors. They have found what works, what is appropriate, and most important, what lasts here on Earth. This is the real news of biomimicry: After 4 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival. Termites have been experimenting for over 300 million years on our symbiotic planet and their current abundance and distribution attests to their co-evolutionary success.

If we want to consciously emulate nature's genius, we need to look at nature differently. In biomimicry, we look at nature as model, measure, and mentor (Anon 2008; & 2011). Nature as model: Biomimicry is a new science that studies nature's models and then emulates these forms, process, systems, and strategies to solve human problems – sustainably. Nature as measure: Biomimicry uses an ecological standard to judge the sustainability of our innovations. After nearly 4 billion years of evolution, nature has learned what works and what lasts. Nature as mentor: Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but what we can learn from it.

Capra (1997) takes the view that we need to become ecologically literate. Being 'ecoliterate' means understanding the principles of organisation of ecological communities (i.e., ecosystems) and using those principles for creating sustainable human communities. We need to revitalise our communities – including our educational communities, business communities, and political communities – so the principles of ecology become manifest in them as principles of education, management, and politics.

This theme is also expressed by Capra (2002) who has broadened his understanding of 'growth mania' to include the problem of world terrorism, and how we might address it by moving towards a sustainable value-system of eco-design. There is no simple defence against terrorism, as we live in a complex, globally interconnected world in which linear chains of cause and effect do not exist. Capra (2003) considers that to understand this world we need to think systemically – in terms of relationships, connections and context. He feels that we might address this by moving towards a sustainable value system of eco-design.

Thinking systemically means realising that energy, agriculture, economics, security, and climate change are not separate issues but different facets of one global system. It leads us to understand that the root causes of our vulnerability are both social and technological, and that they are the consequences of our resource-extractive, wasteful and consumption-oriented economic system.

1.1 Co-evolution of termite communities

Termite communities have co-evolved for millions of years into 'super-organisms'. The word superorganism was coined in the 19th century by Herbert Spencer to apply to social organizations. Strictly speaking a superorganism is an organism that is composed of other organisms. A superorganism is any aggregate of individual organisms that behaves like a unified organism. Members of a superorganism have highly specialized social cooperative instincts, divisions of labor, and are unable to survive away from their superorganism for very long. The standard example of a superorganism is an ant colony, but there are many others -- termite mounds, bee hives, wasp nests, coral reefs, bacterial and fungal colonies, groves of genetically identical trees, etc. In the human context that would mean social organizations, but the concept has a broader application. Two organisms that exist in a symbiotic arrangement and perhaps could not survive without the partner would be a superorganism.

More recently, at an international conference at Arizona State University, USA, (18-20 February 2010), entitled 'Social biomimicry: Insect societies and human design', explored how the collective behaviour and nest architecture of social insects can inspire innovative and effective solutions to human design challenges (Figure 1).



Fig. 1. *Coptotermes* termite constructing a bridge to reach food source in a laboratory set-up test Jars.

It brought together biologists, designers, engineers, computer scientists, architects and business people, with the dual aims of enriching biology and advancing biomimetic design (Holbrook et al., 2010).

We know that termites are masters of constructing 'buildings' that meet all the needs of their colony members. From their ability to regulate their gaseous environment (French et al., 1997), temperature and moisture in their buildings (=nest colonies) all year round (French & Ahmed 2010), store adequate nutritional resources within the walls of their buildings for their energy usage, but also to control waste disposal needs, shelter, and food sources for many other animals and insects. We need to emulate the symbiotic abilities of termites to survive over time, for as Margulis (1998) pointed out, "we all live on this symbiotic planet, and symbiosis is natural and common".

1.2 Termite modification of soil water availability

Termites improve soil biochemical and physical characteristics, in a symbiotic relationship with soil micro-organisms. Both play a pivotal role in rehabilitating degraded ecosystems and widening soil and plant microbial diversity. The role of invertebrate macropores, particularly termites are essential and dynamic in enhancing soil water infiltration (Colloff et al., 2010). The major environmental themes of Australian and other deserts are soil infertility and highly variable rainfall. Yet, termites are abundant in Australia's desert ecosystems, due to abundant carbohydrate, fire-proneness, abundance of invertebrate consumers of sap and other C-rich plant products, and striking aquatic systems (Morton et al., 2010).

The role of termites and their symbiotic microbes in organic matter decomposition and water conservation is well recognized. However, few studies have examined using the behavioural and ecological approach of termites in relation to water and soil conservation in order to manage soil and water. Sustainable water and soil management is a key to every society's survival and development. Degraded soil structure and surface sealing of soils impede water infiltration and plant root growth, limiting the usefulness of local lands for crop and animal production. It is likely that we can learn much from termites in addressing these issues.

Termite modifications have a great impact, in terms of time and space, on the vegetation even after their structures have been abandoned or eroded or their colonies have been disturbed or died (Dangerfield et al. 1998) or flooded (Osbrink et al., 2008). The capacity of some termite species to survive under high levels of disturbance may have positive implications for initiating the recovery of soil function and productivity (Dawes, 2010; Colloff et al., 2010). The ease with which a termite colony and activity can be activated with the use of locally available organic matter or mulch in a relatively short period of time (Mando et al., 1999; Stroosnijder, 1984) makes them one of the primary candidates for the fight against global warming and desertification.

Termites use their saliva and other body wastes to cement soil particles together when constructing their mounds with preferably finer soil particle sizes. When compared to the mounds, however, the construction of feeding galleries and burrowing galleries improves the soil porosity and water transmission characteristics in which the macropores would otherwise be significantly reduced or eliminated during the packing and remoulding process in the mounds. The network of short dead-end tunnels found in the irregular sponge-like outer walls of *Coptotermes lacteus* mounds that serve to 'trap' excessive moisture

from within the mound, and so avoid moisture dripping down into the core of the mound. Furthermore, we hypothesize that this mound architecture allows rapid access to moisture for the colony members in times of prolonged drought and in order to carry out repairs and extensions to the mound. But, equally important, we suggest that this water source sustains their symbiotic micro-organisms (particularly actinobacteria, Kurtboke & French 2007, 2008) within the mound materials and within themselves (French & Ahmed 2010).

The resulting high bulk density associated with the mound's massive structure and low total porosity, even in abandoned ones, inhibits plant growth due to its poor physical condition, higher compaction and impermeability (Rogers et al., 1993). In contrast the feeding galleries and burrowing channels formed, the resulting soil structure and structural stability, porosity coupled with changes in the decomposition processes and chemical fertility improve the amount and rate of water infiltration into the soil and its storage for plant use (Stroosnijde and Hoogmoedr, 1984).

Termites create numerous voids on the sealed surface of the soil by their extensive subterranean excavation and construction of feeding galleries and channels as well as foraging holes, thereby significantly increasing infiltration by a average factor of two to three (Mando et al., 1999) or even as much as tenfold (Leonard & Rajot 2001). Not only would these macropores help increase the infiltration rate depending on their stability and connectivity to the surface and to each other, but also help in intercepting the runoff water with the help of some roughness created on the surface (Whitford & Elkins, 1986). In fact the ability of the macropores to intercept the running water is one of the critical factors in the infiltration process (Leonard & Rajot 2001). In other words termite activity increases the time until ponding or surface storage is formed and therefore delays the formation of runoff. Their interconnectivity also helps in the continuity of infiltration even after the soil has become saturated and thus increases water availability (Mando et al., 1999).

Termites transport finer particles to the soil surface enriching the nest surroundings with fine particles as well as constructing the mound (Konate et al., 1999). The relative compactness and higher clay content of the termite mound increases its water holding capacity by decreasing its porosity, or increasing the proportion of macropores. The same structure, therefore, discharges as runoff most of the rainwater to the surrounding soil (Whitford & Elkins, 1986). It is also responsible for the shrinking/swelling capacity of the mounds that in dry areas help increase the infiltration of water into the mound and its deep percolation (Konate et al., 1999). Infiltrated water is readily available to plants when it is stored in the macropores. As the water stored in the soil is related to the amount of water input by infiltration, termite modified soil structure ultimately increased soil water stored (Mando et al., 1999). Medina (1996) reported that termite modification resulted in an increase in soil water content of up to 50mm (from an average 150mm in non termite plots to 200mm in plots without termites in the top soil) in the driest year during an experiment to improve the soil water balance in crusted Sahelian soils.

Response of natural vegetation or crops to the improved water availability due to termite effects is a relevant field to explore when considering the effectiveness of soil and water management techniques (Medina, 1996). The analysis of termite activities with respect to their role in the restoration of degraded ecosystems or mitigating effects of climate change, global warming and desertification becomes imperative if we are to maximise the ecological benefit we get from them or at least adopt some of the complex mechanisms they use in

their efficient micro-systems, and that maintain sustainability in impoverished environments, such as deserts and semi-arid regions (Waugham et al., 1981).

1.3 Termite thermoregulation and moisture control in their mounds

In the most comprehensive Australian studies in recent times of how termites regulate temperature, water, and gaseous emissions (Ewart & French, 1986; Bristow & Holt, 1986; Ewart, 1988; Khalil et al., 1990; French et al., 1997) the following conclusions were made. Regardless of site, either clear or shaded, *Coptotermes lacteus* maintained the core temperatures in the nursery area much higher than that of the soil and well above that of the enveloping air (French et al., 1997). Termites maintained this difference within fine limits on a daily scale, while the seasonal change was more marked. Spring and summer are the most active periods for the termite colony, as reflected in the high methane and carbon dioxide emission measurements.

We have described the network of short dead-end tunnels found in the irregular sponge-like outer walls of *C. lacteus* mounds that serve to 'trap' excessive moisture from within the mound, and so avoid moisture dripping down into the core of the mound. Furthermore, we hypothesize that this mound architecture allows rapid access to moisture for the colony members in times of prolonged drought and in order to carry out repairs and extensions to the mound. But, equally important, we suggest that this water source sustains their symbiotic micro-organisms (particularly actinobacteria) within the mound materials and within themselves (French & Ahmed 2010).



Fig. 2. *Coptotermes acinaciformis* mound displaying outer structure (7cm thick of 50% soil and 50% organic matter) with internal structure of ventilation space 1.5 cm and moist nest material with live termites.

Heat conduction out from the mound area during periods of high air temperatures is another aspect of 'moisture control' within the mound (Ewart & French, 1986). As moist soil and wood conduct heat better than does dry soil or wood, there is an advantage in having a moist outer wall to assist in heat transfer. It seems that the concentric thin-walled structure of the nursery is a region of low thermal conductivity, in which major changes of temperature takes place relatively slowly. Holdaway & Gay (1948) observed that there was little evidence that the termites are capable of lowering temperature when environmental temperatures are high, other than by departure from the mound. It may be that termites can effect internal temperatures by transporting water to the dead-end galleries just below the hard outer wall material and above the nursery. Bristow & Holt (1986) studied the harvester termite, *Tumulitermes pastinator*, and have suggested that termites create energy sinks when regulating mound temperatures. They may achieve this by introducing water to the nursery environment, thereby increasing heat capacity of this part of the mound and dissipating energy through vapourisation. However, they did not mention the presence of any dead-end galleries that we have hypothesized as active (Figure 2).

Termites, together with their microbial symbionts, have a highly significant impact on biodegradation and biorecycling as well as shaping soil functions and properties in the tropics and subtropics (Bignell, 2006). The precise role of actinobacteria and other microbes in the life-cycle of a termite colony is still an area of research that is wide open for study (Kurtboke & French 2007).



Fig. 3. *Amitermes meridionalis* (grass feeding) cathedral mound in Northern territory, Australia

However, we know that such symbiogenesis is a hallmark of the termite-actinobacteria interrelationship, an aspect of termite ecology that has not been exposed to intensive ecosystem level experimentation (French, 1988). The presence of dead-end galleries may be

a site for 'culturing' actinomycetes that have properties ranging from thermophilic abilities to providing cellulases and lignases, and other enzymes necessary in a termite's physiological life. To our knowledge, there are no studies on the role of actinomycetes within termite nests over the various seasons. The fact that the temperatures in the nest drop during winter may have bearing on the functioning of the actinomycetes at such lower temperatures, which would ensure that their symbionts partners, the termites, have optimal conditions to sustain the nest colonies (Figure 3).

1.4 Building with termites

While there have been examples of biomimetic design for climate control in buildings such as Eastgate Centre, Zimbabwe, built in 1996, and London's Portcullis House, built in 2001, and CH2 in Melbourne, built in 2006. These buildings operate on passive cooling systems that are a viable alternative to artificial air-conditioning. Passive cooling works by storing heat in the day and venting it at night as temperatures drop. It is estimated that such buildings use only 10% of the energy needed by a similar conventionally cooled building (Doan, 2007).

The future toward 'building with termites' thus holds immense challenges, intellectual and practical, for architects, builders, the wood protection industry as a whole, and building regulators. For instance, will the gaseous environment of a "living building" affect structural components? Also, the notion of water-trapping may indeed 'attract' termite foragers to buildings, thus taking 'termite management systems' into a new era. Appropriate laboratory bioassays and ecosystem level experimentation in the field will be required to evaluate termite-susceptible components of such "living buildings" (French 1988). The Australian Standards for buildings would have to be amended and updated to ensure compliance by designers, architects, builders, and the building authorities. The Building Code of Australia (BCA) would need to incorporate these standards into "deemed-to-satisfy" clauses within the Standards.

Multi-component biocide systems have been developed that protect wood in buildings from mould fungi, decay fungi, borers and termites for interior application, either as remedial or preventative treatments (Clausen and Yang 2004, 2007; Turner 2008). Basically, these systems comprise a glycol borate base, with the synthetic pyrethroids deltamethrin and permethrin, and a fungicide, propiconazole. These systems protect timber-in-service for the life of the building (Lloyd et al., 1999; Smith & Lloyd 2004).

1.5 Towards designing eco-friendly buildings with in-built termite protection

An American scientist, James Hansen of the National Aeronautics and Space Administration, put climate change squarely on the agenda of policymakers on 23 June 1988. Hansen told a United States of America (USA) Senate Committee " he was 99 percent certain that the years record temperatures were not the result of natural variation". Hansen concluded that the rising heat was due to the growing concentration of carbon dioxide (CO₂), methane (CH₄) and other atmospheric pollutants. Global emissions of carbon dioxide from fossil fuel combustion and cement production rose from 22.6 billion tons in 1990 to an estimated 31.2 billion tons in 2007 – a staggering 37 percent increase. This is 85 million tons of carbon dioxide spilled into the atmosphere each day – or 13 kg on average per person (Flavin & Engelman 2009; Engelman 2009).

Between 1990 and 2008 USA emissions of carbon dioxide from fossil fuel combustion grew by 27 percent – but emissions from China rose 150 percent, from 2.3 billion to 5.9 billion tons. In 2006 China passed the USA in emissions (Lewis, 2008).

Accelerating emissions are not the only factor driving increased concern. Tropical deforestation – estimated at 13 million hectares annually is adding 6.5 billion tons of carbon dioxide to the atmosphere each year. But more alarmingly, the Earth's natural sinks (oceans and biological systems) appear to be losing their ability to absorb a sizeable fraction of these increases. As a result, the increase in atmospheric carbon dioxide concentrations has accelerated to the fastest rate ever recorded (Anon 2007).

The guiding principles of international efforts to deal with climate change were established in 1992 in the United Nations Framework Convention on Climate Change, which was adopted in Rio Janeiro at the Earth Summit: “The ultimate objective of this Convention and any related legal instruments is to achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner” (Hare, 2009).

So how are our wood protection and allied chemical and building industries dealing with the major challenge of global warming, namely the stabilization of greenhouse gas emissions? Are we designing buildings and the wood protection systems to combat termites and wood decay fungi that will minimise our carbon footprint? If the answer to both of these questions was in the affirmative, we could be forgiven to think that our industries are meeting the climate-change challenge! However, the reality is that the wood protection systems in current use are not designed to limit or reduce greenhouse gas emissions. We are still relying heavily on chemical solutions that can only be viewed as environmental pollutants, such as chromium and arsenic.

In researching building products that can meet the challenge facing our industries, reduce carbon emissions, and have termite resistant properties, we focussed on the carbon-neutral, bio-composite, Hemcrete® (French et al., 2010). This paper explores the utilisation of this product that we suggest would be economically attractive, meet the challenges of eco-friendly building products, and at the same time offer in-built termite protection. Hemcrete® is a blend of lime based binder (Tradical® HB) and specially prepared hemp (ca. 10-15 mm in length) (Tradical®HF) which has virtually no narcotic content (Roaf, et al., 2007). Together these form a sustainable bio-composite construction material that combats climate change by capturing carbon and delivering high performance airtight, insulating walls. The lime hemp walls can be solid with no need for a cavity and consequently the constructed details are simple and robust (MacDougall, 2008). History shows us that buildings like these are comfortable to live in (warm in winter and cool in summer) and can last for centuries. In addition using hemp in this way will help reduce the demand for aggregates and offer new economic opportunities to farmers (Roaf, et al., 2007). To date most of the hemp buildings that have been built are non-load bearing, with a separate timber frame. However, research is ongoing to develop lime composites that can be used in a load-bearing capacity (Roaf et al., 2007).

Preliminary field tests of Hemcrete® against the most economically important wood-feeding species, *Coptotermes*, in semi-tropical and tropical Australia indicated that there was no feeding or penetration of the substrate after two weeks continuous contact within and on

termite mound colonies. Our experience (JRJF & BA) with evaluating Granitgard, a graded particle barrier of granite screenings (1.7 to 2.4mm diameter), and other physical barriers in laboratory bioassays since 1987, show that if *Coptotermes* termite species do not tunnel/penetrate/breach a physical barrier within the first 24-48hrs, they never succeeded after 2-4 weeks exposure in all bioassay studies (French et al. 2003). This pattern of behaviour has been consistent in all our laboratory and field bioassays (French et al., 2010).

It is considered that the high insulation of Hemcrete® in-fill means that single wall structure provides sufficient insulation and does not require additional insulation and avoids the need for cavity wall construction. This makes construction speed and simplicity a most attractive feature of Hemcrete® construction compared with our current brick veneer and wall cavity constructions.

Our experience in Australia clearly indicates that the most likely path for termite entry into the brick work is either through perpend (vertical joint) or at the base of the wall. The base is most likely as often the footing and is commonly covered with some soil in places onto which the base course of mortar is spread. For a base entry it does not matter if there are graded particle barrier material between the brickwork and the strip shield as, if they come up between the vertical leg of the shielding and the brickwork on reaching the horizontal leg they will be forced to the external face of the brickwork which is within the inspection zone required by AS 3660.1 - 2000. Also for the perpend it is not really critical, as often these are not filled and there is an open void within the perpend and entry through a perpend will also result in them being forced, either up the horizontal surface of the strip shielding or down into the graded material. If they are foraging in between the horizontal part of the strip and the brick, they most likely would have a mud tube up the outside of the brickwork in the inspection zone. It is the maintaining of the 75mm inspection zone that is the main concern (French et al., 2009).

1.6 Future termite control and co-existence requires partnerships between industry, government and people.

On June 1995 in Australia, when the use of organochlorines in termite control were banned, the pest control industry, together with the housing and timber industries, and performance of the State regulatory agencies were philosophically ill-prepared to consider alternative termite control measures (French & Ahmed 2006). However, conditions have drastically altered and there is an awareness of such alternatives as bait and dust toxicants, and reticulation systems such as the Plasmite Termite Reticulation System using bifenthrin within cavity walls. But, termite barriers need to be termed more accurately, as termite monitoring systems, as they do not protect timber-in-service within buildings, merely intercept and detect termites. Thus, we still require thorough annual termite inspections of buildings, with chemical termiticides needed to eradicate termite activity when found during inspections. So, physical termite barrier methods will need to be coupled with chemical eradication systems.

In the future, we will experience a move from mono-component biocide systems to multi-component biocide systems (Clausen & Yang 2004, 2007; Lloyd et al., 1999). This will require innovative, flexible and performance based testing to evaluate candidate termiticides and biocide systems. Another feature of termite control in Australia is the paucity of scientific data to assess termite distribution and to determine the hazard faced by buildings in Australia to wood-feeding termites. But the distribution of house type across Australia is not uniform, so the influence of house age, construction type, and termite protection method

also needed to be determined. To obtain a random sample of houses, not those reported to pest control operators as having termite infestations, a Termite Tally was instigated by Dr John French through Commonwealth Scientific and Industrial Research Organisation's (CSIRO's) Double Helix science club, with the data collected by the school children members of the club. There was some initial concern about the reliability and randomness of this survey method, however a verification study revealed a high level of accuracy in the data instigated hazard ratings (Cookson & Ahmed 1998). The termite tally survey provided results for 5122 dwellings. The mean house age was 30 years, and the mean occupancy duration was 11 years. The dominant factor affecting termite incidence inside a house was house age. The occurrence of termites inside a house was not significantly affected by house construction type (timber, masonry, concrete, steel or their combinations). Termite eradication was most successful by soil or wood treatment. The study indicated that the most important factor determining termite distribution is temperature, followed secondly by rainfall. Vegetation and soil types appear to play a more minor role within the dominant effects of temperature and moisture (Cookson & Ahmed 1998; Cookson, 1999).

We recommend the further use of school children in garnishing scientific data on future termite surveys and hazard evaluations assisted by enthusiastic professional scientists. But again, this requires a total partnership approach, with industry, government and people engaging in an integrated pest management (IPM) approach to termite control based on sound ecological parameters and social priorities. These include adopting a mix of alternative strategies as mentioned above, plus planning to ensure continuous funding for termite Research & Development (R & D) and training and education programs to supply 'termite expertise' in the future.



Fig. 4. Subterranean termite feeding is not random and balances the feeding territory within a living tree structure only attacking the dead cells (xylem cells) while keeping the sapwood living cells intact. Termites follow the Compartmentalization of Decay in Trees (CODIT) model perfectly. Of course, given time, the termites, just as the decay-causing microorganisms will breakdown all matter. But, in the early stages, the termites, just as the decay fungi in products, follow the CODIT model. And again, the termites will follow wound-altered wood that was preset in the living tree (see Shigo, 1979).

Unfortunately, with the closure of CSIRO Forestry and Forest Products and reduction by State Governments into termite R&D, there are few government establishments offering impartial, professional research, training and education in termite control measures. Target research seems to be the order of the day, with scant emphasis on “blue-sky research”. Meanwhile, given these obvious limitations in having centres of termite research excellence, screening and evaluation methods of new generation termiticides have to be flexible, in the main stream of biological and chemical thinking, and considerate of ecological impact to humans and the environment. Assessors would be required to have a broader knowledge than just termiticide toxicity data and termite control methods (Figure 4).

1.7 Modelling termite behaviour and engineering to create sustainable human buildings

We believe that by understanding more about termite ecology and behaviour, and wearing “termite spectacles” as it were, we will gain better understanding in applying and adopting biomimetic systems that we will need in a sustainable future. This will also allow us to pass on the “message of biomimicry”, advise the community to adopt such a pathway, and develop policies inclusive of all ecosystems, human and otherwise. We need to educate and ensure that policies address problems that affect all levels of the community, develop sustainable partnerships with industry, government and people. This also means involving school children, awaking in them a sense of ‘stewardship’ with their whole environment, and contributing into similar projects as the CSIRO Double Helix Club Termite Tally as mentioned above.

Janine Benyus (1997) in her book on biomimicry suggests looking to Nature as a "Model, Measure, and Mentor" and emphasizes sustainability as an objective of biomimicry. Nature as model: Biomimicry is a new science that studies nature's models and then emulates these forms, process, systems, and strategies to solve human problems – sustainably. Nature as measure: Biomimicry uses an ecological standard to judge the sustainability of our innovations. After nearly 4 billion years of evolution, nature has learned what works and what lasts. Nature as mentor: Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but what we can learn from it.

We can plan and create communities in which citizens will enjoy sustainable, secure, equitable, socially just, exciting, curious, peaceful and satisfying lives, without diminishing the chances of future generations.

2. Conclusions

The core idea of biomimicry is that nature, innovative by necessity, has already solved many of the problems we are grappling with. Margulis (1998) considers that the major kinds of life on Earth are bacteria, protocists, fungi, animals and plants. All have become the consummate survivors. They have found what works, what is appropriate, and most important, what lasts here on Earth. This is the real news of biomimicry: After nearly 4 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival. Termites have been experimenting for over 300 million years on our symbiotic planet and their distribution and abundance attests to their evolutionary success.

We have discussed the richness and abundance of the termite fauna in Australia (Ewart and French 1986; Colloff *et al.*, 2010). Also, we have shown the beneficial aspects of 'living with termites' particularly their role in the restoration of ecosystem function to revegetation communities, enhancing soil water infiltration and as invertebrate primary consumers and abundant and widespread macropores.

Termites have inspired us to create sustainable human buildings modelled from their mound colonies, with examples at the Eastgate Centre, Zimbabwe (1996), London's Portcullis House (2001), and CH2 in Melbourne (2006). These buildings operate on passive cooling systems that store heat during the day and vent and release heat at night. It is estimated that such buildings use only 10% of the energy needed by a similar conventionally cooled building.

Janine Benyus (1997) suggests looking to Nature as a "Model, Measure, and Mentor" and emphasizes sustainability as an objective of biomimicry. We concur and promote the challenge of innovative sustainable human buildings modelled on 'termite engineering' with respect to carbon footprints, energy, and durability for life of the building. The mention of the Hemcrete®, the bio-composite, carbon neutral product that is termite resistant, was merely an illustrative example of the type of building that could mimic termite mounds with respect to insulation, thermoregulation, energy efficiency, moisture control and water storage, leading to the development of human buildings that enhance eco-friendly materials, and buildings of high comfort and durability.

An integral part of promoting such eco-friendly, carbon neutral buildings is addressing the issue of foraging termites attacking and damaging such buildings. We are proponents of protecting wood in service using multi-component biocide systems that comprise glycol borates, with synthetic pyrethroids (deltamethrin and permethrin) and a fungicide (propiconazole). This spray-on treatment diffuses deep into structural timbers protecting them from decay fungi, mould fungi, borers and termites for the life of the building.

While this paper has dealt with termite behaviour and engineering to inspire and create sustainable human buildings, our ultimate objective would be the message as enunciated by the Biomimicry Guild (Anon 2011), namely, that "our mission is to nurture and grow a global community of people who are learning from, emulating, and conserving life's genius to create a healthier, more sustainable planet".

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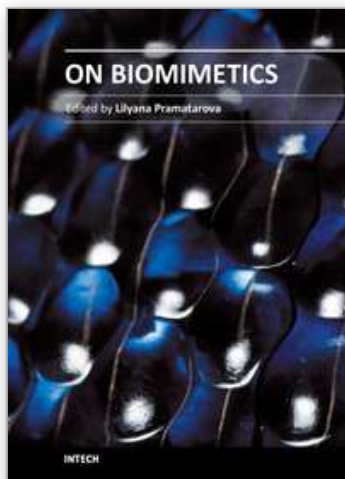
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Bio-mimicry is fundamental idea – How to mimic the Nature™ by various methodologies as well as new ideas or suggestions on the creation of novel materials and functions. This book comprises seven sections on various perspectives of bio-mimicry in our life; Section 1 gives an overview of modeling of biomimetic materials; Section 2 presents a processing and design of biomaterials; Section 3 presents various aspects of design and application of biomimetic polymers and composites are discussed; Section 4 presents a general characterization of biomaterials; Section 5 proposes new examples for biomimetic systems; Section 6 summarizes chapters, concerning cells behavior through mimicry; Section 7 presents various applications of biomimetic materials are presented. Aimed at physicists, chemists and biologists interested in biomineralization, biochemistry, kinetics, solution chemistry. This book is also relevant to engineers and doctors interested in research and construction of biomimetic systems.

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