BIOINSPIRED ARCHITECTURAL DESIGN TO ADAPT TO CLIMATE CHANGE

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Summary

International research suggests that the built environment may be responsible for at least a third of global green house gas (GHG) emissions and that measures should be implemented to mitigate these. It is also the built environment, as the principle habitat of humans that will need to adapt to climate change impacts to keep people comfortable and safe. Architects and designers may need to explore new ideas that are reflective of a shift in both climate and in expectations of the built environment. This paper explores the potential of biomimicry, where organisms or ecosystems are mimicked in human design. The question is posed: in what way is mimicking the living world useful in the design of buildings that are able to either mitigate green house gas emissions or adapt to climate change impacts?

This paper investigates two possible options for an architectural biomimetic response to climate change. The first is integrating biomimetic technologies able to mitigate green house gas emissions into buildings. The second approach is use biomimicry to adapt to the direct impacts of climate change on the built environment. Documented successes and potential benefits and difficulties inherent in such approaches are discussed.

As well as a reduced or potentially negative carbon footprint for the built environment, this paper analyses further significant benefits that such an approach may offer. It is posited that the incorporation of an understanding of the living world into architectural design could be a significant step towards the creation of a built environment that is more sustainable and one where the potential for positive integration with and restoration of natural carbon cycles is increased.

1. Introduction

As the impacts of climate change increase, policies and actions to mitigate green house gas emissions must expand rapidly. This will be particularly crucial in the built environment. Not only is the built environment responsible for at least a third, and potentially more of global green house gas (GHG) emissions, leading to climate change, it also will have to adapt to climate change impacts, as the principle habitat of humans (Hunt 2004; Lend Lease Corporation, et al, 2007). O'Connell (2003) points out that *'investigation into the… effects of climate change, the synergy between adaptation and mitigation strategies, and understanding the importance of adaptation… is seen as critical...'*

Parallel to this, the definition of cutting edge sustainable architecture is changing rapidly. Aiming for 'neutral' or 'zero' environmental impact buildings in terms of energy, carbon, waste or water are worthwhile and difficult targets. It is becoming clear however, that buildings will need to go beyond having little negative environmental impact in the future, to having net positive environmental benefits (Rees 1999). Reed (2007) describes the transition from conventional practice (negative environmental impact), to sustainable architecture (zero impact), through to design with positive environmental impact, termed by him restorative, or regenerative design. By looking to the living world, there may be models that can be mimicked to create and maintain a resilient and adaptable built environment, and possibly improve its capacity for contribution to restoring or regenerating the health of ecosystems (Pedersen Zari and Storey 2007).

2. Biomimetic Architecture

Biomimicry is the emulation of strategies seen in the living world as a basis for design. It is the mimicry of an organism, an organism behaviour, or an entire ecosystem, in terms of its forms, materials, construction methods, processes, or functions, (Pedersen Zari and Storey 2007). It is a source of innovation, particularly in the creation of more sustainable and potentially regenerative architecture (Reap, Baumeister, and Bras 2005). In a similar way to the functioning of an ecosystem for example, a building could be designed to: produce energy and nutrients (materials); clean air and water; use and transform waste; and store carbon in a complex, adaptive and cyclic system (McDonough and Braungart 2002).

Looking to plants or animals that are highly adaptable or ones that survive in extreme climates or through climatic changes may provide insights into how buildings can or should function. Examining the qualities of ecosystems that enable them to be resilient may also offer potential avenues to follow. Although no comprehensive body of research has applied biomimicry to the impacts of climate change in the built environment, several noteworthy examples of biomimetic architecture, or technologies able to be applied to the built environment exist that will be examined in the following sections of the paper.

3. Climate Change and the Built Environment

Changes in climate that will affect the built environment are numerous and have been explored by several researchers. Impacts also will vary greatly depending on the local quality and density of the existing built environment and which specific local climate changes occur. The impacts that climate change will have on the built environment are both direct and indirect. Direct impacts will affect the actual physical fabric of the built environment. Indirect impacts will affect the economic, social and environmental context that the built environment operates in and will therefore also have implications for the built environment (O'Connell and Hargreaves 2004).

Providing detailed explanations of each impact is beyond the scope of this paper; however some of the main direct impacts that appear in a survey of international research[1] have been summarised in Table 1. Such changes to the climate are expected to increase in intensity in the future (IPCC 2001). These factors suggest a re-evaluation of the existing built environment, and that preparations for adaptations or additions may be necessary.

Table 1 Direct Climate Change Impacts on the Built Environment

Potential Direct Climate Change Impacts:	Consequences for the built environment:
Changes in temperatures (Likely to increase in most areas)	Increased overheating and air conditioning load Decreased winter space heating Decreased water heating energy
Increased intense weather events.	Damage to buildings and infrastructure
Changes in precipitation patterns	Damage to foundations Increased inland flooding Damage to facades and internal structure due to rain penetration Increased subsidence Increased erosion, landslips, rock falls Changes in aquifers and urban water supply and quality. Increase pressure on storm drainage Increased storm water run off and leaching of pollutants into water ways or aquifers
Thermal expansion of oceans and changes in the cryosphere (ice systems) such as retreating snow lines, ice packs and melting glaciers	Increased coastal flooding Increased erosion Changes in sedimentation patterns Changes in water tables and possible infiltration of aquifers. Relocation from coastal areas Loss of inter tidal areas acting as buffer zones
Changes in wind patterns and intensities	Changes in wind loading on buildings
Increased air pollution	Increased ventilation needed and provisions for clean air

4. Responses to Climate Change in the Built Environment

As acknowledged by several sources, even if all GHG emissions were immediately halted, the climatic impacts of past emissions would still be experienced. O'Connell and Hargreaves (2004) also point out that despite international treaties such as the Kyoto Protocol, global GHG emissions are increasing. It is important therefore that professionals of the built environment are not only able to mitigate the causes of climate change, but are also able to adapt to the impacts.

The responses to climate change in the built environment broadly fall into two categories:

1: Mitigating the cause of climate change by reducing GHG emissions.

2: Adapting the existing and future built environment to predicted climate change impacts.

Many technologies and established design techniques already exist that are able to mitigate the causes of climate change, adapt to the impacts or climate change and work towards restoring the healthy functioning of ecosystems and global biogeochemical cycles (including the carbon cycle). Lowe (2000) estimates for example, that reductions of 80% in carbon emissions associated with the built environment are possible using current technologies. The potential of well known design techniques to reduce dependence on fossil fuel derived energy, such as passive solar architecture for example are also well understood and documented. However, new techniques, or technologies that are able to mitigate and adapt to climate change with significant other benefits may be revealed by careful study of how organisms and the ecosystems they create are already able to do this. *'Climate change* [is] *now widely viewed as the main challenge facing humankind for this century. We believe that Biomimicry has a huge potential to tackle some of major issues raised by this global change'* (Biomimicry Europa 2006).

5. Biomimicry to mitigate green house gas emissions

Several examples of new technologies illustrate biomimicry that is focused on mitigating GHG emissions, and can be divided into three categories. The first approach is mimicking the effectiveness of living

[1] See reference section for papers referred to in summarising main direct impacts.

organisms and systems in transforming materials and energy in a way that is less resource intensive that what humans typically do. The impetus is that by being more energy efficient, less fossil fuel is burnt and therefore less GHGs are emitted onto the atmosphere.

The second approach is to devise new ways of producing energy to shift human dependence on fossil fuels, and therefore prevent additional GHGs from being emitted.

The third is looking to the living world for examples of how organisms or processes within them are able to sequester and store carbon. Mimicking this comes with the intention of preventing GHGs that are emitted through human activities from reaching the atmosphere and causing additional climate change.

5.1 Biomimicry for energy effectiveness and energy efficiency

Various biomimetic technologies and products have been developed for the purposes of improving energy efficiency. There are numerous examples of living organisms and systems that are highly energy effective and that could yield an understanding of how humans could build and carry out their activities without a dependence on fossil fuels (McDonough and Braungart 2002).

An example of such an approach is DaimlerChrysler's prototype *Bionic Car*. In looking to create a fuel efficient, large volume, small wheel base car, the design was based on the aerodynamic boxfish (*ostracion meleagris*). 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 appears almost skeletal, as material is allocated only to the places where it is most needed (Vincent et al. 2006).

Mick Pearce's Eastgate Building in Harare, Zimbabwe and the CH2 Building in Melbourne, Australia are examples of architectural biomimicry using this approach to address the causes of climate change. 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 that uses much less mechanical cooling (and therefore produces less GHG emissions). 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.

Improving energy efficiency in general is an important part of addressing climate change, but is however an intermediate step. As McDonough and Braungart (2002) point out, improving efficiencies, or 'being less bad' helps to reduce the intensity of GHG emissions but does not challenge basic assumptions about how we make and operate our technologies and does not address the underlying causes of climate change such as dependence on fossil fuels.

The *Bionic Car* illustrates the point. It is more efficient in terms of fuel use because the body is more aerodynamic. 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.

Improving energy efficiencies does however allow positive changes to be made to existing technologies and buildings rather than make a complete rebuild necessary and is therefore an important step in the transition of the built environment in positively addressing climate change.

5.2 Biomimetic energy generation for mitigating climate change

Several biomimetic technologies or systems aim to replace the use of fossil fuels as the primary energy source that humans use in an attempt to mitigate GHG emissions in the long term. Looking to the living world for inspiration is appropriate because almost all other organisms source energy from renewable sources, predominantly contemporary sunlight (Kibert, Sendzimir, and Guy 2002). An example of research in this direction is the development of artificial photosynthesis, that may eventually be applied to solar cell technology, such as the work done at Arizona State University (Benyus 1997; Moore et al. 2004) and by scientists in Australia (Davidson 2003).

Sea and wave energy technologies are also in development that mimic how sea kelp or tuna tails work in water. Australian company BioPower, is testing prototypes in Tasmania, Australia in 2008. According to company literature, the power generators oscillate in ocean waves and currents rather than rotate like a turbine. Through the use of permanent magnet motors, the low-speed high-torque oscillation is converted into high-speed low-torque rotation. It is anchored to the ocean floor by the use of a series of small root-like devices to avoid large and complicated drilling and installation. The generators rotate freely to orient themselves towards currents and in the same way can lie flat in storm events to avoid damage (BioPower Systems 2007).

Finding methods to replace the use of fossil fuels with contemporary sunlight and other renewable energy sources, is an approach to mitigating the causes of climate change conducive to a long tem solution. Significant time and resource needs to be applied to develop such technology however. While replacing the use of fossil fuels will prevent some additional GHG emissions from being created, biomimicry may also offer ways to address excess carbon dioxide already in the atmosphere.

5.3 Biomimetic Sequestering and storing carbon

There are several organisms and processes in nature that are able to store, sequester or recycle carbon, that are being investigated in the development of technologies that can be applied to industrial processes and the built environment.

In Quebec for example, $C0_2$ Solutions is developing carbon sequestration technology based on certain chemical processes that occur in the human body. The technology mimics the enzyme carbonic anhydrase which is able to convert carbon dioxide into bicarbonates ($C0_2$ Solution 2007; Geers and Gros 2000). In keeping with Benyus's (1997) observation that processes in the living world tend not to need huge amounts of energy to work, the $C0_2$ Solution process works at atmospheric pressure and ambient temperatures, thus it is highly energy efficient (Fradette 2007).

According to the company's literature, the process generates environmentally benign bicarbonate, which can be stored or reused in industrial process in cement works or paper mills. The aqueous solution where the conversion of carbon dioxide to bicarbonate occurs is reused in a closed loop. The technology is intended to be able to be retrofitted onto existing facilities such as power plants, cement works and oil sands operations, or integrated into new ones ($C0_2$ Solution 2007; Atkinson 2007).

Another example of the potential of biomimicry is illustrated by research conducted at the Rocky Mountain Institute in the United States, investigating an alternative material to concrete. Cement production accounts for approximately 5% of the world's anthropogenic carbon dioxide emissions (Vanderley 2003). This new material mimics the abalone, which is able to grow a crack resistant shell harder than any ceramics humans are able to create, using only seawater and a series of proteins (Benyus 1997). This process of bio-mineralisation stores carbon much like the growing of forests, locks carbon into the structure of the trees and soil for some time. The concept was that the new material would be able to grow over a structure, with the simple additive of seawater, using proteins imitated from the abalone (Koelman 2004).

As several authors point out, there is no waste in non-human living systems (Kibert, Sendzimir, and Guy 2002; McDonough and Braungart 2002). Detritus is an important part of continuing the process of cycling nutrients and is a fundamental part of the health of an ecosystem (Odum 1969). In using biomimiry to address excess carbon in the atmosphere, researchers such as Benyus have advocated using it as a resource rather than considering it a source of pollution (Benyus 2007). In response, some biomimetic systems look at how biomimicry may be used to replace fossil fuels and store carbon at the same time. An example is a proposal for biofuel crop plantings to be based on how naturally occurring prairies grow, resulting in a controversial net reduction of atmospheric carbon, while improving the fertility of the land (Russelle et al. 2007; Tilman, Hill, and Lehman 2006).

A company formed out of recent research done at Cornell University called Novomer, are examining mimicking carbon sequestration in living organisms, particularly plants, by turning carbon dioxide into carbon-based polymers, or biodegradable plastics. The zinc-based catalyst that is needed for the process works at ambient pressure and temperature. The use of carbon dioxide and monoxide as feedstocks, rather than corn or starch as is used in other biodegradable plastics, means that the plastic does not compete with food production, and may help in sequestering and storing carbon. More research is yet to be done into the characteristics of its carbon release properties on decomposition (Patel-Predd 2007).

A challenge with this approach to addressing climate change impacts is that sequestering carbon by itself does not deal with the problem of excessive burning of fossil fuels, causing climate change, but rather is an anther interim step in becoming more sustainable (Fradette 2007). The issue of depletion of fossil fuels themselves is also not addressed, and there are several logistical, economic, technological and environmental problems with current attempts at carbon sequestration (Schiermeier 2006). Its benefit however is that such technologies may help to retrofit and adapt existing building infrastructure, while addressing GHG emissions in the short to medium term (Herzog 2001).

Several of the examples of a biomimetic approach to carbon sequestration or storage discussed reveal that secondary and useful products are made, such as plastics and potential new building materials, without toxic by-products and the use of high amounts of energy. There may also be important restorative capacity in lowering the amount of atmospheric carbon by using carbon dioxide as a feedstock for new materials. More research needs to be done to investigate the feasibility of this. The built environment uses at least 40% of the materials consumed by the global economy (Rees 1999), so building materials that store carbon long term, or that are made from carbon dioxide itself, if appropriate, durable and safe, have potential to have significant positive benefit in mitigating the causes of climate change.

6. Adaptation to Climate Change

Biomimicry offers several avenues in addressing the issue of adaptation to climate change. The first is responding to anticipated direct impacts of climate change on the built environment (see Table 1). The second is a more comprehensive approach to altering the built environment to be more adaptable as a whole system.

6.1 Responding to Direct Impacts of Climate Change

Several architectural examples of biomimicry exist that look to respond to direct impacts of climate change. Two proposed architectural projects discussed here might be suitable responses to changes in precipitation patterns and a projected water shortage for example.

Grimshaw Architects have used biomimicry to design a building that can desalinate seawater with minimal energy input. They propose that the desalination plant will form a large outdoor theatre called *Teatro del*

Agua in the Canary Islands. The Namibian desert beetle, and the hydrological cycle itself, have been used as inspirations for the design. The stenocara beetle lives in a desert with little rainfall but is able to capture moisture from the swift moving fog that passes over it by tilting its body into the wind. Water condenses on the surface of the beetle's back because its shell is cooler than the surrounding air. 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). The hydrological cycle is based of course on evaporation and precipitation.

The Grimshaw design team in collaboration with Seawater Greenhouse have taken an understanding of these examples from the living world and in 2005 proposed the unique desalinisation process. Seawater will be passed over a series of evaporative grills and, as the sea breeze moves through them, some of the water will evaporate, leaving salt behind. The moist air then continues until it hits pipes holding cool seawater, pumped up from the deep ocean. As the warm moist air touches the cool pipes, condensation forms and clean fresh water trickles down to be collected for use. The seawater pumps are powered by wind turbines using the same sea breeze and any excess water and the resulting cooling can be transferred to neighbouring buildings. This kind of biomimetic system may be useful in areas that are coastal and have difficulties sourcing fresh water, exacerbated by climate change.

Matthew Parkes of KSS Architects demonstrates biomimicry also inspired by the Namibian desert beetle's unique features, with his proposed fog-catcher design for the Hydrological Center for the University of Namibia (Killeen 2002). In a low rainfall environment part of the building is carefully designed and orientated to capture the water from the fog without the use of pumps and large amounts of energy.

This approach has a number of benefits and difficulties associated with it. It requires people to accurately know what the impacts of climate change will be, and to allow enough time to research and implement possible responses to it. A benefit of such an approach however, is that technologies and architectural responses to direct impacts may be transferable to other places that have similar issues. This process of developing technological solutions for individual buildings fits into the current method of extending and renewing the built environment, which is typically a building by building or addition by addition process (Brand 1984). This approach is helpful for a gradual response to the impacts of climate change, particularly if the ability to research, develop and test technologies continues. The living world offers numerous examples of organisms that effectively solve the same problems the built environment will face. Organisms and ecosystems exist that effectively manage overheating, high winds, and erosion for example.

Developing individual technologies or buildings to deal with the myriad of direct climate change impacts on the built environment does not however ready the built environment for unpredicted changes, or address multiple impacts concurrently. Understanding local built environments as whole systems in terms of their strengths and weaknesses may be effective way to plan for future unpredictable climatic changes.

6.2 Improving the built environment as a system

Although ecosystems are typically resilient and many are able to move though massive changes while still supporting organisms to survive, the ability of ecosystems to adapt to the rapid changes that may become apparent through climate change is largely unknown. Mimicking ecosystems may however offer insights into how the built environment could function more like a system than as a set of individual objects (Pedersen Zari and Storey 2007). Ecosystems are readily available models for designers to examine in creating robust, resilient and adaptable systems. Several authors advocate methods for incorporating an understanding of ecosystems into architectural design (Graham 2003; Kibert, Sendzimir, and Guy 2002; Van der Ryn and Pena 2002; McHarg 1992; Reap, Baumeister, and Bras 2005).

As described by Pedersen Zari and Storey (2007), a comparative analysis was conducted of related knowledge of ecosystem principles in the disciplines of ecology, biology, industrial ecology, ecological design and biomimicry and was used to formulate a group of ecosystem principles aiming to capture cross disciplinary understandings of ecosystem functioning. Features of ecosystems that make them resilient were identified in subsequent research as: capacity for self healing; capacity for decentralised organisation; complex feedback loops; interdependence of organisms; diversity in types of organisms and relationships; a responsiveness and dependence on local conditions; and optimisation of the whole system rather than single parts. How such principles may meaningfully be applied to the existing built environment requires more investigation. There are however two notable examples of mimicking ecosystems for greater adaptability that may offer insights.

In designing the Lloyd Crossing Project proposed for Portland, Oregon in 2004, the design team including Mithūn Architects and GreenWorks Landscape Architecture Consultants used estimations of how the ecosystem that existed on the site before development functioned. The stated goals of the project included: reducing environmental impact to pre-development levels; achieving carbon balance; and living within the site's rainfall and solar budget. By understanding the system that had worked previously on the same site, the design team were able to determine appropriate goals for the ecological performance of the project over a fifty year time period (Portland Development Commission 2004).

Examples of successful industrial ecology such as the Kalunborg Project, in Denmark also demonstrate the advantages of a systems approach in creating a resilient and robust environment where energy and materials are circulated and shared, eliminating waste and duplication of effort or energy use in some areas (Jacobsen 2006).

A benefit of such an approach is that through careful urban planning and an integrated and multidisciplinary design method, buildings as part of a larger system, able to mimic natural processes and functions in their creation, use and eventual end of life, have the potential to adapt more readily to climate change. That a greater understanding of ecology and systems design is required on the part of design teams is implicit with such an approach. Increased collaboration between fields that traditionally seldom work together such as architecture, urban design, and ecology would also be required. Systems based climate change adaptation challenges conventional architectural design thinking, particularly the typical boundaries of a building site and time scales a design may be initially designed for.

Barriers include the current competitive economic context of the built environment in many places in the world. Encouraging greater interdependence and the sharing or exchange of resources between buildings requires a different economic and legal frame work to operate than that which is currently in place. The final drawback to this approach is that because it requires communities to become linked, interdependent systems, it requires a coordinated and cooperative approach from land owners and authorities to make it happen at a large scale, which may prove difficult in some areas. The built environment obviously varies greatly between different areas and climates and economic contexts, and systemic approaches that are appropriate to specific places will also vary greatly (Reed 2007). Because there may therefore be limited transfer of knowledge between differing geographic regions, the adoption of such an approach may be slow. Although there are some draw backs to a whole systems based adaptation of the built environment, it may be a suitable solution for a longer term response to addressing climate change impacts.

7. Benefits of a Biomimetic Approach to Architecture

This paper demonstrates that various biomimetic ideas can be applied to a short, medium and long term response to climate change. Biomimetic approaches to climate change mitigation and adaptation in the built environment are diverse and are not preventative of other non-biomimetic approaches being employed. While existing technologies will be crucial in the short and medium term, biomimetic approaches may form an important part of long term solutions to climate change, particularly in the replacement of the use of fossil fuels, development of technologies to address direct impacts on the built environment, and importantly in systemic improvement of the built environment based on ecosystem based biomimicry (Fig 1).

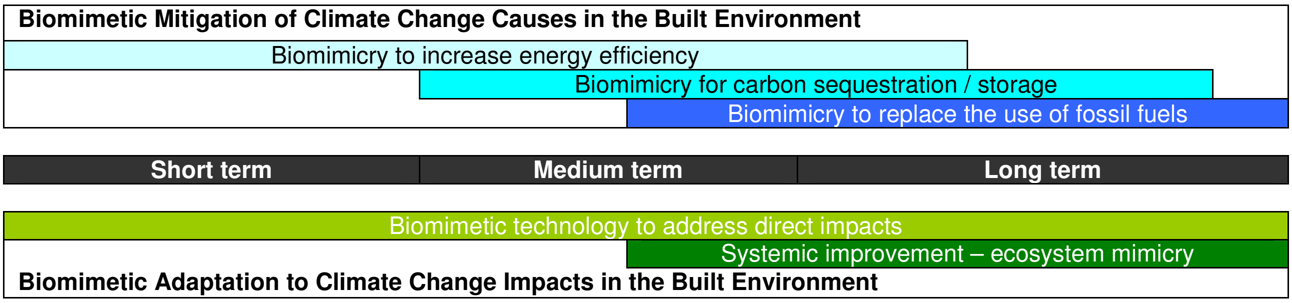

Figure 1 Time line of biomimicry approaches to address climate change

As well as a reduced or potentially negative carbon footprint for the built environment, other significant social and economic benefits of biomimicry in the built environment may exist. Several authors investigate the relationship between bio-inspired design and improved psychological and physical health (Pedersen Zari 2008; Kellert 2005). It is possible, that with a greater understanding of the living world, and its relevance not only to increasing sustainability, but also its possible contribution to psychological wellbeing, architectural design will change accordingly. Links with increased human productivity in commercial buildings that demonstrate aspects of bio-inspired design have been demonstrated (Heerwagen et al. 1998).

As GHG emissions are increasingly regulated, buildings that do not met legal or performance expectations may be more difficult to sell, lease or insure and may have higher financial life cycle costs. There is also growing evidence of 'sustainable' buildings demanding premiums over conventional ones. (Fullbrook, Jackson, and Finlay 2006).

It is posited that the incorporation of an understanding of the living world into architectural design could be a significant step towards the creation of a built environment that allows for positive integration with and restoration of natural carbon cycles. Increased positive integration with ecosystems and a restorative rather than damaging effect on ecosystems may have significant benefits on maintaining biodiversity and the ecosystem 'goods and services' that humans are dependant on for survival (Daily et al. 2000). If the built environment is to become truly regenerative it will increase human and community wellbeing as well as that of ecosystems.

8. 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 (Doughty and Hammond 2004). It is becoming increasingly clear that a shift must be made in how the built environment is created and maintained (Reed 2007). 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 built environments that may be able to be entwined with the habitats of other species in a mutually beneficial way while addressing climate change causes and impacts.

New approaches will be useful to professionals and governing bodies as they address climate change impacts in the built environment. By looking to the living world, there may be models that can be mimicked to create and maintain a robust built environment, and possibly improve its capacity for contribution to restoring or regenerating capacity in ecosystems. Several case studies have been used to exemplify this.

This paper has considered the different ways that biomimicry may be applied to both climate change mitigation and adaptation to direct climate change impacts. This has illustrated the ways in which mimicking the living world is useful in the design of buildings that address climate change. Distinctions between the different kinds of biomimicry and their short, medium or long term potential in addressing climate change in the built environment has also been examined.

Technologies that increase energy efficiencies and are able to sequester or store carbon may form part of an important short to medium term approach, but should be seen as intermediate steps. As well as a reduced or potentially negative carbon footprint for the built environment, examples of developing biomimetic technologies reveal approaches that use current excess carbon dioxide as a resource for new materials. Design that mimics how ecosystems are able to function in a resilient way, has the potential to form part of a long term response to climate change in relation to the built environment. Along with this, biomimetic technologies that address direct climate change impacts, and biomimetic technologies or systems that prevent further GHG emissions could be implemented alongside systemic change in the built environment.

It is posited that the incorporation of an understanding of the living world into architectural design could be a significant step towards the creation of a built environment that is more sustainable and resilient and is able to adapt to climate change.

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