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Research paper

Unearthing ecological wisdom from natural habitats and its ramifications on development of biocement and sustainable cities

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HIGHLIGHTS

- Due to rapid urbanisation urban infrastructure faces huge sustainability challenge.
- Nature has been producing habitats for millions of years sustainably.
- Understanding and emulating Nature's way may hold a key to urban sustainability.
- Biomineralisation, closest to human adaptation where organisms produce minerals.
- It is promising for development of a low energy biocement for sustainable cities.

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ABSTRACT

As the world population migrates to the urban areas in increasingly greater numbers, building and maintaining urban infrastructure in a sustainable fashion is a great challenge. Present construction technologies use too much material and energy and produces huge quantities of greenhouse gases. Nature, on the other hand, has been building habitats such as ant hills, coral reefs and silk webs that has been sheltering billions of species for millions of years in a sustainable way. The ecological wisdom embodied in these high-performance prototypes may give us clues to sustainable urban infrastructure. In this paper we highlight some of the amazing ecologically wise natural habitats. Although many amazing natural examples have been recently highlighted, emulating them in engineering practice has remained a challenge. One of the most promising biological processes that are closest to human adaptation is biomineralisation by which living organisms produce minerals, chiefly carbonate products that offer strength to bones, shells and antlers. With the help of some microorganisms, it is possible to produce and deposit minerals (e.g. calcium carbonate) and emulate some of the biological processes such as formation of corals. This paper briefly discusses biomineralisation technology. The present status of application of the technology in urban infrastructure has been summarised.

1. Introduction

This paper addresses two themes of this special issue (Xiang, 2014): (i) ecological wisdom as domain knowledge; and (ii) ecological wisdom as actionable knowledge, in the context of ecological wisdom prevalent in natural habitats (domain knowledge) and applying them as a means of building sustainable cities (actionable knowledge). Construction of our cities must be made sustainable as the whole world is experiencing a rapid movement of humanity towards urban areas. The share of global urban dwellers has gone up from 10% in 1900 to more than 50% now and likely reach 5 billion by 2030 (United Nations, 2010). This demographic change has produced demands on services that ecosystem provides. In the past century urbanisation has occurred in less than 3% of global terrestrial land, yet 78% of carbon emission, 60% of residential water use and 76% of industrial wood use are attributed to the cities (Brown, 2001). Urban infrastructure and its use plays a major role in urban pollution. In China alone, more than 300 million people are likely to migrate to the cities continuing the already unbelievable construction juggernaut (Fernández, 2007). Application of ecological principles can be resorted to in solving the urban environmental problems (Grimm et al., 2008).

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The present technology of urban construction consumes way too much energy for a sustainable urban development (Achal & Mukherjee, 2015). Experts predict that consumption of highly energy consuming building materials such as Portland cement is likely to grow for the next fifty years (Schneider, Romer, Tschudin, & Bolio, 2011). This is due to growing dependence on concrete as the construction material of choice. Since last century, concrete has become the most widely used man made material. Due to increasing urbanisation the projected annual concrete demand by 2050 is 16 billion tonnes (Mehta & Monteiro, 2005). Concrete is mainly produced from its precursor, cement that is responsible for 70–80% of the global industrial energy use by the non-metallic production units, 5% of the global anthropogenic CO_2 emissions, and 3.4% of the global CO_2 emissions (Worrell, Price, Hendricks, & Meida, 2001). Understandably, Portland cement is not at all a sustainable material (Gerilla, Teknomo, & Hokao, 2007). Thus, urban sustainability problems due to Portland cement usage can be categorised as the wicked one (Rittel & Webber, 1973; Xiang, 2013). Nature, on the other hand, has been building habitats such as anthills, corals and spider webs with negligible consumption of resources for millions of years. Moreover, these habitats are built from recycled materials and they are recyclable and self-healing. Thus, emulating nature can be a key to solve the wicked problem of usage of Portland cement.

This paper discusses the ecological wisdom embedded in the natural habitats and how this knowledge can be made actionable in the development of biocement that contributes towards making our cities sustainable. The hypothesis on wicked problem is applicable to Portland cement (Xiang, 2013) that could be solved by a proposed solution in terms of a sustainable or low energy cement, which seems to be novel, innovative and a promising idea. The alternative and potentially complementary strategy to facilitate such idea is to look out further for ecological wisdom based on evidence driven hypothesis, principles, strategies, and even approaches that could create sustained longevity for sustainable cities (Xiang, 2014). For example, reports from antiquity include addition of animal blood, molasses, eggs and animal dung in earth for construction. Modern research shows that these additives can activate microbial action in earth and strengthen it without any significant environmental impact. This aspect of the traditional construction remained unexplored in its modern avatars. Building technologies that massively cut down the energy requirement and CO_2 emission can contribute a great deal in maintaining the momentum of growth while controlling the ecological damage.

This paper presents theoretical and practical wisdom derived from nature to achieve a novel building material for urban construction that is actionable in terms of environmental sustainability. A brief discussion on biological materials inspired from nature has been provided with respect to their role in civil engineering. Further, one of the Nature inspired technologies that promises to revolutionise human construction is critically reviewed. This papers presents contemporary and emerging theoretical and practical frameworks with respect to the ideas, principles, strategies, and approaches of ecological wisdom in construction materials.

2. Ecological wisdom in nature

Ecological wisdom is deemed as actionable knowledge with practical implication (Xiang, 2014). Palmer (2012) defines actionable research as that with potential to modify existing planning by keeping nature and ecology in mind, to inform decisions for improvement of human beings on socio-enviro-economic basis, to improve public policies, or to influence public- or private-sector strategies and behaviours that affect the environment. In case of buildings, ecological wisdom is manifested in the results of millions of years of experiments on sustainable habitats by natural creatures. Nature has developed a large number of ingenious solutions, which still wait to be discovered and serve as a source of inspiration (Aksay & Weiner, 1998). In the recent years, due to the advent of precision equipment, great progress has been made in understanding the natural materials and compare them with manufactured ones (Wegst & Ashby, 2004). It gives us an opportunity of simultaneously studying natural and manufactured materials for construction of habitats.

In ecologically meaningful engineering projects are developed in harmony with the existing ecosystems for overall environmental benefit. In fact, natural creatures do that in an amazingly elegant fashion. Building of nests or habitats is one such activity and infrastructure engineers can learn a lot by studying natural habitats. For example, coral reefs are biodiversity hotspots. On some tropical coral reefs there can be 1000 species per m^2 (GCRMN, 2008). In other words they are metropolises of the ocean. Thus they may unlock some of the mysteries of how to make our cities sustainable. Nature has most often selected the solutions best adapted to the prevailing environmental conditions throughout millions of years of evolution (Pereira, Monteiro, & Prazeres, 2015). Through evolution, nature produces the most efficient multifunctional surface structures. Nature follows norms for adaptability for the unique reactive environment (Malshe et al., 2013). By understanding these creations and mimicking them it is possible to create and maintain a resilient and adaptable built environment to improve its capacity for ecosystems health regeneration (Pedersen Zari & Storey, 2007).

Nature always develops the design solutions with fine-tuned mechanical properties especially of biological origin that inspire engineers in designing structures by mimicking them (Ehrlich, 2010). Biomimetic approach depends on an understanding of functions, structures and principles of various biological materials seen in the living world for design and a source of innovation, with potential to contribute to the creation of more sustainable architecture or systems of commercial or societal or industrial value (Benyus, 1997). It is the mimicry of an organism or an entire ecosystem that could be claimed as nature inspired ecological engineering. Nature inspired ecological engineering is related to ecological wisdom, which contains rules, postulates and hypotheses concerning the state of affairs in our universe, as defined by Naess (Drengson & Inoue, 1995). More closely, in our paper the source of ecological wisdom is coming from biological materials of nature that inspire us to look into problems of urban construction and solve by the process of biomineralization, a hypothesis with actionable and practical implications. In terms of nature inspired ecological engineering, ecological wisdom can be further simplified (if not defined) as nature driven wisdom for the welfare of the planet that could bring human prosperity and environmental sustainability.

The biological materials, which have attracted scientific curiosity and technological ingenuity and worthy to explore in the context of civil engineering towards sustainable cities include ant hills, coral reefs, silk, teeth, bone, skin, shells and many more (Wegst & Ashby, 2004). These are composites of an inorganic mineral phase with a biopolymer, created in a process called biomineralisation (Chen, McKittrick, & Meyers, 2012). These are being used to inspire design elements by their process in architecture and developing building materials that are stronger and more eco-friendly. The following sections briefly explain some of those biological materials.

2.1. Ant hills

Ants construct anthills that have multiple functions apart from being their home and a place to raise children. Life of ants revolves around building and maintaining the hill. Worker ants dig the ground and move grains of sand from the centre to the outer edge of

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