FIMEK

Journal of Agronomy, Technology and Engineering Management

Article

Intervention of Biomimicry for Sustainable Construction: The use of Bio-Concrete

Peter Adekunle[1,*], Clinton Aigbavboa[1] and Opeoluwa Akinradewo[1]

[1] cidb Centre for Excellence & Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa.

* Correspondence: adekunlepeter90@gmail.com

Received: 30 September 2021; Accepted: 11 October 2021

Abstract: Biomimicry construction is defined as the science and art of solving human's construction difficulties through emulating best biological proposition of nature. The benefits of biomimicry includes environmental and aesthetic factor. The use of materials such as bio-concrete increases environmental impacts exponentially. One of the major benefits of bio-concrete is that it is self-healing and it increases the effectiveness of any project design. Sustainable construction implies the use of materials that can be renewed and recycled, as well as reduce waste and energy consumption when building new edifice. To examine this intervention, this study employs a systematic literature review and site observation of how the use of bio-concrete can be adopted for the construction of buildings in the construction industry. Findings from this study revealed that biomimicry has helped to aid the development of sustainable construction. The use of bio-concrete which is a by-product of biomimicry will enable buildings to last for decades and also reduce maintenance cost. The usage of bio-concrete will also reduce concrete negative impact on the environment. The study concluded that the cost of producing bio-concrete is lesser than that of traditional abiotic reinforced concrete. By using bio-concrete for construction, assurance of a healthy environment is achievable.

Keywords: Biomimicry; bio-concrete; bacteria; self-healing; sustainability; environment.

---

1. Introduction

Sustainable construction is the process of making construction projects life span rise over time by making use of recyclable and renewable materials which simultaneously reduces consumption of energy and wastage [10]. It is a living entity and it differs in framework which is based on the need of the people. The ideology of sustainable construction was given birth to during the discussion of sustainable development [23]. Sustainable development is defined as the act of meeting the need of everyone in the present without negating the capacity of future generation to also satisfy up surging desires when the period comes [18]. Environment, society and economy are three socially interconnected systems that interconnects in sustainable development. This implies that sustainable construction has a great impact on the environment, society and economy [33].

The implementation of sustainable construction into the environment and economy served as a support for the theory of limits-to-growth [18]. The theories of pro-growth in the early days that opined that the maintenance of economic growth would negates sustainability in the long term [18]. This made scholars to find fault with sustainable construction for being too value-based since its utility definitions differs heavily depending on the peculiarity of the application. This approach allows sustainable construction to be used as a defense for both growth-oriented and limitation-oriented point of views of developmental disagreements notwithstanding their various implications [21]. For this postulation to be productive in situations of reality, different frameworks has been developed in the construction industry [19]. An aspect of this framework is biomimicry.

Biomimicry is the adoption of elements, models and systems derive from nature which is aim at solving networks of human problem [9]. It is understandable that the evolvement of living organisms into structures and materials have been well-adopted through natural selection over geological period of time [24]. This phenomenon have given upsurge to biological solutions encouraged by new technologies at nanoscales and macroscales. Man have examined natural occurrence for solution to problems affecting survival. Nature has helped to solve construction challenges such as harnessing solar energy, hydrophobicity, abilities to self-heal, self-assembly, exposure to the environment and forbearance [29].

Through recombination, mutation and selection, living organisms have been able to adapt to constant change in environment [2]. The major objective of biomimicry ideology is that inhabitants of nature which include microbes, plants and animals possess the ability to solve problems and are able to find the most suitable way to have longer life-span [15]. Similarly, biomimicry in construction seeks lasting solutions for sustainability in buildings as it is present in nature [31]. As a result of deficiency in building designs, the 21st century has witness massive wastage of energy, plus the exaggerate use of energy in the working phase of the wheel of life [16]. There are new opportunities to mimic nature in different construction dimensions due to recent advancement in stimulation of tools, computational imaging and fabrication of techniques. This has resulted to advance growth in conceiving new innovative design procedures and breakthrough in counter energy challenges [6].

Biomimicry construction is one of the multi-dimensional ideas to sustainability in construction that has a defined pattern rather than the use of elocutionary codes. This also goes afar the use of nature as motivation for exquisite constituents of built forms but rather using nature as a solution to the problem of building functions and saving energy simultaneously [12]. The major function of biomimicry in construction includes; minimizing consumption of resources (Conserve), maximizing reuse of resources (Reuse), using recyclable or renewable resources (Recycle/Renew), protecting the natural environment (Protect Nature), creating a non-toxic and healthy environment (Non-Toxics), and pursuing quality in the creation of built environment (Quality) [11].

2. Biomimicry in Concrete (bio-concrete)

Concrete is classified as one of the most important materials in construction. It partakes in an indispensable role in many aspects. It is vastly used in tunnels, bridges, roads, dams, seaports, subways, storage tanks and other similar infrastructures. Concrete is majorly a mingling of water, cement and aggregate (coarse and fine) [1]. Concrete is one of the essential construction materials. After water, it is the most vastly used material on planet earth. Due to it truncated tensile strength, steel is added to it to create reinforced concrete thereby resulting in the protection of the steel by the concrete from corrosion [26].

The most important element in the concrete material is cement. It is used as a binding agent to the aggregates thereby filling the voids between the coarse and fine articles. Concrete is the choice material in many applications because of it availability, strength, durability and ability to compact easily with reinforcement bars. It is easy and possible to cast concrete in desirable shapes and sizes which makes concrete the best choice of material in a lot of applications. In spite of these advantages that concrete possesses, it allows for the penetration of aggressive chemicals into structure [34]. This penetration leads to failure and reduction in durability [30].

The formation of cracks can occur in hardened state or plastic state. In plastic state, when there is crack formation, plastic shrinkage, plastic settlement and formwork movement occur owing to massive deprivation of water from the topside of the concrete [36]. While design error and detailing, constant overload, chemical reaction and external load causes formation of cracks in hardened state. Normally, concrete structures are affected by ductility and comparatively low tensile strength and ductility [41]. To reduce the effect of ductility and low malleable strength, reinforcement of concrete with steel bars that are embedded. These reinforcement bars influences the crack width restriction positively by plastic shrinkage control but does not stop the formation of cracks [3]. Moreover the concrete strength might not be affected negatively in the early stages but the formation of crack is a severe threat to the life span of concrete on the long term basis [13].

A sizeable amount is apportioned to existing structures made of concrete for repair on an annual basis [5]. It estimated that the maintenance and repair cost is around \$147/m^3 of concrete, which is much higher than the cost of production that ranges around \$65 to \$85/m^3 [42]. Therefore, it is necessary to innovate procedures and materials that can stop and eradicate at early stages, the formation of crack in concrete. This ideology led to the intervention of sustainability through the utilization of bio-concrete.

3. Production of Bio-concrete

To promote autonomic healing, chemical signals are released at the site of facture which initiate a systematic response that transmit restoring agents to the fracture site. Bio-concrete is a self-healing concrete that is made via the discharge of chemical signals into concrete fracture which then enhance autonomous healing [41]. Bio-concrete was developed as a result of cracking in concrete that then resulted in a pathway for negative substances such as carbon-dioxide, chlorides and ultimately water and oxygen to access the reinforcement steel causing rust or corrosion, eventually leading to the destruction of the concrete [35]. The act of cracking concrete is a challenge because of the repair needs, which incurs additional expenses, for example, repair of motorway bridges.

In the process of seal cracks formation, there are bacteria that are generated which can also be used to produce limestone and create gums [28]. If it can be incorporated to form cracks or all over the gaps to form limestone and then plug the gums. Concrete is usually exposed to very hostile environment, so therefore, the bacteria used can resist the harsh environmental condition of high alkaline pH producing limestone simultaneously [37]. Three bacteria cultures by researchers in the lab ideally expand in alkaline circumstances that make them appropriate for concrete usage.

One of the pathway in which these bacteria develops is known as the autotrophic pathway [23]. The procedure is done in the existence of carbon dioxide for which the conversion of carbon dioxide to carbonate by microbes is done in three unique ways, namely anoxygenic photosynthesis (by purple bacteria), oxygenic photosynthesis (by Cyanobacteria) and non-methylotrophic methanogenesis (by methanogenic archaea) [31]. In this production, carbon dioxide and oxygen is converted to methane in accordance with the pathway of Non-methylotrophic methanogenesis as interpreted in Eq. 1. Thereafter, sulphate which is an example of electron acceptors oxidizes the methane to produce bicarbonate anaerobically as interpreted in Eq. 2 [5]. After the carbonate has been produced, the produce with the mixture of calcium ions will react to produce precipitation of calcium carbonate as interpreted in Eq. 3. This solution makes bio-concrete self-healing.

$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$ --------------------- (1)

$CH_4 + SO_4^{2-} \longrightarrow HCO^-_3 + HS^- + H_2O$ ------------------ (2)

$Ca^{2+} + 2HCO^-_3 \longleftrightarrow CaCO_3 + H_2O$ ------------------ (3)

Equation 1. Chemical equation for Bio-concrete

The Equation 1.0 further explains the equation stated above; a- represent the bacteria structure, b: shows the presence of cell wall that are negatively charged with the existence of ion charged positively and c: shows the reproduction of biomineral through the binding ions.

4. Materials and Methods

The research method adopted for this article is extensive review of literatures. This method was adopted because several researches have been done in areas of chemical science, exploring bio-concrete. It is therefore eminent to relate the findings of these researches to the construction industry. Quantitative data analysis was considered but ultimately discarded due to the fact that bio-concrete is yet to be a popular element in the construction industry.

5. Results

This bio-concrete will save a considerable amount of money and will also give rise to environmental savings. This is achieved because given to volume of cement that will need to manufacture concrete is between 5% - 7% of carbon dioxide discharge [32]. It is necessary to note that the bacteria used are the ones that produce spores as ordinary bacteria won't survive in harsh conditions [14]. Bio-concrete are very tough building materials and can last for 100 years [8].

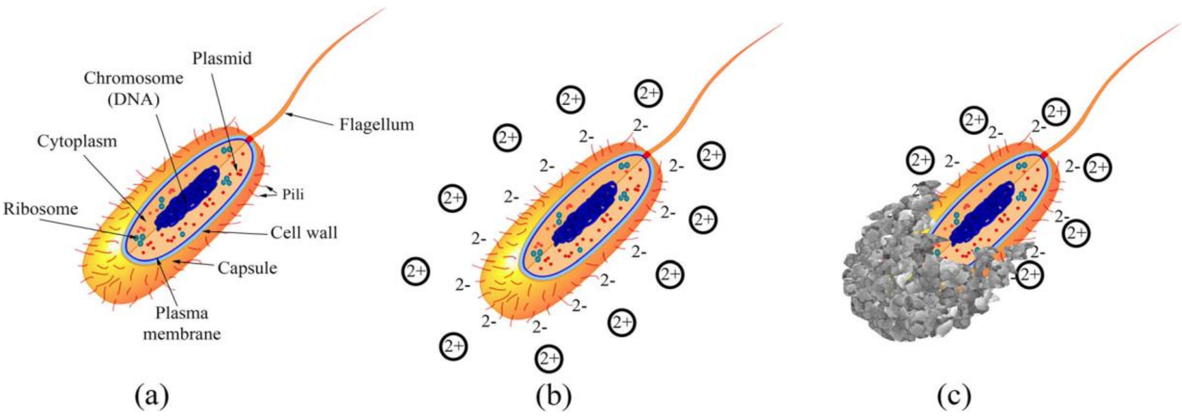

Figure 1. Production of bio-concrete.

The figure here shows that they have succeeded in a medium of liquid culture that is alkaline; it looks clouded, which stipulate that the bacteria is growing up in this medium. This medium has calcium, and in the existence of calcium and carbon dioxide, they turn-out limestone, making it calcium carbonate, and then cracks in concrete which are mixed with bacteria [40]. Bacteria food has calcium, and these bacteria utilizes this calcium and carbon dioxide to bring about calcite. The cracks will then be mended by the bacteria when added, making it a self-healing concrete [38]. So therefore, there is a self-healing concrete that will alleviate the need for repair.

Table 1.0 shows the comparison between concrete and concrete. It shows the environmental impact of the two materials considering the contributing elements to it production. It can be seen that electricity and water has a negligible impacts on both materials. Considering transportation, the impact is minimal in bio-concrete but is a key factor in concrete which makes production of concrete more expensive. Also regarding the production of the two materials, the environmental influence of bio-concrete is half that of concrete due to the fact that concrete recycling or re-use is limited, whereas bio concrete can be recycled to make construction blocks because it is a porous material and it can also be cut easily and it can re-produce another bio-concrete material through recycling [15]. Therefore, there is little or no wastage using bio-concrete.

Table 1. Comparing concrete and bio-concrete.

Material	Processes	Percentage of Score
Bio-concrete	Aggregate Production	0.44
	Water	0.02
	100L bacterial suspension Production	5.00
	Calcium Chloride Production	19.51
	Urea Production	68.08
	Transportation	6.94
	Electricity	0
Concrete	Aggregate Production	11.61
	Water	0.01
	100L bacterial suspension Production	0
	Calcium Chloride Production	0
	Urea Production	0
	Transportation	88.38
	Electricity	0.01

6. Conclusions

It is expected that bio-concrete as self-healing concrete will be used in many essential structures, particularly to ground and water structures, where repair or maintenance is not an option. The cost of producing bio-concrete is lesser than that of traditional abiotic reinforced concrete. By using bio-concrete for construction, assurance of a healthy environment is achievable and housing facilities can be easily made accessible and affordable. Bio-concrete can be re-used by crushing it to form aggregates and then re-cycled to make another bio-concrete using smaller quantities of materials made with bio-cementation. It can also be used for construction of pavement blocks due to it characteristic of being highly porous.

References

[1] Aginum C. H., Chidolue C. A., Nwakire L. *Investigating the Effects of Coarse Aggregate Types on the comprehensive strength of concrete.* IJERA 2013, Vol 3. Issue 4, ISSN:2248-9622, 1140-1144.

[2] Bell G. *Evolutionary rescue and limits of adaptation.* Philosophical Transactions of the Royal Society B: Biological Sciences 2013, Volume 368, No. 1610, B:368:20120080, 1-6.

[3] Bertelsen I. M., Ottosen L. M., Fischer G. *Influence of Fibre Characteristics on plastic Shrinkage cracking in cement-based materials: A review*. Construction Building Materials 230, 2020, 1-17.

[4] Cailleux, E., Pollet, V. Investigations on the development of self-healing properties in protective coatings for concrete and repair mortars. In *Proceedings of the 2nd international conference on self-healing materials, Chicago, IL, USA* Vol. 28, 2009, pp. 1-16.

[5] Castainer S., Metayer-Levrel G. L., Pertuisot A. *Bacteria roles in the precipitation of carbonate minerals*. In: Microbial Sediments. Riding, R. E., Awramik S. M.(eds), Springer: Berlin Heideberg, Germany, 2000; 32-39.

[6] Chrisna D. O. *Agenda 21 for Sustainable construction in developing countries. CSIR Report BOU E*, 2002, 204.

[7] Donella H. M., Demis L. M., Jorgen R., William W. B. *The limits to growth.* In Green Planet Blues: Critical Perceptions on Global Environmental Policies, Sixth edition; Conca K., Dabelko G. D.; Routledge, Taylor & Francis: Milton Park, Abingdon-on-Thames, Oxfordshire, England, 2020; pp 38-53, ISBN 9780813350936.

[8] Durga Chereddy S. S., Ruben Neretla., Sri-Rama Madduru C., Venkatesh Chava. *Performance Studies on rate of self-healing in bio-concrete.* MTP 2020 , Volume 27, Part 1, 158-162.

[9] El-zeing R. M. Biomimicry as a problem solving methodology in interior Architecture. ASEAN Conference on Environment-Behaviour Studies, Bangkok, Thailand, 2012; pp. 502-512

[10] Gatley N. *What is Sustainable Construction and why is it important?* British Assesment Bureau 2019, 1-5.

[11] Gehan A., Nouran O. *Biomimicry an approach for Energy Efficient Building Skill Design*. PES 2016, 178-189, doi:101016/j.proenv.

[12] Gestrelius S., Lyngdtadaas S. P., Hammarstrom L., *Emdogain-periofontal regeneration based on biomimicry*. Springer-Verlay 2000, pp. 120-125.

[13] GIATEC Scientific International: Self Healing Bio-concrete. Available online:www.giatecscientific.com/educational/bio-concrete/selfhealingbio-concrete (accessed on 14/05/2015)

[14] Gonsalves G. M. (Polytechnic University of Catalonia (UPC), Bercelona, Spain); Bioconcrete- A sustainable substitute for concrete?; 2011, 1-56.

[15] Kennedy E., Fecheyr-Lippens D., Hsiung B. K., Niewiarowski P. H., and Kolodziej M. *Biomimicry: a path to sustainable innovation.* Design Issues 2015, Volume 31, https://doi.org/10.1162/DESI.a.00339, pp. 66–73.

[16] Mattews F. *Towards a Deeper Philosophy of Biomimicry Organizations & Environment*. Sage Publications 2011, pp.1-24.

[17] McGranahan G., Satterthwaite D. *Environmental health or ecological sustainability? Reconciling the brown and green agendas in urban development*. Planning in Cities, PAP 2001, pp. 43-57, doi:10.3362/9781780441283.00.

[18] Meadows D. H., Meadows D. L., Randers J., Behrens W. W. *The Limits to Growth-Green Planet Blues: critical perceptions on global environmental policies.* Routledge, Taylor & Francis 2019, Sixth edition, pp. 38-53, doi:10.4324/9780429322204-3, ISBN 978-0-429-32220-4.

[19] Mensah Justice. *Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review.* Cogent Social Sciences 2019, Volume 5, Issue 1, pp 1-21

[20] Mostafa S. A. K. *Bioconcrete: Next Generation of Self-healing concrete*. App1 Microbiol Biotechnical 2016, pp. 2591-2602, D01 10.1007/s00253-016-7316-z.

[21] Mousa Ahmad. "*A Business approach for transformation to sustainable construction: an implementation on a developing country."* Resources, conservation and recycling 2015, Volume 101, pp. 9-19.

[22] Ni Bing-Jie, Peng Lai, Law Yingyu, Guo Jianhua, Yuan Zhigno. *Modeling of Nitrous Oxide Production by Autotrophic Ammonia-Oxidizing Bacteria with multiple Production pathways.* EST 2014, Vol 48, pp. 3916-3924, https://doi.org/10.1021/es405592h.

[23] Pearce D. *Is the construction sector sustainable?: definitions and reflections*. Building research and information 2006 , pp. 201-207.

[24] Reap John, Baumeister Djyna, Bras Bert. *Holism, Biomimicry and Sustainable Engineering.* ASME International Mechanical Engineering Congress and Exposition 2008, pp. 1-8. https://doi.org/10.1115/IMECE2005-81343.

[25] Richard C. Hill., Paul A. B. *Sustainable Construction: principles and a framework for attainment.* CME 2010, Volume 15, pp. 223-239, DOI: 101086/01461997372971.

[26] Sabry Moheb A., El-Sherif, Amir Y. *Biomimicry as an approach for bio-inspired structure with the aid of computation*. AEJ 2016, Volume 55, pp. 707-714.

[27] Samani A. K., Attard M. M. *Lateral Stain model for concrete under compression.* ACI Struct J 2014, Volume 111, pp. 441-451.

[28] Sandle T.-Microbiology Society:*Making bio-concrete*, Available Online: microbiologysociety.org/makingbioconcrete (accessed on 19-03-2019).

[29] Seifan Mostafa, Ali Khajeh Samani, and Aydin Berenjian. *"Bioconcrete: next generation of self-healing concrete."* Applied microbiology and biotechnology 2016, Volume 100, No. 6, pp. 2591-2602.

[30] Spelter Arne, Sarah Bergmann, Jan Bielak, Josef Heggarl. *Long-term Durability of carbon-reinforced concrete: An Overview and Experimental Investigations.* Applied Sciences 2019, Volume 9, No. 8, 1-14.

[31] Tavson Filiz, Sonmez Elif. (2015). Biomimicry in Future Design. 7th world conference on Educatuinal Sciences (WCES). Novotel Athens Convention Centre, Anthens, Greece; pp. 2285-2292.

[32] Turner Louise K., Collins Frank G.. *Carbon dioxide equivalent (CO2-e) emissions: A comparison between geopolymer and OPC Cement concrete*. CBD 2013, Volume 43, pp. 125-130.

[33] UNDP-*Sustainable development goals*. Available online: www.undp.org/sustainable development goals (accessed on 11-12-2018)

[34] Wang J., Van T. K., De Belie N., Verstraete W. *Use of silica gel or polyurethane immobilized bacteria for self-healing concrete*. CBM 2012, Volume 26, pp.532-540.

[35] Wang J. Y., H. Verstrare W, De Belie N. . *Self-healing concrete by use of microencapsulated bacteria spores*. Cement Concrete Res 2014, pp. 139-152.

[36] Wang J. Y., De Beli N,. Verstraete W. *Diatomaceous earth as a protective vehicle for bacteria applied for self-healing concrete*. Jind Microbiology Biot 2012, Volume 39, pp. 567-577.

[37] Wang J. Y., Snoeck D., Van Vlierberghe S., Verstraete W., De Belie N. *Application of Hydrogel encapsulated Carbonate Precipitating bacteia for a realistic self-healing in concrete.* CBD 2014, pp. 110-119.

[38] Wicktor V, Jonkers H.M. *Qualification of crack healing in navel bacteria-based self heealing concrete. Cement Concrete Composites* 2011, Volume 33, pp. 763-770.

[39] Wille Kay, Naaman Antoine E., El- Tawil Sherif, Parra Gustavo J. *Ultra-high performance concrete and fiber-reinforced concrete:achieving strenth and ductility without heat curing*. Materilas and Structures 2012, Volume 45, pp309-324, https://doi.org/10.1617/311527-011-9767-0.

[40] Wu M, JoHennesson B, Geiker M. *A review: sself-healing in cementious materials and engineered cementious composite as a self-healing material.* CBM 2012, pp. 763-770.

[41] Youngblood Jeffrey P., Nancy R. Sottos. *Bioinspired Materials for Self-cleaning and Self-healing*. MRS Bulletin 2008, Volume 33, 1-10.

[42] Yuan Xueliang, Tang Yuzhou, Li Yue, Wang Qingsong, Zuo Jian, Song Zhanlong. *Environmental and economic impacts assessment of concrete pavement brick and permeable brick production process- A case study in China*. Journal of Cleaner Production 2018, Volume 171, pp. 198-208