Article

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

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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 negate 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 at solving networks of human problem [9]. It is understandable that the evolveme
ent 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 its 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 fracture 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-methylo trophic 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.

\[
\begin{align*}
\text{CO}_2 + 4\text{H}_2 & \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \quad \text{(1)} \\
\text{CH}_4 + \text{SO}_4^{2-} & \rightarrow \text{HCO}_3^- + \text{HS}^- + \text{H}_2\text{O} \quad \text{(2)} \\
\text{Ca}^{2+} + 2\text{HCO}_3^- & \leftrightarrow \text{CaCO}_3 + \text{H}_2\text{O} \quad \text{(3)}
\end{align*}
\]

**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.](image-url)
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>
<thead>
<tr>
<th>Material</th>
<th>Processes</th>
<th>Percentage of Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio-concrete</td>
<td>Aggregate Production</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>100L bacterial suspension Production</td>
<td>5.00</td>
</tr>
<tr>
<td></td>
<td>Calcium Chloride Production</td>
<td>19.51</td>
</tr>
<tr>
<td></td>
<td>Urea Production</td>
<td>68.08</td>
</tr>
<tr>
<td></td>
<td>Transportation</td>
<td>6.94</td>
</tr>
<tr>
<td></td>
<td>Electricity</td>
<td>0.00</td>
</tr>
<tr>
<td>Concrete</td>
<td>Aggregate Production</td>
<td>11.61</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>0.01</td>
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<tr>
<td></td>
<td>100L bacterial suspension Production</td>
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<tr>
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<td>Calcium Chloride Production</td>
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<td></td>
<td>Electricity</td>
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</tr>
</tbody>
</table>

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


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