Benefits of Biomimicry Adoption and Implementation in the Construction Industry

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Abstract. Biomimicry, the novel field of discipline which studies and emulates nature's models to solve human challenges in a sustainable way is gradually becoming a global phenomenon. However, the paradigm is still in its infancy in the construction industry compared to other sectors. Despite its potential in providing outstanding innovative solutions, the adoption and implementation are impeded by several factors. This research sets out to address and establish the benefits of embracing biomimicry in the construction industry. A structured questionnaire survey was conducted with biomimicry practitioners and construction professionals as respondents. A quantitative approach to data analysis was employed using the mean scores of the factors identified. Creation of green market and services, protection of biodiversity, and conservation of natural resources are the top three benefits established. This systematic approach towards understanding the taxonomy of the benefits of biomimicry is imperative for aiding and reinforcing sustainable construction practices in the industry.

Keywords: Biomimicry · Construction industry · Innovative solutions
Nature · Sustainability

1 Introduction

Due to its ability to improve the economy and the human physical environment, the construction industry is attributed as one of the most essential sectors [1]. It has also been discovered that the industry remains a sizeable economic contributor, employment provider, and source of vital utilities globally. The use of construction investments as a tool by the government to stabilize the economy attest to the industry's key position in the national development strategies of many countries [2]. It can, therefore, be agreed that urbanization is closely linked to the industry due to its associated developments [3]. These include the provision of critical infrastructures like rail, water, bridges, roads, facility assets (office and residential buildings), and plants for production and transmission of energy amongst many others. Not only is the construction industry an integral part of the modernization process, its labor-intensive nature makes it particularly attractive as a means of creating employment, and stimulating economic growths of developing countries [4].

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Statistics have shown that in the drive towards global economic development and rapid urbanization, the construction industry contributes heavily towards numerous environmental challenges. Such include pollution of the environment, excessive consumption of resources, waste generation and depletion of the global ecological integrity. Buildings and infrastructures which are the direct products of the industry have a long-term environmental footprint as they are known to continuously emit a large amount of pollution [5]. According to a study by the United States Environmental Protection Agency, indoor air levels of pollutants may be 2.5 times and occasionally more than 100 times higher than outdoor levels indicating [6]. Pollutant concentrations within the building space emanating from paints, finishes, backing materials and other components are responsible for making indoor pollutants level higher than those of the outside.

In the quest for solutions to the environmental challenges posed by the construction industry, engineers, architects, innovators, scientists and other sustainability proponents are now heading outside the circle to consult and learn from the natural world [7]. This paradigm is described as biomimicry, a novel and growing field of discipline which, which studies nature's models and then emulates their forms, systems, processes, and strategies to solve human challenges in a sustainable manner [8]. Hence, the objective of this study is to identify the benefits of adopting and implementing biomimicry in the construction industry. This study will also seek to identify the biomimicry principles for the sustainability of the construction industry and measures in bridging the knowledge gap.

2 Historical Background of Biomimicry

The emulation and application of systems in nature is no novel practice. Historically, the early man depended on the natural world for existence and survival, evident through the numerous records of native innovations. Few of these innovations cut across the fields of agriculture and food production; medical and pharmaceutical sciences; shelter architectures; manufacturing; and weapons and defense, including sensors, armors and alarm systems amongst others [9]. Examples of early nature-inspired innovations include Velcro (inspired by the re-attachable system of burrs from burdock plants), also known as hook and fasteners [10], London's Crystal Palace building in England (inspired by the huge leaves of the giant Amazonian waterlily) designed by Sir Joseph Paxton [11], and the Monoplane (also known as Avion III) designed built and first tested by Clement Ader [10].

Biomimicry as a term first appeared in the year 1982 as part of the words constituting the topic of Connie L. Merrill's doctoral thesis. It was titled 'Biomimicry of the Dioxygen Active Site in the Copper Proteins Hemocyanin and Cytochrome Oxidase' [12]. However, the term biomimicry became popularized and widely circulated in 1997 through a book titled 'Biomimicry: Innovation Inspired by Nature'. Janine M. Benyus, a biologist and co-founder of the Biomimicry Guild authored the book and is widely recognized as the founder of this novel field of study [13]. Biomimicry is therefore described as human's effort and quest towards the exploration of nature's masterpieces (natural selection, photosynthesis, self-assembly, self-sustaining ecosystems etc.) and

the emulating these designs and manufacturing processes to solve their problems sustainably [14]. The idea is that nature has been found to have developed highly efficient systems and processes with the potential to propel and proffer solutions to the challenges facing humanity today [15]. Biomimicry proponents believed that the industry needs to study the highly successful Research and Development (R&D) lab that has been operational on earth for over 3.8 billion years in which 10 to 30 million species have learned to do everything humans want to do, without polluting the environment, or mortgaging the common future of generations to come [16].

3 Overview and Conceptual Delineation of Biomimicry

Nature has been found to be a robust source of knowledge, culminating in the discovery and progression of novel innovative solutions to present-day human challenges through the adoption and application of biomimicry [17]. These are challenges emanating from the unchecked global growth in industrialization and the resultant exploitation of natural resources [18]. As quoted by Angela Nahikian of Steelcase, "… nature is constantly innovating, endlessly experimenting and ever reinventing itself in the face of new challenges. From materials to products to business models, biomimicry offers a fresh lens for all the dreamers and doers remaking the man-made world" [19].

Throughout literature, multiple terms have been found to describe emulating and learning from nature. Biomimicry, biomimetics and other terms such as bionics, bio-inspired design, biomimesis, bioinspiration, bioanalogous design and biognosis are often used interchangeably to describe this novel paradigm [10, 20, 21]. However, despite the numerous terms, it has been established that there is no difference in their fundamental meanings [22].

Biomimicry originated from the combination of the Greek words *bios* (life) and *mĭmēsis* (imitation), which literally means 'life imitation' or the 'imitation of life' [23–25]. Biomimicry (**bi•o•mim•ic•ry**) studies nature's models and then emulates their forms, processes, systems and strategies to solve human problems sustainably. It is defined as the examination of systems, processes, and elements of nature with the potential to solve human challenges [11]. In biomimicry, solutions are proffered to human challenges by emulating the mechanisms, principles and strategies unearthed within nature [26].

4 Principles of Biomimicry

Nature has managed to survive for 3.8 billion years with organisms as models that manufacture without heat, beat, and treat; ecosystems that are powered by sunlight; and create opportunities rather than waste [7]. Their resulting designs displayed are found to be functional, effective, efficient, sustainable, and aesthetically pleasing as well. However, in the book 'Biomimicry: Innovation Inspired by Nature', Benyus enumerates nine principles of nature, which are also the basic principles underpinning the concept of biomimicry [14]. They are the following:

Nature runs on sunlight;
Nature uses only the energy it needs;
Nature fits form to function;
Nature recycles everything;
Nature rewards cooperation;
Nature banks on diversity;
Nature demands local expertise;
Nature curbs excesses from within; and
Nature taps the power of limits.

5 Methodological Framework

This paper employed the combination of secondary data (review of literature) and primary data (survey questionnaire) to present informative evidence on the practitioner's perspectives for the adoption and implementation of biomimicry. A structured close-ended questionnaire survey which targeted biomimicry and construction professionals (i.e. architects, construction managers, construction project managers, quantity surveyors, structural engineers) was employed. The respondents adopted in the research are those registered with their various professional bodies in the SACI. The questionnaire survey was administered to one hundred and twenty respondents of which one hundred and four responses were received.

The first part of the questionnaire sought the background information of the respondents (i.e. age, educational qualification, professional qualification, years of experience). The second part sought the respondents' assessment of the biomimicry principles that can promote sustainability. The third part dealt with the barriers to biomimicry adoption and implementation and measures to bridge the knowledge gaps on biomimicry in the construction industry. Concerning the biomimicry benefits, the respondents were asked to indicate their level of agreement to the benefits on a five-point Likert scale (strongly disagree-1, disagree-2, neutral-3, agree-4, strongly agree-5). Statistical Package for Social Sciences Version 16 (SPSS V16) software was used to analyze the data obtained. Descriptive statistics, with the aid of mean and standard deviation, was employed to present the results of the analyzed data.

6 Results and Discussions

6.1 Background of Respondents

The distribution of the respondents according to their profession reveals that biomimicry professionals/specialists constituted 24%, quantity surveyors constituted 19.2%, architects constituted 18.3%, civil engineers constituted 15.4%, and construction project managers constituted 11.5%. The average years of experience of the respondents surveyed ranges between 10 and 20 years, implying that they do have significant experience in the construction industry. The result also revealed that all the respondents

surveyed are duly registered and affiliated with their respective professional bodies. Majority of the respondents had master's degree representing 54.8%, 25% had bachelor's degree, 11.5% had diploma certificates while 8.7% had doctorate degree.

6.2 Application of Biomimicry Principles to Promote Sustainability

Table 1 reveals the level of agreement of the respondents to the application of biomimicry for promoting sustainability in the construction industry. All the 23 principles of biomimicry assessed have mean scores greater than 2.5 for the respondents [27]. This is an indication that the respondents concur that all the 23 biomimicry principles should be considered in all the construction stages if sustainable construction is to be achieved. The results further showed that the respondents consider 'harnessing freely available energy', 'using readily available materials', 'recycling all materials', 'using low energy process', and 'using multi-functional design' as the five most important biomimicry principles to be considered. The results, however, agree in its entirety with the studies of Goss [13], Polit [28], and Kennedy et al. [29] that listed biomimicry principles as important checklists through which sustainability can be evaluated and achieved.

Table 1. Biomimicry principles that can promote sustainable construction practices.

Biomimicry principles	Mean	Standard deviation	Rank
Harnessing freely available energy	4.89	0.309	1
Using readily available materials	4.83	0.380	2
Recycling all materials	4.62	0.658	3
Using low energy process	4.56	0.554	4
Using multi-functional design	4.49	0.521	5
Incorporating diversity	4.43	0.498	6
Replicating strategies that work	4.42	0.569	7
Fitting form to function	4.34	0.877	8
Cultivating cooperative/collaborative relationships	4.32	0.754	9
Leveraging cyclic processes	4.30	0.621	10
Using feedback loops	4.24	0.731	11
Self-organizing	4.18	0.619	12
Building from the bottom up	4.17	0.853	13
Doing chemistry in water	4.11	0.985	14
Maintaining integrity through self-renewal	4.08	0.809	15
Breaking down products into benign constituents	4.01	0.940	16
Embodying resilience through variation	3.92	1.121	17
Embodying resilience through decentralization	3.89	0.965	18
Building selectively with a small subset of elements	3.88	0.862	19
Combining modular and nested components	3.87	1.005	20
Integrating the unexpected	3.81	0.882	21
Reshuffling information	3.65	1.031	22
Embodying resilience through redundancy	3.31	1.215	23

6.3 Benefits of Biomimicry Adoption and Implementation

Mean scores and rankings of the benefits of adopting and implementing biomimicry are presented in Table 2. The results are based on the respondent's assessment of the listed benefits. The results showed that the respondents considered 'creation of markets for green products ad services', 'protection of biodiversity', 'conservation of natural resources', 'restoration of natural resources', and 'global warming reduction' as the first five most important benefits expected from the adoption and implementation of biomimicry in the construction industry. The results agree with the studies of Klein [30] and Zari [31]. It is believed that by embracing biomimicry, biodiversity and ecosystem services will be maintained, thereby mitigating greenhouse gas (GHG) emissions and enhancing adaptation to the impacts of climate change.

Table 2. Benefits of biomimicry adoption and implementation in the construction industry.

Biomimicry benefits	Mean	Standard deviation	Rank
Create markets for green products and services	4.56	.499	1
Protect biodiversity	4.48	.521	2
Conserve natural resources	4.43	.693	3
Restore natural resources	4.41	.495	4
Reduce global warming	4.40	.493	5
Improve air quality	4.38	.578	6
Reduce waste streams	4.38	.685	7
Expand markets for green products and services	4.28	.451	8
Optimize life-cycle economic performance	4.22	.682	9
Improve overall quality of life	4.19	1.255	10
Improve water quality	4.19	.925	11
Create new business opportunities	4.07	1.026	12
Enhance occupant comfort and health	3.98	.945	13
Minimize strain on local infrastructure	3.96	1.254	14
Create employment opportunities	3.78	1.307	15
Improve occupant productivity	3.77	1.081	16
Improve the image of the building	3.68	1.143	17
Reduce operating costs	3.61	1.101	18
Reduce maintenance costs	3.52	1.115	19
Heighten aesthetic qualities	3.52	1.140	20
Reduce the civil infrastructure costs	3.25	1.283	21
Minimize occupant absenteeism	3.13	1.204	22

6.4 Measures of Bridging the Knowledge Gap

Mean scores and rankings of the drivers of adopting and implementing biomimicry are presented in Table 3. The results are based on the respondent's assessment of the listed measures to bridge the knowledge gap. The results showed that the respondents

considered 'providing biomimicry education and training', 'increasing client and stakeholders awareness', 'improving availability of biomimetic technology', 'improving availability of biomimetic materials', and improved affordability of biomimetic materials' as the first five most important drivers of biomimicry adoption and implementation in the construction industry. It is imperative for the government and other stakeholders in the construction industry to encourage and facilitate a multidisciplinary collaboration which will result in remarkable and sustainable solutions to human challenges. By promoting awareness, training, workshops and education, biomimicry will be well propagated across in the construction industry, thereby encouraging its adoption and implementation.

Table 3. Drivers of biomimicry adoption and implementation in the construction industry.

Biomimicry drivers	Mean	Standard deviation	Rank
Providing biomimicry education and training	4.69	.464	1
Increasing client and stakeholder's awareness	4.51	.607	2
Improving availability of biomimetic technology	4.45	.500	3
Improving availability of biomimetic materials	4.39	.645	4
Improved affordability of biomimetic materials	4.38	.685	5
Increasing client demand	4.35	.498	6
Providing economic incentives	4.30	.652	7
Improving multi-disciplinary collaboration	4.19	.712	8
Improving government support and intervention	4.18	.983	9
Improving availability of biomimetic framework/measurement standard	4.11	.787	10
Providing biomimicry innovation and certification	4.05	.989	11
Developing a policy monitoring system	3.96	1.004	12
Developing a legal and regulatory framework	3.91	1.158	13
Providing motivation and commitment (self and corporate)	3.90	.807	14

7 Conclusion and Recommendations

Biomimicry has the potential to offer sustainable solutions to identified human challenges, especially in the construction industry. They can also be beneficial in the invention of a novel and innovative materials, products and technologies with sustainable attributes. However, this study has shown that there is a low level of awareness and knowledge among the stakeholders in the construction industry on the concept of biomimicry. This has impeded the adoption and implementation of biomimicry to optimize sustainability in the industry. Biomimicry principles also play a key role in evaluating for sustainability as they are creative common tools and important checklists to be strictly adhered to when sustainability is in focus. Awareness, training and

education of professionals and stakeholders in the SACI on biomimicry should be encouraged for its adoption and practice to be widely accepted. As the whole world is now feeling the effects of climate change, to which the construction industry is known to be the highest contributor, it is imperative to adopt and embrace biomimicry in its entirety for mitigation and adaptation purposes. This will be justified through the benefits of biomimicry which include protection and conservation of biodiversity and natural resources, the creation of employment opportunities and markets for green products and services, reduced waste streams and effects of global warming, restoration of natural resources, and improved air and water quality, amongst others.

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