Assessing the awareness level of biomimetic materials and technologies in the construction industry

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Abstract. The continuous patronage and utilization of unsustainable construction technologies and materials have been identified as one of the major constraints to realizing the sustainability goals of the construction industry. By proliferating and saturating the construction market with materials and technologies with eco-friendly attributes, the negative environmental impacts of the industry will be grossly mitigated. Hence, the adoption of biomimetic materials known to be novel, effective and efficient in this task as a result of their sustainable credentials. This research paper is aimed at assessing the awareness level of biomimetic materials and technologies in the construction industry. A questionnaire survey was conducted on construction professionals to evaluate their level of awareness. A quantitative approach to data analysis was employed using the mean scores of the variables identified. It is established that there is a low level of awareness and familiarity with biomimetic materials and technologies among construction professionals. Raising awareness level, education and government intervention are few among the recommended ways of bridging the knowledge gap on the use of materials and technologies inspired by nature.

Keywords: Biomimicry, Built environment, Construction materials, Nature, Sustainability

1. Introduction

It is common knowledge that the construction industry (CI) significantly increase the economic growth of developed and developing nations [1]. Provision of critical and essential infrastructures such as water, roads and buildings, job creation and enhanced social status of the population are few among the numerous positive impacts of the CI. However, there has been much attention and concentration on the positive impacts while the negative impacts degenerate the human environment silently and gradually, and until lately, openly. High consumption of energy and natural resources resulting in environmental degradation, greenhouse gas (GHG) emissions and pollution are few of the negative characteristics of the industry [2]. Hence, the identification of several fundamental and complex factors influencing the performance of the CI [3]. Reviewed literature also suggests a variety of largely unexamined and divergent factors responsible for the negative footprint of construction activities and outputs on the human environment. The slow transition of the CI from the typical traditional state to holistic sustainability is therefore traceable to numerous critical constraints.

A major restraining factor identified by [4] is the continuous specification and use of unsustainable construction materials and technologies. According to [5], pollutant concentrations are emanating from...
finishes, backing materials, paints and other building materials which are hazardous to human health as it is estimated that people spend as much as 90 percent of their time indoors. Other cogent barriers identified include lack of knowledge on sustainable technologies [6], limited selection of environmentally responsible materials and products [7], lack of sustainable materials [8], and lack of stakeholder’s awareness on benefits, market availability and reliability of construction materials with sustainable attributes [9]. It is therefore imperative to adopt the use of materials and technologies with strict adherence to sustainability principles in mitigating the impact of the CI on the human and natural environment [10].

Historically, early man depended solely on the natural world for the provision of all the components and materials involved in construction and shelter architecture. Apart from meeting the shelter and food demands of the people, nature was also explored and utilized for survival and sustenance thereby providing essential and native innovations in agriculture, food productions, manufacturing, defence and medicine among many others [11]. However, as the world transcends from the first industrial revolution and now to the fourth industrial revolution (4IR), there is an increasing curiosity about the natural environment. The onward march of technology, science and global quest for sustainability has also seen the role of nature grow to support the human existence and providing eco-friendly, innovative and inspiring ideas to tackle environmental challenges.

A careful evaluation of nature’s modus operandi reveals a systemic adherence to sustainability principles thus making the natural world the most original and cheapest source of inspiration and innovation of sustainable ideas and solutions to human challenges. Hence, biomimicry, which entails the study and emulation of time-tested processes, strategies and systems to proffer environmentally responsive solutions to human challenges. Since it came to limelight, biomimicry has been applied in a broad range of sectors such as human safety, transportation, architecture and the built environment, aerodynamics, material research and product design to mention a few [12]. As a new strategy to proffer sustainable solutions to human challenges, biomimicry has recorded breakthroughs in the innovation of technologies that addresses water and energy issues, disaster management issues, waste management and reduction, climate change mitigation and adaptation, and pollution and emission issues among others. However, without prior knowledge of existing biomimetic (nature-inspired) technologies and the benefits accrued to their adoption and utilization, their application in tackling sustainability issues in the CI will be an uphill task. This research study, therefore, aims to assess the level of awareness of biomimetic materials and technologies in the CI. Carefully selected few of the numerous biomimicry solutions and technologies for the CI are identified and evaluated in this paper in other to test their awareness level to construction professionals. A brief understanding of the concept of biomimicry is discussed followed by the research methodology employed in carrying out the research. The next section presents and discusses the findings followed by the conclusion and recommendations.

2. Understanding the biomimicry paradigm
Nature has been discovered to be an abundant source of novel ideas which has resulted in several innovative solutions to different problems facing humanity today [13] These problems are those that emanate from construction activities, exploitation of the natural environment and unchecked population growth globally [14]. The transfer and emulation of knowledge gained through the careful study of nature’s operations to inform sustainable solutions are made possible through biomimicry. As defined by [15], biomimicry is the creation of eco-friendly (sustainable) designs via the study and purposive emulation of nature’s forms, strategies, systems and ecosystems. Since it became popularized, the application of this new field of study has snowballed in various sectors and profession.

The ingenuity exhibited by nature through biomimicry has seen renowned multinational corporations such as Nike, Coca-Cola, Interface, Natura, Procter and Gamble (P&G), General Electric and Boeing among others, turn to nature (biomimicry) for sustainable ideas and solutions to their design challenges. The subscription of these multinationals to biomimicry firmly attests to the belief of sustainability proponents that it offers a problem-solving methodology which results in solutions that awe in their environmentally responsive attributes. Biomimicry can, therefore, be applied to revamp the sustainability of existing creations [16] and can as well be utilized in creating innovative inventions [17].
3. Nature-inspired materials and technologies

For a construction technology or material to be genuinely green (sustainable), there are some critical attributes it must possess. As stated by [5], construction materials and technologies must be bio-based, non-toxic, sustainably harvested, abundant, recyclable, renewable, local, and waste-based (possess recycled content) before being labelled as green (sustainable). However, the natural world has informed the innovation of materials and technologies that have similar attributes exhibited by natural organisms. Not only are these innovations eco-friendly, they are also discovered to possess chemical, physical, and mechanical properties that are advantageous to the efficiency of the CI [18,19,20]. Since the integration and application of biomimicry in different fields (pharmaceuticals, robotics, engineering, and architecture), numerous innovative breakthroughs have been made. Few of these are self-cleaning materials, nature-inspired tough composite materials, coatings and adhesives, and biotechconcrete. Few examples of these innovations are high-strength material inspired by spider silk, water-proof adhesives inspired by mussel’s ability to attach itself to the ocean floor, and high-strength ceramics inspired by abalone shells [21]. Therefore, in a country like South Africa, where the delivery of essential amenities and infrastructure are the deciding factors for the socio-economic upliftment of the people, it is imperative to necessitate the uptake of biomimetic materials and technologies.

4. Research Methodology

This study aim at assessing the awareness level of biomimetic (nature-inspired) materials and technologies in the CI to promote and optimize sustainability. Relying on [22], a database of biological intelligence organized by engineering and design operations, a list of seventeen biomimetic materials and technologies applicable in the CI was carefully compiled. Primary data (survey questionnaire) and secondary data (literature review) were employed to suggest factual evidence on the professional’s awareness level of the seventeen (17) biomimetic materials and technologies. A total of 120 structured close-ended questionnaires were administered with 104 completed and received, representing a response rate of 87%. The respondents selected are practising biomimicry and construction professionals in the South African construction industry.

The design of the questionnaire was in sections. The first section sought the background information of the respondents which include: number of construction projects involved in, professional affiliation, years of experience, and their employer. The second section measured the respondents’ awareness level of the identified biomimetic materials and technologies applicable in the CI. The respondents were asked to indicate their level of awareness on a five-point Likert scale (not aware-1, slightly aware-2, moderately aware-3, strongly aware-4, very strongly aware-5).

Cronbach’s Alpha test was carried out to test the reliability of the research instrument, and a value of 0.975 is achieved. The Cronbach’s Alpha value of 0.975 confirms that the instrument is highly reliable [23]. Data obtained was analyzed with the aid of the Statistical Package for Social Sciences Version 16 (SPSS V16) software. Frequency and percentage were used to present the results of the background information while mean item score (MIS) and the standard deviation were employed to present the result on the awareness level of respondents.

5. Findings and Discussion

5.1. Background of respondents

The results of the distribution of the sampled respondents according to their professional affiliations reveals that majority are biomimicry professionals (24%), followed by Quantity Surveyors (19.2%), Architects (18.3%), and Civil Engineers (15.4%). The least represented are Construction Managers with 11.5% and Project Managers also with 11.5%. The respondents working for private firms/organizations are 79.8% while those working for the government are 20.2%. The results further showed that majority of the respondents are currently involved in 1-2 construction project, representing 51.0%, while those who are involved in 3-4 construction projects are 19.2%. Those involved in no construction projects are 17.3%, those who are involved in more than eight (8) construction projects are 5.8%, those who are
involved in 5-6 construction projects are 3.8%, and those who are involved in 7-8 construction projects are 2.9%. This result is an implication that most of the respondents have considerable years of working experience in the CI.

5.2. Awareness level of biomimetic materials and technologies

Table 1. reveals the mean values, standard deviation (SD), and rankings of the awareness level of biomimetic materials and technologies in the CI. The functions of the identified biomimetic materials and technologies were also included in the table for proper comprehension of the ingenuity of these materials and technologies. The results are based on the respondents’ level of awareness of the listed biomimetic materials and technologies. The results indicated that the respondents considered ‘Eco-Machine’ (mean = 2.93, SD = 1.850), ‘i2 Modular Carpet’ (mean = 2.92, SD = 1.810), ‘Purebond’ (mean = 2.66, SD = 1.868), ‘Eco-Cement’ (mean = 2.65, SD = 1.642), and ‘Sharklet’ (mean = 2.60, SD = 1.877) as the top five biomimetic materials and technologies they are aware of. However, from Table 1, all the seventeen (17) assessed biomimetic materials and technologies have a mean value of less than 3.0. This result implies that to a large extent, the respondents do not have a fair knowledge of biomimetic materials and technologies and their application in the CI. As established by [4], a major constraint to the sustainability of the CI is the wide usage of unsustainable materials and technologies due to low awareness of sustainable alternatives, hence the need to embrace the biomimetic breakthroughs in this area. The continued utilization of unsustainable materials remains one of the major causes of environmental issues ranging from carbon emission, air and water pollution, poor indoor air quality and many more. The results of the descriptive analysis revealed the existence of a shallow knowledge and awareness level of biomimetic materials and technologies in the South African CI. The paucity of knowledge and awareness of these materials and technologies has therefore substantiated their non-patronage, non-usage, and non-application in the industry.

| Biomimetic material/technology | Function                                                                 | Mean | Standard Deviation | Rank |
|--------------------------------|--------------------------------------------------------------------------|------|--------------------|------|
| Eco-Machine                    | Wastewater treatment that purifies water without chemicals               | 2.93 | 1.850              | 1    |
| I2 Modular Carpet              | Individually replaceable and recyclable carpet tiles                     | 2.92 | 1.810              | 2    |
| Purebond                       | Formaldehyde-free wood glue                                              | 2.66 | 1.868              | 3    |
| Eco-Cement                     | Neutral and strength-enhancing carbon sequestering cement               | 2.65 | 1.642              | 4    |
| Sharklet                       | Surfaces that prevent biofouling without causing resistance              | 2.60 | 1.877              | 5    |
| Lotus Clay Roofing Tiles      | Self-cleaning clay roofs                                                | 2.56 | 1.821              | 6    |
| Aquaporin Membrane Technology | Water filtration and purification system                                 | 2.55 | 1.745              | 7    |
| Self-repairing Concrete       | Self-repairing concrete that increases the durability of structures and reduces life-cycle cost | 2.52 | 1.795              | 8    |
| BioWAVE                        | Harnessing wave energy for power generation                              | 2.49 | 1.843              | 9    |
| Lotusan Paint                  | Automatic self-cleaning coat after the mere rinse of a rain shower       | 2.46 | 1.779              | 10   |
| Sage Glass, Quantum Glass (Europe) | Electrochromic smart windows that provide energy savings by reducing cooling/heating costs | 2.37 | 1.607              | 11   |
| Dye-Sensitized Solar Cells and Panels | Low-cost and efficiently produced electricity by artificial photosynthesis | 2.36 | 1.718              | 12   |
ORNILUX Insulated Glass
The insulated architectural glass that prevents bird collisions 2.35 1.563 13
Biolytix System
Waste treatment and water filtering system 2.20 1.633 14
COMOLEVI Forest Canopy
Leaf color and shape enhanced cooling effects 2.15 1.544 15
HotZone radiant heater using Irlens
Spot heater that focuses radiant heat on users rather than heating an entire space 1.88 1.339 16
Chaac-ha Water system collector for rainwater and dew 1.83 1.536 17

6. Conclusion and Recommendations
It is evident that the broad usage, patronage and application of unsustainable materials and technologies constitutes one of the significant barriers to achieving the greening agenda of the CI. Owing to their low level of awareness of the availability of biomimetic (green) materials and technologies which has been substantiated by this study, construction professionals and other stakeholders are restricted to specifying and use of the available traditional and unsustainable ones. However, with the global call for the CI to adopt sustainable construction practices in order to meet the set sustainability goals, a clear and decisive transition from the use and patronage of traditional materials to sustainable ones is imperative. Nature, through biomimicry, have inspired the innovation of highly efficient and eco-friendly materials and technologies for use in virtually all sectors with the CI inclusive. Energy and water issues, pollution and emission issues, waste, disaster prevention, management and resiliency, and health and safety are categories where the developed and commercialised bio-inspired materials and technologies addresses. Numerous sustainable technologies are also in the development stage as a result of research and development (R&D) inspired by nature. It is established through the study of several researchers that biomimetic materials and technologies possess sustainable characteristics and remarkable capabilities such as light-weight, low manufacturing cost, reusability, recyclability, self-healing, self-cleaning, and self-organizing among many others. These characteristics are highly imperative for the survival and sustenance of the CI in transitioning from the conventional to the sustainable or high-performance state. Findings from this study have therefore been able to sensitize the stakeholders in the CI on the existence and benefits of biomimetic materials and technologies. It is also of utmost importance for the government and other stakeholders in the industry to encourage, support and promote the market, patronage, usage and application of biomimetic materials and technologies which is believed will be a giant stride towards achieving the industry’s sustainability goal.

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References
[1] Plank R, 2008 The principles of sustainable construction. The IES Journal Part A: Civil & Structural Engineering 1(4) 301-307
[2] Windapo A. Examination of green building drivers in the South African construction industry: Economics versus ecology. Sustainability 6(9) 6088-6106
[3] Aigbavboa C, Thwala W, 2014 An assessment of critical success factors for the reduction of the cost of poor quality from construction projects in South Africa. In Proc. 30th Annual ARCOM Conf. 773-782
[4] Oguntona OA and Aigbavboa CO, 2017 Promoting biomimetic materials for a sustainable construction industry. *Bioresins, Biomimetic and Nanobiomaterials*. 6(3) 122-130

[5] Pearce AR, Ahn YH and HanmiGlobal Co, Ltd, 2017 *Sustainable buildings and infrastructure: paths to the future*. London: Routledge

[6] Serpell A, Kort J and Vera S, 2013 Awareness, actions, drivers and barriers of sustainable construction in Chile. *Technological & Economic Dev. of Economy*. 19(2) 272-288

[7] Hankinson M, Breytenbach A, 2013 Barriers that impact on the implementation of sustainable design. Cumulus Conf.: Northern World Mandate 1-11

[8] Ametepey O, Aigbavboa C and Ansah K 2015 Barriers to successful implementation of sustainable construction in the Ghanaian construction industry. *Procedia Manufacturing*. 3 1682-1689

[9] Darko A and Chan AP 2017 Review of barriers to green building adoption. *Sustainable Dev*. 25(3) 167-79

[10] Florez L, Castro D and Irizarry J 2013 Measuring sustainability perceptions of construction materials. *Construction Innovation*. 13(2) 217-34

[11] Murr L.E, 2015 Biomimetics and biologically inspired materials. *Handbook of Materials Structures, Properties, Processing and Performance*. Springer International Publishing, 521-552

[12] Al Amin F and Taleb H, 2016 *Biomimicry Approach to Achieving Thermal Comfort in a Hot Climate*. Proc. of SBE16 Dubai 2016, United Arab Emirates

[13] Nyckha J.A and Chen P, 2012 Nature as Inspiration in Materials Science and Engineering. *Journal of the Minerals, Metals & Materials Society*. 64(4) 446-448

[14] Rinaldi A, 2007 Naturally Better. Science and Technology are Looking to Nature's Successful Designs for Inspiration. *EMBO Reports*. 8(11) 995-999

[15] Benyus J.M, 2011 A Biomimicry Primer. *The Biomimicry Institute and the Biomimicry Guild*

[16] Zari M.P and Storey J.B, 2007 *An Ecosystem Based Biomimetic Theory for a Regenerative Built Environment*. Lisbon Sustainable Bldg. Conf. 07, Lisbon, Portugal

[17] Okuyucu C, 2015 Biomimicry Based on Material Science: The inspiring art from nature (review article). *Matter*. 2(1) 49-53

[18] Bhushan B, 2009 Biomimetics: Lessons from Nature - An Overview. *Philosophical Transactions. Series A. Mathematical, Physical, and Engineering Sciences*. 367(1893):1445-1486

[19] Mirkhalaf M, Zhu D and Barthelat F, 2013 *Biomimetic hard materials*. Engineered Biomimicry. Waltham, MA, USA: Elsevier

[20] Yazdi M.F.A, Zakaria R, Mustaffar M, Abd. Majid M.Z, Zin R.M, Ismail M and Yahya K, 2014 Bio-composite materials potential in enhancing sustainable construction. *Desalination and Water Treatment*. 52(19-21) 3631-3636

[21] Benyus J.M, 1997 *Biomimicry: Innovation Inspired by Nature*. (New York, USA: William Morrow & Company)

[22] AskNature, 2018 *Inspired Ideas. The Biomimicry Institute*. Retrieved from https://asknature.org/?s=&p=0&hFR%5Bpost_type_label%5D%5B0%5D=Inspired%20Ideas#.W75qf2gzbIU on September 4, 2018

[23] Pallant J, 2011 *SPSS Survival Manual: A step by step guide to data analysis using SPSS version 18*. Maidenhead, Berkshire: Open University Press