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APPLICATION OF BIOMIMICRY CONCEPT TO IMPROVE THE SUSTAINABILITY OF THE CONSTRUCTION INDUSTRY: A LITERATURE REVIEW

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ABSTRACT

The growing need for urbanisation has resulted in the intense development of the construction industry, which has negatively impacted the conservation of the environment. In this regard, to preserve the ecosystems, the concept of sustainable development was introduced, however, the effectiveness of the existing sustainability practices in the construction industry is at a questionable level. Meanwhile, the evolving concept of biomimicry, which inspires and learns from natural processes, has proven the capacity to achieve sustainable parameters when incorporated into construction processes. Yet, there is a noticeable gap in applying the biomimicry concept to improve the sustainability of the construction industry. Therefore, this study aims to comprehend the applicability of the biomimicry concept in improving the sustainability of the construction industry. Accordingly, a comprehensive literature review was conducted on existing studies related to the biomimicry concept. The content analysis method was used to analyse the collected data. The findings suggested that the biomimicry concept can contribute to sustainable parameters such as material efficiency, energy efficiency and zero-waste concept. Accordingly, this study reveals the potential to improve the sustainability of the construction industry by comprehending the application of the biomimicry concept in detail. In this regard, the study discovers the enablers, barriers and strategies for biomimicry application in the construction industry. Accordingly, this study contributes to the theory and bridges the knowledge gap in utilising biomimicry applications to enhance the sustainability of the construction industry. It demonstrates how various biomimicry inspirations can positively impact sustainable parameters such as material efficiency, energy efficiency, and zero waste, thereby revealing the concept's applicability in developing a sustainable built environment.

Keywords: *Barriers; Biomimicry; Construction Industry; Enablers; Strategies.*

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1. INTRODUCTION

The construction industry contributes to the development of a country as a key contributor to the national economy (Oguntona & Aigbavboa, 2020). Nonetheless, the excessive resource consumption and waste generation of construction activities have termed the industry as one of the most disastrous industries in the world (Huo et al., 2018). According to research, 40% of the natural resources are consumed by the construction industry while accounting for 40% of the global waste generation and 33% of harmful emissions (van Stijn & Gruis, 2020). Thus, a worldwide concern was developed focusing on the sustainability of the construction industry to minimise the industry's harmful impact on nature (Chua et al., 2018).

With the growing interest in sustainable construction practices, resource minimisation practices, including the use of secondary materials (recycled or used materials), were greatly followed in construction projects as a solution to excessive resource consumption (Singh, 2018). Additionally, a clear focus was driven towards creating a healthy and non-toxic environment, formation of sustainable construction standards, pursuing quality in the built environment and establishing sustainable construction technologies (Seferlis et al., 2021). Furthermore, education and training opportunities on sustainable construction activities were implemented to increase the sustainability of the construction sector (Mikhno et al., 2021). Besides employing sustainable practices in the construction industry has a proven capacity to offer numerous benefits mainly including the progression of a firm's competitiveness and profitability (Ahamed et al., 2022). Additionally, sustainable construction practices provide further benefits including reduction of expenses, increased energy efficiency, and health and safety benefits (Hosseini et al., 2019).

Even if sustainable construction practices provide numerous benefits, the successful adoption of sustainable practices is hindered in the construction industry due to several challenges (Ogunsanya et al., 2022). Availability issues of sustainability materials and technologies are a key issue for the successful establishment of a sustainable construction industry (Opoku et al., 2019). Additionally, lack of focus, shortage of rules and regulations and economic barriers impact the effective implementation of sustainable construction practices (Al-Otaibi et al., 2022). Furthermore, limited government support is considered a key reason for the lower adoption rate of sustainable practices in the construction industry (Pham et al., 2020). Besides, the lack of effectiveness in sustainability practices is considered a key barrier to the successful adoption of sustainable construction practices (Ogunsanya et al., 2022). Unlike other barriers such as regulatory barriers and economic barriers, the issues on the effectiveness of sustainability practices are more prevalent since the successful employment of sustainable construction practices strictly relies on this matter (Williams, 2022). Accordingly, the need to introduce new concepts to enhance the effectiveness of sustainable practices was heightened to stimulate the transition to a sustainable built environment (Moshood et al., 2022).

In this context, the concept of biomimicry was introduced, mimicking nature's philosophies to resolve human problems (Beermann & Austin, 2021). The biomimicry concept emulates models, elements, and systems of nature to develop innovative and sustainable design solutions (Khoja & Waheeb, 2020). Accordingly, the biomimicry concept has been integrated into structural material creation, and examples include the

functionally graded concrete, which is inspired by porcupine quill and sea urchins' spines, and sandwich structures, which are inspired by the wings of the green hairstreak butterflies (Ahamed et al., 2022). Furthermore, integrating the biomimicry concept has led to improvements in building shapes. A notable example is the Eastgate Shopping Centre in Zimbabwe, which was designed by mimicking the shape of termite mounds (Yacubov & Smith, 2020). Additionally, the biomimicry concept follows peculiar techniques such as incorporating diversity, combining modular and nested components, and using multi-functional designs (Ahamed et al., 2022; Austin et al., 2020; Oguntona & Aigbavboa, 2019a), which are highly significant in improving the effectiveness of sustainable practices in the construction industry.

Nevertheless, the shortage of biomimicry experts and lack of biomimicry education and training opportunities have hindered the successful adoption of the biomimicry concept in the construction industry (Oguntona & Aigbavboa, 2019a). Furthermore, research is still underway on the biomimicry concept's performance and technical requirements (Zari & Hecht, 2020). Accordingly, studies have been conducted on integrating biomimicry applications into the transportation industry (Kong et al., 2020), healthcare sector (Chairiyah, 2021), agriculture industry (Stojanovic, 2019) and automation industry (Kazasidis et al., 2021). Meanwhile, the studies on integrating biomimicry applications into the construction sector rather focus on applying the biomimicry concept to industrial mechanisms regardless of assessing the role of biomimicry in improving the sustainability of the construction industry (Oguntona & Aigbavboa, 2019a). However, preliminary investigations have been conducted on the intervention of biomimicry applications in achieving the sustainability of the construction industry, including the areas of sustainable construction projects where biomimicry principles can be applied (Adekunye & Oke, 2023), the link between the biomimicry concept and sustainable principles such as repairing, maintaining retrofit and reusing existing buildings (Sai & Lakshmi, 2020) and the connection of organism-based and eco system-based biomimicry applications with sustainable buildings (Syed, 2021). Accordingly, earlier research focused only on specific applications and none of these studies have consolidated all these applications to comprehend the potential of applying the biomimicry concept in improving the sustainability of the construction industry. Nevertheless, it is highly significant to assess the role of the biomimicry concept in enhancing the effectiveness of existing sustainability practices to ensure the endurance of a sustainable built environment (Williams, 2022). Accordingly, to fill this knowledge gap, this study aims to comprehensively investigate the applicability of the biomimicry concept to enhance sustainability in the construction industry based on existing literature.

2. RESEARCH METHOD

The research method is a way of providing accurate responses to the research problem (Pandey & Pandey, 2015). The methodological process of research is developed by stabilising the background of the study, reviewing the existing literature related to the study, and ultimately analysing the collected data related to the identified research problem (Edwards & Brannelly, 2017). Accordingly, the research process followed in this study is illustrated in Figure 1.

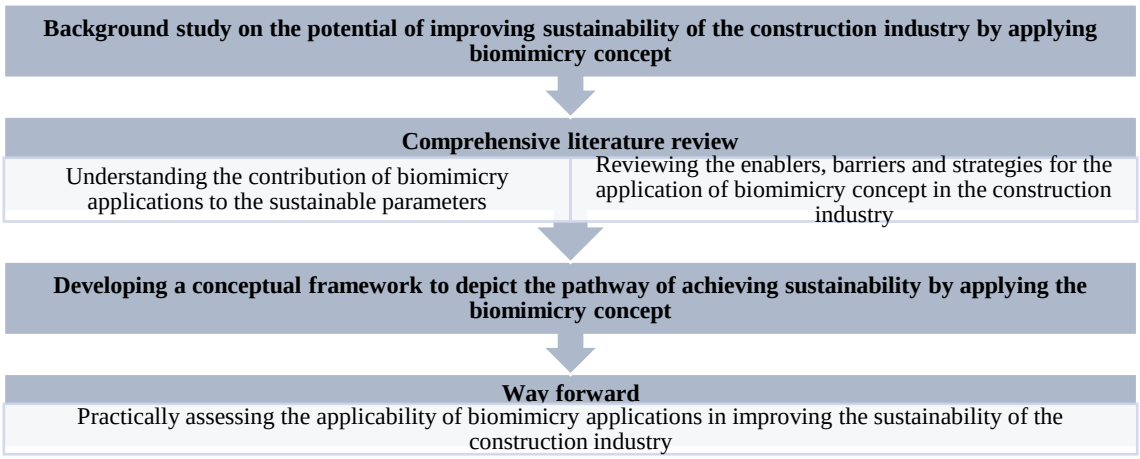

Figure 1: Research process

As explained in Figure 1, a background study was conducted to understand the potential of improving the sustainability of the construction industry by applying the biomimicry concept. From the background study, the importance of conducting a study on applying the biomimicry concept to enhance sustainability was revealed. Herein, a comprehensive literature review was conducted on the research area since reviewing literature assists researchers in distinguishing the updated and structured overview of the existing body of knowledge related to the specific area of the research (Pautasso, 2019). Accordingly, the existing studies were searched in three databases, i.e. (i) Google Scholar, (ii) Web of Science, and (iii) Scopus by filtering through the key terms of "biomimicry", "sustainability" and "construction". Approximately 150 journal articles, conference papers and theses were referred to. The gathered data from the literature review was analysed using the content analysis method since this method has a straightforward criterion for categorising data to improve the contextual significance (Kyngäs, 2020). A conceptual framework was developed from the findings since it acts as an important research element that assists further investigations on the research area (Martín et al., 2019).

3. FINDINGS

The existing sustainability practices in the construction industry and the issues related to their effectiveness were revealed from the literature review on the study area which is presented in this section. Furthermore, the approaches and applications of the biomimicry concept were discovered by literature findings with their capability to achieve sustainable parameters that were supported by real-life example projects. Moreover, the enablers, barriers and strategies for biomimicry applications were revealed by literature findings which are comprehensively presented in this section.

3.1 SUSTAINABILITY IN THE CONSTRUCTION INDUSTRY

Sustainability in the construction industry refers to the creation and accountable upkeep of a healthy built environment based on ecological and resource-efficient principles (Ahiabu et al., 2022). Sustainable construction projects develop into a sizable competitive advantage, increasing the profitability of the venture through higher rents and reduced life cycle costs, which is highly valued by investors (Sanchez et al., 2020). Simultaneously, it has been demonstrated through empirical research that the presence of

environmentally friendly production correlates with the firm's profitability and competitiveness (Ahamed et al., 2022). Due to the wide range of benefits offered by integrating sustainability into the construction industry, construction practitioners are highly motivated to execute sustainability practices in construction projects (Mensah, 2019). Accordingly, Table 1 provides the sustainability practices that are implemented in the construction industry.

Table 1: Existing sustainability practices in the construction industry

Sustainable Practices	Authors																	
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Resource minimisation				✓											✓			
Maximisation of resource reuse	✓		✓		✓	✓		✓	✓		✓		✓	✓		✓	✓	
Utilisation of renewable or recyclable resources			✓	✓			✓				✓	✓			✓			✓
Protection of the natural environment	✓	✓			✓				✓	✓			✓				✓	
Creation of a healthy and non-toxic environment			✓	✓							✓	✓						✓
Enforcement of sustainable legal		✓				✓		✓		✓				✓		✓		
Standards, guidelines or policies for sustainable construction				✓	✓		✓					✓	✓		✓			✓
Designing based on sustainability principles	✓	✓				✓		✓	✓	✓				✓		✓	✓	✓
Technologies, processes and innovations based on sustainability principles		✓				✓				✓				✓				✓
Achievement of quality in creating the built environment		✓		✓	✓			✓		✓		✓	✓			✓		✓
Measurement and reporting based on sustainability principles																		✓
Education and training based on sustainability principles	✓			✓	✓		✓		✓			✓	✓		✓		✓	

A - (Mikhno et al., 2021), B - (Wuni et al., 2019), C - (Sanchez et al., 2020), D - (Singh, 2018), E - (Cedeño et al., 2018), F - (Hossain et al., 2020), G - (Darko et al., 2019), H - (Ghisellini et al., 2018), I - (Khoshnava et al., 2020), J - (Oyebode, 2018), K - (Athapaththu & Karunasena, 2018), L - (Silvestre & Ţîrcă, 2019), M - (He et al., 2018), N - (Kim et al., 2018), O - (Rai et al., 2021), P - (Yu et al., 2020), Q - (Parn & Edwards, 2019), R - (Seferlis et al., 2021)

As Table 1 suggests, numerous sustainability practices are currently implemented in the construction industry to increase the quality of the industrial processes (Xia et al., 2018). Designing based on sustainability principles is one of the most well-recognised sustainability practices in the construction industry to reduce the effects of building on the environment (Fianko et al., 2021). According to Singh (2018), sustainable building designs focus on using energy-efficient heating, lighting, air conditioning systems, and wastewater recycling technologies to improve the building's environmental performance. Besides, following sustainability guidelines such as using renewable energy sources for construction (e.g., solar power) will improve the sustainable features of the buildings while reducing carbon dioxide and other harmful emissions (Lin & Zhu, 2019).

Even if sustainable construction has captured the attention of the construction industry, it is not effectively practised (Rajamanickam et al., 2019; Ahamed et al., 2022). One of the major reasons for this issue is that sustainable practices frequently have a high initial cost (Aramesh & Shabani, 2020). There are many difficulties incorporated with adapting to sustainable designs (Ogunsanya et al., 2022). For instance, renewable energy sources mostly depend on location and weather conditions because of their natural characteristics, and they are less capable compared to fossil-powered energy sources (Opoku et al., 2019). In addition, some sustainable materials need chemical treatments to perform effectively on fire resistance and durability (Zhang et al., 2023). Sustainable practices lack

effectiveness based on such issues; thus, to increase the effectiveness of sustainability principles, it is highly significant to comprehend the integration of sustainability principles with novel concepts that consider the conservancy of the environment (Tanwar et al., 2022).

3.2 THE CONCEPT OF BIOMIMICRY AND THE CONSTRUCTION INDUSTRY

According to research, nature has the best organisation in terms of form and function, which can produce practical and long-lasting designs (Austin et al., 2020). Therefore, academics, architects, and designers known as Bioneers believe that insights from nature can be used to inform their design processes (Jalil & Kahachi, 2019). Accordingly, an applied science known as "biomimicry" was introduced. Herein, biomimicry uses natural patterns, mechanisms, and systems to generate concepts for solving problems (Sadegh et al., 2022). The word 'biomimicry' became well-known in 1997 with the publication of "*Biomimicry: Innovation Inspired by Nature*," authored by the biologist and co-founder of the biomimicry guild Janine M. Benyus (Jalil & Kahachi, 2019). Afterwards, the biomimicry concept was instituted with several corresponding definitions. Table 2 lists various definitions of "biomimicry" that thoroughly explain the concept and are supported by prior research.

Table 2: Definitions of biomimicry concept

Definition	Authors
A relatively new field of science called "**nature as a model**" utilizes natural phenomena as models for human problems and seeks to replicate or be inspired by them.	(Pathak, 2019)
A novel perspective on and assessment of nature is that of **nature as a mentor.** This new understanding explains where we have faltered thus far and what we can take away from it.	(Beith, 2021)
3.8 billion years of **natural evolution as a measure**, along with ecological norms, quality assurance, and standards, are used to assess the sustainability of inventions. The laws of sustainability have already been discovered by nature. The "rightness" of our inventions is assessed using a biomimicry standard.	(Wan & Subri, 2021)
To solve human issues, biomimicry involves observing nature's most successful innovations and then modelling systems after them. It can be described as **"innovation inspired by nature."**	(Alanbari et al., 2022)

As elaborated by the definitions in Table 2, biomimicry studies natural models and then copies their forms, processes, systems, and tactics to address human problems sustainably (Pathak, 2019). It is an innovation strategy that seeks long-lasting solutions by mimicking proven patterns and processes found in nature (Anwar et al., 2018).

Simultaneously, the studies that have been conducted on the biomimicry concept specifically focusing on the construction context define biomimicry as a concept that gets inspiration from nature for designing, producing and maintaining building systems, elements and processes (Adekunye & Oke, 2023). It is referred to as "imitation engineering" (p.514), which integrates natural science with construction engineering (Sai & Lakshmi, 2020). Moreover, construction projects inspired by the biomimicry concept can be considered a major contributor to developing a regenerative built environment (Syed, 2021). Furthermore, there are several methodologies for applying the biomimicry concept in the construction industry from its inception to its depletion (Adekunye & Oke, 2023). In this vein, the two main methodologies that researchers have introduced for the implementation of the biomimicry concept are; (i) the problem-based (top-down) approach, and (ii) the solution-based (bottom-up) approach (Sadegh et al., 2022).

The problem-based (top-down) approach is initiated by the design problem, where the designers identify the issue and then look for remedies (Jamei & Vrcelj, 2021). The authors further mentioned that this approach encourages biologists to compare the issue to a natural process that has resolved a comparable issue. Therefore, the problem-based (top-down) approach depends on the clear identification of objectives and constraints of the design problem (Austin et al., 2020). Conversely, in the solution-based (bottom-up) approach, the design process depends on the factual knowledge of biologists and scientists rather than problems with human design (Beermann & Austin, 2021). In this approach, natural solutions inspire the design of a process or system, and natural techniques will be converted into technical answers (Abedanzadeh et al., 2021). Accordingly, many inventors follow both biomimicry approaches to optimise their designs with inspiration from nature (Prianka et al., 2018). Consequently, biomimicry is currently at the forefront of scientific and technological research since it offers novel views on the synthesis of ecologically compatible, environmentally non-threatening, and dynamically efficient materials for multiple industries over the globe (Katiyar et al., 2021).

3.3 BIOMIMICRY APPLICATIONS IN THE CONSTRUCTION INDUSTRY

The use of biomimicry in the construction industry focuses mostly on enhancing the built environment through advancements in construction and operation, as well as the reduction in environmental consequences by incorporating insights from nature (Ahamed et al., 2022). Research suggests that the use of biomimicry innovation techniques allows construction professionals and their associated partners to develop high-performance, sustainable, and energy-efficient buildings that adhere to advanced waste management practices (Dash, 2018). Amer (2019) pointed out that while there are numerous historical examples of biomimicry applications in the construction industry, their implementation varies based on the project's specific circumstances and demands. Certain solutions offer design flexibility, while others enhance structural stability by incorporating biomimicry principles into architectural elements, thereby contributing to sustainable construction (Othmani et al., 2018). Accordingly, Table 3 lists several examples of construction projects that utilised biomimicry inspirations to increase the sustainability of the projects.

Table 3: Construction projects that utilised biomimicry inspirations

Name of the building	Biomimicry inspiration	Application to the project	Positive environmental/ economic/ social attainment	Contribution to the sustainable parameters
Eiffel Tower	Thigh Bone	The flare on the outside mimics a femur bone.	Withstand thermal expansion	Material efficiency, functionality and aesthetics in design
Beijing national stadium	Bird's Nest	Contains ETFE panels that act as insulation by cramming tiny pieces of material inside the twigs.	Cost reduction, durable and recyclable materials	Energy efficiency, material efficiency, zero waste, cost-efficient technology
L'institute Du Monte Arabe	Iris of Eye	Cladded with a screen with an automated lens to control light.	Natural lighting and ventilation	Renewable energy usage, energy efficiency, passive design strategy
Sinosteel International Plaza	Beehive	The windows are made in five various hexagonal sizes and arranged in an energy-efficient way.	Energy efficiency achieved by 75%	Renewable energy usage, energy efficiency, passive design strategy
Rafflesia House	Rafflesia Flower	Concave and convex internal walls regulate the flow of air inside.	Utilised zero waste energy	Energy efficiency, zero waste, functionality and aesthetics in design

Name of the building	Biomimicry inspiration	Application to the project	Positive environmental/ economic/ social attainment	Contribution to the sustainable parameters
The Esplanade Theatre, Singapore	Durian Fruit	Use of geometric structure and shape, heat protection for spikes.	Lowered HVAC levels, Durian's form allows for optimum view of the bay	Energy efficiency, material efficiency, passive design strategy
Lily pad, Floating city	Lily pad	An idea for a floating city that is entirely self-sufficient and is meant to offer protection from potential climate change.	Able to process carbon dioxide in the atmosphere and absorb it	Renewable energy usage, energy efficiency, zero waste, passive design strategy
Shi Ling Bridge	Shell Lace Structure	Uses an optimized curvilinear geometry in conjuncture with corrugation to provide stiffness.	Formed an incredibly expressive, unique and economically intuitive bridge	Passive design strategy, functionality and aesthetics in design
Lotus Temple	Lotus Flower	Shapes were translated into formulae using thin concrete shells and used in engineering drawings and structural analysis.	Adequate light and ventilation, structurally efficient design	Material efficiency, passive design strategy, functionality and aesthetics in design
Sydney Opera House	Shell-like sails	Comprise three groups of interlocking vaulted 'Shells' that roof two main performance halls.	Temperature to be 22.5 degrees Celsius to ensure the instruments stay in tune	Energy efficiency, passive design strategy, functionality and aesthetics in design

Source: (Dash, 2018)

According to Table 3, different applications of biomimicry can be identified in the construction industry, which has contributed to the achievement of different sustainability parameters. It is rather clear that to address any construction-related challenge, biomimicry applications need to be comprehended and designed relevant to a specific context and then may be applied to other construction scenarios (Sá & Viana, 2023).

3.4 ENABLERS, BARRIERS AND STRATEGIES TO THE APPLICATION OF BIOMIMICRY CONCEPT

In comprehending the optimum application of the biomimicry concept in the construction industry, it is of utmost significance that the enablers, barriers and strategies are identified for the effective implementation of the concept. Accordingly, Table 4 summarises the enablers, barriers and strategies for the application of the biomimicry concept as identified by the previous studies.

Table 4: Enablers, barriers and strategies for the application of the biomimicry concept

Enablers	Barriers	Strategies
Using readily available materials	Shortage of biomimetic technology	Providing education and training
Incorporating diversity	Absence of biomimicry in the university curriculum	Increasing stakeholder awareness
Recycling all materials	Limited availability of biomimetic materials	Improving the availability of biomimetic technology
Using low-energy processes	Shortage of incentives for adopting biomimicry	Improving the availability of biomimetic materials
Fitting form to function	The absence of a database and information on biomimicry	Improved affordability of biomimetic materials
Building from the bottom-up concept	Absence of a well-defined biomimicry approach	Increasing client demand
Doing chemistry in water	Shortage of client demand	Providing economic incentives
Breaking down products into benign constituents	Risks associated with the implementation of biomimicry	Improving multi-disciplinary collaboration
Maintaining integrity through self-renewal	Time commitment	Improving government support and intervention

Enablers	Barriers	Strategies
Embodying resilience through decentralization	Shortage of real-life examples	Improving the availability of biomimetic framework/ measurement standard
Building selectively with a small subset of elements	Perceived high cost of adopting biomimicry	Providing biomimicry innovation and certification
Embodying resilience through redundancy	Absence of biomimicry training and education programme	Developing a policy monitoring system
Combining modular and nested components	Lack of awareness	Developing a legal and regulatory framework
Reshuffling information	Lack of governmental and regulatory support	Providing motivation and commitment (at individual and corporate levels)
Leveraging cyclic processes	Lack of professional knowledge in biomimicry	
Using multi-functional design	Absence of building codes and regulations	
	Shortage of biomimicry measurement framework	

Sources: (Ahamed et al., 2022; Varshabi et al., 2022; Jamei & Vrcelj, 2021; Oguntona & Aigbavboa, 2019a; Beermann & Austin, 2021; Zari & Hecht, 2020; Blanco et al., 2021; Oguntona & Aigbavboa, 2019b; Bumgardner & Nicholls, 2020; Austin et al., 2020; Soteriou et al., 2021)

As Table 4 suggests, there are various enablers, barriers and strategies for applying the biomimicry concept in the context of the construction industry. Accordingly, using readily available materials, incorporating diversity (e.g. in the biomimicry concept, benefits are obtained by bringing designers from diverse backgrounds and expertise for construction planning and designing) and recycling the materials will effectively enable the successful implementation of the biomimicry concept in the construction industry (Ahamed et al., 2022). Besides, combining modular and nested components, leveraging cyclic processes and using multi-functional designs will require complex technologies, yet they will stimulate the successful adoption of the biomimicry concept in the construction industry (Varshabi et al., 2022). At the same time, there are numerous technology-related barriers, including a shortage of biomimetic technology, the absence of databases and information on biomimicry and the absence of a well-defined biomimicry approach, which hinders the successful adaption of biomimicry applications in the construction industry (Blanco et al., 2021). Furthermore, regulatory barriers, including the absence of building codes and regulations and the shortage of biomimicry labelling/measurement framework, obstruct the effective implementation of biomimicry applications in the construction industry (Jamei & Vrcelj, 2021). In this regard, strategies such as developing a policy monitoring system, developing a legal and regulatory framework, and improving government support and intervention can be performed since it will positively impact overcoming the regulatory barriers for the implementation of the biomimicry concept in the construction industry (Oguntona & Aigbavboa, 2019a). Moreover, providing biomimicry education and training, increasing stakeholder awareness and improving multi-disciplinary collaboration will enhance the success rate of biomimicry adaption in the construction context, which will eventually increase the sustainability of the construction industry (Soteriou et al., 2021).

4. CONCEPTUAL FRAMEWORK

A conceptual framework detailing how to study the research problem can be created by evaluating the literature on the research area (Guo et al., 2020). Additionally, it describes the crucial considerations to make while conducting research in either a graphical or narrative manner, which may involve diagrams, flow charts, mind maps, and other visual aids (Ahmadi et al., 2020). Accordingly, Figure 2 illustrates the conceptual framework

for assessing the applicability of biomimicry applications to improve the sustainability of the construction industry.

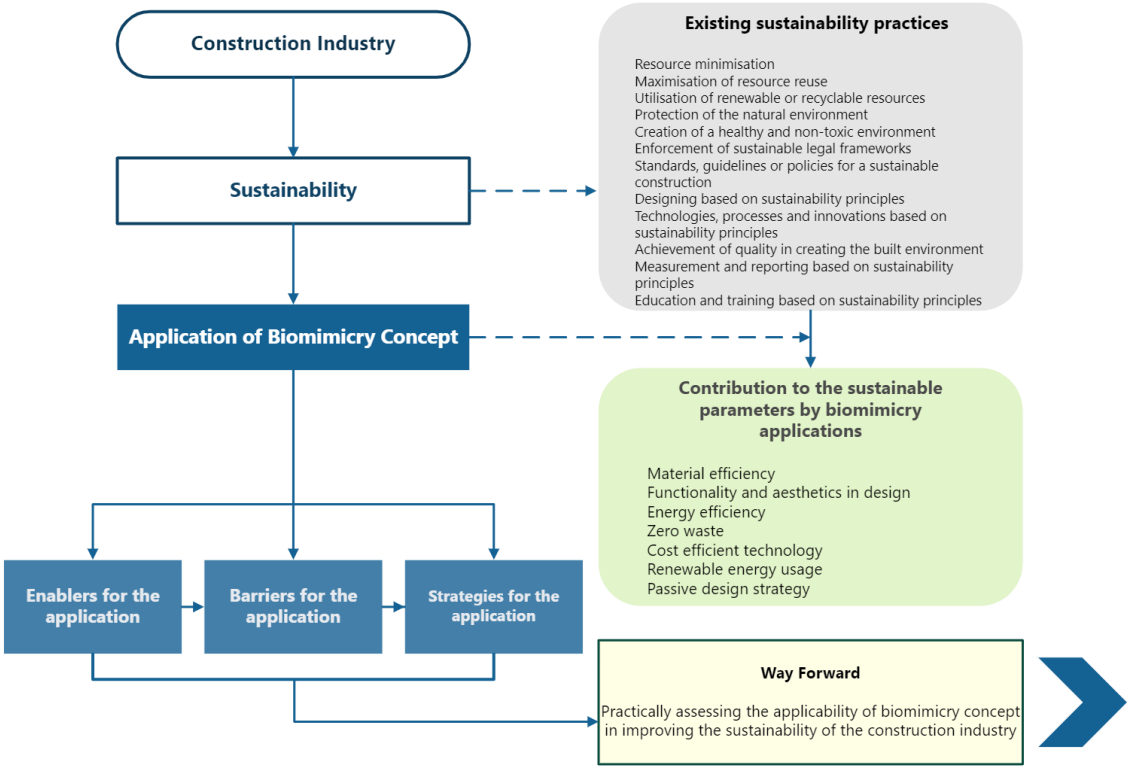

Figure 2: Conceptual framework for assessing the applicability of biomimicry applications to improve the sustainability of the construction industry

The comprehensive path to fill the research gap with the findings of the collected literature is demonstrated in Figure 2. Accordingly, the existing sustainable practices in the construction industry can be improved by biomimicry applications since they help to achieve sustainable parameters such as material efficiency, energy efficiency and cost-efficient technologies. For instance, biomimicry inspirations such as thigh bone and lotus flower will improve the material efficiency which will eventually increase the effectiveness of sustainability practices such as resource minimisation and sustainable designing (Dash, 2018). However, barriers such as limited availability of biomimetic materials, risks associated with the implementation of biomimicry and lack of awareness hinder the successful adoption of biomimicry applications, which can be overcome by strategic implementations, such as improving the affordability of biomimetic materials, providing economic incentives and increasing stakeholder awareness (Austin et al., 2020; Oguntona & Aigbavboa, 2019b; Varshabi et al., 2022). On this note, it is important for future researchers to comprehend the enablers, barriers, and strategies for biomimicry applications practically to address the research gap in employing biomimicry applications to improve the sustainability of the construction industry.

5. CONCLUSIONS AND RECOMMENDATIONS

With the excessive ecological damage caused by the construction industry, sustainability practices are considered as the key explanation to secure the environment. Nonetheless, this study reveals the need to increase the effectiveness of the existing sustainability practices, and novel concepts such as biomimicry applications can be implemented in the

construction industry to increase the sustainability of projects. Accordingly, this study finds that the two approaches of the biomimicry concept, i.e., (i) the top-down approach, and (ii) bottom-up approach, have the potential to integrate the insights from nature into construction processes and eventually contribute to sustainability parameters such as energy efficiency, material efficiency and cost-efficient technology. Additionally, this study reveals that there are numerous enablers, barriers, and strategies for the implementation of biomimicry applications in the construction context, which need further exploration to successfully adapt the concept within the construction industry.

Accordingly, this study serves the theory by bringing the gap in using biomimicry applications to increase the effectiveness of sustainability practices in the construction industry. Practically, this study serves by providing insights to industry practitioners on utilising biomimicry applications for their construction projects. It is highly recommended that industry practitioners adhere to novel concepts such as biomimicry inspirations since it has a positive impact environmentally, socially and economically. While biomimicry applications offer effective solutions to certain challenges, they cannot address issues related to government support and economic barriers. Therefore, further research is needed to find appropriate solutions for these issues. Furthermore, future studies are directed at practically assessing the applicability of biomimicry applications in improving the sustainability of the construction industry. Moreover, it is highly recommended to conduct further studies on the enablers, barriers and strategies in detail for the application of the biomimicry concept in the construction industry since it is of utmost significance to ensure the conservation of the ecosphere with the progressive development of a sustainable built environment.

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