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Biomimicry and the BREEAM category of energy for sustainable architecture and sustainable urbanism

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Abstract

The paper aims to understand the combination of biomimicry and the BREEAM category of energy to identify innovative solutions for sustainable architecture and sustainable urbanism. It purposes to find similarities between biomimicry and the BREEAM category of energy by selecting and analyzing literature. The study aims to indicate potential applications of biomimicry, and the BREEAM category of energy focused on building design. The main question of this research is to discover how biomimicry and the BREEAM category of energy could combine to identify innovative solutions to address sustainable architecture and sustainable urbanism? The research required a systematic literature review for identifying, collecting, and analyzing relevant studies. JSTOR, Science Direct, and Microsoft Academic were used as repositories and led to the identification of 3855 studies. After screening, eligibility, and inclusion, 39 studies were included in the systematic literature review. More studies discussed sustainable architecture and required classification through subthemes: biomimetic design and associated principles; building skin; integrated framework; designing with BREEAM. The paper provides insight into biomimetic design approaches and energy management combining to ensure sustainability ranging from a building to an urban environment. The chosen research method causes the research results to lack generalizability since it does not associate with other BREEAM categories such as health and wellbeing, innovation, land use, materials, management, pollution, transport, waste, and water. The research fulfills the need to study the combination of biomimicry and one of the BREEAM categories to identify innovative solutions for sustainable architecture and sustainable urbanism.

Keywords: Nature-based solutions; Biomimicry; BREEAM; Sustainable architecture; Sustainable urbanism

1. Introduction

Nature-based design approaches such as biomimicry could create solutions to sustainable architecture and sustainable urbanism. Biomimicry is the imitation of models, systems, and elements of nature to solve complex human problems [1]. Biomimicry has its history when contributing to the creation of sustainable architecture and sustainable urbanism. Due to the worldwide concern of buildings contributing to global CO_2, and other GHG emissions, the issue of building performance in sustainable architecture and sustainable urbanism has grown. Previous research discovered different uses of building components such as walls and building facades for integrating systems, infrastructure, and acoustic control [2]. Studies also showed that building performance is enhanced by the volumetric expansion of existing buildings that form prosthetics reducing the negative environmental impacts to the natural environment and improving the sustainability of the built environment [3].

Humans have relied on natural systems for food and materials for their livelihood. This knowledge has passed on from generation to generation, and humans kept on learning about natural systems for making optimal usage of seasons and their patterns. Due to an increase in the knowledge of natural systems, humans began to domesticate animals needed

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for farming such as livestock. After securing their basic needs, humans decided to consider more complex applications for processing nature's raw materials. Some of these applications included building materials, weapons, and cooking equipment. Due to advanced mechanization movements such as the Industrial Revolution, the exploitation of natural resources elevated, led by practices relating to metallurgy, petrochemicals, internal combustion, and manufacturing. Humans understood that they could make diverse and distinct specialized and super-specialized products from natural resources and stopped making attempts to understand nature's multiparameter space, its mechanisms, and the interrelation of its counterparts.

Lesser focus on natural systems was directly proportional with an accelerated increase in the scale of products on the planet so much so that humans exceeded the planet's carrying capacity [4]. Most of the products and solutions devised in the last three centuries [5] have not been adaptive enough to our natural ecosystems. These products and solutions have led to substantial global challenges such as climate change, deforestation, and the creation of pollution. A balance between the development of the built environment and preservation of the natural environment is possible if engineering knowledge is combined with the knowledge of natural systems rather than just the extraction of resources and, therefore, to foster biomimicry and innovation inspired by nature.

Benyus [5] went into more detail and proposed several ways in which innovations have taken inspiration from nature, such as form: aerodynamic shapes, non-chemical adhesive methods, structural finishes; process: heating and cooling systems, nutrient cycles, filtration, desalination, energy capture, energy storage; and ecosystem: feedback loops, diversity, organism niches, interactions, symbiotic relationships, food webs, energy and material flows, resilience. A few notable examples of innovations inspired by nature's form include Velcro: designed after understanding cockleburs under a microscope leading to the observation of hook-like shape; Gecko Tape: analyzing the walking methods of gecko lizards on surfaces; Vortex Generator: studying the wing plumule structure in owls; and Stomatex: realizing the function of stomata in leaves leading to the discovery of a fabric providing passive humidity control.

To maintain the balance between the development of the built environment and the preservation of the natural environment, and due to the growing concern of building performance, environmental assessment methods (Table 1) were developed. Environmental assessment methods help architects, engineers, designers, contractors, and clients compile attributes of a building. Examples of building environment assessment and certification systems include BREEAM (1990) operated by BRE Global, LEED (1998), Leadership in Energy and Environmental Design, owned by the US Green Building Council, CASBEE (2001) designed by the Japan GreenBuild Council (JaGBC) and the Japan Sustainable Building Consortium (JSBC), green building rating system used in projects throughout Japan, Green Star (2002) designed by the Green Building Council of Australia (GBCA), NF/HQE (2005) owned by AFNOR and AIMCC, operated by Certivéa, and DGNB (2008), the German Sustainable Building Council's assessment method.

Table 1 Leading environmental assessment methods by age

Environmental assessment methods	Year of origin
BREEAM	1990
LEED	1998
CASBEE	2001
GREEN STAR	2002
NF/HQE	2005
DGNB	2008

BREEAM is selected for this research as it is the most developed in terms of the scope of assessments (buildings of different typologies, communities). It is the world's most foremost environmental assessment method and rating system for buildings, with 200,000 buildings with BREEAM assessment ratings and over a million registered for assessment since it launched in 1990. BREEAM is also most suitable for this research as it recognizes measures of performance, set against established benchmarks, to evaluate a building's specification, design, construction, and use. These measures represent a wide range of categories: energy, health and wellbeing, innovation, land use, materials, management, pollution, transport, waste, and water. BREEAM has a simplistic and straightforward scoring system, which is transparent, flexible, easy to understand, and supported by evidence-based science and research. Other very significant reasons for selecting BREEAM for studying it with biomimicry to achieve sustainable architecture and sustainable urbanism include its robust technical standard with rigorous quality assurance and certification. BREEAM covers all building types, such as schools, healthcare buildings, offices, and industrial units.

2. Methodology

Discovering innovative solutions developed by combining biomimicry and the BREEAM category of energy for achieving sustainable architecture and urbanism opted for a systematic literature review. A systematic literature review identifies specific and measurable gaps in existing knowledge. This section identifies the undertaken strategy and methodology [6] for collecting and analyzing existing literature. The chosen method provides a sequential description of techniques used to select and determine relevant studies. A systematic literature review evaluates and interprets all available research related to the proposed research topic, research question, or phenomenon by applying an accurate methodology [6]. Most research needs a literature review, and if it is not focused, certainly, it would not have scientific value. The main research question is how the combination of biomimicry and the BREEAM category of energy could create innovative solutions to achieve sustainable architecture and sustainable urbanism. Various search strings were determined, from the specified research question aimed to discover maximum relevant literature. These search strings included biomimicry for sustainable architecture, biomimicry for urban planning, BREEAM and sustainability, BREEAM category of energy for sustainable architecture, and BREEAM category of energy for urban planning. These search strings were used to gather studies available on JSTOR, ScienceDirect, and Microsoft Academic, leading to the identification of 3,855 studies. The next step was to delete duplicates (2,407 studies), followed by screening by keywords from other fields (e.g., medical science, tissue engineering, computer science, business, gene technology, nanotechnology, textile engineering). The remaining 1,492 studies were scanned by title and abstract; leaving 122 studies for which inclusion and exclusion criteria were established. The inclusion criteria entailed online accessibility of research papers published in English and related to biomimicry, BREEAM, energy, sustainable architecture, and sustainable urbanism. The exclusion criteria included research papers from other fields such as geography, management, business, finance, commerce, nanotechnology, and medical science. After all steps from identification to screening to eligibility, 39 studies were a part of the systematic literature review. Table 2 shows the described SLR steps. Table 3 shows the included studies, identified themes, and subthemes. The next section and its subsections concentrate on presenting and analyzing these studies.

Table 2 Systematic literature review steps and number of studies

	Repositories		
Steps	**JSTOR**	**Science Direct**	**Microsoft Academic**
Identification	3855		
Screening	1492		
Eligibility	122		
Inclusion	39		

Table 3 Themes related to included studies

Theme	**Included studies**
Addressing sustainable architecture	[7-28]
Biomimetic design and associated principles	[7-11]
Building skin	[12-21]
Integrated frameworks	[22-26]
Designing with BREEAM	[27,28]
Addressing sustainable urbanism	[29-45]

3. Systematic literature review

3.1. Addressing sustainable architecture

Several subthemes were identified from the included literature studying the combination of biomimicry and the BREEAM category of energy achieving sustainable architecture. These subthemes addressed sustainable architecture through the discovery of biomimetic design and associated principles, through the building skin, through integrated frameworks, and by designing buildings with BREEAM.

3.1.1. Biomimetic design and associated principles

Li [7] proposed a three-ring model of sustainability first for determining the process behind the sustainable design of buildings. The author admits that the successful resolution of a design depends on its harmonious dynamic relationship between architecture, the natural environment, the economy, and society. The three-rings of sustainability are natural environment, economy, and society. The research recognizes BREEAM and its sustainable building code issued in 2006 describing environmental compliance and suggests a few new factors for the category of energy. These factors include dwelling emission rate, building fabric, internal and external light, low and zero-carbon technologies, and cycle storage. The study findings predicated five principles for sustainable architecture which were:

- The principles for giving top priority to the sake of the whole, based on the conception of respecting nature;
- The principle of satisfying the needs of joint, sustainable, and harmonious development between humans and nature;
- The principle of making full use of natural resources according to the rule of less consumption and more utilization;
- The principle of using suitable measures to local conditions to creating a user-friendly environment;
- The principle of creating flexibility for buildings by adjusting links in designing process.

One of the EU's policies is to mitigate climate change and set ambitious goals for energy and carbon reduction for the built environment [8]. The EU targeted the UK Government's Climate Change Act 2008 and set up a target to reduce greenhouse gas emissions in the UK by at least 80% from 1990 levels by 2050 [8]. The study identified that attention is being paid to carbon reduction from the built environment with new EU directives, more stringent building regulations and general environmental concerns have encouraged the development of Standard Assessment Procedure (SAP), Simplified Building Energy Model (SBEM), Code for Sustainable Homes (CSH), and the Building Research Establishment Environmental Assessment Model (BREEAM). Gaps in current approaches to building design were identified such as building energy simulation tools and their application, applications of building regulations and codes for sustainable design, and the current architectural practice and low carbon design [8]. A design framework and a set of integrated IT tools are proposed to enable the analysis of building design energy performance active and passive renewable energy technologies at instances where the opportunity to improve whole lifecycle energy performance is still possible [8]. To add perspective and context to the designed framework; it was integrated with the RIBA's plan of work and its key stages - one of the most widely used frameworks for construction project delivery. The framework that incorporated low carbon design into architectural practice was integrated into the Concept (Stage 3) stage of the RIBA Plan of Work as different design alternatives are developed which meet the client brief [8]. The framework was tested to check its efficacy by a case study using a multi-story social housing apartment building in Manchester, UK. The research identified the need for integrating methods and tools to support sustainable design with architectural practice and presented practical guidance to design professionals on how and when to use building energy simulation tools and sustainable building codes to support environmentally sound design practices in current business practice.

Biomimicry enables architects and designers due to its potential for innovative architectural solutions for a more sustainable regenerative built environment [9]. The investigation historicized nature-based design approaches (biophilia, biomimicry) and supported that these approaches reduce energy use in buildings and are essential for a sustainable future [9]. The research explored biomimetic applications with biophilic qualities in historical architecture and analyzed the ecosystem level of mimicry involving components of an organism working together as a multiple-elements-system rather than as a singular element [9]. A few examples were described, such as medieval Islamic houses proven to be a more sustainable, energy-saving system, and wind-catchers are factors of the Chimney Effect [9]. The research is significant for this subtheme as it refers to the ability to develop these historical systems into dynamic responsive systems relating to human needs sensitive to comfort, energy, and climate responsiveness through modern technologies [9].

Buildings are high energy consumers and high emitters of other non-CO_2 GHG emissions such as halocarbons, chlorofluorocarbons (CFCs), and hydrochlorofluorocarbons (HCFCs) as buildings' need cooling, refrigeration, fire suppression, and due to the case of halocarbons and insulation materials [10]. The research advocates that biomimicry is pivotal for energy effectiveness and energy efficiency. Living organisms offer innovative and sustainable methodologies on how humans can perform their activities without depending on non-renewable sources of energy and become more energy efficient to enable lesser GHG emissions into the atmosphere [10]. Biomimicry facilitates energy generation if humans take inspiration from plants as plants optimize energy usage sourced by renewables like solar energy [10]. Marine life also has precedents (sea kelp and tuna tails in water) that enable technology development for energy generation transferring from kinetic and mechanical energy to generate clean energy [10]. The most notable finding from this study is the speculation that a comprehensive application of triadic views of biomimicry (nature as mentor, model, and measure) will lead towards the innovation and development of energy generation technologies eliminating the usage of fossil fuels.

Nature has been a reservoir of ideas, and recently sustainability has attracted attention to guide architects to imitate nature in their designs [11]. The research opted for a literature review, extensive interviews with architects, and SWOT analysis is needed to understand the potential of biomimicry for sustainable architecture [11]. The interviews suggested that newly emerging concepts can carve the future of the construction industry [11]. Five major strengths consist of the effective use of energy, higher prestige level, climate adaptation ability, enhancing comfort, and higher value and rental costs [11]. The research identified several weaknesses regarding the application of biomimicry for designing sustainable buildings. These weaknesses included:

- A higher initial or maintenance costs;
- The lack of systems expertise;
- The need for coordination of different professions;
- Special production requirements;
- Complexity in design.

The research suggested five opportunities comprising of supportive top management, sustainability focussed development strategy, technological improvements, increase in demands of environmentally responsible buildings, and incentives from government bodies. The potential threats included unfamiliar systems, system failures, difficulties in project financing, material non-compliance with standards, and market conditions [11]. The final paper for the subtheme of biomimetic design and associated principles conducted a SWOT analysis as a research method to discuss the internal and external environmental situation and presented ideas for further exploration of research related to biomimicry studies giving greater insight to design professionals to apply the most plausible concepts to the design of sustainable buildings [11].

3.1.2. Building skin

An actual energy analysis of high-performance buildings is necessary to identify how the combination of biomimicry and the BREEAM category of energy inform sustainable architecture through the building skin [12]. 51 high-performance office buildings from the US, Europe, China, and other parts of Asia were classified to study the energy performance and drivers of energy use to reveal significant variation in real energy usage worldwide [12]. The research indicated that almost half of the selected buildings did not meet the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard energy target, which highlighted whether a building is energy-efficient and emphasizes design improvements and operations management to realize its energy-saving potential [12]. The selected buildings were investigated through climate influence, building size, and building technologies relating to building energy performance, and concluded that all factors are important, and no single factor plays a decisive role in building energy use [12]. An unclear and obstructed correlation was observed between the building size and energy usage, due to which the research was unable to identify a set of efficient technologies that correlated with low energy use intensity. The study results predicate that no single factor determines the actual energy of high-performance buildings, and multiple efficient technologies do not ensure the improvement of building energy performance [12]. A holistic design approach is needed, which is receptive enough to take account of climate, technology, occupant behavior, operation, and management practice on energy performance to ensure energy savings in high-performance buildings. This study points out that in relation to holistic design consideration and climatic considerations, building skin plays a vital role due to cooling and heating loads, use of daylight, and the design and operation of natural ventilation [12]. Architects, designers, and engineers should take inspiration from the biological principles of natural surfaces of plants and animals to devise innovative facade design solutions optimizing energy usage in high-performance buildings.

Considering the combination of biomimicry and the BREEAM category of energy addressing sustainable architecture through the building skin, architectural researchers [13] have defined that the building industry is accountable for 40% of the global energy consumption, and heating and cooling account for 50-70% of building's total energy use. Badarnah [13] presented an abstract analogy showing that heat regulation of buildings and formulated a nature-based framework for heat regulation focused on the functions of heat gain, heat retention, heat dissipation, and heat prevention. For each of these functions, associated processes were interlinked to other factors such as for heat prevention, minimum irradiation is shown as a process related to factors of posture, morphology, color, reflectance, and volume/surface ratio. With the function-process-factor, examples of organisms and systems are presented such as the elephant skin.

Further investigations were undertaken to understand the ability of reducing energy consumption through the application of biomimicry on building skin design for the development of a design matrix where the main criteria were thermal regulation, water efficiency, etc. [14]. These criteria were coupled with site contexts such as tropical, polar, and arid climate. The inspiration for meeting the main criteria included reptiles, plants, polar bears, violet tailed hummingbird, geometric patterns, and Namibian desert beetle. Conclusive evidence from this study includes the realization that nature has been a sustainable and energy efficient force for billions of years and natural organisms have developed strategies to be energy efficient [14]. Their characteristics are applicable to resolve complex human problems associated to architecture by mimicking nature to approach energy efficient building envelopes. By emulating nature's strategies, the energy consumption level can be minimized through the biomimetic approach [14].

60% of the total consumed energy in buildings is used for heating and cooling and the building envelope has a vital impact in controlling energy consumption in buildings and maintaining internal comfort [15]. It was delineated that building skin can be designed using biomimicry. Al Obaidi et al. [15] provided a classification and compared adaptive approaches in biology, engineering, and architecture to identify similarities between biological and building skins. The research classified sustainable materials designed using biomimicry into four clusters:

- Smart materials that change and react to external stimuli,
- Surface modification with innovative surface functions,
- Nature-inspired material focused on innovative form and structural arrangement,
- Technologies that improve current systems due to adaptive parameters.

The first cluster highlighted organism-like smart materials having the ability to change specific characteristics and parameters in relation to environmental conditions [15]. The second cluster discussed materials with surface modifications (drag reduction, and anti-reflective properties) [15]. The third cluster included material types which have a natural endoskeleton and exoskeleton that have various structural applications, such as the two-layer Beetle elytra maintaining itself through a series of interconnecting attachments. The last cluster highlighted materials with technologies for specific applications such as locomotion and transport. This cluster represents the largest area for biomimetic application in robotics, vehicle movement, and advancements in new types of transport [15].

Various advancements in façade design have been created to reduce energy consumption in buildings [16]. Biomimetic research can aid in the development of novel façade design solutions since biologically adapted solutions are complex, multifunctional, and highly sensitive. Through design case studies, the research identifies certain innovations, one of them makes use of bio-inspired innovations to improve thermal insulation of the envelope for saving energy [16]. It demonstrates the possibility of a responsive and adaptive temperature system that adapts to changes in temperature passively through the application of reflective envelopes on existing facades to achieve passive temperature control from sunlight by using three-dimensional covering surfaces in materials with special light-reflecting properties [16].

Recent developments related to high-performance skins have caused the emergence of innovative manufacturers that integrate real-time environmental responsiveness, upgraded materials, dynamic automation with built-in microprocessors, wireless sensors and actuators, and design-for-manufacture procedures [17]. This application has revolutionized architects' thought processes during the early stages of building design, with a shift in focus from form to performance, and from structure to envelope. The envelope is becoming the starting point for research and development in the field of high-performance buildings [17]. This study aimed to discuss the design of three strategies used in the construction of adaptive building envelopes of multi-story buildings, integrating improved energy performance and architectural innovation to facilitate and control physical environmental factors (heat, light, and sound) and improve occupant comfort. The authors presented the Media-ICT building in Barcelona, Spain, the Al Bahr Towers in Abu Dhabi, UAE, and the Terrance Donnelly Centre for Cellular and Biomedical Research in Toronto, Canada to deduce that the adaptive building façade is responding intellectually and accurately to fluctuating climatic conditions and indoor requirements, where it will utilize natural energies to light, heat, and ventilate the spaces and can achieve energy savings in comparison to conventional technologies, while obtaining maximum thermal comfort conditions [17].

The paper also proved that perhaps in the future the cost of photovoltaics may be reduced as the onsite power systems are integrated with the glass façade and those skins evolve into local, non-polluting energy suppliers to the building. In relation to future planning and design of high-performance buildings it is expected that active façade technologies would work in intelligent coordination with HVAC and lighting systems to deliver comfortable and ambient internal settings utilizing lesser energy [17].

Studies also reveal that the visual and thermal comfort of inhabitants relies on the outer environmental climatic conditions which keep fluctuating [18]. Due to these mutual conflicts, maximizing visual and thermal comfort simultaneously is a complex problem. The study analyzed the façade in its literature review as a complex interaction between the inner structures and outer environment, with the ability to function as a protective and regulatory layer and feature against significant swings in external climate [18]. Six interconnected subjects were investigated in this study, which comprised of dynamic façade, biomimicry, building form as a microclimate adjuster, energy efficiency, comfort condition, and parametric design thinking [18]. The study addressed the following research questions: (1) what are the multidisciplinary subjects relevant to kinetic façade design process for building an innovative architectural process? (2) Based on multidisciplinary research, what is the most significant component in kinetic façade design aiming to improve occupants' aesthetic and thermal comfort simultaneously? Previous research has discovered several aspects related to kinetic façade concepts, tactics, principles, and criteria, however multidisciplinary studies are uncommon. Adaptive daylight façade with daily solar geometric fluctuation has become predominantly significant. Conclusively a generative-parametric and fast shape finding approach for adaptive to varied climates is a solution for increasing adaptation to dynamic daylight [18]. The intent of the research was to present a dynamic façade design technique capable of simultaneously improving occupant visual and thermal comfort by regulating on-site renewable energy resources such as solar radiation and/or wind [18]. The building skin is the only contact between the indoor environment and outer structure recognized by intrinsic functional features such as complexity, heterogeneity, and multidisciplinarity. Various interconnected subjects have an impact on façade form individually and collectively in relation to functional scenario, shifting the perspective of kinetic façade from an exquisite and stylish state to a functional and practical component [18].

Khosromanesh and Asefi [19] describe three experimental designs of adaptive building facades inspired by plant processes: Flectofin (a hingeless flapping apparatus inspired by the deformation principle found in the South African plant Strelitzia reginae), HygroSkin (derived from the elastic bending behavior of thin plywood sheets) [20], and Hy-Fi project. HygroSkin was created after researching wood's ability to adjust to relative humidity. Wood cones open when relative humidity rises and close as internal moisture falls. The Hy-Fi project is a bio-brick tower built of farm waste and fungus culture developed in a brickmould. It highlights the use of recycled materials in the construction sector. The authors' core concept involves a new approach to building envelope design that considers environmental adaption systems while developing a building façade.

Similarly, Kuru et al. [21] propose bioadaptive building skin concept breakdown while analyzing biomimetic adaptive building skins for energy and environmental regulations. According to the concept breakdown, if biomimetics is employed for design generation and adaptive building skins are used as design products, then biomimetic adaptive building skin becomes a façade typology. Kuru et al. [21] go into greater detail, defining four properties of the biomimetic adaptive building skin. To begin, the scale characteristic is given for estimating the size of the system, which includes an envelope, façade, façade component, and façade subcomponent [21]. Second, the concept of adaptability is introduced, which refers to the responsiveness of bioadaptive building skin to external elements, the number of functions it has, and the inputs it receives [21]. The third characteristic of a biomimetic adaptive building skin is how a technological problem is investigated and solved utilizing a biological solution, or vice versa [21]. The final criterion is performance, which indicates the effectiveness of functional strategies. This trait entails defining a performance target, analyzing the system, and measuring improvement [21].

3.1.3. Integrated frameworks

In relation to the combination of biomimicry and the BREEAM category of energy addressing sustainable architecture through an integrated framework, numerous studies are present. The concept that conventional, modern architecture is not sustainable is not a new one [22]. Most typical approaches attempt to better use energy and materials. Architects, designers, and engineers may develop structures that are fascinating, useful, productive, and regenerative by design by clearly comprehending natural processes and their interconnections with human needs [22]. This research analyzes biomimetics and its relation to building materials and design. Biomimetics was discussed as an abstraction of good design from nature and an enabling interdisciplinary discipline particular to developing features of materials and structures of hierarchical organization [22]. Biomimetics provides concepts related to: graded functional of materials (nano-scale), adaptive response (nano-, micro-, and macro-scales), integrated intelligence (sensing and actuation at all scales), architecture, and added functionality [22]. Numerous examples in biology present evidence of plants and animals' emergent responses to temperature, humidity, and other changes in their physical habitats based on relatively simplistic physical principles. Inspiration for man-made structures should arise from application of design solutions leveraging these principles. The study examines specific examples (energy and resource efficiency, elimination and control of hazardous substances, use of renewable and biological materials, and added functionality and structures) of sustainability from nature and the benefits or value that these solutions have provided to various organisms. A better understanding is developed on how some of these solutions can be integrated into the realm of sustainable buildings and how, as architects and building engineers, we can evaluate its real use in designing and constructing sustainable structures [22].

Wahl and Baxter [23] emphasized that to establish an integrated framework, architects must be more aware of their capacity of imagination and become facilitators of transdisciplinary collaboration. The authors propose that for an integrated framework to be successfully implemented, responsible individuals should become co-designers of our sustainable future. Architects and designers are facilitators of transdisciplinary collaboration and integration can help change cultural dominant worldviews [23]. Transdisciplinary design dialogue would allow the incorporation of qualitative considerations related to whole-system health, happiness, wellbeing, meaning, and quality of life into the decision making and design process. Transdisciplinary dialogue for designing sustainably will facilitate the integration of specialist knowledge of various disciplines in the quest for more sustainable solutions [23].

Klein [24] advises designers to consider beyond the replacement of one set of architectural design norms with "greener" alternatives such as green façade systems when implementing these integrated frameworks. Klein [24] believes that "greener" alternatives are required to reduce energy usage; but a holistic approach to sustainable architectural design is required to deepen the interrelationship between the built and natural environments. Authentic biomimicry must recognize the fundamental significance that each of us plays in being on Earth and in being with one another [24]. Traditional sustainability approaches may be necessary to shift energy consumption balances and reduce our environmental impact, but the author believes that this standard approach fails to recognize a deeper shift in the ways we design and make our places—a shift that is required if we hope to engage and strengthen the intricate and interconnectedness between humans and the natural and built worlds [24].

In terms of an integrated framework, Oguntona and Aigbavboa [25] describe and demonstrate biomimetic techniques for the sustainable reinvention of the construction industry. They propose potential for long-term innovation in three areas: technology, policy, and education. In terms of technology, Oguntona and Aigbavboa [25] state that various biomimetic materials, technologies, and inventions related to energy management and sustainable design are already commercialized, patented, or in the development stage. Eco-cement, inspired by sea snails, serves as a carbon-sequestering cement that is both neutral and strong. Concerning policy, the authors demonstrate that for biomimicry and energy management to contribute to sustainable design, these ideas must be supported and implemented by stakeholders [25]. In relation to education, the study highlights that several impediments are impeding the goal of sustainable architecture. The authors describe two key techniques in biomimicry that exist to provide more clarity to the realm of education: the problem-based approach and the solution-based approach. The problem-based approach is defined by the authors as a problem-driven biologically inspired technique that consists of eight steps: define, identify, integrate, discover, abstract, brainstorm, emulate, and measure [25]. A solution-driven biologically inspired method is characterized as a solution-based strategy. The constituent phases do not progress in the same way as the problem-based method. The steps in this method are as follows: discover, abstract, identify, define, brainstorm, integrate, emulate, and measure [25].

The last study related to the combination of biomimicry and the BREEAM category of energy addressing sustainable architecture through an integrated framework revealed that environmental concerns and energy scarcity, as well as high energy usage in structures and a lack of supplies, are major global issues [26]. Buildings are the most intensive energy consumers, accounting for 40% of global energy consumption, far more than transportation [26]. Carbon dioxide emissions from buildings are expected to expand faster than emissions from other industries during the next 25 years [26]. As a result, architects must seek ways for managing building energy use. Biomimicry, which is described as the applied science that obtains inspiration for solutions to human issues via the study of natural design principles, is one of the emerging inventive techniques. Although biomimicry is regarded as a novel integrative method to creating sustainable buildings, architects still lack sufficient access to it, particularly when it comes to implementing biomimetic design strategies in architectural projects. The research promotes awareness among architects who employ biomimetic methodologies to create more accessible facilities [26]. The study suggests developing a tool-setting relationship to codify and bridge biological and architectural knowledge, as well as investigative tools to explore the ability of biomimetic methods on efficient-energy building design to reduce energy consumption.

3.1.4. Designing with BREEAM

The combination of biomimicry and the BREEAM category of energy addressing sustainable architecture can be explored when designing sustainable buildings using BREEAM. The Building Research Establishment environmental assessment technique (BREEAM) has been widely employed for building projects in the United Kingdom in recent years [27]. This creates various issues to design teams, not the least of which is the necessity to manage and incorporate the BREEAM requirements in their design. Using eight case studies, this research investigated the impact of the BREEAM evaluation process on the design of building projects in the United Kingdom [27]. The most significant consequences were discovered in the areas of construction characteristics, materials, and water services. This influence varied depending on the building type, location, targeted/required BREEAM rating, date of assessment, assessor's function, and the team's knowledge of the assessment procedure. Significant design alterations were made in the cases striving for the highest BREEAM rating [27]. The findings show that BREEAM may constrain design teams in some circumstances by directing their emphasis to obtaining BREEAM credits rather than the holistic building design. For example, BREEAM tends to dictate design solutions rather than focusing on the objective – for example, a designer may prioritize large leak detection over water conservation [27]. The article explored the possibility of incorporating BREEAM criteria into building codes [27]. The study concluded that there appears to be a possibility for BREEAM requirements to be included in both building rules and planning applications (e.g., sustainable drainage system - SUDS). BREEAM is projected to become more stringent in the coming years to keep up with ever-changing legislation [27]. This will certainly impose additional constraints on architectural design teams in terms of incorporating BREEAM requirements into their designs. BREEAM 2011, for example, often known as 'BREEAM New Construction,' has made significant strides toward promoting optimal design solutions, notably in terms of operational energy and water usage, as well as operational waste [27]. As a result, BREEAM 2011 is likely to have an even greater impact on design than earlier versions. Furthermore, because BREEAM was discovered to have a significant impact on material specifications such as windows, BREEAM-compliant products would be increasingly required by construction practitioners, posing a challenge to manufacturers [27]. As a result, while this study contributes to understanding the effect of BREEAM on actual building design, future research is needed to discover how the BREEAM evaluation process could be effectively executed in order to achieve the greatest advantage from BREEAM (e.g., early involvement of the BREEAM assessor) [27].

Contrarily, Ewuosho [28] argues that BREEAM is a voluntary environmental assessment method for green buildings developed by BRE in the United Kingdom and now used globally. The author demonstrates how BREEAM has become an accepted part of the sustainability movement. According to Ewuosho [28], its performance is debatable, and planning and creating sustainable architecture with BREEAM is contentious and places an undue load on the contractor. 'Genuine' sustainable architecture is only achievable if the client is totally committed to sustainability and the design team responds appropriately [28]. Overall, the study found that BREEAM is not seen to add to the economic value to a development. There is tacit agreement that monitoring carbon emissions is necessary to slow climate change, and BREEAM is seen to focus too rigidly on the construction process, without adequate attention to the building's life cycle; client education on effective facility operation and maintenance is seen to be neglected, with BREEAM as a badge of environmental sustainability [28]. To deliver a BREEAM project, the main contractor is expected to balance the expectations of all stakeholders, but the bureaucratic nature of the process has been observed to have a negative impact on the dynamic of the project teams, with the client rarely satisfied with the facility's capabilities, having had to trade-off against functional utilities [28]. Even though sustainability is the responsibility of all stakeholders, an engaged client should drive the BREEAM agenda from the early stages of the project [28].

3.2. Addressing sustainable urbanism

Several studies [29-45] have analyzed the combination of biomimicry and the BREEAM category of energy for achieving sustainable urbanism.

Biophilic cities can be designed by integrating nature into urban design and planning [29]. The research provides a substantial account of several biophilic cities from North America, Europe, and Australia, but the principles are globally applicable [29]. A biophilic city is described as a city that yearns for opportunities to repair, restore, and creatively insert qualities of nature into the outdoor environment for residents to care about nature and ensure the sustainability of local and global resources [29]. The research explored the challenges associated with designing and building the biophilic city, such as the importance of nature in urban lives; the nature of and in cities; what biophilic cities entail; biophilic design and planning; tools and institutions to foster biophilic cities; and the growth of the biophilic city [29]. The review defined greater consideration of identifying the ecological and geological forces that contribute to urban vulnerability.

Rosales [30] claimed that the gap for incorporating urban sustainability into the planning process has been bridged. The research illustrated this with a set of indicators for sustainable urban planning. These indicators provided critical information for imagining existing and future vital features that will aid in the construction of a city based on urban sustainability. To quantify and give information for sustainable urban design, four modules of indicators have been defined [30]. The urban safety indicator module addressed various concerns, including the satisfaction of necessities, such as health, education, crime prevention, and disaster preparedness. The urban health indicator module addressed a healthy urban environment as well as a city's obligation to the global environment [30]. This module promoted social interaction and balanced interactions within the city's development patterns and environmental carrying capacity. The visually and culturally appealing city indicator module included the quality of space in cities for collective interaction and social cohesion. This indicator module is directly related to access to local services, public space quality, space vitality, and urban landscape [30]. The final indicator defined is the urban efficiency module indicator, which ensures the preservation of natural, historic, architectural, cultural, and artistic resources. This indicator comprised proper resource management and administration in the short, medium, and long scope to implement suitable activities for serving the demands of the city and promoting a quality urban environment [30].

In the context of Dhaka, Bangladesh, studies also investigated the contribution of an energy-optimized urban planning approach to effective resource usage [31-33]. The “EnUp” model, a conceptual energy optimization model, was designed and evaluated for practicality and adaptation strategies to enhance urban energy use in residential communities [31]. This research used a system analysis and grounded theory methodology, which included field methods such as key informant (KI) interviews and data and information collection from local urban planning departments and other secondary sources [31].

The findings suggested that in Dhaka, adopting an energy-optimized planning approach is both achievable and necessary [31]. The “EnUp” concept can be used to plan new urban settlements as well as adapt existing ones [31]. By ensuring the engagement of multiple stakeholders, technical inputs, and adaptability, this novel model and method might be replicated in a variety of other cities throughout the world [31].

Research explored conceptual ideas for promoting an ecologically responsive, water-centric approach to architectural design, so that design interventions become nature/culture hybrids that connect residents to wider hydrological circumstances [34]. Horizons are one mechanism for determining a sustainable architectural trajectory, one that emphasizes both experiential and environmental concerns at the same time [34]. The consideration of "three architectural realms" (the equipmental—the objects of one's immediate context; the practical—the enclosure of a building; and the environmental—what is beyond) by theorist David Leatherbarrow has been reshuffled in a conceptual shift: The practical extends to the watershed (the bioregion as a common dwelling place), while environmental processes interact with construction equipment, resulting in structures that have a net beneficial impact on the watershed [34].

The investigation concluded that “we are continuously learning that water is our best teacher,” as mentioned by landscape architects Herbert Dreiseitl and Grau Ludwig Dreiseitl, and their work at the interface of architecture and landscapes [34,35]. The changing of the outlines of building/environment systems is prompted by learning from water, paying attention to it, and treating it with the respect it deserves [34]. Urban structures can re-instill habits of increased appreciation of what is most valuable by prioritizing water as a means of linking scales and fusing horizons [34]. A sustainable building sways hydrological habits and instils awareness of the ultimate practicality of our shared biological home by remaking assemblages and moving past surfaces [34].

When it comes to sustainable urban planning as a result of combining biomimicry with the BREEAM category of energy, Cajot and Schüler [36] pointed out that energy is seldomly a concern because urban design often groups diverse sectors together. The study recognized that energy would become a driving force in city development in the future, perhaps jeopardizing other qualitative political goals. Energy should not impose itself technically on urban forms or infrastructure, according to Cajot and Schüler [36], but the interplay between energy and other domains should be examined to enable additional synergies with socioeconomic factors. Efforts comprising of energy efficiency as a method of decreasing public or private costs, renewable energy integration into local energy security and air quality, and efficient district-scale energy systems allow architects and designers to choose materials and shapes with greater flexibility.

Green Infrastructure (GI) evaluation improves the long-term sustainability of neighborhood masterplans, but limited research has been done on the relationship between GI evaluation and masterplan decision-making [37]. The research investigated six English master-planned sites paired with case studies representing three types of neighborhood development (estate regeneration, urban infill, and rural-urban extension) to examine the sustainable neighborhood standard, BREEAM Communities (BC), had an impact on GI evaluation and masterplan decisions [37]. One site had embraced BREEAM Communities, and the other had not in each of the three pairs. The study needed 48 interviews and public documents; Strategy-as-Practice presented a conceptual framework for analyzing 13 evaluation incidents. Despite early design decisions or the use of BREEAM Communities, GI-related recommendations were frequently deprioritized at subsequent masterplan stages, according to the report. Improving practitioners' grasp of GI and boosting accountability at later design stages, such as through sustainability reporting, are two potential methods to improve the embeddedness of GI evaluation practice.

Most of the interviewees in this study recognized that a single cohesive masterplan solution that fulfils all intentions equally was unlikely to be established [37]. Intentions for sustainability, including those linked to GI, frequently lack more immediate and tangible benefits that would motivate a developer to take more responsibility [38-40]. As demonstrated in this study, a normative standard can only go so far in incentivizing dominant decision-makers to adopt a longer-term perspective [41]. External constraints, such as limited public sector capacity [42], can limit the impact of such rules and norms, even if they are required by planning or legislation.

Collaboration between all stakeholders [43], including BRE, will be critical in an era of austerity to further incorporate GI evaluation and redefine current evaluative design and construction practices.

Mohan et al. [44] presented the latest research related to urban biocycle as a strategic flow of resources, usage, and extracting value in relation to nutrients, energy, and materials. The research explains that to ensure sustainable urban planning, urban biocycles need to be combined with biobased economy to enable the closure of all possible loops. Their research discusses that general metabolism in urban areas is linear, supporting urban activities causing waste and 'metabolic disorder.' Mohan et al. [44] explain in more detail that due to these reasons, it becomes significant to circulate and reuse biological materials in the urban ecosystems for achieving circular economy – closing all the loops back to the source [45]. Urban environments usually comprise of a sensitive and intricate system of production and manufacturing [44]. The novel idea of urban biocycles presents a stage of reflection on the contribution of biogenic materials may enable the idea of integrated waste management systems in urban ecosystems.

4. Conclusions

The research aimed to investigate how the combination of biomimicry and the BREEAM energy category may lead to novel ideas for sustainable architecture and urban planning. A systematic literature review was used to discover, gather, and analyze studies for the study. According to the findings, there are more studies on sustainable architecture than urban planning, which has resulted in the development of numerous themes (through biomimetic design and associated principles, through building skin, through an integrated framework, and designing with BREEAM). Discussing the issue of design and related concepts, with the help of supporting top management and government incentives, could lead to the development of sustainable architecture. It may be inferred that a bioadaptive building skin can only be constructed if biomimetics is employed as a design generator and adaptive building skin is used as a design product. The impact of the building skin on sustainable architecture and the effectiveness of functional methods is determined by its scale (envelope, façade, façade component, façade subcomponent) and performance. In relation to the theme of integrated frameworks, it is clear that architects need to gain more expertise and become facilitators of transdisciplinary collaboration. Further exploration, according to research, will necessitate a long-term reinvention of the architectural design practice through technology, policy, and education. Evidence from it reassures that 'truly' sustainable architecture can only be created if the client is totally committed to sustainability and the design team responds appropriately and accordingly. Studies discussing sustainable urban planning discovered that energy and its relationship with other socioeconomic aspects would mitigate expenses, integrate renewable energy production, and provide architects more flexibility in selecting materials.

The research exploring the combination of biomimicry and the BREEAM category of energy for achieving sustainable architecture and urbanism presented numerous strengths and weaknesses. The advantages of this synergy include learning from the biomimetic strategies presented in natural systems for applying to the built environment are promising in relation to energy management. Other advantages include the exponential increase in green buildings competing for reducing carbon emissions to contribute to the sustainable built environment. The disadvantages of the combination include the lack of creative inventiveness and the designer's decision to rationalize whether they are designing for BREEAM or is BREEAM supporting building design? This disadvantage is associated with the commitment of clients to support designs of sustainable buildings and for the design team to respond accordingly and collaboratively. Regarding disadvantages related to sustainable urbanism, the design team would need to invest more time and resources when biomimetically designing a BREEAM excellent or outstanding building for studying its potential impact on the urban fabric it is situated in and responds to. A city council's sustainability strategy needs to align with all stakeholders to enable the biomimetic design of sustainable built environments.

Compliance with ethical standards

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