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BIOMIMICRY AND PERFORMALISM: AN ARCHITECTURAL POINT OF VIEW

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BIOMIMICRY AND PERFORMALISM: AN ARCHITECTURAL POINT OF VIEW

(M.Sc. Thesis)

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ABSTRACT

Biomimicry in architecture is an approach that draws inspiration from natural systems, forms and processes to improve functionality and promote sustainability, mimic the efficiency and adaptability found in biological systems, and create innovative and environmentally friendly design solutions. On the other hand, performative architecture emphasises structures' dynamic and artistically expressive qualities by prioritising movement, rhythm and the visual impact of the design. It goes beyond static aesthetics and focuses on how a building performs over time and interacts with its environment. This research began by questioning whether combining these two fundamental concepts of the 21st century could motivate sustainable and innovative designs. The thesis hypothesised that digital design technologies that consider the final product and its form, function and structure are needed for "biomimicry and performalism" to guide design in understanding and adapting complex design processes. The study discusses what expansions can be made in architectural design by considering biomimicry and performalism together by associating natural inspiration with performative criteria. Therefore, firstly, biomimetic design principles are explained and developed architectural approaches are exemplified. Similarly, building examples that show how performalism is integrated into architectural design are examined. Finally, to investigate how both concepts can be integrated into architectural design, the processes of eight projects selected as buildings thought to be nourished by both approaches are examined from design to construction. The results show a symbiotic relationship between efficiency inspired by nature and visually suggested dynamic architecture. This paves the way for taking the concept of sustainability to the next level due to the emphasis on an innovative and advanced framework that contributes to developing new methodologies that increase performative nature inspiration. It has been observed that advanced software is used to optimise every process in the building from early design stages to implementation and operation, and the building turns into a magnificent structure and shows iconic results. These structures designed with the understanding of biomimicry and performalism have taken their place in the literature as original structures that meet functional requirements, adapt to change and leave their mark on their periods with their performance-oriented aesthetic qualities.

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BİOMİMİKRİ VE PERFORMALİZM: MİMARİ BİR BAKIŞ AÇISI

(Yüksek Lisans Tezi)

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ÖZET

Mimarlıkta biyomimikri, işlevselliği iyileştirmek ve sürdürülebilirliği teşvik etmek, biyolojik sistemlerde bulunan verimliliği ve uyarlanabilirliği taklit etmek, yenilikçi ve çevre dostu tasarım çözümleri yaratmak için doğal sistemlerden, biçimlerden ve süreçlerden ilham alan bir yaklaşımdır. Öte yandan performatif mimari, hareketi, ritmi ve tasarımın görsel etkisini önceliklendirerek yapıların dinamik ve sanatsal olarak ifade edici niteliklerini vurgular. Statik estetiğin ötesine geçerek bir binanın zaman içinde ve çevresi ile etkileşimli olarak nasıl performans gösterdiğine odaklanır. Bu araştırma, 21. yüzyılın bu iki temel kavramını birleştirmenin sürdürülebilir ve yenilikçi tasarımları motive edip edemeyeceğini sorgulamakla başlamıştır. Tez, karmaşık tasarım süreçlerini anlama ve uyarlamada tasarımı yönlendirmek için "biyomimikri ve performalizm" için nihai ürünü ve onun biçimini, işlevini ve yapısını dikkate alan dijital tasarım teknolojilerine ihtiyaç duyulduğu hipoteziyle ilerlemiştir. Çalışma, doğadan ilham almayı performatif kriterlerle ilişkilendirerek biyomimikri ve performalizmi birlikte ele alarak mimari tasarımda hangi açılımların yapılabileceğini tartışmaktadır. Bu nedenle, önce biyomimetik tasarım ilkeleri açıklanmakta ve geliştirilen mimari yaklaşımlar örneklendirilmektedir. Benzer şekilde performalizmin mimari tasarıma nasıl entegre edildiğini gösteren bina örnekleri incelenmiştir. Son olarak, her iki kavramın mimari tasarıma nasıl entegre edilebileceğini araştırmak için, her iki yaklaşımdan da beslendiği düşünülen binalar olarak seçilen sekiz projenin süreçleri tasarımdan inşaya kadar incelenmiştir. Sonuçlar, doğadan ilham alan verimlilik ile görsel olarak önerilen dinamik mimari arasında simbiyotik bir ilişki olduğunu göstermektedir. Bu, performatif doğa ilhamını artıran yeni metodolojilerin geliştirilmesine katkıda bulunan yenilikçi ve gelişmiş bir çerçeve vurgulaması nedeniyle sürdürülebilirlik kavramının bir sonraki seviyeye taşınmasının yolunu açmaktadır. Erken tasarım aşamalarından uygulama ve işletmeye kadar binadaki her sürecin optimize edilmesi için gelişmiş bir yazılım kullanıldığı ve binanın görkemli bir yapıya dönüştüğü ve ikonik sonuçlar gösterdiği gözlemlenmiştir. Biyomimikri ve performalizm anlayışıyla tasarlanan bu yapılar, işlevsel gereksinimleri karşılayan, değişime uyum sağlayan ve performans odaklı estetik nitelikleriyle dönemlerine damga vuran özgün yapılar olarak literatürde yerlerini almışlardır.

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Anahtar Kelimeler : Biyomimikri, performalizm, sürdürülebilirlik, çevre dostu mimari, su hasadı, yeşil enerji, termal düzenleme, dijital tasarım
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SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used in this study are presented below, along with their explanations.

Symbols	Explanations
%	Percentage
CO_2	Carbon dioxide
kW	Kilowatt
m^2	Square meter

Abbreviations	Explanations
ETFE	Ethylene tetrafluoroethylene.
HVAC	Heating, Ventilating, and Air Conditioning.
BIA	Biomimicry in Architecture
BCE	Before the Christian Era
CH2	Council House 2
UK	United Kingdom
BIQ	Bio Intelligent Quotient
BWTC	Bahrain World Trade Center
CNC	Computer Numerical Control
PV	Photovolatic
PBRs	Photobioreactors
DNA	Deoxyribonucleic Acid
LED	Light Emitting Diode
LEED	Leadership in Energy and Environmental Design

1. INTRODUCTION

Architects and designers have accepted the duty of looking for building systems that are more effective and sustainable, motivated by the global impact of climate change. The natural environment has always been a constant source of inspiration, providing various ideas (Aamer, 2021). To attain good structural and mechanical qualities and sustainable solutions for the building industry, nature offers examples of resilient materials as well as structures (Ahamed, Wang, and Hazell, 2022).

Biomimicry, therefore, encompasses physical and functional elements and the creative dimension, going beyond simple duplication of Nature. Benyus (1997) exhibited biomimicry in three dimensions. Vincent (2014) described biomimicry as a technique for resolving design problems inspired by natural systems, components, and models. Drawing inspiration from nature for a built environment has the potential to improve sustainability and perhaps lead to the development of regenerative approaches. They sought solutions to design issues by taking cues from natural systems, components, and models (Pawlyn, 2016). The practice of biomimicry goes beyond merely mimicking an organism's outward. The design strategy entails thorough examination for imitating physiological, morphological, and behavioral aspects of biological phenomena (Faragalla and Asadi, 2022). Internal system integration can improve a building's operating efficiency and help develop sustainable solutions (Knippers, Speck, and Nickel, 2016). Natural systems are renowned for saving energy and cyclically utilizing resources. (Benyus, 1997; Austin, Garzola, Delgado, Jiménez, and Mora, 2020).

On the other hand, two fundamental concepts shape the language of 21st century architecture: sustainability, which aims to have a less environmental footprint in the ecosystem, and "digital design and production" technologies, which enable considering design processes as well as end products with innovative approaches they provide. The intersection of both concepts is called performative architecture; it embraces efficient energy use and environmentally conscious design strategies embodying the essence of digital design, recognizing that the intricate designs of buildings with unique geometries can be effectively conceptualized and executed only through computational technologies. It makes it possible for engineers, in addition to architects, to evaluate complicated systems and implement

design concepts that would be difficult to actualize using conventional techniques (Grobman and Neuman, 2011). The power of architectural items to impact, alter, and do, in other words, how it functions, defines it instead of how it looks, seeking to increase resource efficiency and minimize energy consumption. The convergence of biomimicry and performalism in architecture introduces a unique perspective that blends inspiration from nature, focusing on dynamic, performative aesthetics—creating structures that fulfill functional requirements and captivate with their ever-changing and performative aesthetic qualities. Thus, this paper will aim to address and highlight the comprehensive explanation of the biomimicry principles as well as performalism concept and criteria to investigate the combination of the two concepts through investigating biomimetic examples in architecture as well as performative examples, to finally discuss eight projects as buildings which adopt both, Biomimicry and Performalism aspects, to emphasize on the importance of the conjunction of both concepts and the lead to developed sustainable, eco-friendly, and more innovative designs.

Research question

Despite the importance of the two new and creative concepts in design, which are performative architecture and biomimetic architecture, each own importance and outcomes, besides the combination of those two concepts and what they bring of creative results, was the aim of the study. Attention has been paid to each concept separately, and the conjunction will enhance generative results and outcomes. Thus, this paper will aim to address and highlight the comprehensive explanation of the biomimicry principles as well as the performalism concept and criteria to investigate the combination of the two concepts going beyond conventional aesthetics where nature-inspired efficiency meets the performative and visually expressive qualities of architecture, through investigating biomimetic examples in architecture as well as performative examples to finally analyze and investigate the combination of both criteria in one project.

Enhancing and introducing the explanation of how a building or a design is performative in biomimetic aspects to finally answer the study's main question of how to design a performative building using Biomimicry as a tool. This will be answered through an investigation of the biomimetic design concept. Performative design concept? Moreover, what is the overlap and conjunction of these two concepts? An evaluation of the application

of biomimetic architecture principles to the buildings; how are those principles applied and evaluated to the design? How do they simulate nature? How do we investigate this relationship? How are biomimetic architectural design criteria for performative architecture adopted? What is performalism in buildings or structures, and how is a building considered performative? How is biomimetic architecture performative, and why is performative architecture not biomimetic? What is the benefit of designing using both concepts?

Research aim and objective

This study what is going to presents an introduction to the biomimetic design concept with its approaches, criteria, and examples, along with introducing the performance in architecture and its application, highlighting the relationship between performalism and biomimicry will enhance the understanding of the concept of Bio-performative architecture. Besides, the investigation and evaluation analysis process will shed light to understand more light and understanding the biomimetic design field and its principles, how those principles can be applied to and adopted by buildings and designers, how a design is compared and analyzed according to biomimetic design criteria, and how it is evaluated according those criteria, and relate this with a performative approach through assessing the performance aspects in the designs to introduce the practical results and outcomes which the biomimetic design along with performalism enhance as building energy-saving, nature-friendly, and sustainable environment and buildings to achieve better environment conditions. Both biomimicry and performalism fields and design approaches, due to what they provide of sustainability, are widely interested due to the demand of the globe for energy saving and more nature-friendly applications and will enhance generating solutions to multiple design problems, moreover, create creative new approaches in architecture.

Methodology, structure, and evaluation approach

The theoretical knowledge and explanation of the concepts of Biomimicry and Performalism in Architecture and the qualitative evaluation of several architectural projects or designs, along with the criteria obtained from here, constitute the material and method of this study. The study consists of two general sections preceded by an introductory section. In the first introductory section, explanations are made on the purpose and scope of the research. This will start with a summary of the global challenge, highlighting significant problems the globe

faces and then shed light on the driving force for architects tackling biology to find answers to global problems. In this direction, after the research question and hypothesis are presented, the material obtained regarding the research and the method explaining how this material will be included in the field study are explained. The two general sections represent the theoretical framework, where a literature review was applied to investigate the studied concepts, and an analytical framework, used to study the relation of both concepts and investigate their application in architectural projects to conclude with standard features and correct applications of successful projects that can be used as standards for the future projects.

The theoretical framework consists of biomimicry and performalism in architecture, constituting the first stage of the thesis's literature; the concept of Biomimicry and its relationship with architecture are discussed. Focus is given on the definitions of biomimicry and its terminology through collecting an intensive literature review and the historical background of biomimetic architecture to provide a trial to investigate overlaps between nature and architecture. Biomimicry features and timeline are illustrated, design spiral and biomimicry levels are emphasized as well, the levels of use of biomimicry in designs are given through architectural examples, and Examples of biomimicry in architecture are analyzed at the end of the part. Meanwhile, for the performalism part, the concept and its architectural features are explained and emphasized by introducing performative approaches in architecture and examples of performative buildings.

The analytical framework also consists of two parts; in the first part, the comparison between the two concepts is presented, and an illustration of how biomimetic architecture is performative while performative architecture is not necessarily biomimetic is emphasized. In the second part of the section, and with the data obtained from the theoretical framework section, biomimicry applications used in eight architectural examples selected by the author are evaluated according to both concepts of biomimicry and performalism. At the end of the section, a preliminary assessment is made to understand the use of performalism in biomimetic architecture in the field study. In this direction, the biomimicry and performalism features of each selected project are determined through a project evaluation table created by the author. Throughout the paper, eight different functions, different shapes, and different strategies were selected in order to investigate how those projects relate to biomimicry through the analysis of those projects according to the biomimicry level, whether they were

organism, behavior, or ecosystem-level designed, investigate how those projects concepts were inspired by nature, and how this inspiration was applied in the design, after that, the projects incorporated features will be investigated as well, which performalism criteria, of the criteria and references illustrated in the performalism architecture section, were adopted and how they are important and how they were implied in the design of the building. The result is an analysis of the building containing references for biomimicry and performalism. In other studies, each concept was illustrated as an own concept, emphasizing its important in the architectural projects, however, through this study, the aim is to focus on the important outcomes which can result from combining both of the concepts together, relating inspiration from nature with performative criteria.

In the conclusion and suggestions section, which constitutes the last part of the study, the projects chosen by the author for evaluating the concepts of biomimicry and performalism are compared. In line with this comparison, a determination is made as to how effectively the references of both concepts are adopted together. Summarizing the overall conclusions drawn by the researcher from the research structure, together with suggestions made by the researcher for the architectural strategy used in the study to aid in future research. Furthermore, the study's underlying references were provided. This entire flow is summarized in the thesis flow chart in Figure 1.1.

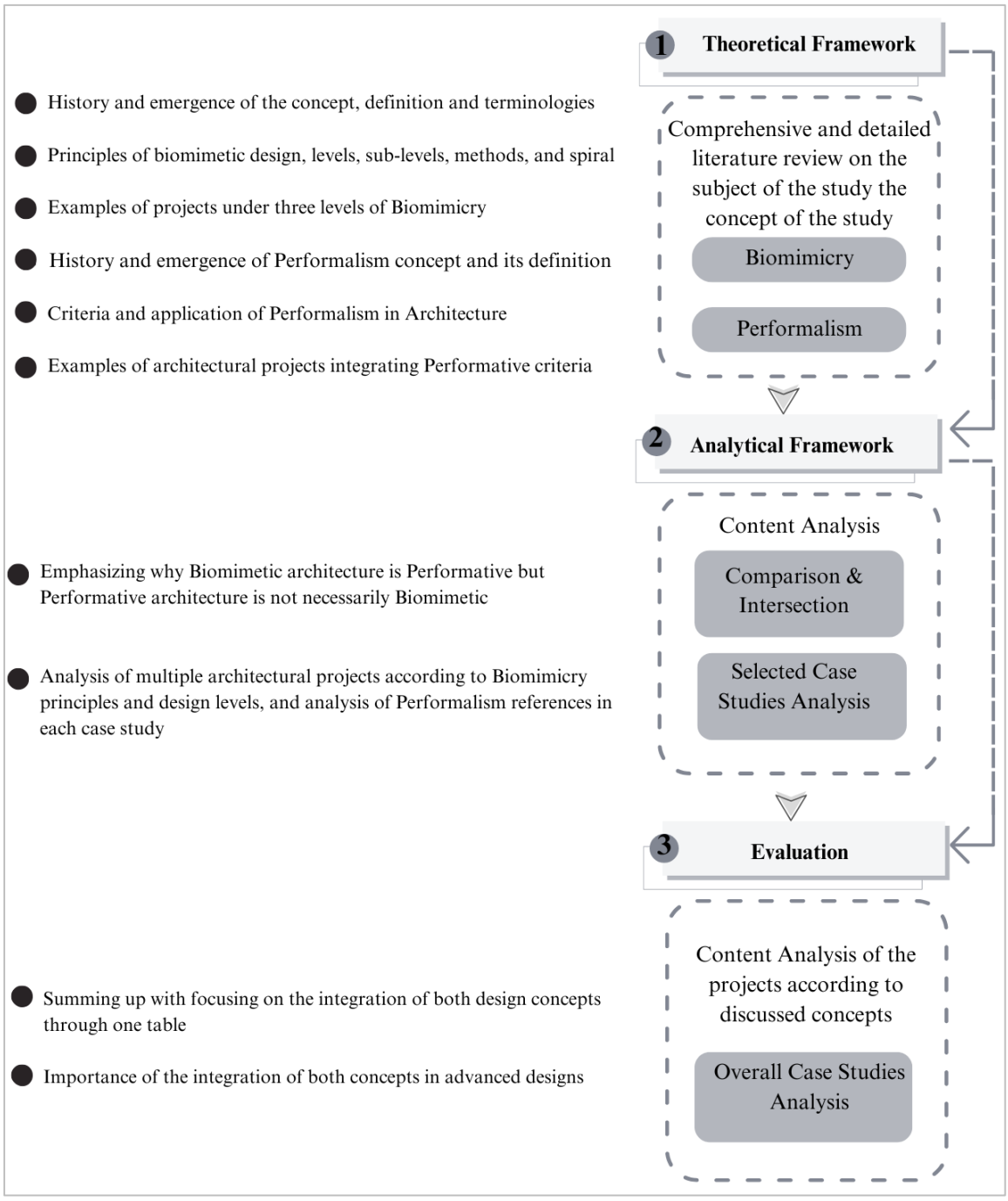


Figure 1.1 Thesis flow chart.

2. LITERATURE REVIEW AND THEORETICAL BACKGROUND

This chapter aimed to show and discuss the terms, terminologies, definitions, and fundamental information about the introduced two concepts of Biomimicry and Performalism. First, the definition, concept, history, and terminologies for biomimicry in architecture is discussed, then, the parameters of biomimetic design is illustrated, after that pioneering examples pf biomimicry in architecture and biomimicry concept-based designed structures were explained, after that the concept t of performalism was introduced with the meaning explanation, later, performalism principles and criteria in architecture were clarified, after that pioneering examples were presented, to finally discuss the performalism concept in biomimetic architecture and the both concept conjunction together to compose a theoretical background about both of the concepts for this study.

2.1. Biomimicry and Architecture Relationship

The term " biomimicry " was first recorded in scientific journals and literature in 1962; the term "biomimicry" gained popularity during the 1980s, especially among materials scientists. The terms "biomimetics" or, occasionally, "bionics" were favored by certain scientists. Over the past 10 years, there has been a massive rise in interest, mainly due to the work of writers in biological sciences, such as Janine Benyus, Steven Vogel, and Julian Vincent, and professors of biomimetics who have written significantly in this field. According to Janine Benyus, it is "the aware emulation of nature's genius," while Julian Vincent describes it as the "abstraction of the good design from nature." The one notable distinction between "biomimetics" and "biomimicry" is that while the former can—and occasionally has—be utilized in domains like military technology, the latter is primarily intended by many practitioners to be explicitly focused on creating sustainable solutions. (Aamer, 2021).

Two other concepts requiring clarification are "bio-utilization" and "biophilia." The term "bio-utilization" describes the direct utilization of nature for advantageous ends, such as adding vegetation to buildings' exteriors to create evaporative cooling. The word "biophilia," made popular by the biologist E. O. Wilson, describes the theory that humans and other living things have an innate relationship. (Benyus, 1997). From the standpoint of

architecture, "biomorphism" and "biomimicry" must be distinguished from one another. Nature has been a common source of unorthodox forms and symbolic associations for modern designers and architects. Magnificent architectural creations like the Johnson Wax building designed by Frank Lloyd Wright and TWA terminal Eero Saarinen are two instances of how that has been accomplished (Benyus, 1997; Khoshtinat, 2015).

The term "biomimetics" was initially coined in 1957 by physicist and bioengineer Otto Schmitt to describe his novel gadget that mimicked the electrical function of a neuron (Sharma and Sarkar, 2019). Jack Steele described bionics as the science of natural systems simultaneously (Radwan and Osama, 2016). The strong influence of cybernetics, a branch of science focusing on regulating systems such as the human body, was strengthened in the 1960s (Knippers et al., 2016; Kolarevic and Malkawi, 2005). The German terms "Technik" and "biology" were combined to create the new term "bionic," which denotes the transfer of biological concepts to technology (Hagan, 2008; Hensel and Menges, 2008). The word was used less frequently over the following thirty years. However, thanks to the book by Janine Benyus, Biomimicry: Innovation Inspired by Nature, it had a significant comeback in the late 1990s (Benyus, 1997). In addition, Benyus is one of the co-founders of Biomimicry Institute (Albayrak Colaço and Tuncer, 2011), which is a platform and organization that brings together the various biomimicry identities of engineers, biologists, and designers to aid in their understanding of the systems as well as processes of nature in real life (Radwan and Osama, 2016). In her book, Janine Benyus (Benyus, 1997) provides the most popular description of biomimicry, using its Greek roots, "*bios*" (meaning life), as well as "*mimesis*" (meaning to mimic). Biomimicry nowadays, as defined by Bajaj (Bajaj, 2020), is the study and modeling of biological structures, ecosystems, and functions that have undergone environmental testing as well as undergone modifications via evolution (Sharma and Sarkar, 2019; Verbrugghe, Rubinacci and Khan, 2023)

2.1.1. Biomimicry Definitions, concept, and History

Biomimicry, also referred to by the terms biomimetic, biognosis, bio-inspirations, and bionic, is a term in science that refers to modifying natural systems and industrial design to produce new products. According to Benyus (1998), biomimicry is a technical word used to search for qualities in live organisms that may be investigated through scientific analysis and observation based on nature and can be learned from. Earlier in the 1950s, scientists

developed the scientific theory of biomimicry, which aims to improve everyday tools and expand human potential. Although various words can describe biomimicry, experts, and researchers will use terms such as bionics and biomimetics to define and distinguish the concept (Khoshtinat, 2015), and multiple definitions are in Table 1.1. The only distinction between biomimicry and biomimetics is the emphasis on creating sustainable solutions, whereas the latter may also be employed in domains like high-tech technologies. The terms "bio-utilization" and "*biophilia*" can also explain biomimicry. The intentional utilization of nature for beneficial purposes, such as constructing evaporative and cooling systems, is known as bio-utilization. The alternative word is biophilia, which E.O. Wilson defines as the innate connection between humans and living things (Khoshtinat, 2015). From an architectural standpoint, "biomorphism" and "biomimicry" were coined to characterize the contemporary architectural movement that regularly looked to nature to mimic its unorthodox forms and, in some cases, for metaphorical or symbolic meaning. Le Corbusier, for instance, employed allusions in this mysterious domain by heavily altering natural forms as related symbolism. That is, to draw distinctions that necessitate a functional revolution to shift from biomorphism, which would provide the desired solutions, towards biomimicry. According to Pawlyn (2006), biomorphism and biomimicry interact to produce a specific natural adaptation that is highly effective. He further advanced the theory that something should be classified as biomorphic if it is not, as long as the creature adapts as it would naturally. (Khoshtinat, 2015) Studying the idea of biomimicry helps us to identify a variety of natural phenomena that can be used as models to be assessed, modified, and used to construct forms, processes, strategies, and systems for developing sustainable solutions. There are two main types of biomimicry approaches to the design process: Identifying a specific trait, function, or behavior in an ecosystem or organism and translating it to human plans is known as biology influencing design (Benyus, 1997). Determining a human need, designing a problem, or looking for how other ecosystems or organisms deal with it is termed design looking for biology (Khoshtinat, 2015).

The phrases bio and mimicry, which imply imitating, are the roots of the term "biomimicry." Some favored the name "bionic," while other scientists favored the term "biomimicry." (Pawlyn, 2016). The primary goal of biomimicry is to produce beautiful designs by modeling diverse living things that have developed over 3.8 billion years. (Benyus 1997, Aziz 2016) "new discipline which studies nature's best ideas and then imitates their designs and processes to solve human problems," according to one definition of biomimicry

(Mirniazmandan and Rahimianzarif, 2018). The practice of "learning from nature" is referred to by several names, including biomimicry, bioinspiration, bionics, and biologically inspired design. (Vincent et al. 2006, Shu, Ueda et al. 2011). Prof. Janine Benyus created and introduced biomimicry in her 1997 book Innovation Inspired by Nature. She introduced biomimicry, a new field of study that draws inspiration from natural models and uses it to create solutions to human issues. (Benyus 1997). Biomimicry is nothing new; humans have long drawn inspiration from nature. Leonardo da Vinci conducted the first scientific investigation in this area in 1482. By investigating birds' flight mechanisms, he tried to generate flying devices. Although he failed with the flying contraption, the Wright brothers were motivated by this concept. They created the first airplane, the most famous biomimicry creation, in 1948 (Vierra, 2011; Fayemi, Wanieck, Zollfrank, Maranzana, and Aoussat, 2017). As shown in the timeline in Figure 2.1.

Table 1.1. Important terminologies in Biomimicry

Term	Definition	Refrences
Biomimetics	Multidisciplinary collaboration between technology and biology or other innovative domains aims to solve real-world issues by analyzing the functions of biological systems, abstracting those functions into models, and then applying those to the challenge at hand. Crossing the boundary between the living and the non-living systems is what biomimetics does. Furthermore, searching nature for answers aims to improve technical functionality.	(Sharma and Sakar, 2019) (Vincent et al. 2006)
Biomimicry	It is an approach to sustainable development. In most expansive, it takes or emulates creative inspiration in nature’s processes, tactics, ideas, impact, and systems to design a robust future. Conscious emulation of life‟s genius. Learning from after that emulation of the biological forms, ecosystems, and processes to create sustainable designs.	(Badarnah, 2017) (Sharma and Sakar, 2019) (Bajaj, 2020) (Chayaamor-Heil and Hannachi-Belkadi, 2017) (Kenny, Desha, Kumar, and Hargroves, 2012) (Benyus, 1997)
Bionics	The science of the systems that have some functions copied from nature or represent natural systems characteristics or their analogs.	(Vincent et al., 2006)
Biomorphism /Biomorphic	Inspiration from nature for unusual shapes and metaphorical associations. Since the nature is epitome of performance-oriented design, it makes sense that its processes rece attention. Biomimetic architecture must focus on how we approach design and consider possibility it might positively affect the environment rather than symbolism or form. As with the creation of a living being, form is the outcome of forces that are contained inside the substance. So, discussion surrounding the design and the visual portrayals of these objects could be approached by the	(Chayaamor-Heil and Hannachi-Belkadi, 2017) (Cazzaro, 2020)

Table 1.1. (continued) Important terminologies in Biomimicry

Term	Definition	Refrences
	perspective of biomorphism, a characteristic shared by related artifacts on several levels, from the figurative of animals to the nearly abstract shape created by the self-organizing matter due to its inherent forces.	
Ecomimicry/ Ecomimesis	Emulation of ecosystems in design, one innovation in innovation is biomimicry. This is still-emerging method of incorporating a green element into innovation process so that new practices and technology can develop environmentally responsibly with non-experts' help. Creative ideas can sometimes come from natural environment.	(Bajaj, 2020) (Marshall, 2015)
Organic Design	In terms of shape and structure, organic designs bear a striking similarity to nature. Form-giving for an organic design poses a unique category of design challenge that requires innovative problem-solving by drawing inspiration and parallels from nature.	(Verma and Punekar, 2022)
Inspire	Refers to a designer creating generative design outcomes.	(Chayaamor-Heil and Hannachi-Belkadi, 2017).
Biomorphic	Anything that suggests or resembles forms of living organisms.	(Biomimicry Institute, 2017)
Biophilic / Biophilia	A term popularized thanks to the E.O. Wilson to describe the extent to which humans need to link with nature and other life forms. The biophilic design highlights the use of natural forms, materials, living things, water, sun, and air in the design.	(Biomimicry Institute, 2017)

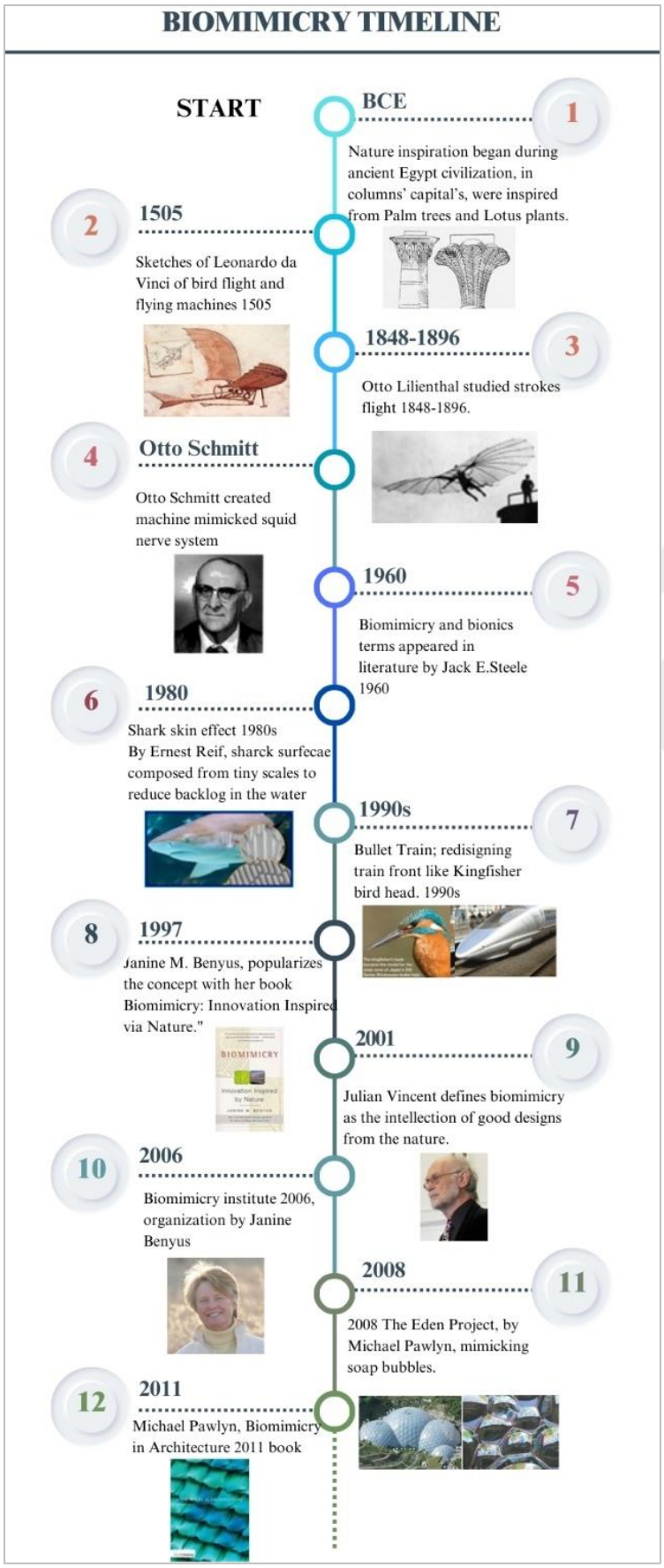


Figure 2.1. Biomimicry Timline

The world's population reached eight billion in 2022 (URL-1). It is widely accepted that excessive consumption in society cannot continue in its current state. Increasing the use of regenerative resources, particularly in the building sector, can reduce greenhouse gas emissions and guarantee that population growth may continue globally. (URL-2). The idea behind BIA is that since nature operates on reusing and recycling rather than producing waste energy, it may be a valuable source of inspiration.

Additionally, incorporating biomimicry into architectural design offers a way to establish reasonable development goals. It also explains how to do this with motivational real-world examples. Reducing human dependence on the use of fossil fuels is the aim of the BIA methodology, which still represents most of the world's energy usage, by the production of additional developments and improvements on the already-used capturing technologies, generating, or producing, concerning resource efficiency and energy generally (Chayaamor-Heil and Hannachi-Belkadi, 2017). It has been evident in recent years, based on Bajaj (2020), that applying a nature-inspired strategy to technology and innovation in architecture may lessen some of the adverse effects of the industrial era.

Biomimicry advances sustainable thinking by using concepts such as connectivity and system integration. Due to the interdisciplinary nature of evolutionary processes, the design concepts are generated from three distinct domains: the issue, the natural environment, and the solution. To tackle a technical problem, a biomimicry-based design method must look for a biological solution (Badarnah, 2017). Building envelopes that can adjust to their environment can improve the resilience and sustainability of a building because they utilize resources more efficiently and use less energy, claims Badarnah (2017). Indeed, by selection, recombination, and mutation processes, evolution enables biological organisms to adapt by producing multifunctional and self-adaptive alternatives. The result is an arrangement that simultaneously meets several needs (Knippers et al. 2016). As of now, BIA is a valuable tool for creating designs that are climate-responsive when it comes to external facades as well as technical systems like natural ventilation (Faragalla & Asadi, 2022). Therefore, biomimicry can be defined as a method that seeks to create long-lasting solutions by imitating natural processes, inferred from the terminology study. Although it is still largely unexplored in architecture, this interdisciplinary design method can expand the designer's conceptual scope. To meet human requirements, it is used to solve architectural difficulties. Its objective is to increase the resilience of structures and, in some instances, incorporate evolutionary

principles through flexible designs, thus improving their ability to restore local ecosystems. The environment makes use of energy-saving methods and closed-loop systems with less waste. When applied to architecture, biomimicry can simultaneously serve several purposes (Verbrugghe et al., 2023). Using biomimicry in architecture offers a fascinating way to combine the creative brilliance of nature with the field of design. Through closely examining and applying the principles inherent in the natural environment, architects can design aesthetically pleasing structures, efficiently utilize energy, and encourage environmentally conscious living. Architects may utilize biomimicry to design visually stunning buildings that also help create a more sustainable future. By studying natural shapes, processes, and systems, architects may maximize resource use, improve energy efficiency, and foster ecological balance (URL-3).

Like architects, nature creates structures. The structures it produces are ideally suited to its surroundings, feature self-contained solutions for every environmental issue, and have just the right amount of missing or additional functionality. Adopting comparable design principles by architects when creating human living places is another significant aspect of natural design. The fundamental ones are protection against predators, operating soil cultivation and structure, food storage, oxygen and respiration, temperature control, water management, and humidity control (Karabetça, 2018). Examples of animal structures are available. In contrast to human constructions, termite mounds serve all these fundamental purposes but are also efficient and durable designs (Yetkin, 2021).

A sustainable building design must consider various factors, including water efficiency, structural efficiency, thermal environment, zero-waste systems, and energy supply (Singh & Nayyar, 2015). For example, we may learn how plants utilize air pollution and transform carbon dioxide into oxygen. This is just one example of how nature may serve as a fantastic tutor for living at peace with it. When considering the three layers of biomimicry— behavior, organism, and the ecosystem—it is possible to create designs without having an influence on the environment by modeling an organism only without modeling how it can interact with its broader ecosystem (Reap, Baumeister et al. 2005). For example, creating a structure in a cactus shape (simple shape copy or mimicking) may not boost the building's sustainability because replicating creatures is just one specific aspect. In the behavior level of biomimicry, an organism's behavior can be imitated. At this stage, architects and designers must determine if humans can imitate organism behavior and what aspects of that behavior will

promote the sustainability of the buildings. For the construction of passively managed thermally pleasant buildings, it could be acceptable to imitate the construction activity of termites. However, if universal human rights are cherished, replicating the social organization of colonies of termites would not be appropriate. Employing the ecosystem level in biomimicry with organismal and behavioral biomimicry offers several advantages (Zari, 2007). The core nine tenets of biomimicry that Janine described are the ideas. According to Janine, the second part of biomimicry is using nature as a model, measure, and teacher. She described biomimicry as a fresh perspective on and appreciation of nature. Benyus further argued that individuals must view nature uniquely to actively replicate nature's intellect, viewing it as a measure, model, and mentor (Figure 2.2). Counseling genius life thereby uses nature's knowledge to make a difference in today's urgent, chaotic, and evil issues (Aamer, 2021):

- Being a Model as biomimicry is a study that examines natural models and mimics or draws inspiration from their structures and operations to address societal issues.
- Being as Measure biomimicry evaluates the viability of our solutions using an environmental standard. After 3.8 billion years of evolution, nature has figured out what lasts, what functions, and which is acceptable.
- Being a Mentor, as demonstrated in Figure (2.2), biomimicry delivers a change in perspective based on deduction from nature and lessons learned rather than merely observation of nature. This makes it a holistic approach to expressing and enjoying nature (Benyus, 1997).

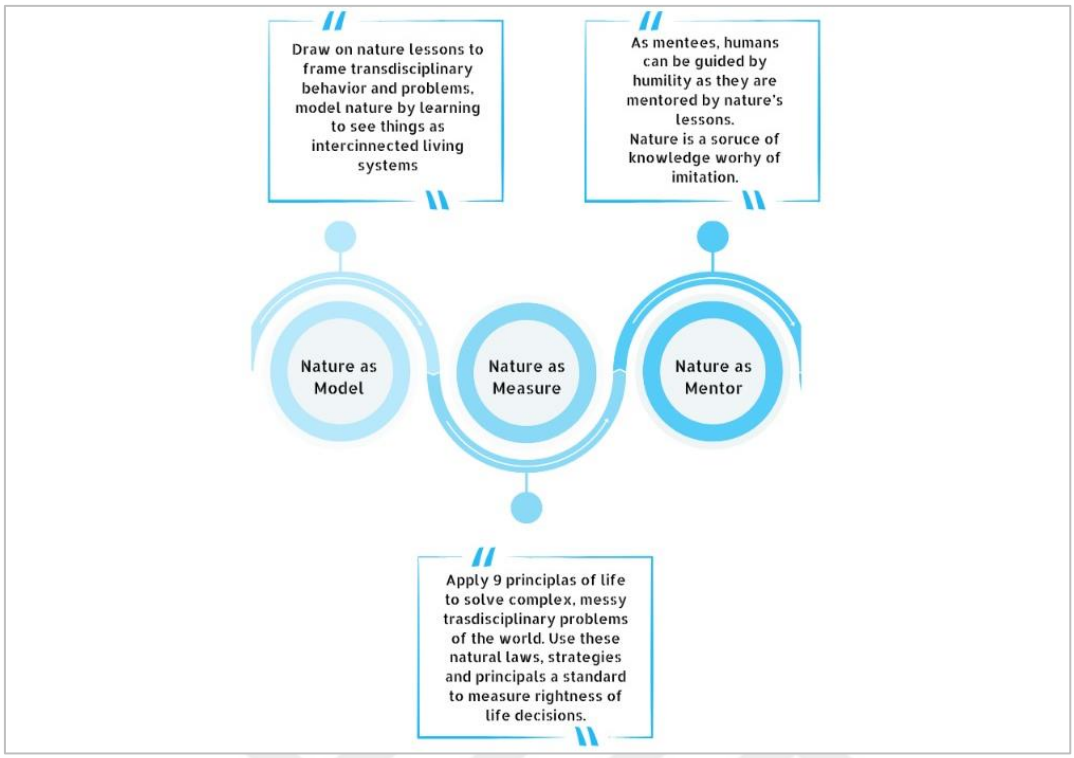


Figure 2.2. Nature as Model, Measure, and Mentor (McGregor, 2013)

Design spiral:

As one of the most potent features of the Biomimicry design, this is Janine's third dimension. The Biomimicry design spiral extends outward in the same manner as spirals naturally occur. The spiral cycle begins from the center, where each 'lap' around the spiral is short and swift. During the early stages of a design procedure, the designer can quickly explore potential opportunities and alternatives, uncover underlying assumptions, generate and sift through various uncontrollably creative concepts, and observe what begins to emerge before concentrating on a particular solution method. This strategy shortens the time needed for sustainable innovation (Aamer, 2021). The spiral method allows for exploring any aspect of the project and focusing on the elements most crucial to the designer and his vision at any moment. This design spiral offers a Biomimicry process based on the intended objective.

The design spiral operates as follows: The Identification stage, which employs biomimicry in design, comes first in the spiral. The "Discover" stage might be the starting point for anyone looking to develop something new. The Abstract phase might start a journey to increase the portfolio of creative and sustainable design approaches and solutions. Moreover, the Emulate stage might be the starting point for achieving the objective of solving problems

and igniting creativity. Ultimately, the Evaluate stage might serve as the starting point for improving the sustainability of an existing design. The spiral diagram in Figure (2.3) for biomimicry design illustrates these processes. (Alanbari, Alkindi, and Alahbabi, 2022).

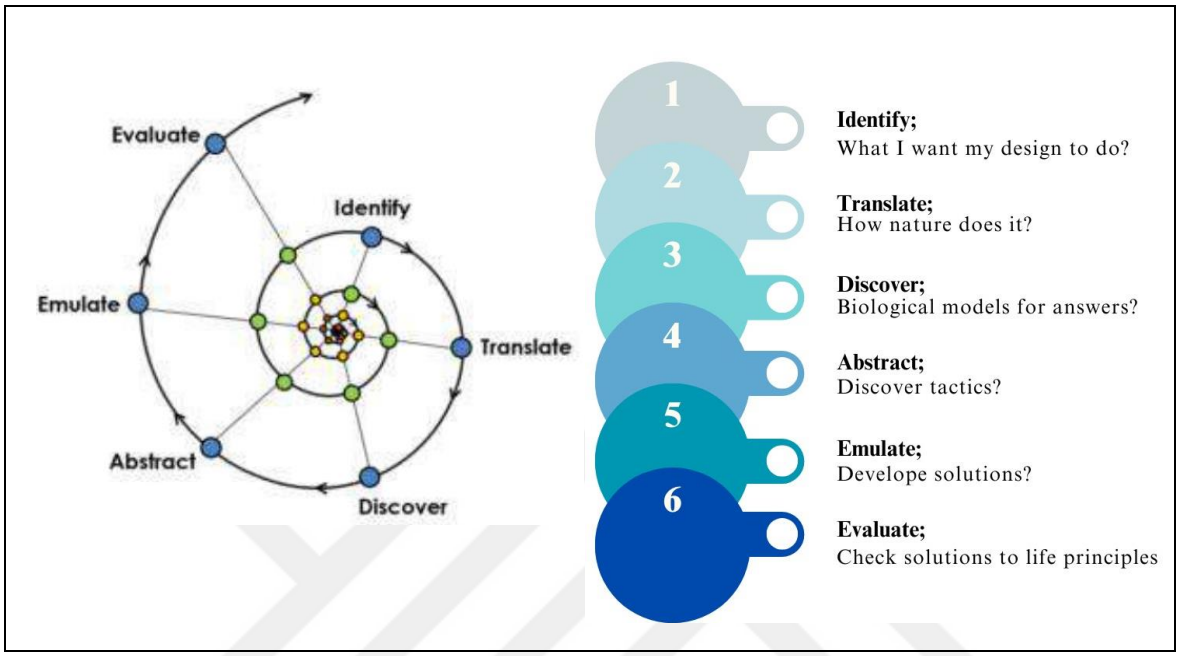


Figure 2.3. Biomimicry Design Spiral Diagram (URL-7)

A methodical approach to turning natural processes into creative and sustainable design solutions is the Biomimicry Design Spiral. Carl Hastrich developed it in 2005. Hastrich is an industrial designer who was among the first to lay the groundwork for modern biomimicry. Hastrich created a standard design method incorporating the incredible advancements needed for Biomimicry. Imitation of one of nature's inevitable instances is then carried out. Hastrich turned it into a spiral process. The Biomimicry Design Spiral is applied when the problem is fully comprehended. The below steps are used to utilize the strategy:

1. Identify where the goal is to determine what you want the design to be able to do and what functions it needs to execute.
2. Translate these strategies into words or a text that makes sense in the biological domain.
3. Discover the strategies used by nature to achieve these functions.
4. Abstract: “reverse engineer” abstractly discovered tactics, describing the capacity of how they perform in terms that make sense for the design occupation.

5. Emulate: using professional skills to generate a design solution by mimicking one or more processes and functions discovered and abstracted.
6. Evaluate: which is used in two dimensions; the first is to evaluate the solution of the design against the original design, and the second is to assess the design compared to nature's unifying approaches (Life Principles) and nature's sustainability rules.

Biomimicry may be applied on both a practical and metaphorical level. Designers with less ecological expertise can still increase a building's sustainability by using metaphors in their designs, as stated (Korhonen, 2001). Contrarily, employing ecosystem biomimicry practically necessitates a comprehensive grasp of ecology and biology, making it challenging for architects to use this sophisticated biomimicry. And the concept of Biomimicry in Architecture and Design potentials and advantages (Jamei & Vrcelj, 2021).

    - function of construction material, besides lifecycle and weight.
- the structure behavior
- the envelope of the building (cooling, heating, and lighting)
- the building facades
- insulation and heating
- direct gain of heat
- cooling
- the thermoregulation
- lighting

Generally, the practice of biomimetics can be either as (Fayemi et al., 2017):

- The solution-based finds a particular trait, function, or behavior inside an organism and an ecosystem and then searches for a design issue that may be solved (Aamer, 2021).
- The problem-based approach is concerned with the design issue before examining how creatures or ecosystems resolve the issue.; (Aamer 2021) as explained in Table1, where the steps of both approaches are illustrated.

Both problem-driven and solution-based approaches to the design, illustrated in Figure 2.4, have distinctive traits throughout the design and vary in their beginning points of view.

Moreover, a thorough examination is necessary to comprehend each process more deeply. (Jacobs, 2014).

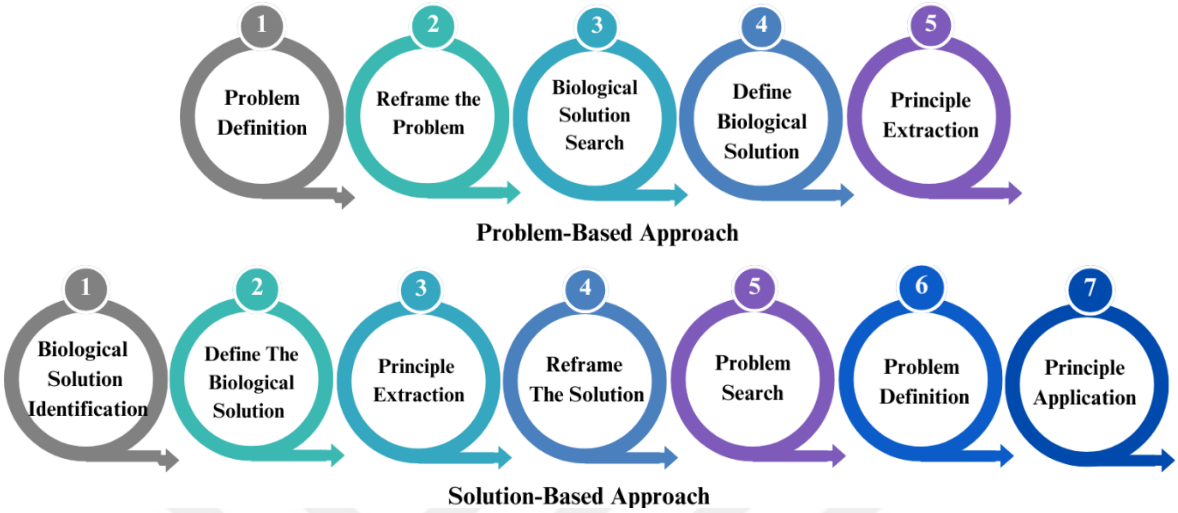


Figure 2.4. Solution-based method and problem-based method (Al-Obaidi, M.Ismail, et al. 2017)

Table 2.1. Study map diagram of biological domain features and the building behavior features (Aamer, 2021)

Biomimetic approach in building behavior			
Biological domain		Architectural domain	
Life criteria	Performance	Elements	Targets
Complexity: Cell-tissue-organ-organism-ecosystem	Color change Growth Deployment Shape change Variety of shapes Hierarchies Self-heating Communication	External elements: Envelope-structure	1-structure efficiency 2-material efficiency 3-indoor environmental quality: Thermal comfort-visual comfort- indoor air quality 4-energy efficiency 5-water quality
Adaptability: Form-structure-texture-chemical res. -physical res.		Internal elements: Building systems-interior elements-materials	
Environmental reactions: Light-air-heat-water-energy.			

Principles of Biomimicry can be as follows (McGregor, 2013; Aamer, 2021): Nature runs on sunlight as it efficiently harnesses energy from the sun through processes like photosynthesis, illustrating the reliance on solar energy rather than fossil fuels; Nature only uses its need of energy as:

- It optimizes its use of limited resources, illustrated in Table 2.1.

- ensuring efficient consumption and preservation without over-exploiting natural capital, Nature fits form to function as it creates efficient and elegant structures within resource limits.
- adapting shapes based on functionality rather than focusing on size or linear forms,
- Nature operates in closed systems where waste is considered a valuable resource, recycled for reuse.
- promoting sustainability and the absence of waste production or pollution.
- Nature rewards cooperation by thriving on integrated relationships and mutually beneficial interactions that make cooperation fulfilling and essential. Nature banks on diversity as it selects the best solutions rather than following a homogeneous approach, allowing for emergent diversity and accommodating changes in needs.
- Nature demands local expertise, as local expertise is relied on for sustainable development without relying on external resources.
- Nature curbs excesses from within as it operates within self-imposed limits, ensuring resource availability before development and maintaining balance with the biosphere to sustain life.
- Nature taps the power of limits as Nature thrives within its limitations, using them as a source of power to avoid deviations.

2.1.2. Parameters of biomimicry design

Architecture is influenced by biomimicry in three different ways: through organisms (which imitate nature), behavior (which imitate natural processes), as well as ecosystem levels (which imitate the operating principles behind ecosystems) (Zari, 2007). At the organism level, the building's form, shape, or structure mainly inspires design and architecture. The interaction between the ecosystem and its surroundings inspires the design at the behavioral level. Moreover, at the ecosystem level, the primary emphasis is on how various organismal components interact on a broad (urban) scale. Features for each level are collected in Table 2.2. This strategy has been developed for design or architectural issues.

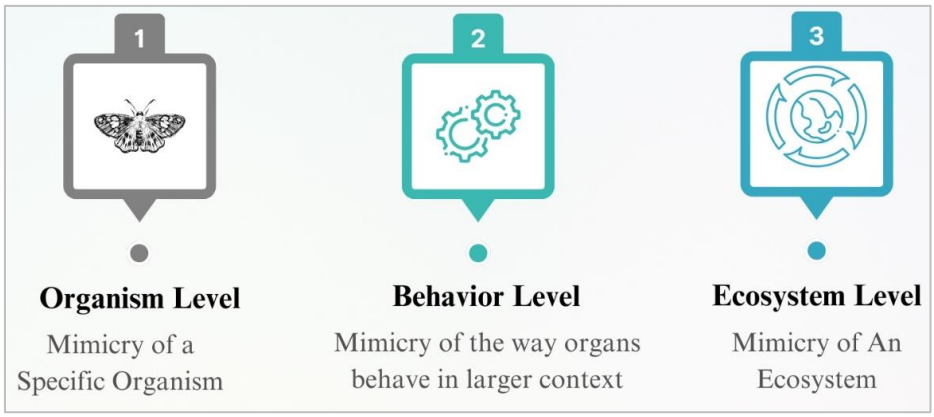


Figure 2.5. Framework for the different biomimicry levels (Nkandu & Alibaba, 2018)

There are five potential aspects to biomimicry at each of those levels: (1) How the ecosystem's structure and appearance are mimicked by design; (2) how the ecosystem's components are represented; (3) how the ecosystem is formed; (4) how ecosystem functions; and (5) what ecosystem has the capacity of accomplishing. These standards are frequently benchmarks for architects who want to incorporate biomimicry concepts in their design and architectural methods to produce efficient, sustainable, and environmentally friendly buildings. Most projects in several architectural and design concepts have been influenced by the shape and mannerisms of specific creatures (animals found in the water or on land) that have adapted ways of dealing with the environment (such as the wind and sun). In various other architectural endeavors, plants that respond differently to harsh environmental circumstances (light, heat, and drought) serve as inspiration sources. Biomimicry consists of three levels: First, replicating a portion or the entirety of an organism is possible at the organism level, which relates to a particular organism, like a plant or animal. The second behavior level is emulating the behavior of an organism, which can involve analyzing a behavior's component or how it fits into a broader context. Moreover, the third level is the ecosystem level, which is the imitation of entire ecosystems and the shared values that enable their efficient operation. In the case of mimicking termites in a building, the table below compares the three biomimicry levels by examining the final form, materials utilized, construction, internal processes, and purpose the building fulfills for each level (Benyoucef, 2018).

Table 2.2. The biomimicry levels (Zari, 2012)

Biomimicry Level		Example: a building which mimics termites
Organism – Mimicry of specific organism	Form	The building looks like a termite.
	Material	The building is made from the same material as a termite; a material that mimics termite exoskeleton/skin for example.
	Construction	The building is made in the same way as a termite, it goes through various growth cycles for example.
	Process	The building works in the same way as an individual termite; it produces hydrogen efficiently through meta-genomics for example.
	Function	The building functions like a termite in a larger context; it recycles cellulose waste and creates soil for example.
Behavior – Mimicry of how an organism behaves in relation to its larger context	Form	The building looks like it was made by a termite; a replica of a termite mound for example.
	Material	The building is made from the same materials that a termite builds with: using digested fine soil as the primary material for example.
	Construction	The building is made in the same way that a termite would build in; piling earth in certain places at certain times for example.
	Process	The building works in the same way as a termite mound would; by careful orientation, shape, materials selection and natural ventilation for example, or it mimics how termites work together.
	Function	The building functions in the same way that it would if made by termites: internal conditions are regulated to be optimal and thermally stable for example It may also function in the same way that a termite mound does in a larger context.
Ecosystem – Mimicry of an ecosystem	Form	The building looks like an ecosystem (a termite would live in).
	Material	The building is made from the same kind of materials that (a termite) ecosystem is made of it uses naturally occurring common compounds, and water as the primary chemical medium for example.
	Construction	The building is assembled in the same way as a (termite) ecosystem; principles of succession and increasing complexity over time are used for example .
	Process	The building works in the same way as a (termite) ecosystem: it captures and converts energy from the sun, and stores water for example.
	Function	The building is able to function in the same way that a (termite) ecosystem would and forms part of a complex system by utilizing the relationships between processes: it is able to participate in the hydrological, carbon. nitrogen cycles etc in a similar way to an ecosystem for example.

The "Bio-inspired" architecture of Gaudi, as well as Calatrava, may be analyzed using a set of factors that can be broken down into both theoretical and practical considerations by looking at literature that is already accessible. In keeping with Pedersen Zari's subclasses of biomimicry, the first column represents the biomimicry levels of organism, behavior, or ecosystem, and second column describes the levels of function, form, structure, material, and process appropriate for the design components of any design for architecture process (Table 2.2) (Imani, 2017).

Organism Level: Living species usually undergo millions of years of evolution before becoming extinct. The survival strategies used by the species still here today have withstood and adjusted to numerous changes during geological time. If an organism is only mimicked without considering its ability to engage with and improve the broader ecosystem in which it lives, this could result in conventional or significantly below-average designs regarding their environmental impact (Reap, Baumeister, et al. 2005). Because organisms are typically mimicked for a single feature instead of an entire system, biomimicry risks becoming an add-on technology for buildings instead of something intrinsic. This is especially true if designers lack biological expertise and do not work closely with biologists or ecologists over the early stages of design. Although this approach might lead to developing novel and cutting-edge building materials or equipment, it may not always investigate ways to improve sustainability (Khoshtinat, 2015).

Behavior Level: Many species have problems comparable to humans and experience similar environmental circumstances. As was mentioned, these creatures often function under the constraints of the ecological carrying capacity of a particular location and the availability of materials and energy. In addition to well-adapted animals continuing to evolve, these constraints and the forces that produce ecological niche adaptations in ecosystems also cause well-adapted organism actions and patterns of relationships between species to change (Reap, Baumeister et al. 2005). Behavior-level biomimicry mimics an organism's behavior rather than the organism itself. Similar interactions among organisms or species might be able to be imitated.

Ecosystem Level: According to (Benyus, 1997) and Vincent (2007), biomimicry includes imitating ecosystems as an essential component. Designing under this biomimicry level has the advantage of being able to be joined with the other levels of biomimicry (behavior and organism). Nevertheless, the possible benefits of total environmental performance may be the main advantage of applying a biomimetic design approach. Ecosystem-based biomimicry can function practically and metaphorically (Khoshtinat, 2015), and the biomimetic levels areas have corresponding practical parameters.

2.1.3. Pioneering examples of biomimicry design in architecture

Minister of Municipal Affairs & Agriculture building (Doha, Qatar): (Mohamed, Bakr, et al. 2019): An example of biomimicry at the ecosystem level; (Benyus, 1997) along with Vincent (2007) identify the imitation of ecosystems as a fundamental part of biomimicry. The advantage of emulating at this stage of biomimicry is that it may be paired with other levels of biomimicry (organism and behavior). However, the most important advantage of employing this kind of biomimetic design approach may be the potential advantages on overall environmental performance (Nkandu & Alibaba, 2018). An office structure in Doha, renowned for its scorching temperatures and scorching desert sun, was created for the Ministry of Municipal Affairs (Figure 2.6). The Aesthetics Architects Go Group architectural firm created the structure. Inspiration of Elements: Due to the arid climate, cacti inspired the building's overall design and purpose (Figure 2.8). The capacity of cacti to shade themselves and keep water from evaporating in dry conditions served as the model for the building's shading system. Cactus plants limit moisture loss by employing their spines or other thorn-like elements to block air from evaporating near the outer layer of the skin, keeping the plant cool. Moreover, they also serve as sunblocks by acting as shadows. Concept of the Design: From top to bottom, the structure is coated in hues that mimic the spines of cacti. They serve the similar purpose of providing shading for the building's exterior. The shade mechanisms open and close in response to the sun's strength, which is determined by interpreting the transpiration of the cacti. Additionally, the structure purifies contaminated water using several ecological methods. Each biological system separates toxins depending on what it needs to survive and what nutrients it receives from the water. "The use of helpful fungi, bacteria, plants, clams, snails, and fish that survive by breaking down and consuming pollutants" is what such ecological systems depend on. Should this structure be constructed, it will employ biomimetic design principles and function as an organic waste disposal system. Technique of Energy efficiency: The entire surface of the building is coated in hues that resemble cactus spines (Figure 2.7). By limiting the quantity of sunlight that enters the structure, these blinds help to keep it cool. Additionally, it contributes to creating a highly energy-efficient structure by bringing natural light into every space.



Figure 2.6. Photos of the project of the Minister of Municipal Affairs & Agriculture building in Doha, Qatar (URL-4)



Figure 2.7. Cactus Inspiration (Charkas, 2019)

INSPIRED ORGAN	LIFE PRINCIPLES AND NATURE CONNECTION	ABSTRACTION APPLICATION PHASE	BIOMIMICRY LEVEL
Cactus Plant	The capacity of cacti to shade themselves and keep water from evaporating in dry conditions limits moisture loss by employing their spines/thorn-like elements to block air from evaporating near the outer layer of skin	Structure coated in hues that mimic cacti spines , shade mechanisms open and close in response to sun, determined by interpreting transpiration of cacti. Structure purifies contaminated water using several ecological methods	Ecosystem level

Figure 2.8. Minister of Municipal Affairs & Agriculture building ID

The East Gate Centre, Harare, Zimbabwe: An example of behavior-level biomimicry. The behavioral level is created by observing that a vast array of organisms has adapted to live within the constraints of environmental circumstances throughout the material and

energy availability limits. These organisms face identical environmental challenges as humans and, as a result, must find solutions to comparable problems. These constraints, along with the forces that produce ecological specific adjustments in ecosystems, imply that not only do adaptable organisms keep evolving, but also all well-adapted organism behaviors and patterns of relationships among species (Reap, Baumeister et al. 2005). The East Gate Center's design was influenced by self-cooling African termite mounds and native Zimbabwean stonework (Figure 2.11). It employs design techniques to maintain its temperature year-round with remarkably low energy usage. Because of its height and moderate climate, which ranges from 7 to 27 degrees Celsius, passive cooling and heating could be an option for Zimbabweans instead of using mechanical systems. This mid-rise structure, created by architect Mick Pearce and engineers from Arup, lacks traditional heating and air conditioning systems. Thanks to passive cooling and heating strategies, it consumes less than 10% of the energy of a typical structure of this size (Michael Pawlyn, 2011). During the day, termites continuously open and close several cooling and heating vents on the mounds, regulating the temperature of the building. Similar principles apply to the East Gate Structure: outside air is pulled in by vertical ducts over the first level and depending on which part is hotter—the air or the structure's concrete—the building mass either warms or cools the air. Subsequently, it is forced through the central spine of both buildings and into the building's levels, ultimately emerging through chimneys at the summit (Okeke, Okekeogbu & Adibe, 2017).

Steel bridges connect the two buildings, allowing the building to be open to the surrounding breezes. The bridges cross the below atrium and are supported by cables hanging from steel lattice beams. The bridges have a glass covering on top of them. Protruding stone components on both buildings shield the windows from the building façade, enhancing nighttime heat loss and reducing daytime heat gain. Based on a 1998 study that examined how the East Gate Building effectively controls the temperature of the concrete floor, the outside air, and the inside space of the building (Pawlyn, 2011) is illustrated in Figures 2.9 and 2.10. Following a thorough simulation, Pearce received a set of guidelines from the engineering firm, Arup Engineers, to adhere to in his design: It is required that the North façade's exterior walls not receive direct sunlight. The proportion of windows to walls cannot be higher than 25%. Windows must act as light filters, reducing glare, noise, and security. The windows that rely only on the duct system for ventilation must be sealed due

to noise pollution and variable wind temperature and pressure. (Shankar Shiva, 2016; Nkandu & Alibaba, 2018).



Figure 2.9. (a) Termite mound, (b) Eastgate center, (c) Mechanism (Majumder and Saha 2014, URL-5)

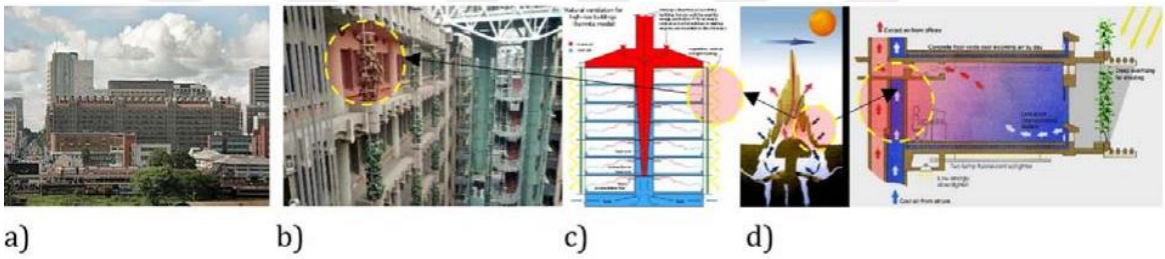


Figure 2.10. Eastgate building biomimetic concept. (a) The Eastgate building. (b) Eastgate Building Facade (C) The section of the Eastgate building (d) Inspiration of Eastgate building skin (URL-6, URL-7, URL-8).

INSPIRED ORGAN	LIFE PRINCIPLES AND NATURE CONNECTION	ABSTRACTION APPLICATION PHASE	BIOMIMICRY LEVEL
Termite mound	Termites continuously open and close several cooling and heating vents on the mounds, regulating the temperature of the building	The building opens and brings in more air; ducts push that up to provide support for fans. Providing Thermal comfort and Air Quality	Behavior level

Figure 2.11. The Eastgate Center ID

The Sino Steel International Plaza (Mohamed, Bakr, et al. 2019): An example of biomimicry at the organism level. Understanding the detrimental effects of human activity on the environment and many of the world's ecosystems could be easier using the organism-level methodology. Organisms have endured and coped with numerous changes throughout billions of years. As a result, humans have access to many examples to learn and develop solutions for issues already being tackled, especially when efficiently using resources and energy (Nkandu & Alibaba, 2018). The Sino Steel Plaza is a glass-only high-rise commercial structure. It is close to Rivonia Road and Grayston Drive. Located in Tianjin, China, and was created by Beijing-based architects, MAD 9 is now under construction. The development comprises an office tower rising to a height of 358 meters and a nearby hotel at 88 meters. Inspiration of Elements: The buildings outside design was inspired by a bee hive or honeycomb, figure 9. Five distinct-sized hexagonal honeycomb windows make up the external construction. To control the temperature within the towers, these were positioned in the direction of the wind and the sun in that setting. Concept of the Design: The two structures have a straightforward shape that resembles a rounded box. The façade is made up of five distinct-sized hexagonal windows that resemble honeycombs. These windows are arranged throughout the structure in a pattern that is both random and organic, much like cells proliferating. This pattern alters people's perceptions of architecture and provides it with life (Figure 2.12). The hotel podium forms a verdant hill from which the buildings rise. Technique of Energy efficiency: The honeycomb-inspired pattern allows the building to adapt to changes in the direction of the sun and wind, resulting in increased energy efficiency. Different-sized windows have been placed to minimize heat gain in the summer and heat loss in the winter by analyzing the various air flows and solar directions across the site. Figure 2.13 shows the Sino Steel International Plaza ID.



Figure 2.12. Sino Steel International Plaza is inspired by the Beehive (URL-61)

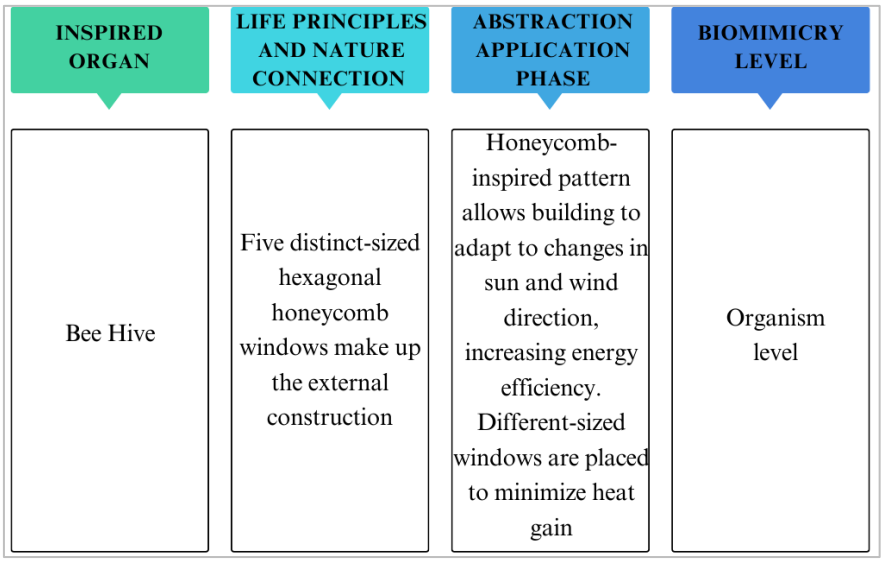


Figure 2.13. Sino Steel Iinternational Plaza ID

The table 2.3 below is an analysis of the discussed projects, highlighting their inspiration, design concept, and the techniques of saving energy adopted and created in them:

Table 2.3. Analysis of the three biomimetic buildings

Building	Inspiration	Concept of the Design	Techniques for Saving Energy
Minister of Municipal Affairs & Agriculture	Plant of Cactus	The entire structure is covered by shades that mimic the cactus's spines and serve the same purpose of providing shade across the surface of the building.	Regulating sunlight amount that enters the structure to maintain a cool temperature and abundant natural light inside the rooms.
The East Gate Centre, Harare, Zimbabwe	Termite mound	By mimicking the behavior of termites, they keep their mounds at a constant temperature by sealing and opening holes in the outer mound's shell to permit air to ventilate and balance the temperature inside. Eastgate uses ducts and fans instead of termites to work using the same method as mounds.	Using passive cooling and heating methods consumes less than 10% of the energy of a traditional building of the same size.
Sino Steel International Plaza	Bee Hive	In order to preserve energy, the windows are designed in five hexagonal sizes.	Hexagonal forms have a minimal energy consumption.

2.2. Performative Architecture

Two basic concepts shape the language of 21st century architecture. The first of these is the one that aims to have less of an environmental footprint in the ecosystem. The other is "digital design and production" technologies, which enable the consideration of the design

processes and the product with the innovative approaches they provide in architecture, as in all design disciplines. The intersection of these two approaches can be called "performative "architecture" and has begun to take its place in the literature as a holistic way of designing and "optimizing" all the "more" such as better, lighter, more effective, more economical for a sustainable environment. When it comes to "optimizing" more parameters for sustainability, the importance of computational tools and advanced technology emerges. "Performative architecture," which includes many sustainable architectural products, is a concept that has emerged with digital technologies in recent years (Kazimov et al. 2017).

2.2.1. Performalism definition

Performative architecture represents a harmonious blend of two pivotal concepts—sustainability and digital design (Figure 2.14). This innovative approach is intrinsically linked to sustainability, enhancing the utilization of natural resources and promoting eco-friendly practices. Performative architecture embraces better green approaches, striving for efficient energy use and environmentally conscious design strategies. Simultaneously, it embodies the essence of digital design, recognizing that the intricate designs of buildings with unique geometries can be effectively conceptualized and executed only through computational technologies. The synergy of sustainability and digital design in performative architecture contributes to resource optimization and transforms buildings into works of art. (Kazimov et al. 2017). These structures are not just functional; they perform as aesthetic expressions, creating a dynamic relationship between form, function, and the environment, showcasing the possibilities that arise when sustainability and digital innovation converge in architectural design.

- Buildings and structures play a crucial role in the urban environment and people's lives due to their transformative capabilities. Determining buildings' height, form, and structure involves addressing multiple parameters simultaneously for optimal functionality. Achieving this optimization requires using simulation methods and integrating evaluations into the design process.
- Elements of performative architecture include lighter structural systems, reduced energy consumption, increased natural light, the use of natural materials, and interactive building systems. Adopting digital design and production techniques is emphasized to realize these themes.

- Specific criteria influencing the performance in the design of buildings/structures are such as site selection, plan, form, function, core design, fire safety, facade selection, sun control, and structural design.

Leatherbarrow (2005) asks, "What is the function of buildings, and what is architecture in reality?" He asks another question: "What does it do?" He answers his question by reminding Aristotle's definition that "architecture is the imitation of human actions and life" and defines performance as the theme, purpose, or foresight of the building, and performative architecture as architecture that brings these to the fore (Kolarevic & Malkawi, 2005), While (Malkawi, 2004) and Sasaki (2007) mention the role of analytical techniques that support productive processes in increasing the potential of numerical models, they say that performance is the whole of physical and environmental targets that can be tested and evaluated through these models. Thus, the targeted high-level integration between architecture-engineering disciplines can be achieved. (Grobman & Neuman 2011) see the concept of performalism, which they define as a manifesto for the performance of architecture, as "an effort to achieve a very personalized yet performative architecture in a century that integrates digital tools by determining the design and architectural attitude (Kazimov et al., 2017).

The focus of performative architecture revolves around what the building does instead of what it is; it emphasizes the need for architecture to remain flexible enough to change with the times and environments in which it exists. Consideration is given to a design issue, then performative architecture is used to create the solution. The change in the focus of the architectural theory also changed the practice, transforming what a building is into what it does, which is known as performative architecture. As a result, it describes the architectural item in terms of how it works rather than how it looks or how it might impact, alter, or accomplish anything—integrating performance concepts into the design from the conceptual stage being the first phase of performative architecture. Therefore, rather than only being an assessment criterion, performative ideas are a structuring and creative component. Using a new concept of performance-based that encompasses a more extensive range of areas, performative architecture (Albayrak Colaço & Tuncer, 2011). The power of architectural items to impact, alter, and do, which is, in other words, the way it functions, defines it instead of how it looks. A more challenging message than purely aesthetic ones involve knowing how a structure functions. Buildings, therefore, require comprehension of their usefulness

and motivation rather than appealing to looks. They might be technical, geographical, economic, ecological, or structural. The Performative architecture seeks to avoid these conflicts using optimization techniques (Albayrak Colaço & Tuncer, 2011).

It can be understood that Performative architecture refers to an approach in architectural design that emphasizes the functional and experiential aspects of a building or space. It focuses on how architecture can actively engage with its users and the environment, going beyond aesthetics and form to consider factors such as sustainability, energy efficiency, social interactions, and user well-being. In this context, the term "performative" suggests that architecture is not just a static structure but an active participant in performing various functions and experiences. It implies that architecture can transform its surroundings and the people who interact with it. Some key aspects of performative architecture are listed below:

- Prioritizes sustainable design strategies to minimize environmental impact. This includes considerations such as passive solar design, natural ventilation, use of renewable materials, energy-efficient systems, and integration of green spaces.
- Focuses on the efficient use of space and the optimization of building functions. It aims to create spaces that support the intended activities and user needs, enhancing usability and productivity.
- Places importance on the experiential qualities of a building or space. It considers lighting, acoustics, ergonomics, and spatial arrangement to create comfortable, inspiring environments conducive to well-being.

The importance of performance-based adaptable buildings has increased significantly due to the variable climatic factors. Due to the combination of the other disciplines alongside architecture, the performance-based adaptable building envelopes that can react to the environmental elements increase user comfort, assure sustainability, lower operating costs, and prolong structure life. Various techniques are used in architectural design. Moreover, one of them is performance-based adaptable architecture, which has become vital to studying architectural challenges with the help of different fields, including engineering, the natural sciences, and the social sciences, since they are tied to many other aspects (Karakoç & Cagdas, 2015). Building performance has grown increasingly important in architectural design over the past few decades, resulting in highly interactive relationships between architecture and many other disciplines. Building performance and sustainability

concepts are now deeply woven into the building design process. Recent developments in the discipline and the acceptance of these ideas in architectural practices seem somewhat sluggish (Ataman & Gursel Dino, 2021).

Performative architecture refers to the design approach that emphasizes the performance and functionality of a building. It focuses on how the architecture responds and adapts to various environmental, social, and programmatic factors. Performative architecture considers the following aspects:

- Functional Performance involves analyzing the building's program, spatial organization, circulation, and usability to optimize functionality and meet the specific needs of users.
- Environmental Performance evaluates the building's response to environmental conditions such as solar orientation, wind patterns, daylighting, and thermal comfort. It aims to maximize efficiency and minimize energy consumption.
- Technological Performance involves the integration of advanced technologies, systems, and materials to enhance the building's performance in terms of energy efficiency, structural integrity, acoustics, and safety.

Performative architecture aims to create dynamic and responsive spaces that actively engage with their surroundings and function optimally. In terminological terms, "performative architecture" describes a design strategy that emphasizes a building's usefulness and performance, as well as how architecture reacts to and changes in response to diverse programmatic, environmental, and social elements—indicating a shift in the emphasis of architectural theory and practice from the intrinsic aspects of the structure to its utilitarian influence. Instead of focusing exclusively on a particular architectural object's look, it alters its capacity to affect change and accomplish tasks. Performative architecture's primary goal is to balance various performance factors using optimization techniques, resulting in a well-rounded and efficient design that can carry out its intended duties. Performative architecture is also anticipated to have generative capabilities, enabling it to adjust and change in reaction to various demands and restrictions (Albayrak Colaço & Tuncer, 2011).

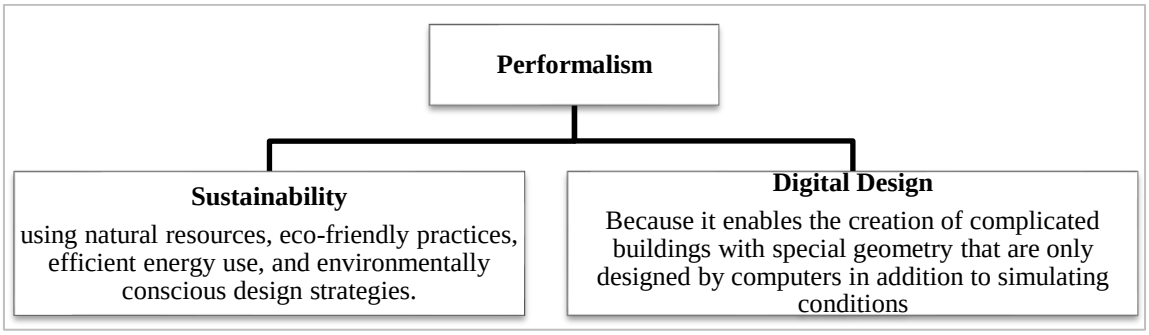


Figure 2.14. Performalism concept definition and meaning

To provide better reactions, plans, designs, and projects, the consequence of biomimicry using performalism is an area and issue of enormous relevance and interest. A comprehensive approach to sustainability within architecture has been made possible by technological advancements, considering factors like convertibility, recyclability, security, circulatory systems, and interaction, alongside computational technologies taking an essential part in optimizing designs of financial, aesthetically pleasing, as well as performance-oriented results (Kolarevic, 2004). Performative design results from this convergence, which uses solid models to analyze environmental performance while modeling factors such as solar or structural loadings, thus integrating buildings into their surroundings (Kolarevic, 2004). Whereas sustainability is linked with performative architecture, scholars (Hensel & Menges, 2008) propose that it should also consider factors like semantic, social, shelter performance, and ideological (Hagan, 2008). The performative architecture tackles complex design issues by defining constraints, requirements, and goals. It turns the design procedure into a method of optimization that considers lightweight construction, natural lighting, energy efficiency, the utilization of natural materials, and interactive building systems. Moreover, Architecture naturally helps sustainability through clever and innovative design methods (Kolarevic, 2004).

2.2.2. Principles and criteria of performalism in architecture

Various criteria play pivotal roles in influencing performance in building and structure design. These criteria encompass critical aspects such as site selection, where the strategic placement of a structure profoundly impacts its overall functionality. The plan, form, and function of a building are equally significant, dictating how the space will be utilized and experienced. The structure's core design and vertical circulation contribute to its efficiency

and accessibility. Fire safety measures are imperative, ensuring the well-being of occupants in the face of potential hazards. The selection of facades, sun control strategies, and structural design further shape a building's performance, impacting its energy efficiency, aesthetic appeal, and overall structural integrity. Perofrmalim concept combines two ideas: focusing on aesthetics and form and how a building responds to structure or environmental requirements. Creating architectural concepts enhances structural integrity, energy efficiency, and user experience. Performative architecture and Performalism in architecture prioritize the functionality and efficiency of buildings and their aesthetic qualities. "Performative architecture," which may be described as the meeting point of these two methods, has started to appear in the literature as a type of holistic design and optimization to make all of these "better" things—such as lighter, cheaper, and more efficient—more sustainable. A building is a significant example of performative design by incorporating technologies and engineering advancements. With its form, the building harnesses wind energy through turbines located on its mechanical floors. Compared to a similar structure, it uses less energy because of several sustainable elements, such as a double-skin chilled ceiling system, curtain wall, solar panels, daylight harvesting, and under-floor ventilation. These criteria collectively form a comprehensive framework that architects and designers navigate to optimize the functionality and sustainability of buildings and structures and are explained more as follows (Kazimov et al. 2017):

Having sculptural form and design:

The design process integrates both aesthetics and performance from the outset. Performs the form itself, aesthetic quality. In addition to adaptability and dynamic design, performalism encourages the design of buildings that can adapt over time to changing environmental conditions or user needs. This may involve innovative materials, dynamic facades, or other technologies that allow for real-time adjustments, which have a significant role in achieving and getting the structural form and emphasizing the quest for performance, reliability, and economy in building design and construction, showcasing the precision in material production and the resulting faster and more economical production process.

Efficiency in water management:

Integrates water harvesting strategies, rainwater harvesting, recycled water, grey water, etc. (Figure 2.15). Incorporating water-saving fixtures and technologies, with a daily target of collecting gray water, aims to reduce water consumption. Emphasizing more efficient water use in the design of a building/structure through design strategies intended to collect rainwater, for example, which is then integrated into a rain collection system. Both rainwater and gray water are recycled for use in toilets and garden irrigation systems. Incorporating water-saving fixtures and technologies, with a daily target of collecting gray water, aims to reduce water consumption.

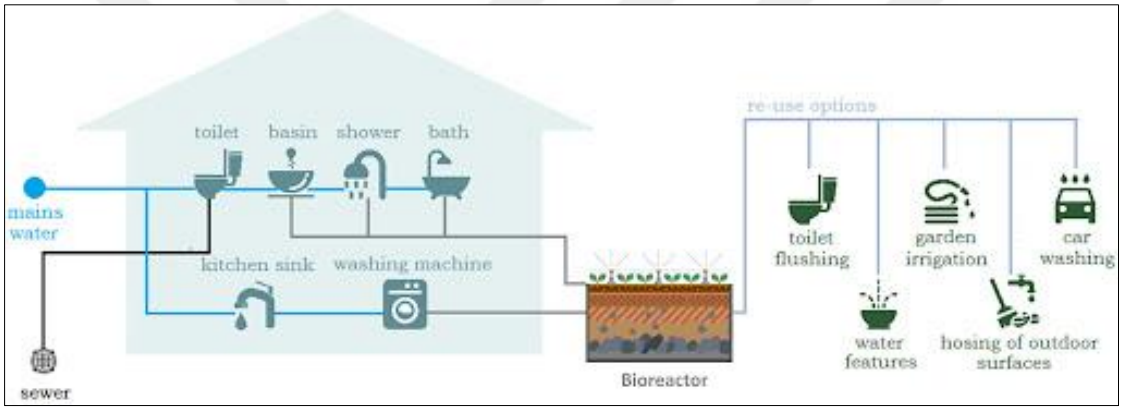
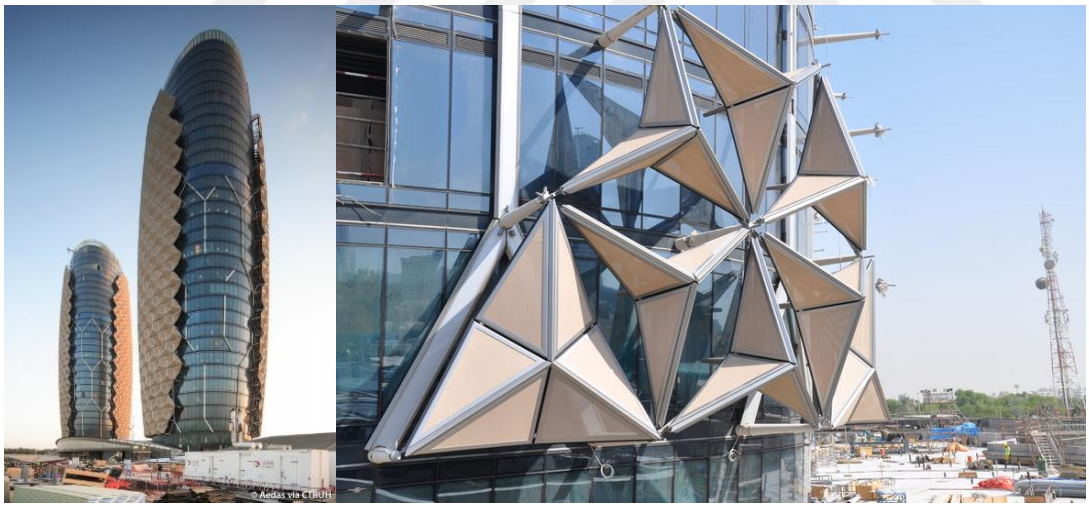


Figure 2.15. Grey water recycling concept (URL-9)

Green energy and energy efficiency:

It involves integrating sustainable practices into the design, such as using renewable energy sources, reducing energy consumption, and minimizing the environmental footprint of the building, such as wind turbines, using Passive Design Strategies like Using natural resources like sunlight, wind, and thermal mass to reduce energy consumption. This might entail planning for natural ventilation, adding shade devices, and improving building orientation, in addition to high-performance envelopes, such as designing the building envelope (walls, windows, and roof) to reduce heat gain in the summer and heat loss in the winter, renewable energy sources include integrating solar panels, geothermal systems, or wind turbines to generate energy on-site: natural lighting, natural ventilation, and efficient solar control. In addition, Performalism encourages the design of buildings that can adapt over time to changing environmental situations or user requirements and have a function. This may

involve using innovative materials, dynamic façades, or other technologies that allow for real-time adjustments, emphasizing the significance of facades in buildings and structures for energy efficiency, natural ventilation, and lighting. For example, double-skin facade systems are highly effective for saving heating and cooling energy, providing natural illumination, and controlling solar effects. Moreover, a transparent facade facilitates natural air conditioning. Another example is the inclusion of "Sky lobbies" in the design, acting as ventilated buffer zones and contributing to maintaining a balanced indoor temperature. The paragraph underscores the importance of natural ventilation in a building with mechanical equipment planned for optimum flexibility and cost-effectiveness. The anticipated result of these design strategies is a substantial reduction in the building's carbon emissions. One example of natural lightning is Al Bahar Towers in Abu Dhabi. Aedas Architects designed the façade of the towers. The way the facade interacts with the surroundings is reminiscent of the morning glory flower opening out to the sun (Figure 2.16). The building's automation system controls the flower-like shade features outside, which open and close in reaction to the sun (URL-10).



(a) (b)

Figure 2.16. (a) Al Bahar Towers, (b) Al Bahar Towers faced patterns responding to the sun (URL-13, URL-14)

The implementation of greener energy practices, such as the installation of wind turbines in buildings/structures, not only reduces the carbon footprint of the building but also serves as a visual environmental indicator, creating a positive impact on the public and generating energy and serving as on-site energy production of the overall electrical energy required for the building, showcasing a commitment to sustainable and renewable energy sources. The

integration of wind power into the building design, capturing wind for energy generation and presenting how the geometry of the building significantly enhances turbine performance in conjunction with its mass and facade design. One example is the Castle House, Elephant and Castle in southward, London, UK. (Figure 2.17).



(a) (b)

Figure 2.17. (a) The Castle House building, (b) Turbines of the Castle House (URL-11, URL-12)

Structural efficiency and material optimization:

Performalism emphasizes the use of advanced computational methods to create structures that are both stable and material-efficient. The form is often driven by reducing material use while maintaining structural integrity. Moreover, carefully selecting and using materials based on their performance characteristics, such as strength, sustainability, and thermal properties, ensures that the building performs well under various conditions. Using materials has a long-life span and is renewable or recycled. Also, the design uses fewer materials. Emphasizing the quest for performance, reliability, and economy in the design and construction of a building, showcasing the precision in material production and the resulting faster and more economical production process. For example, the material used in the design of the Eden Project, ETFE, enabled the creation of the structure's shape, covering a large span and allowing more sunlight inside the structure (Figure 2.18). In addition to Stability Against Strong Winds, strategic decisions in designing a building or structure should address the significant wind loads and issues. Such as creating some solutions in the design, informed by simulation models and tests. Resulting in economic significance because of the design

choices. Using advanced technologies to determine the building form is crucial for optimizing performance and cost-effectiveness.



(a) (b)

Figure 2.18. (a) The Eden project made from ETFE material, (b) the Eden project interior view (URL-15, URL-16)

Integration of technology:

Using innovative building systems in the application of multiple functions in the building and using innovative technologies to enhance the design and simulation of the building. Through strategic decisions in the design of a building or structure to address the significant wind loads and issues. Such as creating some solutions in the design, informed by simulation models and tests. Resulting in economic significance because of the design choices. Using advanced technologies to determine the building form is crucial for optimizing performance and cost-effectiveness.

2.2.3. Pioneering examples of performalism in architecture

Buildings that exhibit performance often do so through innovative design, sustainability features, and functionality that goes beyond mere aesthetics. Below are some examples with their explanations of how they relate to performalism and are considered performative:

One Central Park - Sydney, Australia:

It performs as a sustainable urban living design by architect Jean Nouvel and features vertical gardens by Patrick Blanc. One Central Park incorporates sustainable design elements. The

towers utilize heliostat mirrors to reflect sunlight into shaded areas, maximizing natural light. The green walls contribute to improved air quality and aesthetics. Hydroponics and heliostats are two examples of technologies that One Central Park incorporates deeply into its infrastructure and design and then implements in direct proportion to the site. With hydroponics, plants that can grow over tower façades in extremely shallow slab-edge containers or on thin, vertically green walls can be watered with recycled water from a blackwater treatment plant. Heliostats enable the project's shadowed portions to get heat and light by preset levels of direct sunlight. Both technologies have a lengthy ecological history, and in the last 20 years, mass manufacturing has transformed them from novel experiments into widely used techniques for sustainable energy production and agriculture (Nouvel & Beissel, 2014). its extensive green walls and vertical gardens. It not only contributes to the aesthetics of the building but also serves practical purposes. They provide insulation, lessen the impact of urban heat islands, and enhance air quality through absorbing pollutants. The greenery helps regulate the temperature inside the building and enhances its overall environmental performance. Including sky gardens and landscaping on various levels of the building contributes to biodiversity, provides shade, and improves the overall microclimate. It incorporates sunshades and a heliostat system that involves mirrors that reflect sunlight down to street level, ensuring that lower levels receive sunlight even when surrounded by taller buildings. Enhancing natural lighting decreases the need for artificial lighting throughout the day and promotes energy efficiency. Moreover, the building includes numerous energy-efficient technologies, such as high-performance glazing and solar panels (Figure 2.19). These features contribute to decreasing energy consumption and promoting renewable energy sources. It also incorporates systems for harvesting and recycling water for irrigation, and wastewater is treated and reused within the building.

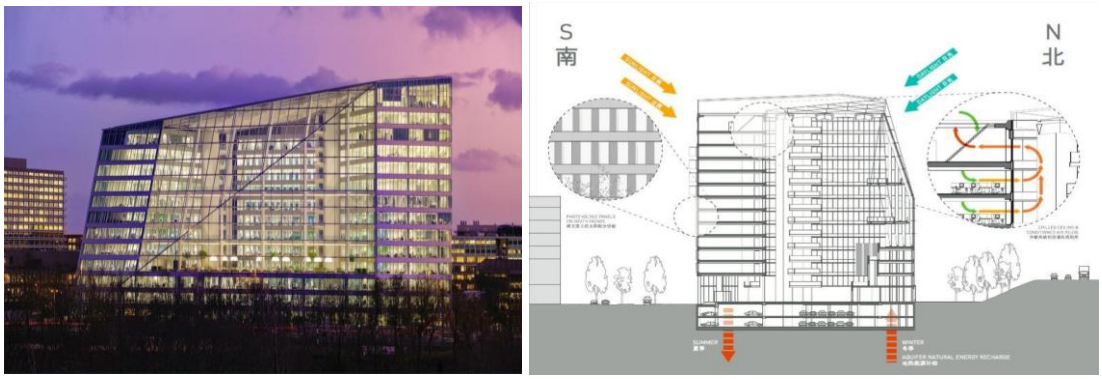


(a) (b) (c)

Figure 2.19. (a) The building of One Central Park in Sydney, (b) a section of the building, (c) The mirrors found on the One Central Park building (URL-17, URL-18)

The Edge (Deloitte Headquarters) - Amsterdam, Netherlands:

Performs as an innovative Building Technologies is considered one of the greenest and smartest buildings in the world. It features many energy-efficient technologies, including solar panels, rainwater harvesting, and a smartphone app that allows occupants to customize lighting and climate settings in their workspaces. The first step was to align and shape the Edge precisely to attain headquarters' outstanding energy and climate efficiency. Most office spaces are naturally lit by daylight thanks to the vast floor plates arranged around a majestic 15-story north-facing atrium. The load-bearing buildings and the smaller and glazed openings of the south-facing façade provide thermal mass and shade. The building's lung, the atrium, uses less energy in winter and summer by ventilating the office area and acting as a barrier between it and the outside, as shown in Figure 2.20. The Edge not only has energy-neutral control of temperature, energy-efficient architecture and design, and green energy-producing technology, but it also gathers and stores rainfall underground for usage in indoor and outdoor gardens, watering, plant, and toilet flushing. (URL-19).

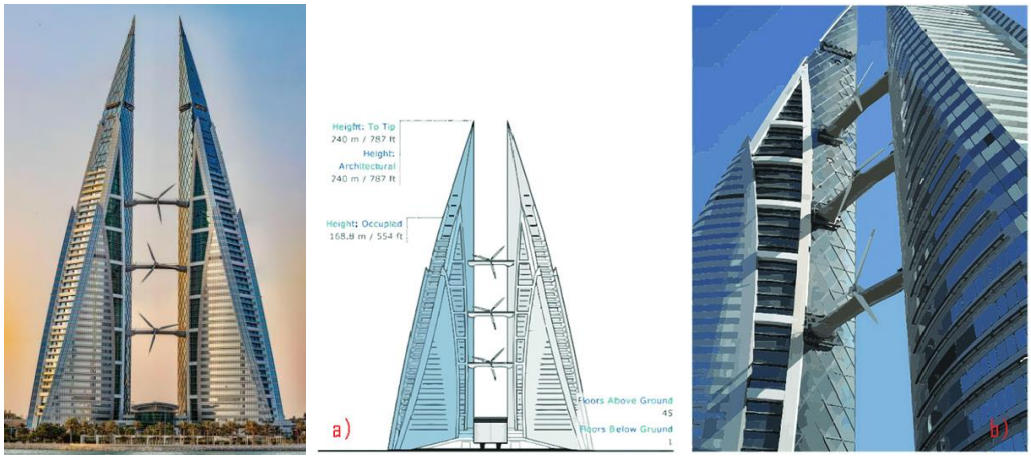


(b) (b)

Figure 2.20. (a) The building of The Edge, (b) the working mechanism of the structure (URL-20, URL-21)

Bahrain World Trade Center - Manama, Bahrain:

Performs wind power integration as this iconic building, designed by Atkins, incorporates large, integrated wind turbines within its structure. The turbines harness wind energy, contributing to the building's power needs. It is a notable example of how architectural form can serve a functional purpose beyond aesthetics. The two towers of the Bahrain World Trade Center (BWTC) are in Manama, Bahrain. Each tower has fifty stories and is roughly 240 meters (787 feet) high. 2008 saw the design and construction of the skyscrapers by the international architectural firm Atkins. It is recognized as the world's first skyscraper, and its structural design includes wind turbines. Three bridges connect the BWTC twin towers with a 675 kW wind power capability. Each bridge is equipped with a 225 kW wind turbine. The diameter of each turbine is roughly 29 meters (95 feet), as shown in Figure 2.21. The three turbines face north, meaning north and north-northwest winds are predominant in Bahrain. However, the wind is intended to be funneled into the opening by sail-shaped twin towers, which will speed up the wind's passage through turbines (Saeed, 2017).

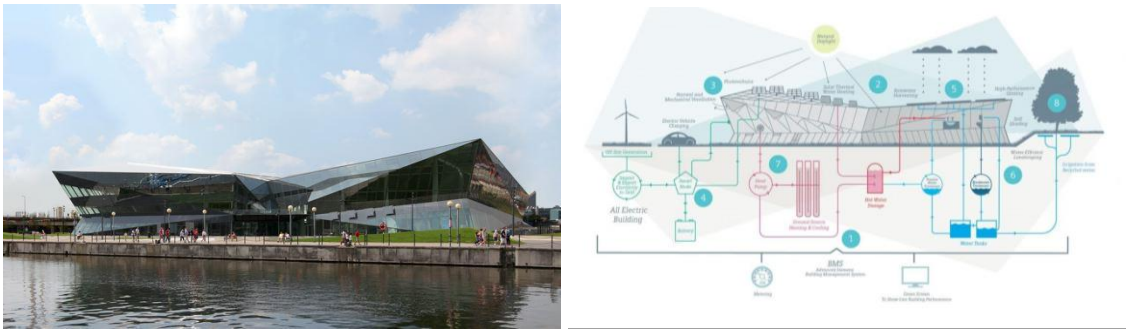


(a) (b)

Figure 2.21. (a) The Wind turbines joined in between two towers of the Bahrain World Trade Center: elevation view, (b) general view (URL-22, Stathopoulos, Alrawashdeh, et al. 2018).

The Crystal - London, United Kingdom:

Performs as Sustainable Design and Exhibiting Technologies, serving as an exhibition space for sustainable technologies. It incorporates energy-efficient features such as solar panels, rainwater harvesting, and innovative building technologies, making it a showcase for sustainable practices. Rainwater is straight gathered from the building roof and kept in a storage container below ground measuring 30 m^3. UV disinfection and filtration are the methods used for treating water. Following recycling, blackwater undergoes the most extensive treatment in a biological container with two treatment regions (anoxic and aerobic) and two filters (a membrane filter and a long-life carbon filter). Throughout the property, recycled water is utilized to flush toilets and irrigation. All the water used for WC flushing comes from non-potable resources. Ground-based heat pumps and solar thermal water heating from the roof provide nearly 80% of the building's heated water. The building is entirely electric, thanks to the 1580 m2 of solar photovoltaic roof panels covering two-thirds of the roof, producing about 20% of the structure's total electricity. High-performance solar glass, used in the self-shading façade of The Crystal, lets roughly 70% of visible light via each window yet preserves about 30% of solar energy, as shown in Figure 2.22. There is an Argon cavity and three layers in the glass. Since nearly every area in the structure receives natural daylight, artificial lighting is not required as much (URL-23).



(a) (b)

Figure 2.22. (a) The building of The Crystal in London, (b) the working mechanism of the building (URL-24, URL-25)

Dynaform Frankfurt (2001). BMW Trade Fair Pavilion:

To create the illusion of motion, the area of the pavilion surrounding the cars is accelerated. The membrane structures used hollow box girders that were CNC plasma-cut and included the first membrane in history to span unilaterally over frames composed of 30,000 separate pieces. More light to the inner space. Positioned within a parametrically produced rhythmic structure, voids take on the form of "dancing voids." As shown in Figure 2.23. Different kinds of footprints for every potential void location while maintaining the weight-bearing structure and shafts are the foundation for their programming. A self-developed automated program configures the different kinds based on pre-defined chances. These probabilities specify, for example, the maximum number of vertical repeats required before a horizontal jump void at one or two locations can occur. Because of this, every domestic high-rise has a distinct rhythmic structure and is made up of nine similar structures but also distinctive. Designers produced many versions of every façade thanks to programming, which improved the building's external beauty and the interior lighting efficiency for each apartment. As a result, a new typological method for creating multi-story housing structures is developed (Grobman & Neuman, 2011).

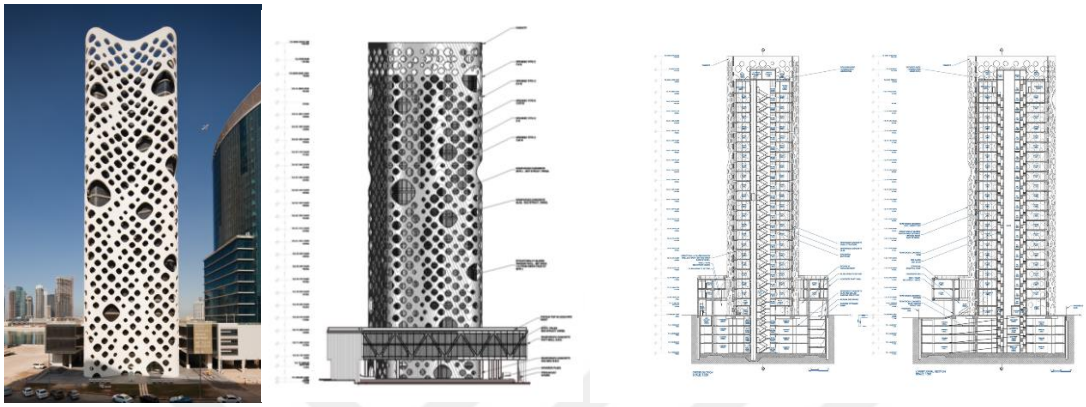


Figure 2.23. Photo of The Dynaform Frankfurt 2001 BMW Trade Fair Pavilion (URL-26)

O14, Dubai, (2006-2009) Office Tower:

The 22-story O14 skyscraper is encased in a 40-centimeter-dense concrete exoskeleton shell that is punctured by more than 1,300 modulated apertures to create a lace-like façade that acts as a sunscreen, letting in light, air, and views., as shown in Figure 2.24. Additionally, the shell frees the structure from shear walls and columns by acting laterally and gravitationally. Depending on views, brightness, sun exposure, and structural requirements, the apertures at the shell alter. The chimney effect produced by the exoskeleton's detachment from the enclosure lowers the cooling demands by 30%. Because atmosphere and impact are directly derived from a building's fabric, the ambient dimension of architecture remains within the architect's control. On the other hand, perceived stabilities like programs are far more ephemeral and are typically outside the architect's control. Like any material effect, the ambient dimension affects meaning and interpretation but neither determines nor is influenced by it. The rabbi cites the Israelites' arrival at Mount Sinai before they were given the Ten Commandments and their observation of the mountain blazing with signs and wonders, indicating that they knew something was coming but were unsure. There was only the certainty that something profound and primordial was taking place. Some were confused, some were afraid, and some waited joyfully. Individuals displayed conflicting feelings within and between them; intensity was the only thing they had in common. It appears that architecture functions on this level as well. Its influence and fabric may be precisely identified as material systems, and they can be altered to produce entirely different ambiances and atmospheres. In architecture, this is perhaps the most permanent

characteristic that can be achieved with the highest level of accuracy. It is no coincidence that several instances of the same structure hold religions with radically diverse perspectives across time and even simultaneously throughout the history of religious architecture (Grobman & Neuman, 2011).



(a) (b) (c)

Figure 2.24. (a) Photo of O14 Officer Tower, (b) height of the building, (c) design concept and structure of the tower (URL-27 and URL-28)

2.3. Performalism in Biomimetic Architecture

Biomimetic and performative architecture are both approaches that prioritize functionality. Biomimicry offers generative and creative solutions to architecture, and performalism is the merge of sustainability and digitalism. However, the two have distinct differences, with biomimetic architecture focusing specifically on emulating nature's solutions, while performative architecture encompasses a broader range of design considerations.

- Biomimetic Architecture draws inspiration from nature to replicate its efficiency and adaptability in the built environment. It incorporates structural, functional, and organizational strategies found in biological systems for enhanced energy efficiency, thermal regulation, water management, and overall sustainability. The goal is to seamlessly integrate buildings with the natural environment and measure their performance based on successful imitation and integration of natural systems.
- Performative Architecture Performative architecture extends beyond biomimicry and emphasizes sustainability, functionality, user experience, contextual integration, and technological advancements. It incorporates strategies like passive solar design,

renewable materials, energy-efficient systems, and innovative technologies while considering comfort, ergonomics, cultural context, and environmental factors. It embraces technological advancements in design and building operations.

While biomimetic architecture is performative in terms of its focus on replicating nature's efficiency, it is not a comprehensive term to describe the broader considerations of performative architecture. Performative architecture incorporates biomimetic principles, which aim to create buildings and spaces that optimize sustainability, functionality, user experience, contextual integration, technological integration, and resilience. Overall, it can be concluded that biomimetic architecture is a subset of performative architecture, specifically focused on emulating nature's solutions.

- The concepts differ; as what was noticed in some projects through architects' designs, one architect known for his interest in performative architecture is Bjarke Ingels. Bjarke Ingels and his architectural firm, BIG (Bjarke Ingels Group), have designed innovative and performative structures focusing on functionality and sustainability. They often incorporate cutting-edge technology and creative design concepts to achieve architectural performance goals. While Bjarke Ingels is primarily known for his innovative and performative architecture work, his portfolio does not revolve around biomimetic architecture as a central theme. His architectural designs often focus on sustainability, functionality, and striking aesthetics but may not always explicitly incorporate biomimetic principles. Biomimetic architecture is a specialized field that emulates nature's designs and processes, which may not be a primary focus in all his projects (URL-29).
- The concepts are met, like in some projects seen through architects' designs. Michael Pawlyn is known for his work on biomimetic and performative architecture, and one of his notable projects is the "Eden Project" in Cornwall, UK (Nkandu & Alibaba, 2018). This project is a prime example of his approach to biomimicry in architecture. The Eden Project features a series of massive biomes that mimic natural ecosystems and house a wide range of plant species. These structures are architecturally innovative and highly functional, creating ideal environments for various plants while demonstrating sustainable design principles. It showcases the integration of biomimetic and performative elements in architecture.

From here, it can be said that biomimetic architecture is performative due to the importance of adopting performative approaches in its designs. In contrast, performative architecture is not necessarily biomimetic as it could encompass wider spans, approaches, and designs not mimicked from nature. Exploring the intricate relationship between biomimicry and performalism within architecture is a captivating endeavor driven by the promise of innovative solutions and groundbreaking advancements. Biomimicry, as a discipline, not only identifies and extracts ingenious solutions from the natural world but also serves as a wellspring of inspiration for architectural design challenges. In parallel, performalism emerges as a dynamic synthesis, uniting sustainability's profound impact on the environment with the transformative capacities of digital design and computational processes. This synergy propels the creation of intricate and aesthetically compelling structures, utilizing advanced software to optimize form, structure, and energy consumption. The exciting prospect lies in the realization that this convergence enhances architectural sustainability and transforms buildings into artistic expressions and captivating spectacles. My primary objective is to unravel and showcase the multifaceted potential of this interplay, illustrating how both biomimicry and performalism converge to redefine architecture, fostering designs that perform optimally and captivate as works of art. The convergence of biomimicry and performalism in architecture introduces a unique perspective that blends inspiration from nature with a focus on dynamic, performative aesthetics. While biomimicry emulates nature's efficiency and sustainability, performalism in architecture prioritizes design's expressive and dynamic aspects. Biomimicry, as applied in architecture, often draws inspiration from natural forms, systems, and processes to enhance functionality and promote sustainability. Architects explore ways to mimic the efficiency and adaptability found in biological systems, creating innovative and environmentally conscious design solutions. On the other hand, performalism in architecture emphasizes structures' dynamic and visually expressive qualities. Architects employing performalist principles prioritize movement, rhythm, and the overall visual impact of a design. This approach goes beyond static aesthetics, focusing on how a building performs visually over time and in response to its surroundings—the integration of biomimicry and performalism results in a symbiotic relationship between nature-inspired efficiency and visually dynamic architecture. Designers seek to create structures that fulfill functional requirements and captivate with their ever-changing and performative aesthetic qualities. Architectural projects that embody this fusion can be found worldwide. From facades inspired by the kinetic aspects of natural elements to structures that dynamically respond to environmental conditions, the marriage

of biomimicry and performalism contributes to a new paradigm in architectural design. In summary, combining biomimicry and performalism in architecture signifies a holistic approach beyond conventional aesthetics (Figure 2.25). It represents a dynamic and evolving expression of design, where nature-inspired efficiency meets architecture's performative and visually expressive qualities, shaping a future where buildings are functional and engaging works of art.

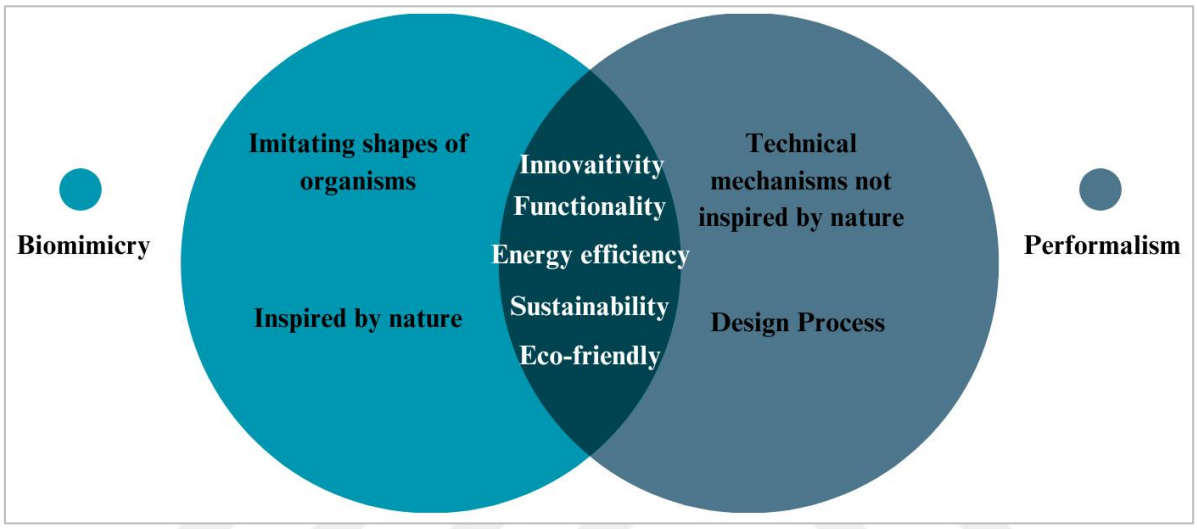


Figure 2.25. Common concepts between biomimetic and performative architecture

3. BIOMIMICRY AND PERFORMALISM AS DESIGN METHODOLOGY

During this study, eight projects with different backgrounds and designed by different architects and for different purposes were investigated; this number of projects, in addition to the different architects, emphasizes the importance of the concept in recent architecture studies, along with the concept of performalism which is adopted in all the projects. All of the chosen projects of the Pearl River Tower in China; the BIQ House in Hamburg, Germany; Las Palmas Water Theatre in Spain; Council House 2 - CH2, the Tao Zhu Yin Yuan building in Taiwan; the Singapore Arts Centre in Singapore, Beijing National Stadium in China, and the gherkin tower in England incorporated biomimetic and performative features as the primary goal of the study is the investigation of the application of both concepts in the architectural projects, Data in reliance to each project was collected and illustrated to give background of each project's architect, design concept, structure, materials used, and green strategies adopted, allowing comprehensive understanding of each project, and each project is analyzed through an analysis table according to:

Biomimicry features:

- Illustrating the building's ID identity, usage, location, and date of construction. Visualize the building about the organism or natural system it is inspired from. Determination of building levels of biomimicry and elements using Zari's 2007 table.

Performalism features:

- Determination of each project's performalism incorporated features Emphasizing how building integrates each performative criteria through examples.

Finally, the collected and analyzed data are gathered in two analytical and evolutionary tables. The analytical table illustrates the inspired methodology by nature by showing how it is applied in the design. The adopted performalism features are emphasized for each project. At the same time, in the evaluation table, each project is assessed according to the design method approach, biomimicry levels and sub-levels, life principles, and performalism features, recording a score that shows how the building integrates both concepts of Biomimicry and Performalism, emphasizing the impact of both concepts of biomimicry and performalism in the case studies and enabling the identification of the relationship between both concepts, forming the hypothesis and the aim of the study.

3.1. Pearl River Tower



(a) (b) (c)

Figure 3.1. (a) Sea Sponge (URL-30), (b) The Pearl Tower (URL-31), (c) The Pearl Tower Facade (URL-32)

Architect: designed by Skidmore, Owings, and Merrill LLP (SOM).

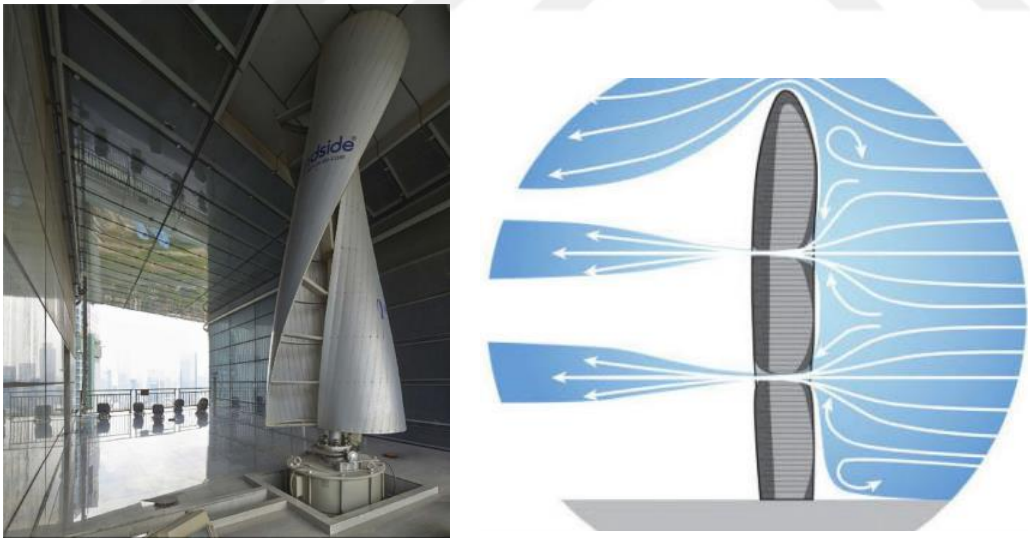
Concept: Like sponges pump millions of water gallons into their holes to get nourishment; wind turbines use the four holes in their tower to pull wind and produce power. They utilized the sponge's structure, allowing it to absorb gallons of water and creatures in a single day, as inspiration for their designs requiring less energy. Sponges obtain their nourishment by pumping thousands of water gallons every day. A variety of small residents who profit from the flow of the food-bearing water are also housed and protected by them. To generate power from high winds that blow above the earth, the wind turbines are housed in four holes in this porous tower (Figure 3.1). The building's photovoltaic system outside the solar shading system and the glass outer layer allows it to absorb solar energy (Frechette & Gilchrist, 2008). Energy consumption of the building is lowered 58–60% with the help of these and other energy-saving techniques like radiant cooling (Delgado, 2007).

Structure: A 71-story skyscraper with a sculpted form that directs wind to two apertures at its mechanical levels, where passing winds activate turbines that create energy for the structure, is one of several sustainable and green tall buildings that have lately arisen. Additional integrated sustainable features that improve the energy efficiency of the building include under-floor ventilation, solar panels, a chilled ceiling system, double-skin curtain walls, and daylight harvesting. After completion, the building uses around 30% less energy

than a comparable structure constructed by China's strict energy regulations (Tomlinson et al., 2014). The site's natural components gave rise to the building's distinctive design, which was then tailored to the site's specific sun and wind patterns to maximize their energy and use it to power the structure. Photovoltaic panels embedded in the building's exterior capture and store solar energy, while wind directed down the tower's vertical face toward several energy-producing wind turbines. The two pairs of wind turbines are situated on every mechanical floor and are seamlessly incorporated into the structure. These turbines provide energy supplied to mechanical equipment using the least loss possible. The double wall facade's curve maximizes the system's potential energy and velocity by acting as an air intake for the turbines throughout the structure. The energy generated via the turbines is either consumed immediately or stored for later use in batteries. A geothermal heat sink, used throughout the structure, provides extra energy. The system's goal is to lower the amount of water and electricity used by the building's cooling system. Standard HVAC cooling systems use cooling towers to reject heat outdoors and eliminate all of the building's thermal energy. Large amounts of fan energy are needed for this operation, and the evaporative-type tower uses much water. Before the cooling tower water is sent to the towers, the HVAC system of the tower routes it through embedded tubes inside the caissons of the structure. Using the earth's energy will significantly decrease water usage and fan energy. Additionally, the system will "recharge" the earth's energy during the hours that the water in the cooling tower dips below the ambient temperature. As a result, less energy is used the next day (URL-32).

Material: Reinforced concrete and structural steel are used in its lateral load-resisting structural system to withstand wind, earthquake, and gravity stresses. The reinforced concrete core, steel perimeter columns, outrigger and belt trusses, composite corner mega columns, and steel end bracing comprise its outrigger frame system. The building's rectangular central core is made up of reinforced concrete shear walls that range in thickness from 70 cm at the top to 150 cm at the base throughout the building's height (Tomlinson et al., 2014; Smith, 2012; Gonchar, 2015) Torsional rigidity is provided via a closed shear wall. The shear wall system at the mechanical equipment floors is connected to the steel perimeter columns through a series of belt and outrigger trusses. The composite corner mega columns are connected by steel end bracing (Tomlinson et al., 2014; Smith, 2012; Gonchar, 2015).
Green features: having wind power within the building, it assists in catching wind energy for energy generation, the tower's placement is changed from the city's prevalent grid. The south and north façades are convex, while the west and east elevations are straight. The

structure includes four sizable apertures in its concave face, where the mechanical floors and the four wind turbines—two meters wide and five meters tall—are positioned (Figure 3.2). Air is physically drawn through perforations in the envelope through the negative pressure on the protected south side, causing wind speed in Guangzhou to accelerate to roughly 18 mph (Epstein, 2008). Turbines are expected to supply 1% of the energy requirements of the building (Sharpe, 2010). The shape is determined to significantly improve turbine performance in conjunction with the building mass and facade design (Table 3.1). The tower's sleek, aerodynamic shape was created by examining city's sun and wind patterns. The final design makes the most of the sun's path and maximizes its benefits for the structure. Facade is composed of two layers: inside layer and insulated outer layer, with air space between them (Epstein, 2008). Moreover, the tower's glass outer shell and exterior solar shading system incorporate a photovoltaic system. Automated sunshade devices are installed within cavities to control glare and provide solar shading, and operate automatically in reaction to photocells that monitor the sun's location relative to elevation. To reduce solar heat, Building Management Systems automatically adjust the sunshades' angle in response to sunlight amount, solar altitude, and solar azimuth (Tomlinson et al., 2014).



(a) (b)

Figure 3.2. (a) A turbine in one of the four intakes in the Pearl River Tower, (b) Sponge-like function of Pearl River Tower (URL-34)

Table 3.1. Analysis of Pearl River Tower according to biomimicry and performalism criteria

Building Identity					
Building usage	Commercial offices		Design goal	Consume less energy by creating electricity through its turbines and sun energy.	
Design date and place	2013, Guangzhou, China.				
Biomimetic References:					
Nature Inspired Items	Sea sponge.				
Level of biomimicry	Biomimetic Element				
	Form	material	construction	process	function
Organism level	x			x	
Behavior Level				x	
Ecosystem Level					
Evaluation					
• The building looks like a sea sponge • The building works like the sea sponge works by absorption. • The building mimics how the sea sponge behaves and works.					
Performalism References:					
Having Sculptural form and design	X	The tower's sculpted shape directs wind to two apertures at its mechanical levels, where it activates turbines to produce electricity for the structure; the shape significantly improves turbine performance in conjunction with the building mass and facade design.			
Efficiency in Water Management	X	A geothermal heat sink, used throughout the structure, provides extra energy. The system's goal is to lower the amount of water and electricity used by the building's cooling system.			
Green energy and energy efficiency	X	The Tower's glass exterior skin and external solar shading system are merged with an efficient photovoltaic system. For solar shading and glare management, motorized sunshade devices are installed inside a cavity. These devices are automatically controlled by photocells that monitor the sun's position.			
Structural Efficiency and Material Optimization		NA (Not Applicable).			
Integration of technology	X	Automated sunshade devices are installed within cavities. Operate in reaction to the sun's position.			

3.2. Las Palmas Water Theatre

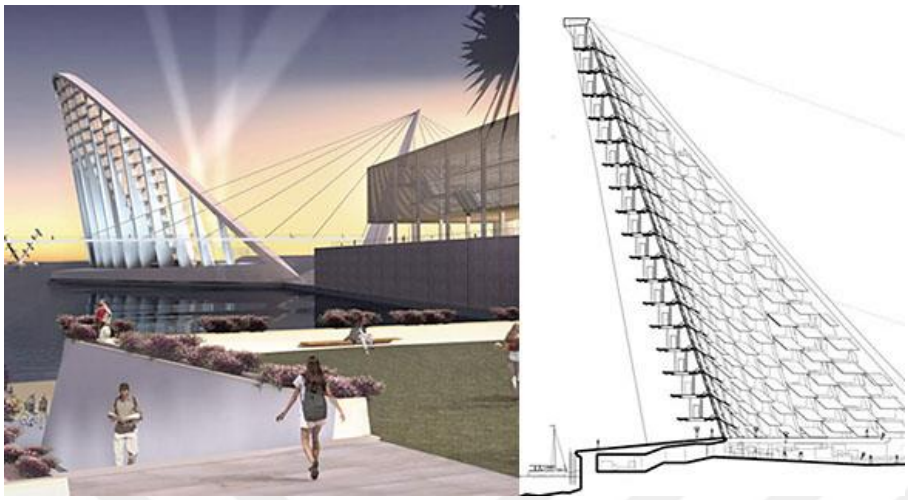


Figure 3.3. Las Palmas Theater design (URL-35)

Architect: Grimshaw.

Concept: The design of this theater was inspired by the Namibian fog-basking beetle and leveraged X10 energy savings to generate freshwater. It was proposed for Las Palmas city in the Canary Islands (Figure 3.3). Thermal solar panels are installed on this structure's roof to heat the seawater used for the evaporators. The wind once again dampens the theater. Fresh water is gathered while the cooling process condenses the air. After that, it is utilized for irrigation or drinking (URL-36). The inspirational feature is the water harvesting. The insect's elytra condense the water droplets in the hazy air, which then canalize into its mouth with the unique action course (fog basking behavior); its Morphological Characteristics Rugged elytra with a combination of a hydrophilic and a hydrophobic surface made up of hydrophilic mounds and hydrophobic grooves (Aslan, Selçuk and Avinç, 2022).

Structure: The Namibia Desert Beetle, which inhabits dry locations, found inspiration for its watering technique in constructing the Las Palmas Water Theater. The structure uses moisture harvesting, which draws water from fog using the same principles as the Namibian Desert Beetle (Figure 3.4). It incorporates biomimetic features into various design choices, from material quality to location. First, a biomimetic approach was used in the project's location and placement selections. The beetle set its body at a 45-degree angle to the airflow to collect moisture by condensation from wet air striking its exoskeleton. Because of this, the building is situated along an axis at a region with a dense, moist airflow, and its angled

façade is aligned with this axis. The building's façade has unique condensation panels that allude to the protuberances seen on the exoskeleton of Namibian desert beetles. The façade, in which these panels are situated, provides the water. By introducing the placement requirement for water-efficient design to the agenda, the building has, in this sense, accomplished an innovative design. Furthermore, eschewing conventional techniques and extracting water through a highly specialized façade design constitutes an innovation. The structural components of the structure that are specifically made to retain the water in the air make it stand out. These features are designed to mimic the behavior of fog-basking of the insect in the fog. In order to best meet the mist air flow, the structure is constructed and positioned at a specific height and angle. The Namibia Desert Beetle's exoskeleton also features bumps with a hydrophilic (water-absorbing) structure that promotes water condensation (Aslan et al., 2022).

Green features: X10 energy savings in freshwater production, building characteristics. Water harvesting is a feature transferred to the structure (Table 3.2). Employing the water harvesting technique, Humid air causes water droplets to condense and gather on the building's exterior. The façade's unique design uses panels designed to collect water in the moist air and uses specific positioning. The building was situated where the ocean breeze predominated (Aslan et al., 2022).



Figure 3.4. (a) Namibian Beetle, (b) The Las Palmas Theatre (URL -35)

Table 3.2. Analysis of Las Palmas Water Theatre according to biomimicry and performalism criteria

Building Identity					
Building usage	Theater		Design goal	Water Harvesting and savings in energy used for freshwater production	
Design date and place	Gran Canaria, Canary Islands, Spain.				
Biomimetic References					
Nature Inspired Items	Namibia Desert Beetle				
Level of biomimicry	Biomimetic Element				
	Form	material	construction	process	function
Organism level	x				
Behavior Level				x	
Ecosystem Level					
Evaluation					
• Namibian beetle elytra is morphologically imitated (at the organism level) • The behavior of Fog-basking is developed by the insect for harvesting water is imitated (at the behavior level)					
Performalism References					
Having Sculptural form and design	X	Specific Positioning: The building is located along an axis with a dense flow of moist air, and its angled façade aligns with this axis. This is because the construction was placed in a direction dominated by ocean breeze.			
Efficiency in Water Management	X	Water harvesting and energy savings: Solar thermal panels are installed on the roof of this building to heat the seawater sent to the evaporators. Moisture is returned to the theater by the breeze. The chilling process condenses the air and collects new water. After that, it is utilized for irrigation or drinking, utilizing the method of water harvesting of Humid air, which causes water droplets to condense via the building's facade and pile up.			
Green energy and energy efficiency		NA (Not Applicable).			
Structural Efficiency and Material Optimization		NA (Not Applicable).			
Integration of technology		NA (Not Applicable).			

3.3. Council House 2, CH2



Figure 3.5. The council house2 facades (URL-37)

Architect: Mick Pearce, Rob Adams.

Concept: Council House 2 (CH2) is where the city of Melbourne's municipal offices are situated. (Figure 3.5). According to Rayner, Raynor, and Williams (2010), it was the first green building in Australia to be rated six stars. When it was created, its goal was to provide users with a comfortable, adaptable, and stimulating work environment. Additionally, the building promoted a new relationship between the city and the natural environment and sought to be almost carbon-neutral (Hes, Morrison, & Bates, 2012). According to a 2013 analysis, the building's energy performance approaches four stars, achieving higher than "average" constructions but below its potential (Hoogland & Bannister, 2013). However, by employing a regenerative impact on its surroundings, CH2 is an example of BIA that extends beyond sustainability (URL-38). According to Radwan and Osama (2016), the translation of CH2 was highly successful. The building, which resembles a tree and filters the air, is almost wholly composed of renewable and recyclable materials (Radwan & Osama, 2016). Nature serves more as an inspiration source than as a realistic example. In actuality, the structure was motivated by the concept of synergy—the overlapping of systems, each of which is bigger than the sum of its parts.

Structure: The building uses biomimicry in a variety of areas. For instance, a tree's skin structure inspired the western facade. The facade's ability to regulate the outside weather inspired this (Figure 3.6). The bronchi of a tree served as the model for southern and northern facades, which were utilized as windpipes to allow air ducts to pass through the CH2 exterior (Radwan & Osama, 2016). Due to its location, Australia's northern facade is the most exposed, and this is where ventilation shafts are positioned strategically. The air that escapes the north vents more readily is replaced by the cold air from the southern vents, which is warmer when it enters. The vents on the north face are painted black for further heat absorption, whereas the vents on the south side are painted a bright color to reflect the heat and improve this process even more (Mohamed, Bakr, & Hasan, 2019). The service core and restrooms comprise the eastern core and the façade, designed to resemble tree bark. The skin filters light and air from the vented moist region behind it, a protective barrier (Radwan & Osama, 2016).



Figure 3.6. The council house timber facade (by Dianna Snape at URL-37)

Material: The city office building, consisting of a 10-story, 135,000-square-foot, employs several avant-garde techniques, such as using phase-changing materials instead of traditional chillers to cool water and mining sewers for no potable water. The west side features hydraulically operated recycled timber shutters that open and close, responding to the sun's position; the north shield windows have balconies with planter boxes. The fresh-air shafts integrated from the top down, located behind five "shower towers," which serve as external cooling towers for the mechanical system, define the south (URL-39). The outside skin, epidermis, inner skin, or dermis make up the façade. The outside zone of the structure, which

houses the stairwells, elevators, balconies, ducts, vegetation, and sunscreens, is known as the "dermis." At the same time, the inner line delineates the boundaries of the "fire compartment." The dermis was created with a steel frame and lightweight construction. In addition to providing the building's principal light and glare control, the epidermis also creates a semi-enclosed microenvironment. The precast concrete ceilings' 'wavy' design increases thermal mass capacity by maximizing surface area; the concrete's thermal mass is flushed during the night through a night purge, which enables it to absorb "coolth" from the night air and draw in heat from the atmosphere during the day; the "wavy" design collects warm air at ceiling height and channels it out of the structure and towards the ventilation stacks. A perforated metal structure that serves as a thermal chimney and provides shade for the east-facing façade is used. Naturally occurring ventilation is made possible by heat rising and drawing air throughout the eastern portion of the structure. Nine floors of vertical gardens are supported by balconies and steel trellises on the façade facing north (URL-40). In addition to shielding the structure from the sun, the flora reduces interior glare by filtering sunlight. Light shelves reflect the natural light inside the structure and offer shade. These fabric-covered steel-framed light shelves are mounted outside. A system of movable timber louvers covers the west-facing façade, maximizing the amount of natural light and the view penetration. Additionally, these louvers shield the facade of the intense Western sun. L louvers open and close depending on how much sun is shining on the western façade. The louvers are moved using a computer-automated hydraulic system and are constructed from reclaimed lumber that has not been treated. Together with the double-glazed windows to increase insulation and decrease heat gain and loss, the building's low-voc, volatile organic composite paints and finishes improve air quality by lowering emissions of dangerous elements (URL-40).

Green Features: Council House 2 is the closest to being environmentally friendly, regenerative, and sustainable since it mimics several different processes rather than just one. An example of Eco-mimesis, Council House 2 uses a lot of renewable energy sources and closed-loop systems of resources to mimic the surrounding ecology (Table 3.3). Council House 2 emphasizes the overall sustainability of every part of the structures and utilizes reclaimed lumber for its outside face (Radwan & Osama, 2016). How the termite mounds control their temperature and serve as the model for the building's heating and air conditioning system. Applying the same idea to the building, passive heating and cooling were used to reduce the need for HVAC systems, which utilize energy and add to greenhouse

gas emissions (Mohamed et al., 2019). Its façade mimics the bark and skin of trees, and its shading systems adapt to the sun. It also features a water harvesting system that collects rainwater, a ventilation system, louvers, and shading devices that act like leaves do in response to light (Figure 3.7).

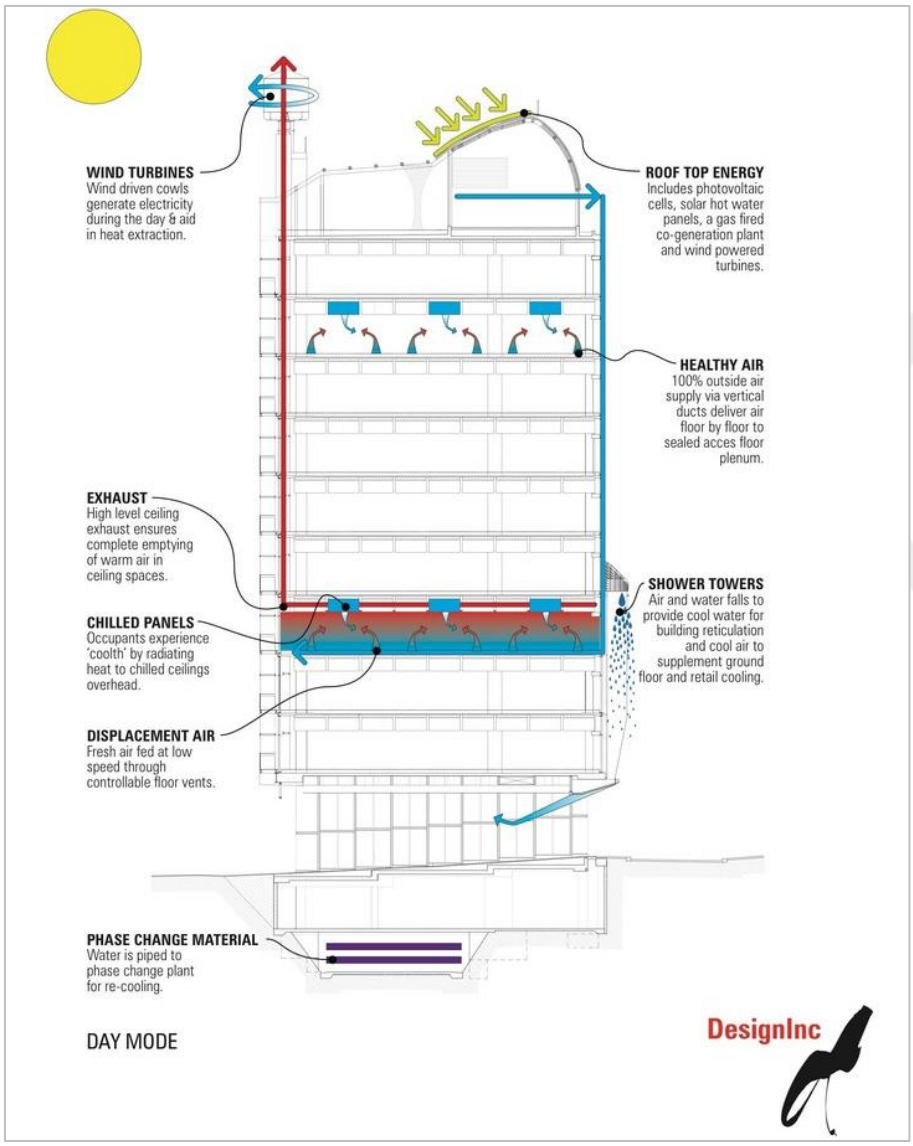


Figure 3.7. The council house2 work mechanism, by DesignInc (URL-37)

Table 3.3. Analysis of Council House 2, CH2, according to biomimicry and performalism criteria

Building Identity					
Building usage	Municipal offices building.		Design goal	Thermal and visual comfort, Air quality.	
Design date and place	2006, Melbourne, Australia.				
Biomimetic References					
Nature Inspired Items	The synergy of a plant/tree filters the air.				
Level of biomimicry	Biomimetic Element				
	Form	material	construction	process	function
Organism level				x	
Behavior Level					x
Ecosystem Level					
Evaluation					
• It is considered a process element at the organism level because it works in the same way nature works, such as the trees and the termite mounds. • It is considered a biomimicry in behavior level because it mimics the behaviors in nature, for example, water use, air quality, regulating temperature					
Performalism References					
Having Sculptural form and design	X	The structure of a tree's skin inspired the Western facade—the facade's ability to regulate the outside weather inspired this. The bronchi of a tree served as the model for southern and northern facades, which were utilized as windpipes to allow air ducts to pass through the CH2 exterior; the service core and restrooms make up the eastern core and the façade, which is designed to resemble tree bark.			
Efficiency in Water Management	X	As it features a water harvesting system that collects rainwater.			
Green energy and energy efficiency	X	The structure is nearly entirely made of recyclable and renewable materials and uses a lot of renewable energy sources and closed-loop systems of resources to mimic the surrounding ecology. Passive heating and cooling were used to reduce the need for HVAC systems, louvers, and shading devices in response to light; the pre-cast concrete ceilings' 'wavy' shape increases thermal mass capacity by optimizing surface area.			
Structural Efficiency and Material Optimization	X	The west side features hydraulically operated recycled timber shutters that open and close, responding to the sun's position; the north shield windows have balconies with planter boxes. The fresh-air shafts integrated from the top down, located behind five "shower towers," which serve as external cooling towers for the mechanical system, define the south.			
Integration of technology	X	The west side features hydraulically operated recycled timber shutters that open and close responding to the sun's position; louvers open and close depending on how much sun is shining on the western façade. The louvers are moved using a computer-automated hydraulic system.			

3.4. The BIQ House



(a) (b)

Figure 3.8. (a) The BIQ Building, (b) the inspired algae concept (URL-41)

Architect: Splitterwerk Architects in collaboration with Arup.

Concept: The first pilot program in the world for applying residential buildings with a bio-reactive facade is the BIQ (Bio Intelligent Facade) house (Figure 3.8). SolarLeaf, a bio-reactive facade, harnesses solar thermal heat and algal biomass to generate renewable energy. In particular, the 200 m² algae-filled bio-reactive panel of the BIQ house in Hamburg provides all the energy required for the structure and lowers the emissions of carbon dioxide (CO2) each year by 6 tons. This pilot project is an example of a building-integrated system that uses microalgae to absorb CO2 emissions, generates biomass, and heats utilizing renewable energy resources. Additionally, this creative system showcases the technology's full potential by combining features like dynamic shading, sound reduction, and thermal insulation. With the help of this mechanism, the BIQ house may employ algae to absorb CO2 and produce carbon-neutral energy. Therefore, it serves as a model for future building construction, fostering the development of low-carbon cities and creating better living environments. In conclusion, the BIQ House is an important test project for carbon capture and reduction in the construction sector. It serves as a model for future low-carbon building practices in urban areas. It is possible to generate, store, and use energy from the facade of an energy-efficient building with a sustainable energy design (URL-42).

Structure: The building has 15 apartments spread across four floors and a rooftop level, each having between 50 and 120 square meters of living space and a gross floor area of around

1600 square meters (URL-43). 200m² of integrated photo-bioreactors in 120 panels mounted on the façade of a low-energy residential building generate heat and algae biomass as renewable energy sources. The algal facade panel system reduces noise, creates dynamic shade, and creates a microclimate that is thermally managed around the building (URL-44). The primary source of all energy processes, microalgae, are grown in flat panel glass bioreactors at the southwest and southeast elevations. These bioreactors convert and distribute various forms of energy to meet the building's needs for heat and power. Inside the PBRs, sunlight and continuous turbulence prevent algae from aggregating, allowing the microalgae to flourish and produce heat. The efficiency of this heat is 38% as opposed to 60–65% for a traditional solar thermal source, and the biomass is 10% as opposed to 12–15% for a regular PV source. Thus, the energy management center receives the heat and biomass produced by the façade panels (URL-43BIQ sets a new standard as the world's first building with a bioreactor façade. In the glass components that make up its "bio-skin," the microalgae are grown there. In addition to being utilized for energy production, they may regulate light and offer shade. A second outer shell is integrated into the façade of the building on its sun-facing sides. Microalgae – tiny plants, most no more significant than bacteria – are produced inside this shell. They make the home self-sufficient in energy. Algal growth is the only task they require. A separate water system running through the façade constantly provides them with liquid nutrients and carbon dioxide. Algae can grow up and perform photosynthesis using sunlight. Utilizing the most recent advancements in energy and environmental technologies, this façade is the first in the globe (URL-45).

Material: One of the most famous examples of an inventive application of bio-adaptive facades is the BIQ Building in Hamburg, Germany. Transparent panels, including microalgae cultures and known as algae-filled bioreactors, are used to construct the building's facade. The southwest and southeast faces of the structure have these panels installed; Glass panels that contain microalgae and water are called bioreactor panels (Table 3.4). With the help of carbon dioxide and sunlight, the algae proliferate and expand, creating biomass that can be harvested for energy. The facade is made of high-performance glass to support the bioreactor panels and for thermal insulation. The steel and aluminum framework holds the bioreactor panels in place and secures them to the building. Moreover, Reinforced concrete makes up the walls and floors of the building, which are its primary structural components.

Green features: Germany's BIQ House uses biomimicry by incorporating algae into an ingenious exterior design (Figure 3.9). The algae are raised in a greenhouse created by 200 square meters of panels. Carbon dioxide and liquid nutrients are circulated throughout the facade to maintain the health of the algae and to maintain the health of the facade. The algae grow as sunlight reaches the outside, providing shade for the building. The algae are gathered and fermented over time to produce biogas, which power the building. It produces five times as much biogas as land plants (URL-46).



Figure 3.9. Algae Bioreactor Modules Carbon Dioxide facades and panels (URL-47, URL-48)

Table 3.4. Analysis of The BIQ House according to biomimicry and performalism criteria

Building Identity**:**					
Building usage	Residential building		Design goal	Incorporates algae-filled bioreactor panels, contributes to its green credentials by producing renewable energy and providing shading and insulation.	
Design date and place	2013, Hamburg, Germany.				
Biomimetic References:					
Nature Inspired Items	Algae.				
Level of biomimicry	Biomimetic Element				
	Form	material	construction	process	function
Organism level					
Behavior Level				x	
Ecosystem Level					x
Evaluation:					
• The algae bioreactor panels function in the same way the algae functions. • The BIQ building works the same way the algae works.					
Performalism References:					
Having Sculptural form and design		NA (Not Applicable).			
Efficiency in Water Management		NA (Not Applicable).			
Green energy and energy efficiency	X	Incorporates algae-filled bioreactor panels, contributes to its green credentials by producing renewable energy and providing shading and insulation, Sustainable construction as it incorporates eco-friendly materials/Algae, the algae-filled bioreactor panels, provides shading and insulation, produces biomass, heats using renewable energy sources, and absorbs CO2 emissions by cultivating microalgae, it can produce, store, and use energy from its facade.			
Structural Efficiency and Material Optimization		NA (Not Applicable).			
Integration of technology	X	By combining functions such as dynamic shading, thermal insulation, and sound reduction			

3.5. Tao Zhu Yin Yuan Building



Figure 3.10. Tao Zhu Yin Yuan Residential Building (URL-49)

Architect: Vincent Callebaut for BES Engineering Corporation, Taipei.

Concept: Inspired by the structure of human DNA and the principles of skiing.

Structure: The concept was modeled by the architects using the DNA strand. This building has a very different look (Figure 3.10). It is a characteristic double-helix-shaped construction that twists 90 degrees from top to bottom. The tower is inspired by the structure of the DNA double helix (Figure 3.11). Two full-floor housing units represent each double helix in the proposal. The 20 inhabited levels in the double helix twist and stretch at a 90-degree angle from the bottom to the top.

Material: The effort has focused on developing carbon-absorbing architecture to combat the climate change crisis and global warming. The project aims to prevent climate change and global warming by promoting carbon-absorbing buildings and lowering the earth's temperature. Several cutting-edge and environmentally friendly materials were used to construct the Tao Zhu Yin Yuan skyscraper in Taipei, Taiwan. High-strength steel is employed, like in the Tokyo Skytree Tower and Taipei 101. To be more precise, the structure is made of high-strength rebar, SS steel, and steel materials like KBSA630 and SM570M

that guarantee outstanding strength and seismic resistance. The inside flooring is constructed from concrete strong enough to support large loads, giving it excellent stability and longevity. Additionally, the building has a double-glass skin facade that lowers interior temperatures and improves natural ventilation, which lessens the necessity for air conditioning. The overall sustainability and energy efficiency of the building is enhanced by this facade (URL-49, URL-50).

Green features: The idea behind the architecture is to create a building that can run on its energy, whether it be thermal, electric, or something else entirely. Ecosystems that sequester carbon and climate-friendly anti-global warning systems. The ground floor garden covers its open areas with plants, trees, shrubs, and other vegetation. The amount of carbon absorbed each year is approximately 130 tons. Planting a variety of tree varieties that can better absorb carbon. Balconies with plants provide greenery, moisture retention, and noise reduction. Supplying warmth in the winter and ventilation in the summer. It combines natural ventilation, wireless monitor management of LED lighting, rainwater recycling, fiber optic connection, light guidance system, and solar/wind power to save energy and reduce carbon (Table 3.5). The tower's body structure serves as the model for the structure. Green roofs have produced energy savings, environmental advantages, and aesthetic value. Many environmentally friendly elements are incorporated into the building, such as solar panels, rainwater recycling systems, and many plants—roughly 23,000 trees, shrubs, and other vegetation—that aid in absorbing carbon dioxide from the atmosphere. The design emphasizes its dedication to energy efficiency and environmental responsibility by aiming for LEED Gold certification (Altinöz, Mihlayanlar, & Yardimli, 2017).



Figure 3.11. (a) the DNA, (b) the Tao Zhu Yin Yuan Residential Building design (URL-51, URL-52)

Table 3.5. Analysis of Tao Zhu Yin Yuan Residential Building according to biomimicry and performalism criteria

Building Identity:			
Building usage	Residential high-rise building	Design goal	Carbon-absorbing, sustainable residential tower; the project aims to promote carbon-absorbing architecture to lower the earth's temperature and combat climate change and global warming.
Design date and place	2013-2017, Taipei, Taiwan		

Biomimetic References:

Nature Inspired Items	DNA Spiral				
Level of biomimicry	Biomimetic Element				
	Form	material	construction	process	function
Organism level	x				
Behavior Level					
Ecosystem Level				x	x

Evaluation:

- Organism- Form, as it mimics the form of the DNA being a twisting structure.
- Ecosystem- Process, as it mimics the ecosystem of a forest in the process as it uses photosynthesis and energy capture in addition to water recycling management
- Ecosystem- Function, as it mimics ecosystem in function in climate regulation terms and through natural ventilation and daylight.

Performalism References:		
Having Sculptural form and design	X	Being a characteristic double-helix-shaped construction that twists 90 degrees from top to bottom, the twisting form optimizes wind flow and shows cutting-edge technology in structural design,
Efficiency in Water Management	X	It includes rainwater recycling systems.
Green energy and energy efficiency	X	Double-glass skin facade that enhances natural ventilation and reduces indoor temperatures, thereby decreasing the reliance on air conditioning. It blends natural ventilation, rainwater recycling, fiber optic connection, light guiding system, wireless monitor control of LED lighting, and solar/wind power to accomplish energy savings and carbon reduction. Using green roofs has achieved aesthetic value, environmental benefits, and energy-saving. The construction includes many sustainable features, such as solar panels, rainwater recycling systems, and significant greenery.
Structural Efficiency and Material Optimization	X	Utilizes high-strength steel, including SS steel, high-strength rebar, and steel materials, which ensure high toughness and seismic resistance, and interior floorings are made with concrete designed to withstand heavy loads.
Integration of technology	X	Several cutting-edge and environmentally friendly materials were used in the construction.

3.6. Beijing National (Bird Nest) Stadium



Figure 3.12. The Birds’s Nest Stadium (URL-53)

Architect: constructed with the primary goal of serving as the Olympic Games' main stage and hosting several parties for the 2008 Beijing Olympics' Olympic Football Tournament. It was designed by Swiss architects Jacques Herzog and Pierre de Meuron (Figure 3.12).

Concept: evolved through the emergence of nesting birds. The design is inspired by bird nests, both physically and aesthetically (Figure 3.13). When seen from the outside, the entire structure mimics the nests' branches, which combine to create fantastic weather resistance. The stadium seems to be positioned like a spacecraft in the center of the complex, including other Olympic structures. Its minor undulation enhances its serene majesty (Mehta, Thakur, & Atha, 2019).

Structure: Constructed from a tangle of multiple twisted metal things that evoke its topic field structure, the original settlement plan was inspired by a nested plot and resulted in a web of many twigs. This is precisely why it won the 2002 international convention—twisting steel sections fit together because they bend and twist to follow the surface precisely. The main components combine to form a grid pattern and support one another. The stadium's stand is a shear wall system made of concrete with a seven-story height (Mehta, Thakur, & Atha, 2019). The stand's upper section and the stadium's steel structure are divided from one another, although they are both built on a shared foundation that complies with geometry and has 36 kilometers of exposed steel (Berawi, 2015; Lianto & Trisno, 2022).

Material: The stadium's dimensions are 220 meters wide, 69 meters high, and 330 meters long. Steel, which constitutes the numerous nest branches, is the predominant material. In between, several inflatable ETFE (ethylene-copolymer tetrafluoretileno) "cushions" provide the stadium with a "quilted" presence. Metal structural components interlock and support one another. The light from the outside enters through a translucent membrane that makes up the ceiling. A second layer of acoustic insulation and a translucent coating shielding the remaining portion of the building from inclement weather are applied.

Green features: Green has the advantage of being readily recyclable, highlighting sustainable design and the fundamental ideas of biometric design (Table 3.6). The exposed bird nest pieces serve as the Stadium's primary aesthetic motif, drawing inspiration from nature. Not much material is used to hide the structure. Following the bird's nest concept, the façade is covered with translucent ETFE panels, like a nest is insulated by sandwiching little items between the building's twigs. ETFE panels let sunshine through to nourish the natural grass field while shielding onlookers from the weather and acting as acoustic insulation (Lubow, 2006). Moreover, the panels have a lower dead load on the roof due to their lesser weight than glass or aluminum panels. In addition to being long-lasting and self-cleaning, the panels save expensive upkeep. As air passes through the stadium's public concourse and escapes via the primary aperture in the roof structure, openings in the façade facilitate natural ventilation (Mehta, Thakur, & Atha, 2019).



Figure 3.13. the concept of the bird nest application to the stadium (Mehta et al., 2019)

Table 3.6. Analysis of Beijing National Stadium/Bird Nest Olympic Stadium according to biomimicry and performalism criteria

<table>
<tr><td colspan="7">Building Identity:</td></tr>
<tr><td>Building usage</td><td colspan="2">Stage of the Olympic games.</td><td colspan="2">Design goal</td><td colspan="2">Create a rigid and stable structure.</td></tr>
<tr><td>Design date and place</td><td colspan="2">2008, China.</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="7">Biomimetic References:</td></tr>
<tr><td>Nature Inspired Items</td><td colspan="6">Bird Nest.</td></tr>
<tr><td rowspan="2">Level of biomimicry</td><td colspan="6">Biomimetic Element</td></tr>
<tr><td>Form</td><td>material</td><td>construction</td><td>process</td><td>function</td></tr>
<tr><td>Organism level</td><td>x</td><td></td><td>x</td><td></td><td></td></tr>
<tr><td>Behavior Level</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ecosystem Level</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Evaluation:</td></tr>
<tr><td colspan="7">• Organism-form level as it mimics the appearance of a bird's nest, with an interwoven network of steel beams resembling twigs.
• Organism – construction level; as the construction technique used to assemble the interlocking steel beams mimics the natural weaving process of a bird building its nest where the twigs interwove to create a strong and stable shape</td></tr>
<tr><td colspan="7">Performalism References:</td></tr>
<tr><td>Having Sculptural form and design</td><td>X</td><td colspan="5">Originated as a result of nesting birds' development. The design is based on bird nests, not just visually but structurally. When seen from the exterior, the entire construction looks like branches of nests that, when combined, provide unbelievable resistance.</td></tr>
<tr><td>Efficiency in Water Management</td><td></td><td colspan="5">NA (Not Applicable).</td></tr>
<tr><td>Green energy and energy efficiency</td><td></td><td colspan="5">NA (Not Applicable).</td></tr>
<tr><td>Structural Efficiency and Material Optimization</td><td>X</td><td colspan="5">The construction technique used to assemble the interlocking steel beams allows for a robust and resilient structure capable of withstanding various loads and stresses and being easily recyclable.</td></tr>
<tr><td>Integration of technology</td><td></td><td colspan="5">NA (Not Applicable).</td></tr>
</table>

3.7. The Singapore Arts Centre/Museum:



Figure 3.14. Esplanade Theater entertainment complex (URL-54)

Architect: Michael Wilford & Partners with Atelier One and Atelier Ten.

Concept: comprised of two enormous theater structures, outdoor stages, offices, and residences (Figure 3.14). The exterior skin of durian inspires the sun shading in the middle, while the thorny shell of this fruit influences the center. The durian fruit and the polar bear inspired the building's shade scheme. The durian plant is covered with thorn-like projections that shield its seeds from the sun's rays and heat. These thorns function as shade mechanisms modeled after those found on durian plants. The polar bear's apparent white fur comprises black skin and translucent hair follicles (Figure 3.15). When this transparent hair is upright, it lets light in and gets absorbed through the black skin when the sun is out. When it is not, it returns to its usual position. This is what was imitated since heat is not required in this structure, unlike the polar bear. (URL29; Mohamed, Bakr, and Hasan, 2019).

Structure: The double-curved building envelope's metal shading devices resemble the thorns of the durian fruits, sticking out to offer shade and moving like the polar bear's hair in response to changes in light intensity and sun position via photovoltaic sensors, safeguarding the art center's interior (Table 3.7). The exterior shading system, which consists of aluminum shading devices, lowers the HVAC level and gives natural lighting and shadow to the interior rooms throughout the day (Mohamed et al., 2019).



Figure 3.15. Durian fruit and thorns and polar bear fur (Mohamed, Bakr, and Hasan, 2019)

Material: Motivated by durian fruit, which has a strong, thorny husk that shelters the seeds within, a cladding system made of triangular aluminum sun shields attached to lightweight space frames of curved steel was created (URL-55). After a thorough analysis, it was discovered that the local sun path is nearly precisely east-west, which dictated the design and depth of sunshade louvers. Shields were adjusted in shape and position according to the angle at which the sun struck them during the day using sophisticated geometry analysis and computer modeling (Rahimzadeh et al., 2013). Thus, this dynamic solar shading method offers an ideal balance between letting sunshine in and maintaining the panoramic vistas, helping to prevent interior warming. Along the façade, deep overhangs, sky gardens, spiral landscape ramps, and sunshade louvers also used to create livable microclimates (URL-56).

Green features: The Durian fruit's spiky, shielding shell served as the inspiration for the center's dynamic façade (Figure 3.16); it functions in concert with the sun to protect its interior from tropical heat while allowing an abundance of natural light to enter the built area and cutting energy usage by 30% and artificial lighting by an incredible 55% (URL-57).

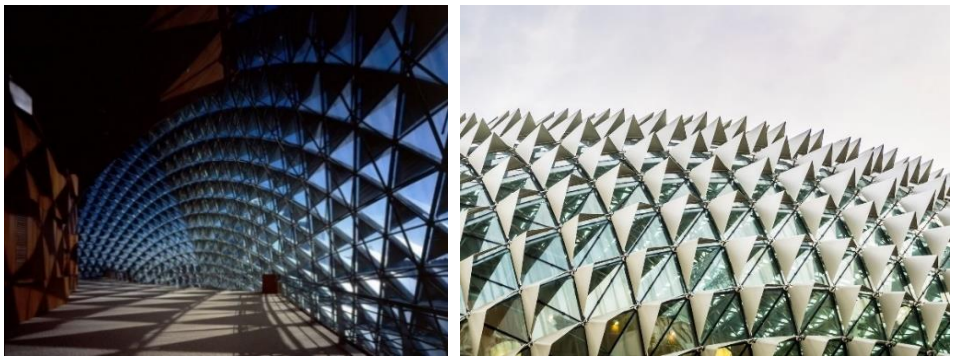


Figure 3.16. The envelope structure and its sun-shading protection patterns are seen from the interior and exterior (URL-58, URL-59).

Table 3.7. Analysis of Singapore Arts Centre/Museum according to biomimicry and performalism criteria

<table>
<tr><td colspan="7">Building Identity:</td></tr>
<tr><td>Building usage</td><td colspan="2">Arts Centre.</td><td colspan="2">Design goal</td><td colspan="2">A dynamic facade for sun shading and natural lighting.</td></tr>
<tr><td>Design date and place</td><td colspan="2">2002, Singapore.</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="7">Biomimetic References:</td></tr>
<tr><td>Nature Inspired Items</td><td colspan="6">Durian fruit, its thorns, the polar bear, and its fur.</td></tr>
<tr><td rowspan="2">Level of biomimicry</td><td colspan="6">Biomimetic Element</td></tr>
<tr><td>Form</td><td>material</td><td>construction</td><td>process</td><td>function</td></tr>
<tr><td>Organism level</td><td>x</td><td></td><td></td><td>x</td><td>x</td></tr>
<tr><td>Behavior Level</td><td>x</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Ecosystem Level</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Evaluation:</td></tr>
<tr><td colspan="7">• Organism: form- looks like the durian fruit; The double-curved building envelope's metal shading devices resemble the thorns of the durian fruits.
• Organism: process – works like the fruit's thorns and the bear's fur as they adjust according to the relation with sunlight to provide natural lighting and sunshade.
• Organism: function – It functions as the bear fur as it adjusts according to sunlight
• Behavior: form – the same way the throne and the fur are located.</td></tr>
<tr><td colspan="7">Performalism References:</td></tr>
<tr><td>Having Sculptural form and design</td><td>X</td><td colspan="5">Made up of two enormous theater structures; the exterior skin of durian inspires the sun shading in the middle, while the thorny shell of this fruit influences the center. The Durian fruit's spiky, shielding shell inspired the center's dynamic facade, which moves in tandem with the sun.</td></tr>
<tr><td>Efficiency in Water Management</td><td>X</td><td colspan="5">The structure includes Y-shaped columns that collect rainwater, which is then treated and used for cleaning the facade and watering the plants around the building.</td></tr>
<tr><td>Green energy and energy efficiency</td><td>X</td><td colspan="5">The double-curved building envelope's metal shading devices stick out to offer shade and move in response to changes in light intensity and sun position via photovoltaic sensors. The exterior shading system consists of aluminum shading devices that lower the HVAC level and give natural lighting and shadow to interior rooms. It enhances Energy Efficiency, such as the aluminum sunshades help reduce solar heat gain, thus lowering the energy required for cooling. Moreover, it is considered stable because it is Constructed with concrete and steel. Moreover, some design aspects promote natural ventilation, reducing reliance on air conditioning and its primary goal for daylighting and sun shading.</td></tr>
<tr><td>Structural Efficiency and Material Optimization</td><td>X</td><td colspan="5">The lightweight space frame system allows for reduced material usage. It provides larger spans and cladding for thermal and visual optimization and is made of triangular aluminum sun shields attached to lightweight space frames of curved steel.</td></tr>
<tr><td>Integration of technology</td><td>X</td><td colspan="5">The local sun path is east-west, which dictates the design and depth of sunshade louvers. Complex geometric analysis and computer modeling were used to calibrate the shields so that their shape and orientation changed according to the angle where the sun struck them.</td></tr>
</table>

3.8. The Gherkin Tower

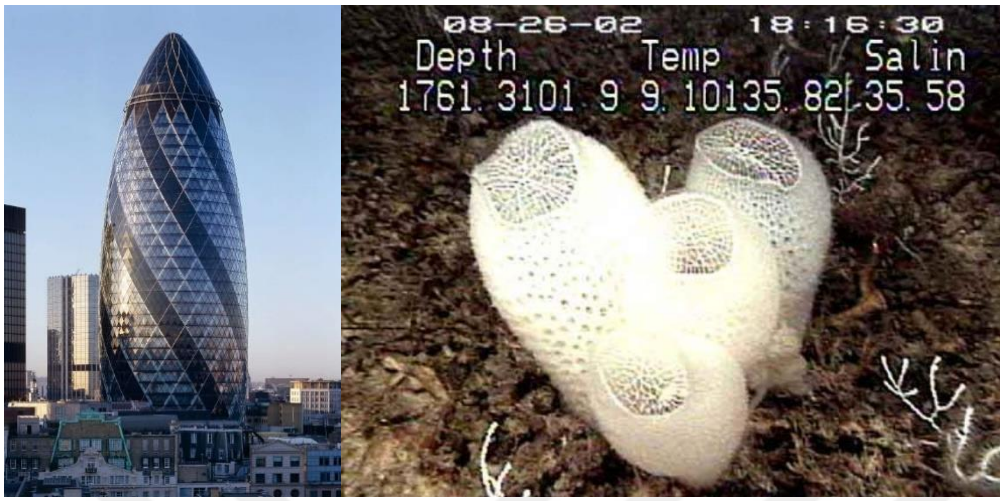


Figure 3.17. (a) The gherkin tower, (b) the sea sponge (URL-60)

Architect: Arup, Norman Foster.

Concept: The concept is inspired by Venus' flower basket design, a sea sponge found in the depths of the Pacific Ocean. Its lattice exoskeleton and conical shape offer stability against powerful currents and tolerate enormous depths (Figure 3.17). The building's upper dome, known as the lens, is panoramic. The building's diameter is 49 meters in the base, rises to 56.5 meters at its widest point, then falls to 26.5 meters at its topmost level, creating the impression that it resembles a cucumber or rocket, as many in London say. Because each story rotates five degrees relative to the one before, this design enhances wind flow around facades while reducing pressure on the structure and preventing wind from reaching the ground. Most rooms have an outside view. It resembles a radial plan in shape. Natural light could enter because of the continuous triangular glass skin covering the walls and ceilings. Because of its energy-saving measures, illustrated in Table 3.8, the building utilizes half of the skyscraper, similar in size and energy. Six shafts are created by the gaps on each story, offering the structure as a whole a system of natural ventilation. (Mckenna, 2015; Gaber, Maarouf, & Fath, 2022) Shafts use passive solar heating to warm the structure's interior in the winter and remove the warm air from it in the summer.

Structure: The tower has 41 floors, making up an 80-meter tall building. Its form is curved like a pickle. The construction gradually expands as it climbs from the ground and tapers to a curved point. This design increases the public space at the structure's base while reducing

the whirling wind. Although the entire building is curved, the only curved glass is the lens at the top of its panoramic dome. Extracted from the Venus flower basket sponge, a specific type of glass sponge. The sponge can survive at very low depths because of its spherical form and lattice-like exoskeleton, making it stiff and disperse the stresses from strong currents. A network of silica spicules that can absorb stress via bending where they intersect gives its body structural stability. The sponge's silica structure forms its hollow "basket," which filters saltwater for nutrients. Flagella guide water upward through a lattice. Each floor is unique. Because of the building's design, the structural components must join at various angles for every story. Steel nodes, which are plates bonded at appropriate angles to join the crossing steel tubes, were used to do this. Like the Venus flower basket sponge that supports itself within water, this arrangement offers adequate vertical support with no need for inner columns and additional wind resistance. The white, diamond-shaped coating covering the round steel tubes gives them a sponge-like look (URL-60).

Material: The steel structure that makes up the building's structural frame gives its distinctive, curving shape the stability it needs. The double-glazed glass curtain wall that makes up the building's outside facade adds to its contemporary design and improves energy efficiency by letting natural light into the internal rooms while acting as insulation. Aluminum, which is lightweight, strong, and resistant to corrosion, is used to frame the glass panels and is perfect for high-rise buildings. Moreover, concrete was employed in the building's core and foundation for further structural stability and support (URL-60).

Green features and relation to biomimicry: The Gherkin mimics a sponge's shape and lattice structure to replicate its actions in water. The spherical shape of the structure creates the external pressure differentials required for powering the HVAC system while reducing wind deflections. Using a rectilinear design, the construction enables more effective air flow throughout than a typical office skyscraper. The outside is surrounded by a lattice-like structure that is diagonally braced, allowing for an open floor layout without interior columns. Additionally, because of the openness, much natural light can enter. For sustainability, the Gherkin was planned to "breathe" like a lung and have natural ventilation. Air moves through flooring spaces between levels to provide this natural ventilation. Each level has six atria, which span between many stories simultaneously using a diagonal lattice structure. The only breaks are for firebreaks, and they happen every sixth story. Through passive cooling and heating, the air between an additional glass set at the double-skin façade

produces a double-glazing effect, insulating the office area. Because of its natural ventilation and insulation design, the tower uses as little as half of the energy of a skyscraper of comparable size. The façade's opening panels in the atria let in fresh air. That air is distributed among the connecting levels via pressure differentials for natural ventilation. Depending on the season, this mixed-mode ventilation system provides both passive heating and cooling advantages. Through passive solar energy, the insulating effect maintains the structure warm during the winter. Warmer air is drawn out of the summer by external pressure differentials. The air that passes through the structure allows it to breathe out and in. How air enters and ascends through the structure is modeled after how water and nutrients pass through the sponge-like Venus flower basket (Figure 3.18). The building is only designed to use conventional air conditioning in extremely hot or cold conditions (URL-60).

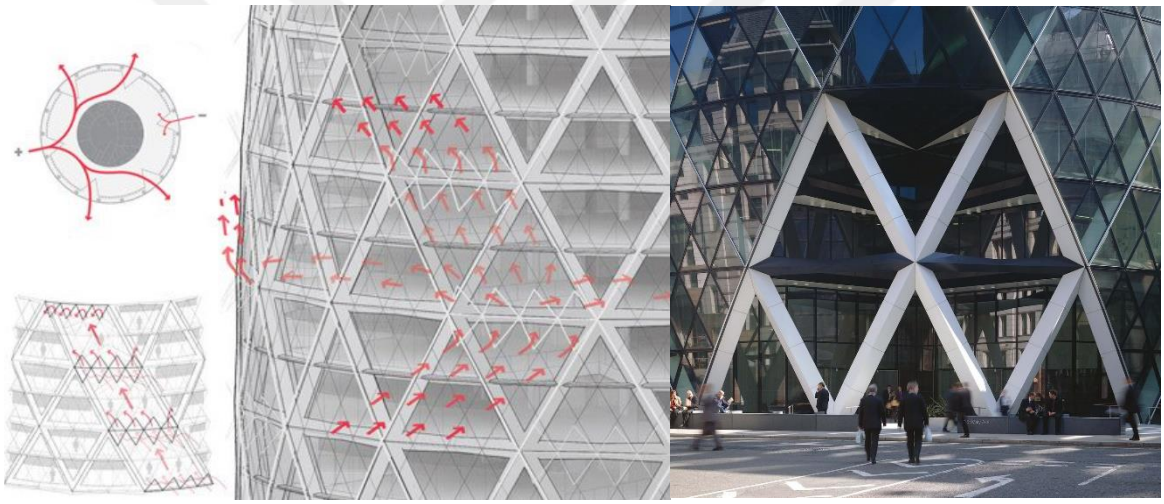


Figure 3.18. Diagram of Air Flow in the Tower (left) and diagrid structure of the tower (right) (URL-60).

Table 3.8. Analysis of The Gherkin Tower according to biomimicry and performalism criteria

Building Identity:					
Building usage	Commercial skyscraper		Design goal	Enhance Sustainability.	
Design date and place	2003, London, England				
Biomimetic References					
Nature Inspired Items	Venus's flower basket.				
Level of biomimicry	Biomimetic Element				
	Form	material	construction	process	function
Organism level	x		x		
Behavior Level				x	x
Ecosystem Level					
Evaluation:					
• Organism: form- looks like Venus flower sponge basket. • Organism: construction- lattice exoskeleton and conical shape. • Organism: process - mimics the lattice structure of sponge to do in air what sponge does in water. • Behavior: process - mimics lattice structure of sponge to do in air what the sponge does in water. • Behavior: function – the natural ventilation system reduces energy consumption, the same as the sea sponge regulates its internal environment.					
Performalism References:					
Having Sculptural form and design	X	The tower's lattice exoskeleton and conical shape offer stability against powerful currents and tolerate enormous depths, and the round building shape reduces wind deflections.			
Efficiency in Water Management	X	Incorporates sustainable water management practices equipped with a rainwater harvesting system to collect rainwater from the roof. It uses greywater recycling systems, collecting and cleaning wastewater from showers, sinks, and other sources outside the toilet. Sustainable drainage solutions that control surface water runoff are part of building design.			
Green energy and energy efficiency	X	Due to its energy-efficient design, natural ventilation systems, water recycling, diagrid structural system, and use of durable materials, all contributing to reduced environmental impact and enhanced structural stability, and through energy-efficient systems like natural ventilation, advanced glazing for insulation, and intelligent building management systems, reducing energy consumption and optimizing operations for environmental sustainability and efficiency.			
Structural Efficiency and Material Optimization	X	Its diagrid design, double-glazed facade, and strategically placed atriums enhance energy efficiency, reduce heat gain, and maximize daylight penetration. Its lattice exoskeleton and conical shape offer stability and tolerate enormous depths, and its round building shape reduces wind deflections. Because each story rotates five degrees relative to the one before it, this enhances wind flow around facades, reducing pressure on the structure and preventing wind from reaching the ground.			
Integration of technology	X	Because of its energy-saving measures, it utilizes half the energy of a skyscraper of similar size and uses cutting-edge techniques in its construction and operation; computational design was used to optimize geometry for wind and load resistance and distribution.			

The below Table 3.9 analyzes each project according to its biomimicry level, application, and reliance on performalism.

Table 3.9. Analysis of the investigated projects in Biomimicry and Performalism

Project	Biomimicry level	Inspired organ	How it was applied in design	How Performalism is Applied in Design	Reference
The Gherkin tower	Behavior level	Venus flower sponge	Sponges may live at considerable depths because of their round shape and lattice-like exoskeleton, which offer rigidity and distribute the stresses from powerful currents. The building's circular form generates the exterior pressure differentials that power the natural ventilation system and lessen wind deflections.	Through ventilation, lighting, and stiffness.	(URL-56) (Mckenna, 2015) (Gaber, Maarouf, & Fath, 2022)
Bird Nest Stadium	Behavior level	Bird Nest	Both structurally and visually, the design is centered on bird nests. Reflecting the branches of the nests that gain stability when they cooperate.	a Robust and resilient structure capable of withstanding various loads and stresses.	(Mehta, Thakur, & Atha, 2019) (Berawi, 2015) (Lianto & Trisno, 2022)
Singapore Arts Centre	Organism and Behavior	durian fruit	The epidermis of the durian plant is covered with thorns that shield the seeds from the sun—serving as shade mechanisms modeled like the durian plant. Polar bears have black skin, and white fur made up of translucent hair follicles. Whenever there is sunlight, this hair's upright posture allows light to enter and be absorbed by the black skin, returning to its natural position.	Natural light, sun shading, energy reduction, and rainwater collection.	(Mohamed, Bakr, and Hasan, 2019) (URL-51) (URL-52) (URL-53)

Table 3.9. (continued) Analysis of the investigated projects in Biomimicry and Performalism

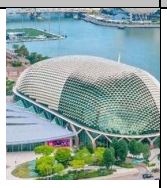
Project	Biomimicry level	Inspired organ	How it was applied in design	How Performalism is Applied in Design	Reference
Pearl River Tower	Organism and Behavior	Sea sponge	Wind turbines produce power by sucking wind into the tower's four holes, the same as sponges extracting nourishment by pouring millions of water gallons into their holes.	Through wind turbines	(Frechette and Gilchrist 2008) (Delgado 2007) (Tomlinson et al. 2014) (Smith, 2012) (Gonchar, 2015) (Epstein, 2008) (Sharpe, 2010)
BIQ House	Organism and Behavior	Algae	SolarLeaf is a bio-reactive façade that uses solar thermal heat and algae biomass to generate sustainable electricity.	supplies energy, reduces carbon dioxide, dynamic shading, thermal insulation, and sound reduction	(URL-38) (URL-45)
LasPalmas	Organism and Behavior	Namibia Desert Beetle	gathers water from fog. Gathering water during the driest conditions	savings in energy used for freshwater production	(Aslan, Selçuk and Avinç, 2022) (URL-32) (URL-33)
Council House 2, CH2	Organism and Behavior	plant/tree-termite mounds	Adapting to sun positions, it also resembles a tree that filters the air, plus the facade's ability to regulate the outside weather. The bronchi of a tree served as the model for southern and northern facades, which were utilized as windpipes to allow air ducts to pass.	Thermal and visual comfort, Air Quality	(Rayner, Raynor, & Williams 2010) (Hes, Morrison, & Bates, 2012) (Hoogland & Bannister, 2013) (Radwan and Osama 2016) (Mohamed, Bakr, & Hasan, 2019)
Tao Zhu Yin Yuan	Organism and Ecosystem	DNA Spiral	It has a distinctive twisting structure that is shaped like a double helix.	Energy self-sufficient, warmth, ventilation, carbon reduction, natural ventilation, rainwater recycle, wireless LED lighting control, light guiding system, fiber optic connection, and solar/wind power	(Zaki, 2023) (Altinöz, Mihlayanlar, & Yardimli, 2017) (URL-46) (URL-47)

Tables 3.10 and 3.11 identify the relationship between biomimetic and Performalism concepts based on data from previous projects. It examines how effectively biomimicry and Performalism approaches are added to the projects. The table compares and analyzes the data from the projects under four main headings: "biomimetic levels," "biomimetic elements," and "performalism references." This allows the relationship between biomimicry and performalism, which forms the hypothesis of the thesis, to be determined.

Table 3.10. Analysis of the projects according to biomimicry and performalism References

References	Project	Pearl River Tower	Las Palmas Theater	Council House2	BIQ House	Results
	Criteria					
Biomimicry Approach	Solution Based	x	x	x	x	4/4
	Problem based					0/4
Biomimicry Level	Organism	x	x	x		3/4
	Behavior	x	x	x	x	4/4
	Ecosystem				x	1/4
life principle	Adaptability	x	x	x	x	4/4
	Reactions			x	x	1/4
	Complexity	x	x	x	x	4/4
Biomimetic Element	Form	x	x			2/4
	Material					0/4
	Construction					0/4
	Process	x	x	x	x	4/4
	Function			x	x	2/4
Performalism References	Having Sculptural form and design	X	x	x		3/4
	Efficiency in Water Management	X	x	x		3/4
	Green energy and energy efficiency	X		x	x	3/4
	Structural Efficiency and Material Optimization			x		1/4
	Integration of technology	x		x	x	3/4
Score	100%	61%	50%	72%	50%	

Table 3.11. Analysis of the projects according to biomimicry and performalism References

References	Project	Tao Zhu	Bird Nest Stadium	Singapore Arts Centre	Gherkin	Results
	Criteria					
Biomimicry Approach	Solution Based	x	x	x	x	4/4
	Problem-based					0/4
Biomimicry Level	Organism	x	x	x	x	4/4
	Behavior			x	x	2/4
	Ecosystem	x				1/4
life principle	Adaptability	x	x	x	x	4/4
	Reactions			x		0/4
	Complexity	x	x	x	x	4/4
Biomimetic Element	Form	x	x	x	x	4/4
	Material					0/4
	Construction		x		x	2/4
	Process	x		x	x	3/4
	Function	x		x		2/4
Performalism References	Having Sculptural form and design	x	x	x	x	4/4
	Efficiency in Water Management	x		x	x	3/4
	Green energy and energy efficiency	x		x	x	3/4
	Structural Efficiency and Material Optimization	x	x	x	x	4/4
	Integration of technology	x		x	x	3/4
Score	100%	72%	44%	77%	72%	

4. DISCUSSION

Throughout this study, light was shed on the incorporation of the concepts of Biomimicry and Performalism under one framework, and it is through this study that both of the concepts were illustrated, emphasizing their criteria and presenting related examples to investigate each concept; later, multiple projects were chosen where the buildings incorporated both of the concepts, such as The Pearl River Tower in China, Las Palmas Water Theatre in Spain, Council House 2 (CH2) in Australia, The BIQ House in Germany, Tao Zhu Yin Yuan Building in Taiwan, Beijing National Stadium in China, Singapore Arts Centre, and The Gherkin Tower in England. This research, through the evaluations of the projects according to the studied concepts, shows that the investigated buildings/projects were built within the framework of a specific design search and applications. In this way, the relationship between applying two concepts in one design, building, and structure is shown, and the areas of intersections are also shown. The projects were evaluated according to biomimicry criteria: Design Approach being either Solution or Problem; Biomimicry Level being the Level of Organism, Behavior, or Ecosystem; Life Principle such as Adaptability, Reactions, Complexity, and Biomimetic Element as Form, Material, Construction, Process, Function. Moreover, Performalism criteria Having Sculptural form and design, Efficiency in Water Management, Green energy and energy efficiency, Structural Efficiency and Material Optimization, Integration of technology, and the below relations and results were observed:

- All projects were designed following the solution method; the most adopted biomimicry level was organism level (in The Pearl River Tower, Las Palmas Theater, Council House2, Tao Zhu Building, Bird Nest Stadium, Singapore Arts Museum, and Gherkin Tower), then it was the behavior with (The Pearl River Tower, Las Palmas Theater, Council House2, Singapore Arts Museum, and Gherkin Tower), the least used was the ecosystem level where it was shown in (BIQ house and Tao Zhu Building).
- All projects were designed as adaptable to their locations, functions, and conditions; only The Council House2 adopted reactions as it through host on the west side features hydraulically operated recycled timber shutters that open and close in response to the sun's position, depending on how much sun is shining on the western façade, louvers open and close.

- Among the biomimetic elements, form and process were the dominant features through most of the projects, followed by function and construction, while in performalism means and criteria, the investigated projects showed higher adoption for having sculptural form and design and efficiency in water management besides green energy and energy efficiency features in comparison to structural efficiency and material optimization and integration of technology.
- The building incorporating most features of biomimicry and performalism arranged as Singapore Arts Museum 77%, Council House2 72%, Gherkin Tower 72%, Tao Zhu Building 72%, The Pearl River Tower 61%, BIQ House 50%, Las Palmas Theater 50% and lastly the Bird Nest Stadium 44% (according to table.1).
- It is also readable from the analysis table that the buildings following organism and behavior biomimicry levels adopt more performative strategies.

The investigated buildings are classified into three main categories which are commercial buildings including (The Pearl River Tower, Gherkin Tower, and Council House2 as municipal buildings), residential buildings (Tao Zhu Building and BIQ House), and sports or gathering museums or events hosting (Bird Nest Stadium, Singapore Arts Museum, and Las Palmas Theater).

Through the analysis of the residential buildings, it was observed that the most adopted biomimicry level was the ecosystem; this could be related to the need for a comfortable residing ecosystem for the occupants; both residential buildings used green energy and energy features for more sustainable and eco-friendly outcomes, both BIQ House and Tao Zhu Building integrated technology. In means of biomimicry, Tao Zhu Building adopted three biomimicry elements, form process, and function, as the form is evident through the DNA building form. In contrast, the BIQ house did not; both buildings adopted process and function elements deprived of nature. BIQ adopted algae bioreactor panels that functioned the same way the algae functions. The building works in the same way the algae works. The Tao Zhu Building mimics the ecosystem of a forest in the process as it uses photosynthesis and energy capture in addition to water recycling management and functions in climate regulation terms and through natural ventilation and daylight.

While for the events hosting buildings, Birds Nest Stadium, Singapore Arts Museum, and Las Palmas Theater, through the table of analyses, it was observed that all the buildings were

designed as a solution since these types of buildings and structures are designed to host a large number of hosts and visitors and provide large spaces. Singapore Arts Museum and Las Palmas Theater adopted organism and behavior elements of biomimicry. In contrast, the Birds Nest Stadium adopted the organism element only, which is apparent from the structure and appearance of the building. All the events buildings corporate form element of biomimicry, Birds Nest Stadium incorporated construction, and Singapore Arts Museum adopted process and function. In performalism, the three buildings have the sculptural form: Singapore Arts Museum and Las Palmas Theater have water management features, Birds Nest Stadium and Singapore Arts Museum show structural efficiency, and the Singapore Arts Museum has green emery features and technology integration.

For the commercial building, the three buildings are designed as solution-based as they represent the solution for accommodation environment, comfort, genius designs and areas, energy features, and holding loads. The Pearl River Tower and Council House2 are designed following organism and behavior levels, and only the Council House2 incorporated reaction as the building's west side features hydraulically operated recycled timber shutters that open and close in response to the sun's position, depending on how much sun is shining on the western façade, louvers open and close. The three buildings follow the process element of biomimicry; gherkin and pearl also follow the form element, Council House2 follows function, and the Gherkin Tower follows construction. Performalism means the commercial buildings adopt more performalism criteria in comparison to the other categories of the investigated buildings; the three buildings incorporate sculptural forms, water management, and green energy features, and Gherkin Tower and Council House2 provide structural efficiency. Finally, The Pearl River Tower and The Gherkin Tower include technology integration.

With the data obtained, a question is made about how the performative architecture features can be inspired by biomimicry and what biomimetic approaches are used in the projects that reflect and adopt performative references. In this way, in performative projects designed from a biomimetic perspective, it is possible to determine mutually which performative reference is more related to biomimetic and which biomimetic approach is more effective on performative references, in addition to the relation for the application of both concepts in one designs:

- When the biomimetic elements that express the content of the inspiration levels in the designs are examined, and organisms are addressed in terms of form in three projects, it is revealed that those three designs showing structural efficiency features, such as the Bird Nest Stadium, Singapore Arts Museum, Tao Zhu Building, and The Gherkin Tower
- In investigating the relation between the application of biomimicry in architecture and the application of performalism in the biomimetic designed project, it is observed from the investigated projects that the buildings designed according to form level are reflected in the performative criteria through having sculptural form and design. Accordingly, it is concluded that performative approaches can be acquired from natural elements from designs.
- Through the table, the projects designed according to process and function in biomimicry elements either indicate efficiency in water management features, green energy, and energy-efficient features, or both. This indicates the relationship between the inspiration of the processes in nature and nature's adoption of eco-friendly processes (since they are nature).
- Three of the projects which has reaction abilities which are the BIQ House, The Council House2, and the Singapore Arts Center, are at the same time showing the integration of technology in performalism means, indicating the relation between the need for a performative approach of technology integration when inspiring reactions from the nature.
- While designing environmentally friendly structures that produce their resources, they are inspired by nature at the ecosystem level, such as the BIQ house, which represents performalism features in this way, adopting green energy and energy efficiency.

According to the examples examined and the analysis table, the ideas presented regarding performalism are the goals of making environmentally friendly and nature-compatible structures. In the performative projects and their features, all are looking for sustainable, eco-friendly, and creative solutions, which leads to the fact that nature can be a good solution for inspiration. It can be easily determined that the designs presented through the study are not only imaginary or utopian but also inspire today's designers and all sensitive citizens of the world. It shows the relationship between the two concepts by blending biomimesis, one of today's important design approaches, with the performative designs that criticize today's

environmental problems. This leads to the fact that architecture should be more ecological and sustainable, thanks to biomimetic and performative aspects. Finally, it illustrates that blending both concepts would bring generative designs.

5. CONCLUSIONS AND FUTURE REMARKS

Biomimicry aims to address design and construction challenges in a new and sustainable way by analyzing natural biological systems and patterns. Biomimetic studies have made designers realize that form, structure, and function work well in nature and that all systems are energy-efficient and recyclable. To ensure efficiency in buildings, architects must have a high level of awareness. A design must also meet helpful, durable, and aesthetically pleasing purposes. The natural world provides a rich design database that can stimulate original ideas. The most energy-efficient buildings adapt to their environment and benefit from nature. Consequently, it is essential to appreciate the importance of learning from nature and incorporate these innovations into creating structures that blend with the environment and perform accordingly. Biomimetic architecture offers the potential of biomimicry to provide creative solutions to human challenges and architectural problems, and the nature and environment around us require our attention in various ways: firstly, to preserve it and, secondly, to learn from it. In line with advanced programs and technologies that enhance the creation of such solutions and approaches, it has become urgent to adopt solutions, find them, and, even more, create inversions. This is where the importance of the emerging concept of biomimicry emerges, which refers to observing and learning from nature in different ways and from various levels (organism, ecosystem, and behavior), such as forms, systems, and processes, to create efficient and sustainable architectural solutions. Through simulation, nature and its creatures include various creatures that can provide multiple approaches and mechanisms to create creative and environmentally responsible design solutions, as nature is a mentor, model, and unit of measurement.

In line with the concept of Performalism that emerged in architecture, the dynamic and impressive aspects of design, movement, and rhythm, going beyond static aesthetics and how a building performs and creates performance, have come to the fore. This quest results from sustainability and digitalism embracing better green approaches, striving for efficient energy use, and environmentally conscious design strategies. Simultaneously, embodying the essence of digital design, we can see that complex designs of buildings with unique geometries can only be effectively conceptualized and implemented through computational technologies. Performalism leads to "optimizing" all the "more," such as better, lighter, more effective, and more economical for a sustainable environment. And various specific criteria

play pivotal roles in influencing performance forming collectively a comprehensive framework that architects and designers navigate to optimize the functionality and sustainability of buildings and structures, these criteria include having sculptural form and design; through integrating both aesthetics and performance in addition to adaptability and having dynamic design to changing environmental conditions or user needs, efficiency in water management; through integrating strategies for water and rainwater harvesting gray water and water recycle, green energy and energy efficiency, through integrating sustainable practices and using renewable energy sources to minimize environmental footprint such as wind turbines, passive design strategies, shading devices, solar panels, natural ventilation, natural lighting, and effective solar control, structural efficiency and material optimization; through the using of advanced computational methods which enables creating stable and material-efficient structures, and integration of technology; through using innovative technologies to enhance functions, design, and building simulation. Especially with the collaboration opportunities provided by digital design and production technologies, the search for performative architecture has also begun to shape the language of the 21st century regarding sustainability.

Both concepts currently have important and impressive results for architecture and the environment. Moreover, the application of both concepts in one comprehensive design would reflect multiple achievements, enhancing better and more sustainable and eco-friendly outcomes. Through this study an analysis for building which incorporate both concepts criterias was made, and analysis was established for the relation of both of them, however, for further areas of research under the same topic, there can be a number of complex potential related researches, as researchers can create a framework for the design of a bio-performative buildings, through focusing on relating the inspiration from nature with direct performalism criteria, expanding the research area, furthermore, future designers can make an analysis of a performative criteria found through inspiration from nature, resulting in finding creative solutions for design problems.

In conclusion, Performative design focuses on achieving functionality and efficiency in a broad sense, and biomimetic design looks explicitly to nature for inspiration; this leads to the fact that not every performative design is biomimetic because performance can be achieved through various design approaches without necessarily imitating or being inspired by nature. However, every biomimetic design is performative, as it seeks to leverage the

proven effectiveness of natural solutions to enhance the performance of human-made systems. For this reason, in the discipline of architecture, every new paradigmatic discourse and application regarding 'sustainability' is gaining importance, especially with the collaboration opportunities provided by digital design and production technologies; the search for performative architecture has also begun to shape the language of the 21st century regarding sustainability. Undoubtedly, the values obtained in the examples presented in the study were obtained through the designers' intensive research and development activities aimed at "Biomimicry" and "performance". All this makes the mix between both concepts exciting regarding what brings together creative, sustainable, environmental, and innovative solutions inspired by nature, which provide advances in architecture using advanced technologies and focus on building performances inspired by nature, as merging of biomimicry and performalism in architecture introduces a unique perspective that blends inspiration from nature with a focus on dynamic, performative aesthetics, resulting in nature-inspired efficiency and visually dynamic architecture, enabling offering new and generative solutions to future designers, creating structures that fulfill functional requirements and captivate with their ever-changing and performative aesthetic qualities, going beyond conventional aesthetics, where nature-inspired efficiency meets the performative and visually expressive qualities of architecture, shaping a future where buildings are not only functional but also engaging works of art and presenting a performance show.

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Gazili olmak ayrıcalıktır