NATURE INSPIRED ARCHITECTURE

Item Type	Thesis (Open Access)
Authors	Khan, Salabat
DOI	10.7275/35396820
Download date	
Link to Item	

NATURE INSPIRED ARCHITECTURE

A Thesis Presented

by

SALABAT ALI KHAN

Submitted to the Graduate School of the
University of Massachusetts Amherst in partial fulfillment
of the requirements for the degree of

MASTER OF ARCHITECTURE

May 2023

ARCHITECTURE

NATURE INSPIRED ARCHITECTURE:

A Thesis Presented

by

SALABAT ALI KHAN

Approved as to style and content by:

____
Eldra Dominique Walker

____
Stephen Schreiber
Chair, Department of Architecture

DEDICATION

I want to dedicate this thesis to my mother, Nishath Khan, father, Hashmat Khan, and Sister Zoya Khan, whose unwavering love and support have been essential in enabling me to complete my graduate studies. I am immensely grateful for everything they have done for me, and I love them both deeply.

I would also like to dedicate this thesis to my Pet Cat, Minnu Khan. Whose unwavering presence and unconditional love have been a constant source of comfort and inspiration throughout my academic journey. Thank you for being my loyal companion, for always being there to lift my spirits, and for reminding me to take breaks and enjoy the simple things in life. You are more than just a pet; you are a cherished member of my family and an indispensable part of my life.

ACKNOWLEDGMENTS

I would like to extend my deepest appreciation to my professors - Eldra and Rob, and the staff members who have been invaluable in the successful completion of my thesis. Their unwavering support, guidance, and expertise have been essential in providing me with the resources and direction I needed to succeed.

I especially want to thank Eldra for their dedication to ensuring my needs were met and for being a constant source of inspiration and encouragement. Rob's exceptional design advice was also critical in shaping the outcome of my thesis, and I am grateful for his contributions.

Together, Eldra and Rob's combined knowledge, skills, and commitment to excellence have been an indispensable part of my academic journey. Thank you both for your tireless efforts and the immeasurable impact you have had on my success.

ABSTRACT

NATURE INSPIRED ARCHITECTURE

MAY 2023

SALABAT ALI KHAN, B. ARCH, MEASI ACADEMY OF ARCHITECTURE

M.ARCH, UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Professor Eldra Dominique Walker

The thesis explores the various ways in which Biomimicry can be used to develop sustainable solutions that are derived from the natural cycles of organisms. Some of these include the use of solar and wind energy, as well as waste management. Aside from these, the thesis also explores the various ways in which Biomimicry can be used to develop more sustainable solutions for interior and exterior designs. The thesis explores different ways to help in sustainable architecture for the future as we are heading into the future. By using computational programming, we can design innovative solutions to help offset the carbon footprint of the planet. The design goal is to create a façade system inspired from the principles of biomimicry which helps in offsetting the carbon footprint of building over its lifespan.

CONTENTS

LIST OF FIGURES

Figure Page

CHAPTER I
INTRODUCTION

NATURE INSPIRED ARCHITECTURE

SALABAT ALI KHAN

UNIVERSITY OF MASSACHUSETTS AMHERST
MASTER OF ARCHITECTURE

"We envision a world in which people view nature not as a warehouse of goods but as a storehouse of knowledge and inspiration."

\- *Janine Benyus, founder of Biomimicry Institute*

Nature has inspired architecture in design, construction, and sustainability for millennia. Advances and recent discoveries in the field of biology have led humans to understand more about the complexities of plant and animal life. After centuries of operating as if humans could exploit natural resources without consequences, the world has increased in sea levels, resource depletion, desertification, ecosystem migration, and unprecedented species extinction rates. Architecture, or design with nature, can play a crucial role in foregrounding technologies which help to reduce carbon impact (McHarg, 1969, pg. 41-43). The 20th century enabled the ubiquitous waste of energy due to inefficient building designs, and it continues to be rampant; it is estimated that by 2060, the world will add 2.5 trillion square feet of buildings. Because of this, CO2 emissions will likely continue to rise by 1% every year as they have risen since 2010 ("Why the Building Sector? – Architecture 2030," 2003).

One way to design for this future is through biomimicry. Through biomimicry, a building could use practices from biology to convert carbon dioxide to oxygen, for instance, efficiently convert sunlight into energy during the process. Biomimicry, as an idea, was introduced by Janine Benyus so that people could explore the possibilities of this field of study. As a design practice, it can influence architecture in terms of aesthetics, materials, technologies, heating and cooling systems, and even building structures (McHarg, 1969). Biomimicry is a form of sustainable design that goes beyond codes and regulations. Rather it is a set of principles; looking up to nature for design ideas and inspiration has been practiced since the 15th century. The earliest examples of biomimicry can be seen in the study of a bird's flight by Leonardo da Vinci. The first real flight studies were made in the 1480s and produced over 200 drawings. Da Vinci drew inspiration from the flight of winged animals such as bats, kites, and birds in his design for this invention. His aim was to replicate their

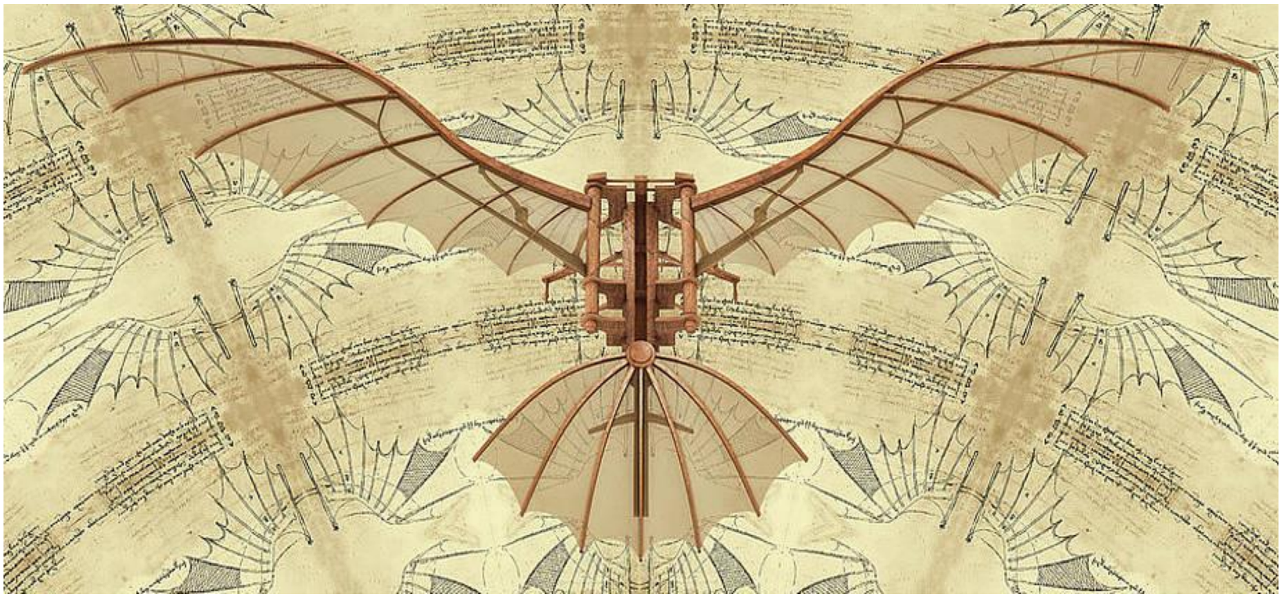


FIGURE 1 - (“LEONARDO DA VINCI AND FLIGHT” 2013)

flight mechanics, as he noted in his writings. (“The-Complete-Works-Leonardo-Da-Vinci, 1888.)

Antoni Gaudi and Buckminster Fuller are more contemporary designers who look to nature for inspiration. Antoni Gaudi is a celebrated Spanish architect who practiced from 1852 to 1926. For Gaudi, nature was paramount; originality exists in returning to the origin," the form and power of nature was the source of all knowledge and inspiration. The imitation of the surface can be easily seen in the detailed decorations - honeycomb gates, Nautilus murals, friezes with a glass effect, and ridges like pyrite crystals. However, on closer inspection, you start to think about the massive structural elements that give it organic form - levees, spiral staircases, conoid ceilings, and wood-inspired columns. Biomimetic architects and scientists continue to explore and expand the complexity of these shapes, forms, and structures. Without modern technology, Gaudi tested his bold ideas in complex model systems - charges, weights, strings, and clay molds. That system of pressure testing the physical limits

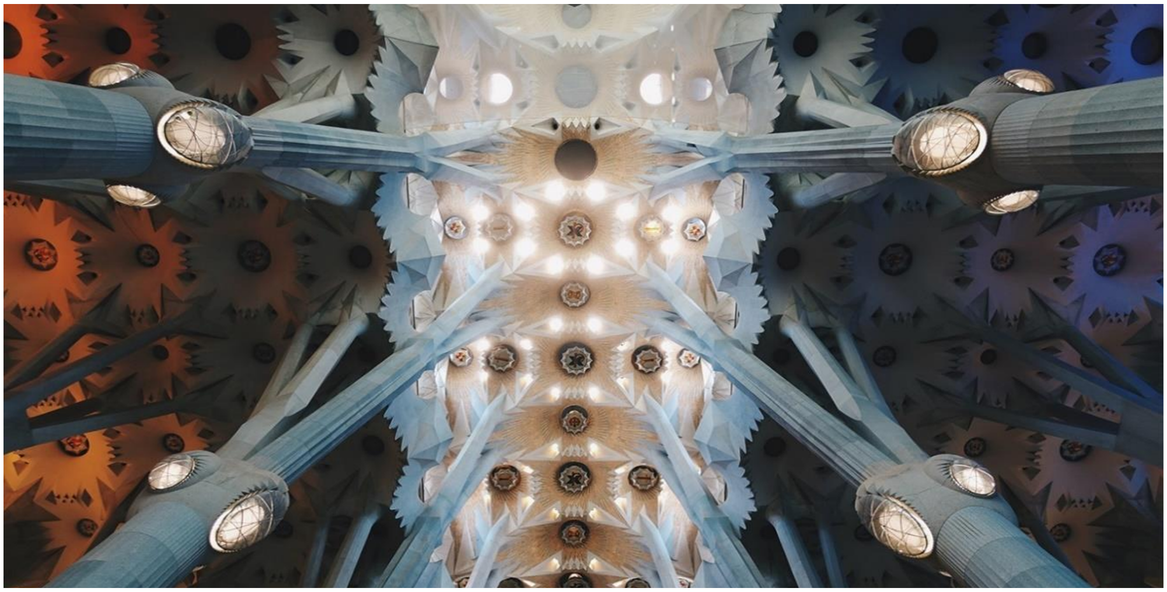


FIGURE 2 - (PANTANO 2013)

of design physically reproduced what architectural software began to calculate with the advent of computers. (“Gaudí, Biomimicry, and Bonsai” 2017).

The American architect Buckminster Fuller and inventor devoted his life to addressing the most urgent global issues. He was a visionary ahead of his time and transformed the design field by introducing radical solutions for problems such as affordable housing, transportation, education, environmental degradation, and poverty. One of Fuller's most notable structures is the geodesic dome—a lightweight, easily assembled dome that enclosed more space without the obtrusive buttresses other structures used. Fuller gained a great understanding of nature by analyzing how the geometric patterns of nature can be applied to the design of structures and thus create enormous possibilities - which he used in his dome design. Fuller built the Dymaxion House using a comprehensive problem-solving approach. A modular house is relatively cheap, easy to mass produce, and environmentally friendly and transportable; The Dymaxion House was the final manifestation of Fuller's ideas. Fuller gained a great understanding of nature by analyzing how the geometric patterns of nature can be applied to the design of structures and thus create enormous possibilities - which he used in his dome design. Similarly, Fuller's Dymaxion car used biomimetic principles to design the features of fish and birds, resulting in a three-wheeled, streamlined vehicle capable of remarkably sharp turns. The house had a single support attached to a base, from which additional supports radiated, creating a circular home. The entire house weighed 3 tons and was self-contained, meaning it could be airlifted anywhere in the world and assembled in days. (“Gaudí, Biomimicry, and Bonsai”).

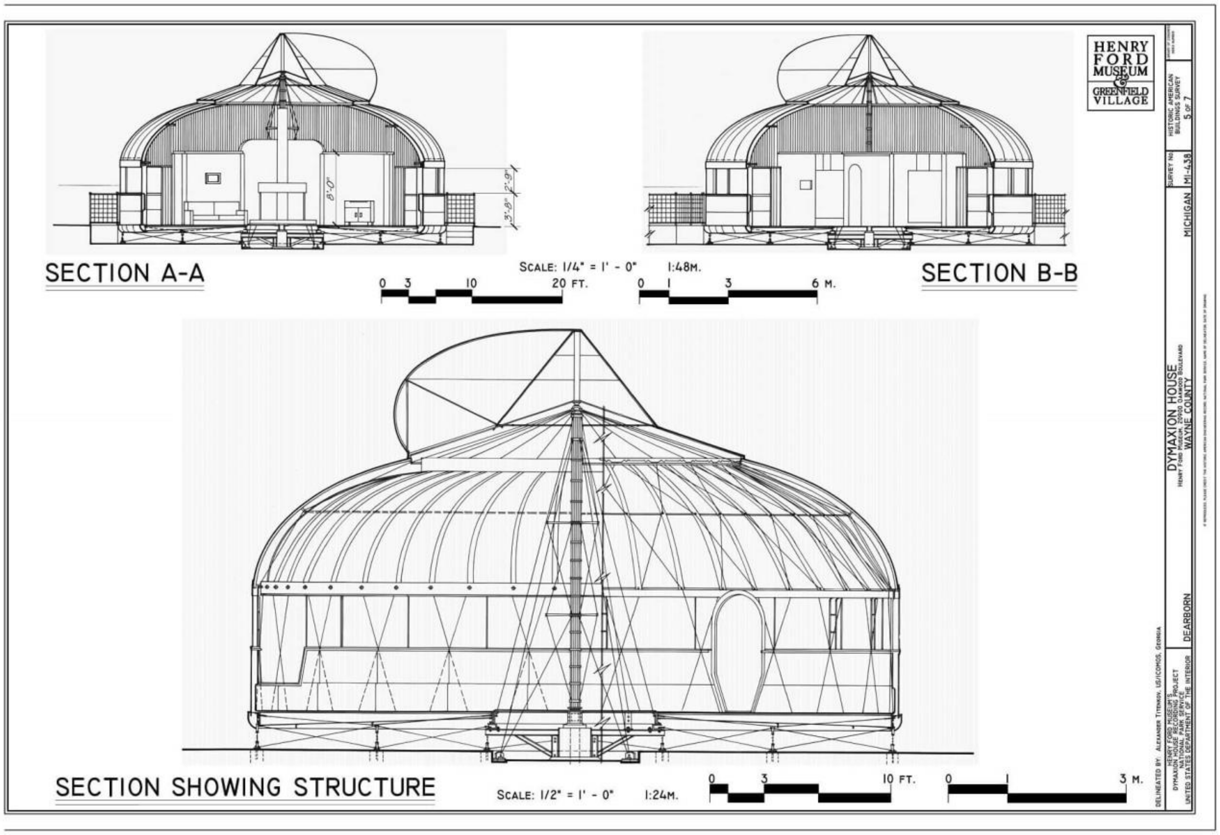


FIGURE 3 ("PRESERVING A PROTOTYPE: BUCKMINSTER FULLER'S DYMAXION HOUSE" 2012)

Our understanding of the natural world has been enhanced by rapid technological development and biological discoveries. By studying the ant termites, we can learn how ventilation and cooling can be performed in a dry environment or by taking inspiration from the beaver to create impressive water retention strategies.

Today, many companies and designers are looking for ways to reduce their environmental impact through the design of their products and processes. Unfortunately, they often end up developing a new architecture that is not sustainable. Instead, they should look to Biomimicry to identify the most effective ways to adapt to the environment. Through a comprehensive study of biomimicry, a few design strategies have been identified that can be used to improve the efficiency and sustainability of an existing building. This project, which is a renovation of an existing building, aims to create a more sustainable and energy-efficient building. The project's design has been used as an example of biomimicry's ability to transform an existing building into a more sustainable structure. (“Dymaxion House,” 2022)

WHAT IS BIOMIMICRY?

The term "biomimicry" implies understanding biological structures and processes and their comparable technological applications, methods, or procedures. Biomimicry is not the mere imitation of nature, neither in material and functional nor creative regard, but rather the grasping of natural principles to aid in comprehending similar technological questions, which could then be solved by applying optimized technology (Pohl and Nachtigall 2015). Biomimicry in architecture uses nature as a model, measure, and mentor for providing architectural solutions across scales inspired by natural organisms that have solved similar problems in nature. Using nature as a measure refers to using an ecological standard to measure the sustainability and efficiency of human-made innovations. In contrast, the term mentor refers to learning from natural principles and using biology as an inspiration (Benyus, 1997). Biomorphic architecture, often known as bio-decoration, refers to using natural formal and geometric features as a source of inspiration for aesthetic properties in planned architecture and does not always have non-physical or economic functions. The use of tree and plant forms in the embellishment of structural columns is a historical example of biomorphic architecture dating back to Egyptian, Greek, and Roman cultures, but this is not biomimicry (Aziz & El Sherif, 2016).

Many terms describe the process of integrating the principles of nature in architecture, such as biomimicry, biomimetics, bionic, and biogenesis. For simplicity, this thesis will use the term biomimicry. Sustainable development has often been criticized as being ambiguous as an underlying principle for the built environment (Roseland, 2012). Animals, plants, and insects have evolved over billions of years to develop more efficient solutions, such as super hydrophobicity, self-cleaning, self-repair, energy conservation, drag reduction, dry adhesion, adaptive growth, etc. These designs are complex, sophisticated, and elegant, often surpassing comparable human-made design solutions. Some of these solutions may have inspired humans to achieve outstanding outcomes. For example, fishing nets may have originated from spider webs; the strength and stiffness of the hexagonal honeycomb may have led to its adoption for use in lightweight structures in an airplane and in many other applications (Eadie and Ghosh, 2001). Although the science of biomimetics has gained popularity relatively recently, the idea has been around for thousands of years. Since the Chinese attempted to make artificial silk over 3000 years ago, there have been many examples of humans learning from nature to design new materials and devices (Bhatnagar, 2022). Further obstacles within the planning, design, and construction of the built environment include design approaches that lack feedback loops and a common language for multiple disciplines to assess built and natural environmental impacts. It is somewhat difficult to trace the origin of biomimicry due to the lack of documentation. However, from the available documentation and analysis, evidence of biomimicry has been in practice since Leonardo da Vinci. It may have inspired the first domes, which may have been designed based on eggs.

Leonardo da Vinci used nature and biology to inspire many of his designs and concepts during his time. He uniquely used biomimicry, by using it for ideas that had not been created before; he searched for an understanding of anatomy and nature, which led to the design of concepts and machines that took inspiration from what he had been analyzing, such as his flying machines based on birds and flight (Pawlyn, 2019). However, the term biomimicry was not referenced in scientific literature until 1962. Using biomimicry for inspiration began in 1980 among material scientists. The practice of using biomimicry for inspiration first began to become popular in 1980 among material scientists who were seeking to redevelop materials based on mimicking nature to improve upon them and find new innovative approaches. DaVinci was known for his interest in the natural world and is considered one of the early pioneers of biomimicry. He observed the flight of birds and the flow of water, among other natural phenomena, and applied those observations to his designs and inventions. Some examples of his biomimetic innovations include studying the structure of bird wings to improve his designs for flying machines and studying the flow of water in rivers to improve his designs for canals and water pumps.

Biomimicry can be categorized into three levels of design - product, process, and policy - based on the extent to which it imitates the life processes of other organisms

Organism level biomimicry

.

Organism level Organism-level biomimicry refers to the mere replication of the form of an organism to inspire product design. The Gherkin is an example of a mimicry at an organism level. The building features an air ventilation system modeled after the fluid dynamics of sea sponges and anemones, which naturally direct fluids through their bodies. In addition to serving as a ventilation mechanism, the building's green pockets provide a welcoming space for occupants to take breaks. ("The History of Biomimicry and Architecture," 2020)

FIGURE 4 - (SEDKY 2023)

Behavioral level biomimicry

Architect Mick Pearce collaborated with engineers at Arup Associates to design the Eastgate Centre, which exemplifies the behavioral level of biomimicry. This approach involves incorporating the concept of Critical Regionalism, which allows a structure to withstand its unique geographical and climatic conditions. The building utilizes passive ventilation systems through numerous small openings, reducing heat gain and promoting ventilation. At night, the heat is released into the building to warm the night air, leading to a significant decrease in energy consumption. (“The History of Biomimicry and Architecture” 2020)

in energy consumption (“The History of Biomimicry and Architecture,” 2020)

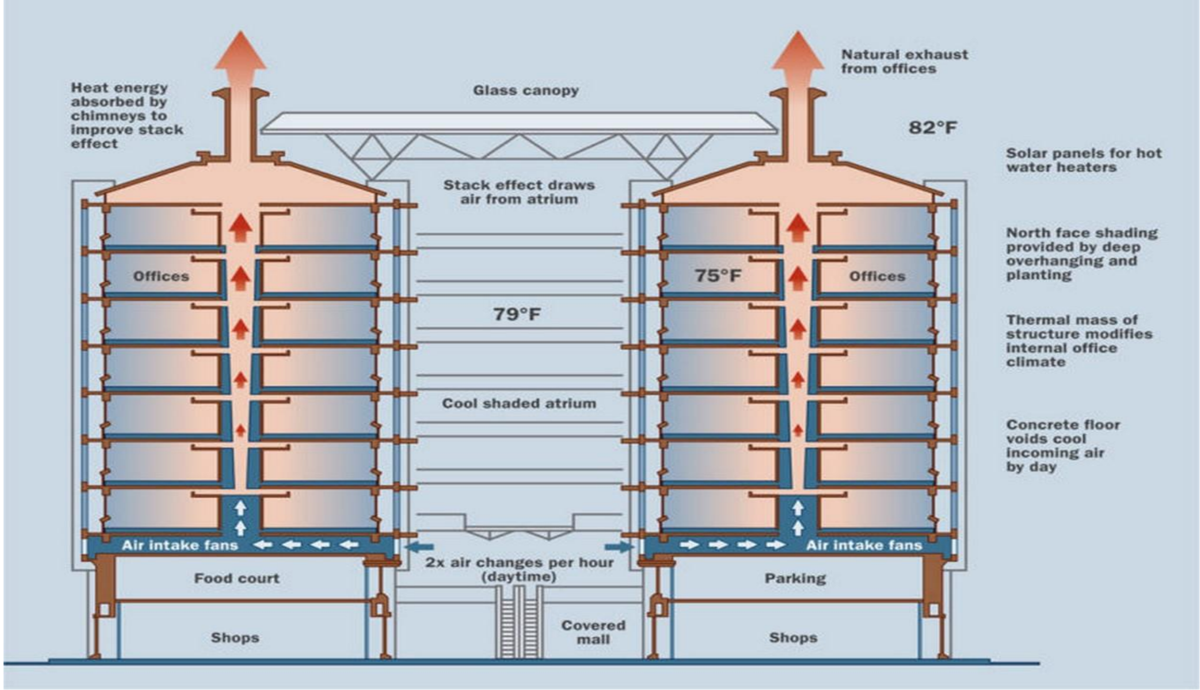


FIGURE 5 (“EASTGATE CENTER DESIGN”, 2013.)

Ecosystem-level biomimetics

Ecosystem-level biomimicry involves circular economy and consumption systems. Graham Wiles' Cardboard to Caviar Project successfully transformed waste into food, resolving the excessive cardboard disposal problem in Wakefield, UK, and the commercial extinction of caviar due to overhunting in the Caspian Sea. The project utilizes a circular consumption cycle where the cardboard is sold as horse bedding, and the waste is used to feed microorganisms in the compost. Advances in technology have enabled new ways of integrating biomimicry in architecture, such as the Hamburg-based 'algae house.' This building uses live algal matter in its walls as a bioreactor façade, which filters light, provides shade, and produces renewable energy through biogas production by feeding biomass with nutrients to trap CO2. (“The History of Biomimicry and Architecture,” 2020)

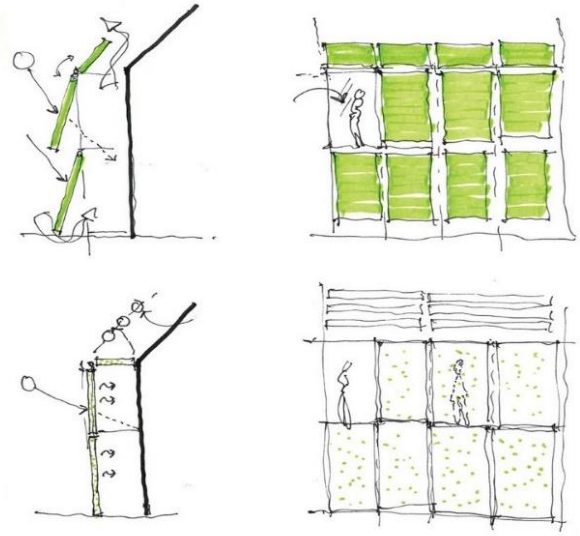


FIGURE 6 (BILORIA AND THAKKAR 2020)

Biomimicry and Architecture

The use of biomimicry in architecture is focused on finding sustainable solutions by studying the underlying principles of natural forms rather than simply copying their physical appearance. It is applicable to various areas within the fields of architecture and engineering, including materials, structural systems, design, and many others. Today's most important convergence of design and biological sciences is based on "innovation" that has been around for millions if not billions, of years ("10 Stunning Examples of Biomimicry in Architecture," 2020). The concept of developing buildings and products that mirror or co-opt natural processes is known as biomimicry in architecture and manufacturing. "Biological systems and constructed systems handle issues in very different ways," says Peter Niewiarowski, a biologist at the University of Akron's Biomimicry Research and Innovation Center. Nature excels at converting waste into food, a crucial tool for balancing ecosystems that architecture has mostly overlooked throughout history. Biology has much to teach designers about resource stewardship and circular economies. Nature also typically follows the tenets of "critical regionalism," or the idea that architecture should reflect its surroundings' topography and culture. For example, certain parasites have evolved so specifically precisely that they can only exist in one species of host. ("Nature Does It Better: Biomimicry in Architecture and Engineering," 2021). Biomimicry in architecture produces not only creative produces not only innovative systems but also induces creative thinking among architects. It uses nature as inspiration to conceptualize architectural landmarks that are both aesthetically and functionally brilliant. Natural forms and structures have just recently been discovered by our technology-driven commercial world in terms of functionality and aesthetics. Nature's operating principles, on the other hand, have been intuitively exploited by people of all cultures: storing water in terraced fields, separating the chaff from the wheat with the help of the wind or natural climate control in living spaces using updraft cooling in earthen dwellings places that are hotter. The needs of contemporary buildings are characterized by the pursuit of efficient discourse with our resources, as they have been for hundreds of years of technical and technological growth. The proliferation of "new" materials and technologies has therefore been accelerated in the current Information Age. The number of choices for designers has grown to unthinkable proportions, many without clear impacts. Individual elements of increasingly ubiquitous technical composite materials, on the other hand, are frequently inflexibly connected to one another as a whole. In this case, nature takes a different path. With computer-aided technology, for example, "genetic design processes "are now possible. Analogies to biological processes, biomorphic architecture, and biomimetically produced detail solutions being incorporated into building structures are all emerging on a larger scale. ("Nature Does It Better: Biomimicry in Architecture and Engineering," 2021)

PERCENT STUDIES: NATURAL FUNCTIONS AND PROCESSES AS PROTOTYPES FOR BUILDINGS

The Termite mound: Solar air conditioning

Termites are mainly found in hot regions like Africa, Australia, and South America, where the temperatures can range from 75 °F to 100 °F. They build their mounds in well-drained areas using a combination of soil, dung, and termite saliva. Despite their seemingly solid appearance, these mounds are highly porous, with numerous tiny holes that allow air to circulate through the structure. The top of the mound contains a central chimney surrounded by a complex network of tunnels, which allows fresh air to mix with the warm air inside and maintains a constant circulation of air. The nest stays cool and well-oxygenated, preventing it from overheating. The entry and exit to the mount are from the base of the mount. They come out at night to collect food when the temperatures are lower. The cellar is 6 feet below the ground, which is the coolest part of the structure. As the moisture evaporates, the temperature falls, further cooling the air around the nest. Despite their resemblance to apartment buildings, termite mounds serve as a ventilation system that keeps the underground colony cool and well-oxygenated. (“The Animal House ~ The Incredible Termite Mound | Nature | PBS” 2011), ("The Harvard gazette,” 2019)

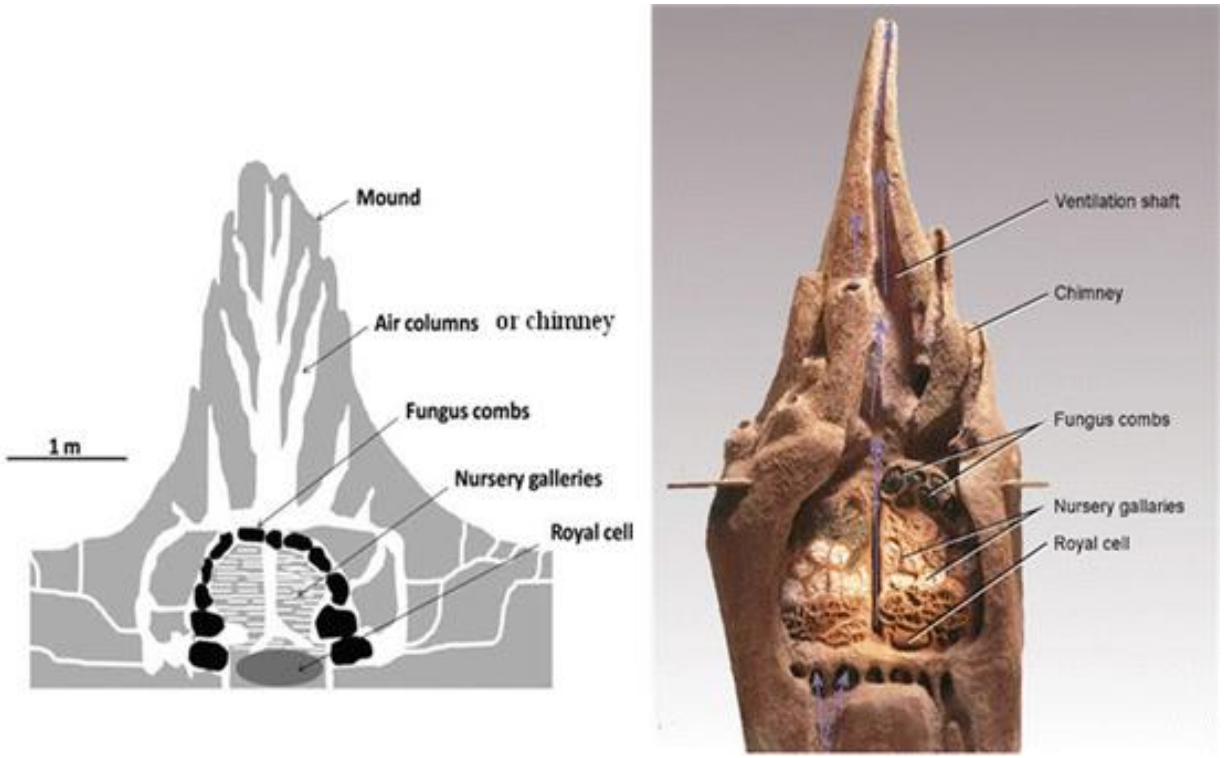


Figure 7 (Ocko, Heyde, and Mahadevan 2019)

Figure 8 (Ocko, Heyde, and Mahadevan 2019)

THE EASTGATE CENTRE, HARARE, ZIMBABWE

The Eastgate Centre is situated in Harare, Zimbabwe, that operates without a conventional, fuel-based air conditioning system. Instead, it employs more energy-efficient and passive mechanisms of climate regulation. The materials used to construct the building have a high thermal capacity, enabling them to absorb and release heat collected from the environment. Fans operate in a timed cycle to enhance heat storage during the day and release it during the night. The building's occupants and appliances generate heat that drives the airflow from the lower floors toward open rooftop chimneys. The construction of the building saved 10% of upfront costs, and rents are comparatively cheaper due to reduced energy expenses. The Eastgate Centre was inspired by the concept of passive internal airflow of termite mounds, even though subsequent research has led to a revised understanding of the function of termite mound structures. ("Passively Cooled Building Inspired by Termite Mounds — Innovation — AskNature" n.d.), ("BIOMIMETIC ARCHITECTURE: Green Building in Zimbabwe Modeled After Termite Mounds" 2012).

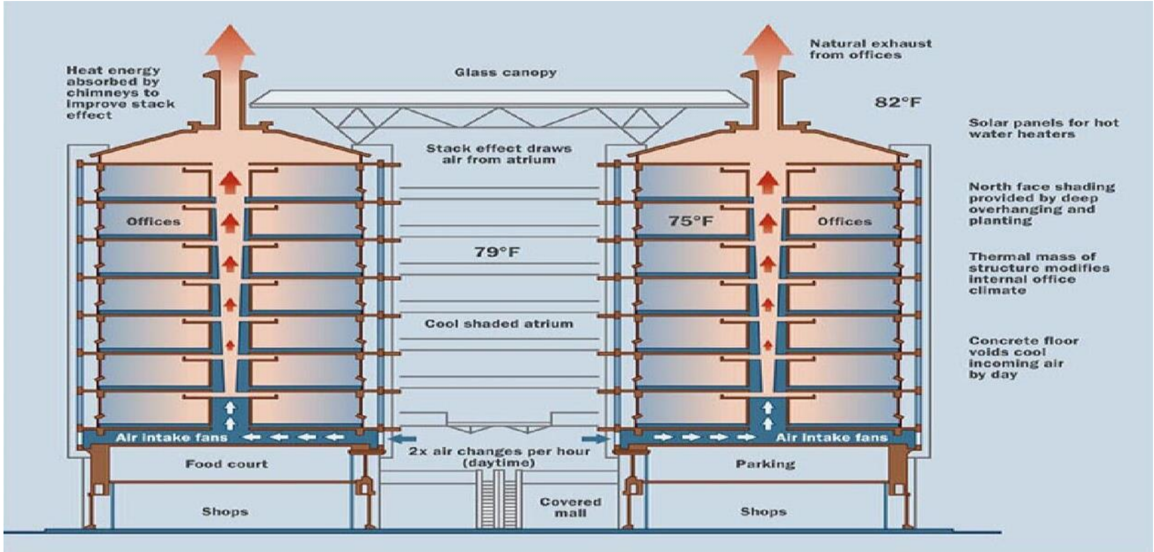


FIGURE 9 (“EASTGATE CENTRE DESIGN” , 2013.)

VENUS FLOWER BASKET SPONGE: LATTICE EXOSKELETON

Venus' flower is a type of sea sponge that resides in the deep ocean near the Philippines. Despite their appearance resembling sculptures rather than living beings, these tube-shaped sponges are capable of filtering small food particles from seawater as it passes through their bodies. The sponges' skeletal structure is composed of spicules, which are tubular structures made up of concentric layers of amorphous hydrated silica separated by thin organic layers. These spicules are arranged into a tube-shaped square lattice, reinforced by struts that run vertically, horizontally, and diagonally. The main frame is made up of two overlapping lattices that can move relative to each other, providing flexibility during growth and additional support against bending, sliding, and twisting forces.

FIGURE 10 (AIZENBERG ET AL. 2004)

THE GERKIN, LONDON

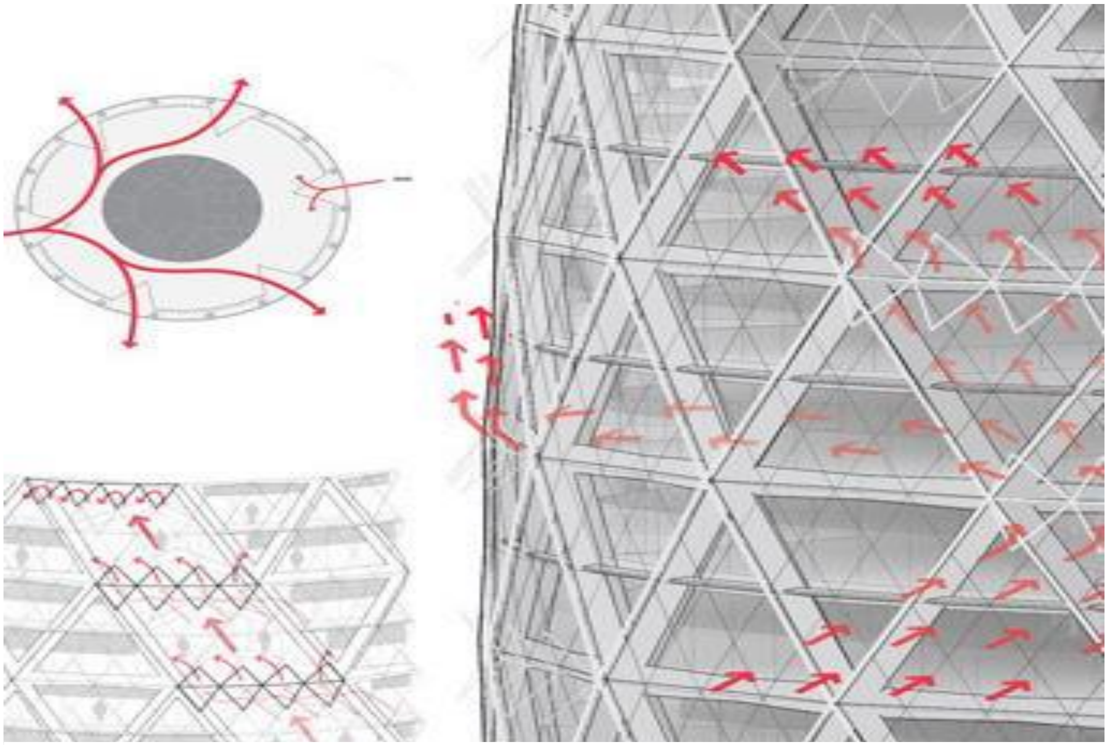


FIGURE 11 (AIZENBERG ET AL. 2004)

The building located at 30 St Mary Axe, popularly known as the Gherkin, is designed in a manner that imitates the Venus Flower Basket Sponge's lattice exoskeleton and shape. This structure of the sponge provides robustness and steadiness while filtering water for nutrients. The building's structural elements are interconnected at various angles on each floor, allowing for a spacious floor plan, vertical support without interior columns, ventilation throughout all levels, and resistance to winds. The cylindrical shape improves ventilation and is engineered to have a comparable structure to that of sea sponges. This design reduces wind forces by enabling air to flow around the building, and it could be employed in future architectural projects to reduce greenhouse gases. ("10 Stunning Examples of Biomimicry in Architecture," 2020), ("Venus Flower Basket Sea Sponge," 2011.)

CORAL REEF – CEMENT INSPIRED BY CONCRETE

FIGURE 12 (HOEGH-GULDBERG ET AL. 2017)

Concrete is a widely-used building material that is favored for its strength, durability, weather, and fire resistance, and affordability. In fact, twice as much concrete is used for construction compared to all other building materials combined, including wood, steel, plastic, and aluminum. However, the production of cement, a key component of concrete, is responsible for about 6% of all human-made carbon dioxide emissions. On the other hand, coral reefs are capable of using dissolved carbon dioxide, or carbonate, of constructing their skeletons. Corals manipulate the pH of the fluid surrounding them to create an environment in which calcium and carbonate can crystallize into their skeleton. This same process can also be used to capture carbon dioxide and convert it into calcium carbonate, which can be stored indefinitely. (Tonn Shara, 2015). While a turn-off traditional cement produces about one ton of CO2, a ton of cement produced with this method sequesters half a ton of CO2 and takes less energy as well ("Brilliant Cement Making Technology Mimics Coral While Removing CO2 From the Atmosphere")

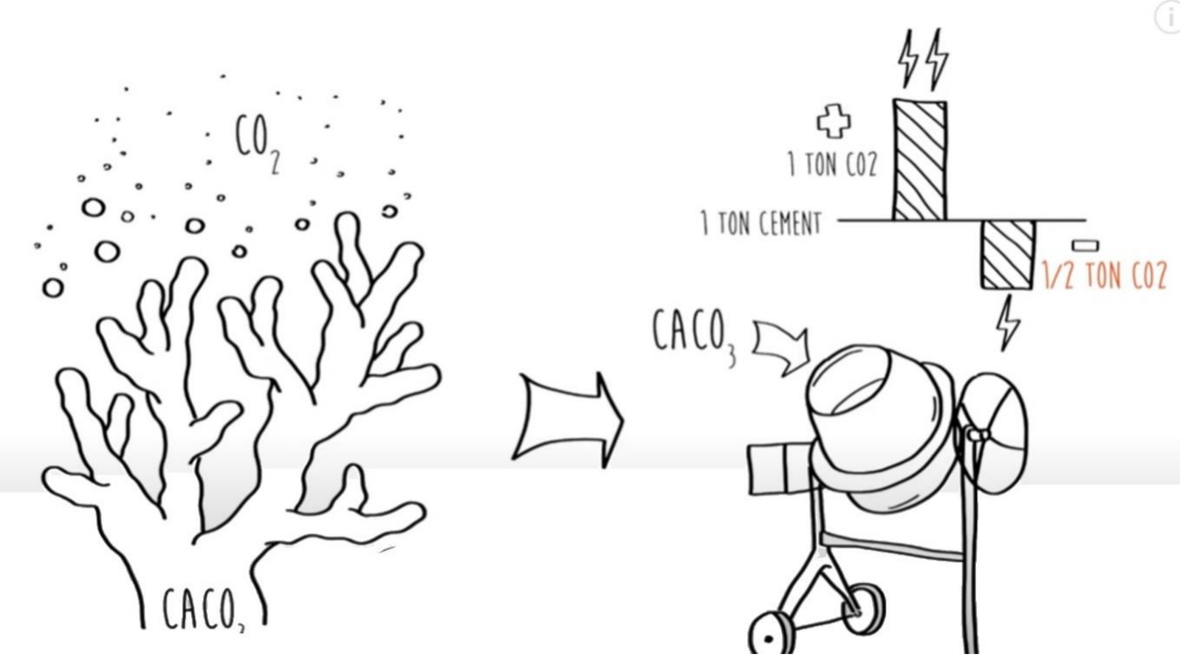


FIGURE 13 (KNOESTER ET AL. 2023)

FAÇADE DEVELOPMENT THROUGH BIOMIMICRY

Biomimicry has been recognized as a crucial tool in the development of sustainable architecture. The application of biomimicry principles to facade design has led to the creation of innovative and energy-efficient building envelopes that can significantly reduce a building's energy consumption and environmental impact. The facade is an essential component of a building, serving as the first line of defense against the external environment and directly impacting the building's energy performance.

The incorporation of biomimicry principles into facade design enables architects to learn from nature's designs and strategies to create more efficient and sustainable buildings. This approach involves analyzing the natural world and translating its patterns, shapes, and materials into building design. For example, the "Lotus Effect" is a biomimetic concept that has inspired the development of self-cleaning facades. The lotus plant has micro-scale bumps on its leaves that prevent dirt and water from adhering to its surface. This concept has been applied to the design of facades, with the creation of micro-textured surfaces that repel water and other contaminants, reducing the need for regular maintenance and cleaning. (Pawlyn, Michael. Biomimicry in Architecture. 1st ed., RIBA Publishing, 2011.)

Another example of biomimicry in facade design is using "biomaterials" inspired by nature's materials. For instance, the fibrous structures found in wood have inspired the development of wood-based composites that can be used in facade design. These materials have the added advantage of being renewable and biodegradable, reducing the environmental impact of building materials. (Tokuç, Avcı Özkaban, and Çakır 2018)

Moreover, biomimicry principles can be applied to optimize the thermal performance of facades. The skin of a polar bear, for example, has been studied for its insulating properties, leading to the development of aerogel-based insulation materials that mimic the bear's fur. By incorporating these materials into facade design, buildings can reduce heat loss in colder climates and limit heat gain in warmer climates, resulting in significant energy savings.

In conclusion, the incorporation of biomimicry principles in facade design presents an opportunity for architects to create more sustainable and efficient buildings. By learning from nature's designs and strategies, architects can develop innovative building envelopes that can reduce a building's environmental impact and energy consumption. The application of biomimicry in facade design is an important essential step towards sustainable architecture and can contribute significantly to the development of a more sustainable built environment. (Jamei and Vrcelj 2021).

CASE STUDIES OF BIOMIMICRY FAÇADE EXAMPLES

The Bullitt Center, Seattle, Washington

FIGURE 14 (HOMCHICK CROWE 2020)

The Bullitt Center, located in Seattle, Washington, is a six-story commercial building considered the world's greenest commercial building. The building has achieved the Living Building Challenge certification, which is the most rigorous and comprehensive green building certification in the world. The Bullitt Center's facade is a prime example of biomimicry in architecture.

The building's design was inspired by the forest, where sunlight filters through the trees, and the trees grow tall and straight towards the sky. The Bullitt Center's facade is covered with windows allowing natural light into the building. The facade is also designed to control the amount of sunlight that enters the building, minimizing the need for artificial lighting and reducing energy consumption.

The Bullitt Center's facade also incorporates other biomimicry principles. The building has a rainwater harvesting system, which collects rainwater and uses it for flushing toilets and irrigating the landscaping. The building's exterior walls are designed to be breathable, allowing air to circulate and maintain a comfortable temperature. The building also has a geothermal system that uses the earth's constant temperature to heat and cool the building.

The Bullitt Center's facade is not only functional but also beautiful. The building's sleek and modern design has a unique, eye-catching, and memorable look. Using natural materials and colors adds to the building's aesthetic appeal. The Bullitt Center's facade is an excellent example of how biomimicry can be used in architecture.

The Bullitt Center's facade is a prime example of how biomimicry can be used in architecture to create functional and beautiful buildings. The forest inspires the building's design, and natural light, breathable walls, and rainwater harvesting are just a few examples of how the building incorporates biomimicry principles. The Bullitt Center is an excellent example of how buildings can be designed to be environmentally sustainable and aesthetically pleasing. ("Bullitt Center | WBDG - Whole Building Design Guide" 2014.).

FIGURE 15 (KENNAWAK 2018)

Algae facade is a biomimicry application that mimics the natural process of photosynthesis, and it involves growing algae on the exterior of buildings to create an energy-efficient facade. This is a unique approach to energy-efficient architecture that taps into the power of nature to generate power for the building while providing various benefits such as thermal insulation, air purification, and aesthetic appeal. Algae facades are not only visually appealing, but they also have an impact on the environment and the overall performance of a building. This technology is gaining traction in the field of sustainable architecture and is being implemented in various structures worldwide.

One of the significant benefits of algae facades is the ability to capture and convert solar energy into usable forms of energy. Photosynthesis involves the conversion of sunlight into energy, and this process can be harnessed to generate electricity or heat. The algae cells cell that covers the facade absorb sunlight and convert it into biomass, which can be harvested and converted into biofuel. This means that algae facades can potentially supply the energy needs of the building, reducing dependence on fossil fuels and nonrenewable energy sources.

Another benefit of algae facades is their ability to provide thermal insulation. The thick layer of algae cells that covers the exterior of a building helps to regulate temperature by acting as a buffer against extreme temperatures. During the summer, the algae cells absorb heat and evaporate water, which cools the surrounding air and reduces the need for air conditioning. In the winter, the algae cells act as an insulator, which reduces the need for heating. This thermal regulation helps to reduce energy consumption, thereby reducing the carbon footprint of a building.

Algae facades also have the ability to purify the air by absorbing carbon dioxide, nitrogen oxide, and other pollutants. The algae cells absorb these pollutants and release oxygen, which helps to improve the air quality of the surrounding environment. This makes algae facades an attractive option for places with significant air pollution problems. Furthermore, the algae cells act as a natural sound barrier, absorbing sound waves and reducing noise pollution.

One of the most significant advantages of algae facades is their aesthetic appeal. The vibrant green color of the algae cells creates a unique and visually appealing facade that can transform the appearance of a building. Algae facades can be designed in various patterns and shapes, creating a dynamic and visually stimulating surface that changes with the seasons and time of day. Additionally, the color of the facade changes depending on the angle and intensity of the sunlight, creating a dynamic interplay between the building and its surroundings. (Hanafi 2021), (Talaei, Mahdavinejad, and Azari 2020).

BIQ BUILDING IN HAMBURG

FIGURE 16(“BIQ HOUSE DE ARUP | IMMEUBLES” N.D.)

The BIQ building in Hamburg, Germany, is an excellent example of biomimicry in architecture. This six-story building was completed in 2013 and boasted the world's first algae facade. The building's innovative design incorporates an active bioreactor system that uses algae to produce renewable energy, heat, and shading for the building's occupants.

The facade of the BIQ building consists of 129 bioreactors, each measuring 2.5 meters high by 0.7 meters wide. These bioreactors contain microalgae nourished by nutrients and sunlight, converting CO2 into biomass. The biomass can then be harvested and used as a source of biofuel or natural fertilizer.

The BIQ building's algae facade was developed by a team of researchers from Germany's Arup Engineering and Strategic Science Consult. The team was inspired by the natural processes of photosynthesis and the way that algae can convert sunlight into energy. They sought to create a building that could mimic these processes and produce energy in a sustainable and renewable manner.

The BIQ building's algae facade has several benefits. Firstly, it provides a sustainable and renewable source of energy. Microalgae produce biomass that can be used as a source of biofuel or natural fertilizer, reducing the reliance on fossil fuels. Secondly, the algae facade provides natural shading and insulation, reducing the need for artificial cooling and heating systems. This, in turn, reduces the building's carbon footprint and energy costs. Finally, the building's innovative design and use of algae make it a showcase for sustainable architecture, demonstrating how nature can be used as a source of inspiration for building design.

The BIQ building has received several awards and accolades for its innovative design. In 2014, it won the GreenTec Award for the best sustainable architecture. It was also nominated for the Mies van der Rohe Award in 2015, which recognizes outstanding architectural design in Europe.

The BIQ building is a pioneering example of biomimicry in architecture. By looking to nature for inspiration and incorporating natural processes into building design, architects can create sustainable, energy-efficient, and visually stunning structures. The use of algae in building design is an exciting development that holds great promise for the future of sustainable architecture.

In addition to the BIQ building, there are several other examples of algae facades in architecture. The Algae House in Hamburg, Germany, designed by Splitterwerk Architects, features a facade covered in a layer of green algae that provides natural shading and insulation. The BIQ and Algae House buildings are part of a more significant trend towards biomimicry in architecture and sustainable design.

In conclusion, the BIQ building in Hamburg is an excellent example of how biomimicry can be used in architecture to create sustainable, energy-efficient, and visually stunning buildings. The building's algae facade is a pioneering development that provides a sustainable and renewable energy source while also reducing the building's carbon footprint and energy costs. The BIQ building is a showcase for sustainable architecture and a testament to the power of nature as a source of inspiration for building design. (Chang et al. 2017) , (Wurm and Pauli 2016).

SYDNEY OPERA HOUSE

The Sydney Opera House is a multi-venue performing arts center in Sydney. Located on the foreshore of Sydney Harbor, it is widely regarded as one of the world's most famous and distinctive buildings and a masterpiece of 20th-century architecture. The design of the Sydney Opera House was inspired by nature, its forms, functions, and colors. The Architect - Jorn Utzon, was influenced in his designs by bird wings, the shape, and form of clouds, shells, walnuts, and palm trees. He looked upon nature for guidance when designing, as nature, over time, combined both efficiency and beauty hand in hand. The roof structures of the Opera House are called shells. The design of the ‘shells’ was one of the most difficult aspects of the building’s design. This spherical solution elevated the architecture beyond a mere style – in this case, that of shells

– into a more permanent idea, one inherent in the universal geometry of the sphere. Jorn Utzon claimed that the final design of the shells was inspired by peeling an orange. It is said that the shells of the 14 separate roofs form a sphere if combined. Jorn Utzon was one of the pioneers in the use of prefabricated modular forms and designing for sustainability. (“SYDNEY OPERA HOUSE- INSPIRED BY NATURE,” 2013.)

FIGURE 17 SYDNEY OPERA HOUSE, CREDITS: BERNARD SPRAGG, NZ

PRECEDENT STUDY CONCLUSION

By understanding the different ways façade plays an important role in building sustainability, experimentation was done using different facades to try and improve the existing conditions of buildings today. Upon further investigation, it was found that 2/3 of the building area present today will be present in the next 50 years. This presents an urgent need to preserve and try and make the existing buildings in our area more efficient. The global floor area is expected to double by 2060. When we look at all the new construction that is projected to take place, concrete plays a big role in CO2 emissions. My focus and proposal are to try and get inspired by nature, retrofit existing buildings, and help them be more sustainable for the future. From understanding the importance of wind in the Gerkin building façade to the energy efficiency of Algae powered buildings, these solutions are for very unique for their building type or very expensive to attain; the focus was to try and find a solution that would help in the sustainability of the building in the long run.

SITE SELECTION

India is a heavily populated country with a relatively low per capita GDP. This combination makes us the fifth-largest economy in the world. The key to India's future is development. And exploitation of our comparative advantage to eliminate the per capita GDP gap with upper middle-income countries and to reduce the gap with high-income countries. The economic reforms underway and the economic & institutional reforms on the agenda for the next few years will sustain the growth of per capita GDP at 6% to 7% during the decade of The 2020s, to make India the third largest economy in the world by 2035. Smart Cities Mission was launched in June 2015. The main objective of the Mission is to promote cities that provide core infrastructure, clean and sustainable environment, and give a decent quality of life to their citizens through the application of 'smart solutions. 'The Mission aims to drive economic growth and improve quality of life through comprehensive work on social, economic, physical, and institutional pillars of the city. The focus is on sustainable and inclusive development through the creation of replicable models which act as lighthouses to other aspiring cities; 100 cities have been selected to be developed as Smart Cities through a two-stage competition.

The Mission is operated as a Centrally Sponsored Scheme. The central Government will give financial support to the extent of Rs. 5000 million over five years, i.e., an average of Rs.500 million per city per year. An equal amount on a matching basis is to be provided by the State/ULB. Additional resources are to be raised through convergence from ULBs' own funds, grants under Finance Commission, innovative finance mechanisms such as Municipal Bonds, other government programs, and borrowings. Emphasis has been given to the participation of the private sector through Public Private Partnerships. ("Transforming India's Built Environment: A 2050 Vision for Wellness and Resilience | Building Technology & Urban Systems Division," n.d.)

Figure 18 https://smartcities.gov.in/

ILLUSTRATIVE LIST

Smart Solutions

E-Governance and Citizen Services

1. Public Information, Grievance Redressal
2. Electronic Service Delivery
3. Citizen Engagement
4. Citizens - City's Eyes and Ears
5. Video Crime Monitoring

Waste Management

6. Waste to Energy & fuel
7. Waste to Compost
8. Waste Water to be Treated
9. Recycling and Reduction of C&D Waste

Water Management

10. Smart Meters & Management
11. Leakage Identification, Preventive Maint.
12. Water Quality Monitoring

Energy Management

13. Smart Meters & Management
14. Renewable Sources of Energy
15. Energy Efficient & Green Buildings

Urban Mobility

16. Smart Parking
17. Intelligent Traffic Management
18. Integrated Multi-Modal Transport

Others

19. Tele-Medicine & Tele Education
20. Incubation/Trade Facilitation Centers
21. Skill Development Centers

FIGURE 19 HTTPS://SMARTCITIES.GOV.IN/

WHY INDIA?

- India forms 1/4 of the world's population and is the fastest-growing economy on earth. The rapid growth of India’s economy and population goes hand in hand with a soaring rise in energy consumption. This causes a lot of problems with some of the basic human needs and quality of living.

- The Indian government has set as its goal to create significantly better living conditions for the entire population. To achieve this, they will need to fundamentally rethink the way cities and habitats are developed.

- In the next 20 years, 200 new megacities will rise, and within the next 20 years, 400 million more people are expected to move from rural India to the training cities that minimize the space for one family.

- 2/3 of India’s land area receives more than 2000 hours of light annually, more than many other regions of similar latitude.

- Each person in the megacity uses up to 400 liters of fresh water every day. Only five liters of that is used for drinking and cooking. Water is one of our most valuable resources.

- Most of the energy is used by air conditioners for calling during the summer months buildings in the future will act as the amount of pollution generated.

-The mission encourages a combination of different land uses based on the specific characteristics of the area. It provides the states with greater freedom to utilize the land for multiple purposes and establish regulations accordingly.

- The development of smart cities necessitates the construction of additional housing units that can serve the needs of diverse groups, including those with limited financial means.

- The Smart Cities Mission aims to minimize overcrowding, enhance safety, decrease air pollution, and stimulate community engagement and economic growth.

- The initiative encourages the implementation of various transportation alternatives, such as transit-oriented development and public transit. . (“India Vision 2050 | EGROW Foundation” n.d.)

FIGURE 20 LIST OF A FEW CITIES IN THE SMART INDIA INITIATIVE

Importance of Solar Energy in Smart Cities in India

- Solar applications such as solar streetlights, solar water heaters, rooftop solar, etc., can go a long way in imparting a clean and green living style to these smart cities. Not only will these smart cities improve the conditions in India in terms of employment generation and an urban living style, but they will also go a long way in promoting the usage of renewable forms of energy and thus help the country fight the growing concerns of global warming and pollution.
- It has already been mandated that 10% of the smart cities' energy requirement will come from solar energy, and at least 80% of buildings should be energy-efficient and green

buildings. With a plan to develop approximately 100 such cities, the rate of renewable energy usage will go up in the country. ("Role of Solar Energy in Developing Smart Cities in India | Green World Investor" n.d.), ("Bloomberg Philanthropies Partners with the Government of India to Encourage Smarter Urban Development That Improves People's Lives.")

Importance of Water in Smart Cities in India

- Today, cities around the world are expected to deliver clean, pressurized, and reliable water to their residents' taps daily. However, with increasing urbanization and population growth leading to rising costs and water scarcity, cities are struggling to meet customer demands. By 2050, 75% of the world's population will live in cities. These cities will face increasing water stress, with demand expected to outstrip supply by 40% by 2030.
- Within a Smart City, a "Smart Water Network" (SWN) allows cities to better anticipate and react to different types of water network issues, from detecting leaks, theft, and water quality incidents to conserving energy and tracking residential water consumption. By monitoring real-time information, city operators can stay informed about what is always going on in the field and respond quickly and appropriately when a problem arises. This results in a city becoming more efficient and reducing the overall cost of service for the customer.. ("The Role of Water in India's Smart Cities," 2016)

Importance of air quality in Smart Cities in India

- Real-time monitoring of air quality provides city administrators with the ability to issue health and safety advisories to combat air pollution and protect the well-being of residents, particularly vulnerable groups such as the elderly, children, and those with respiratory issues. Identifying hotspots enables citizens to make informed decisions about choosing residences based on the duration of air pollution peaks.
- Deploying multiple Ozone monitors city-wide makes it possible to conduct source apportionment studies and empowers policymakers to penalize polluters using secondary data. As a result, hyperlocal monitoring of data becomes feasible, enabling air pollution control bodies to take corrective actions in real time. (“Air Quality Monitoring in Smart Cities,” n.d.)

Importance of waste management in Smart Cities in India

- Planning and implementing a comprehensive waste management program that connects different sectors, including residential buildings, commercial and industrial establishments, hotels, healthcare institutes, transport, public places, and tourism spots, is one of the challenges faced in Smart City projects.
- Smart City consultants have a significant role in assessing and designing a waste management plan that can be integrated into the smart city's development plan. Waste management involves more than just collecting waste from households and commercial establishments; it is a critical issue that affects the health and sanitation of every citizen in the city.
- Under the Smart Cities Mission, cities are selected through a competitive process based on their proposals for implementing smart solutions to urban challenges. The selected

cities receive funding from the government to implement these solutions, which typically involve the use of technology and data to enhance infrastructure, services, and governance.

SITE LOCATION

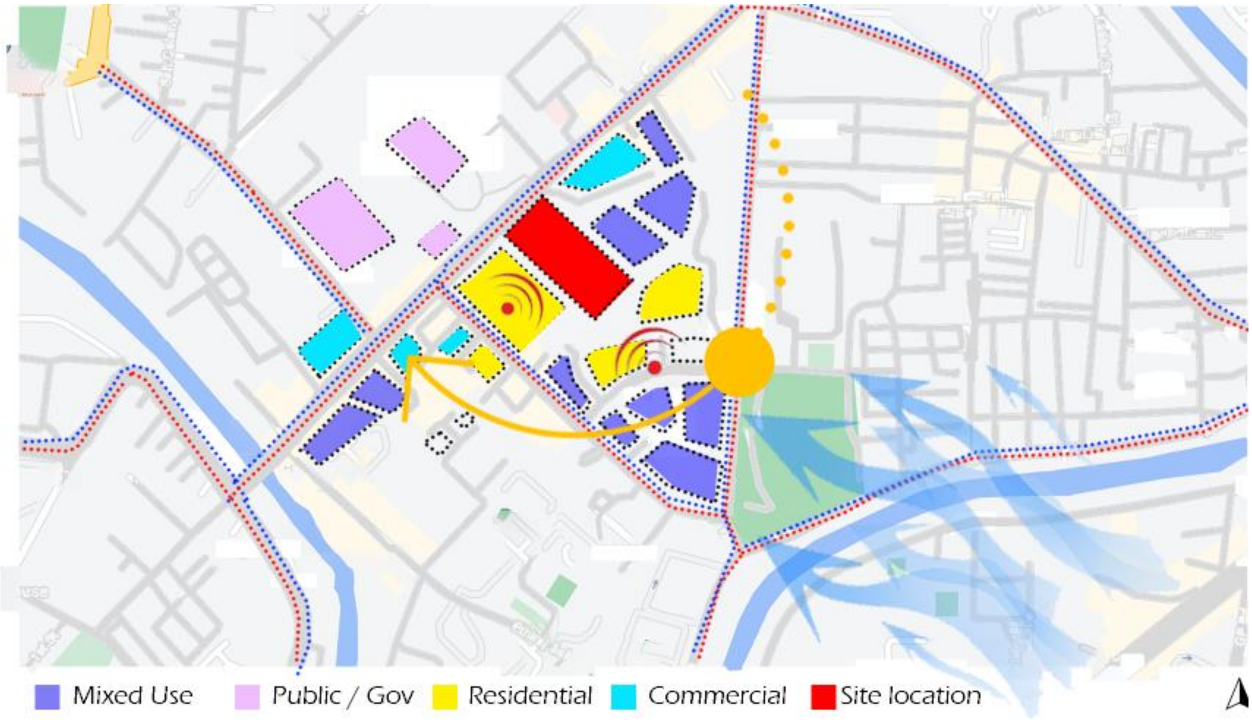


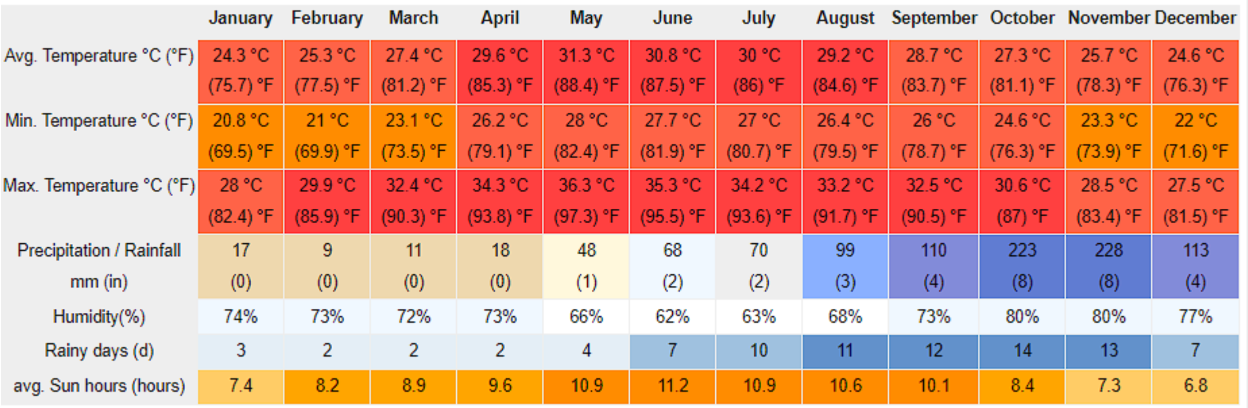
Figure 21 Site analysis

CLIMATIC CONDITIONS

Chennai, located on the east coast of India, has a tropical wet and dry climate. The city experiences hot and humid summers from March to June, with temperatures ranging from 30 to 40°C (86 to 104°F) and high levels of humidity. The monsoon season begins in October and lasts until December, bringing heavy rainfall and occasional flooding. The winter months of January and February are cooler and drier, with temperatures averaging around 25°C (77°F).

Chennai is also prone to natural disasters such as cyclones, floods, and droughts. In recent years, the city has faced severe water shortages due to a combination of low rainfall, poor water management, and groundwater depletion. The government has taken steps to address the issue by implementing rainwater harvesting systems, increasing water conservation efforts, and exploring alternative water sources such as desalination plants.

Chennai is also vulnerable to the impacts of climate change, including rising sea levels and more frequent extreme weather events. To mitigate these impacts, the government and various organizations have taken steps to promote sustainable development and reduce greenhouse gas emissions. These measures include promoting the use of renewable energy sources such as solar power, implementing green building standards, and promoting sustainable transportation options such as electric vehicles and public transportation. In Chennai, the typical wind speed is 3.7 meters per second, with the highest recorded wind speed reaching approximately 11 meters per second. The typical temperature ranges from 19°C to 36.7°C, with an average of 28.2°C. The average relative humidity is about 74.6%, with fluctuations from 41.7% to 96.9%.



	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	24.3 °C (75.7) °F	25.3 °C (77.5) °F	27.4 °C (81.2) °F	29.6 °C (85.3) °F	31.3 °C (88.4) °F	30.8 °C (87.5) °F	30 °C (86) °F	29.2 °C (84.6) °F	28.7 °C (83.7) °F	27.3 °C (81.1) °F	25.7 °C (78.3) °F	24.6 °C (76.3) °F
Min. Temperature °C (°F)	20.8 °C (69.5) °F	21 °C (69.9) °F	23.1 °C (73.5) °F	26.2 °C (79.1) °F	28 °C (82.4) °F	27.7 °C (81.9) °F	27 °C (80.7) °F	26.4 °C (79.5) °F	26 °C (78.7) °F	24.6 °C (76.3) °F	23.3 °C (73.9) °F	22 °C (71.6) °F
Max. Temperature °C (°F)	28 °C (82.4) °F	29.9 °C (85.9) °F	32.4 °C (90.3) °F	34.3 °C (93.8) °F	36.3 °C (97.3) °F	35.3 °C (95.5) °F	34.2 °C (93.6) °F	33.2 °C (91.7) °F	32.5 °C (90.5) °F	30.6 °C (87) °F	28.5 °C (83.4) °F	27.5 °C (81.5) °F
Precipitation / Rainfall mm (in)	17 (0)	9 (0)	11 (0)	18 (0)	48 (1)	68 (2)	70 (2)	99 (3)	110 (4)	223 (8)	228 (8)	113 (4)
Humidity(%)	74%	73%	72%	73%	66%	62%	63%	68%	73%	80%	80%	77%
Rainy days (d)	3	2	2	2	4	7	10	11	12	14	13	7
avg. Sun hours (hours)	7.4	8.2	8.9	9.6	10.9	11.2	10.9	10.6	10.1	8.4	7.3	6.8

FIGURE 22 WEATHER DATA OF CHENNAI

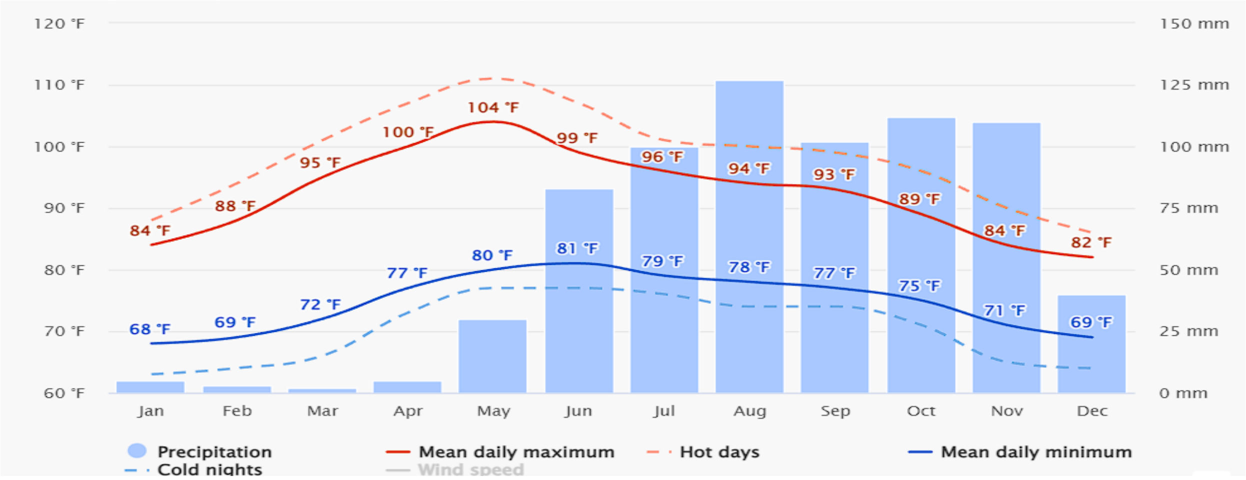


FIGURE 23 PRECIPITATION DATA OF CHENNAI

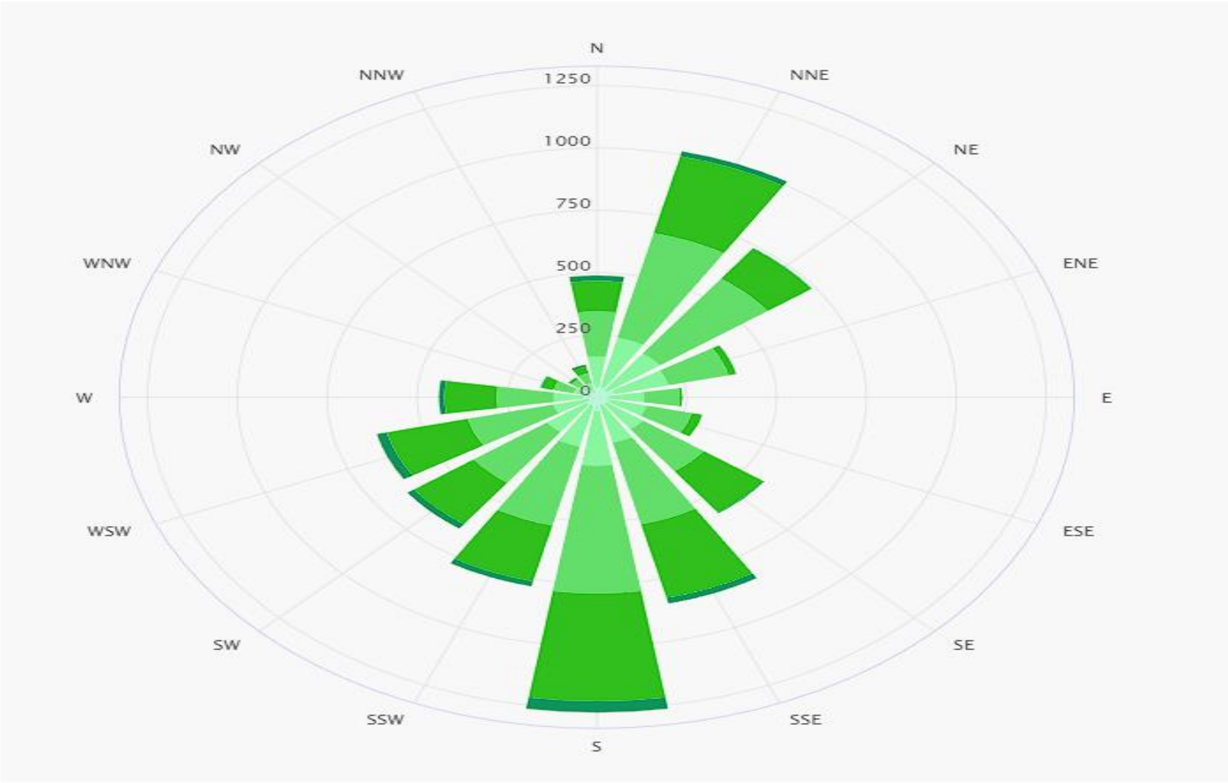


FIGURE 24 WIND ROSE DATA OF CHENNAI

EXISTING CONDITION

Raheja Tower is a Grade-A city-center office building located in the Bandra Kurla Complex (“BKC”). Due to its convenient location near both domestic and international airports and easy access to other parts of the city, BKC has become Chennai's financial center and one of its most well-established commercial micro-markets. (“Raheja Tower | Block G, Plot No. C-30,, | Mumbai Office Properties” 2009.)

The amenities that are available are

- ATM
- Food plaza
- Car parking
- Office Space
- Open Wi-Fi zone

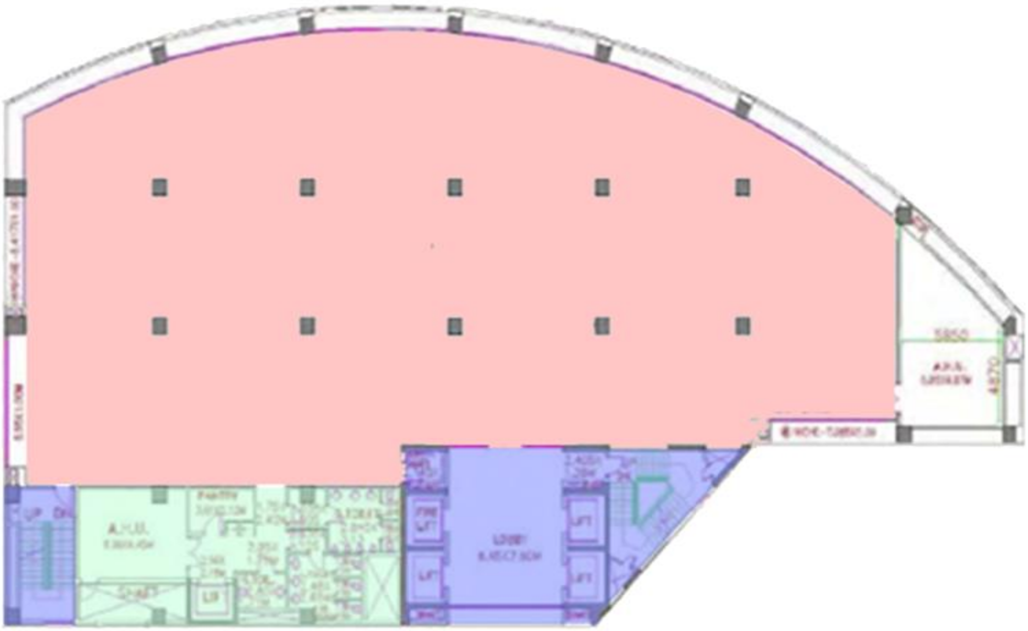


FIGURE 25 FLOOR PLAN OF THE RAHEJA TOWERS ((“RAHEJA TOWER | BLOCK G, PLOT NO. C-30,, | MUMBAI OFFICE PROPERTIES” 2009.)

FIGURE 26 EXISTING CONDITION OF THE RAHEJA TOWERS

WHY PARAMETRIC DESIGN?

Parametric architecture involves controlling the shape and proportions of a design through various parameters or variables. It became a popular concept in architecture around 2008, coinciding with the rise of digital communication technologies and design tools. By altering parameter values, an unlimited number of coherent designs can be produced. Parametric designs are created using sophisticated mathematical programs that perform computations beyond human capability. This approach is known as parametric architecture, and it involves pre-rationalizing geometry and performance requirements using computing techniques.

Contemporary parametric design practices include parametric formalism, workflow parametric, and parametric BIM software and processes. Digital design tools are increasingly used in architecture to enhance the interaction between the analytical and creative processes, thereby closing the gap between design concepts and their goals. New research provides global examples of the application of digital design tools and their effectiveness in producing high-quality design products. (Monedero 2000)

DESIGN METHODOLOGY

A methodology consisting of six phases has been created to ensure a linear connection between each subsequent phase. The research took place in Chennai, chosen due to its rapid growth and importance in the country's development. The city is located near the coast, resulting in a hot arid climate with lower humidity levels. Data for the study was obtained from meteorological data and site observation. The modeling process was divided into a base model and an upgraded model with the application of a parametric/dynamic façade. The results were analyzed, and the effectiveness of the advanced façade was evaluated.

The study was conducted following the below main steps:

- Assessment of the site and building program
- Analysis of the climate
- Designing the base case using organic architecture
- Designing the innovative Parametric/Dynamic Façade
- Modeling and simulating the base case using organic architecture

- Modeling and simulating the innovative Parametric/Dynamic Façade.

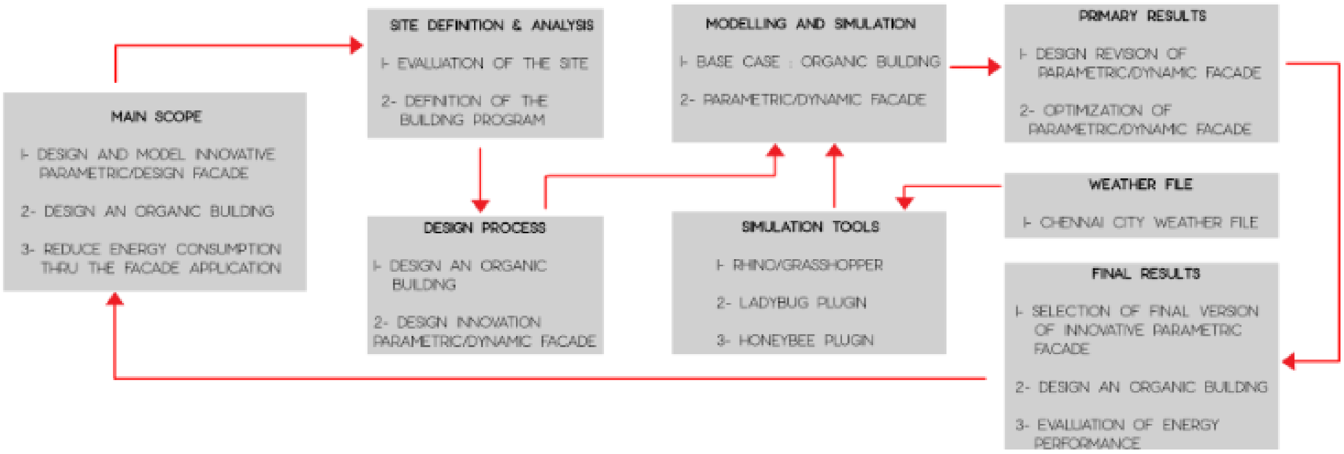


FIGURE 27 DESIGN METHODOLOGY PROCESS

DESIGN PROCESS

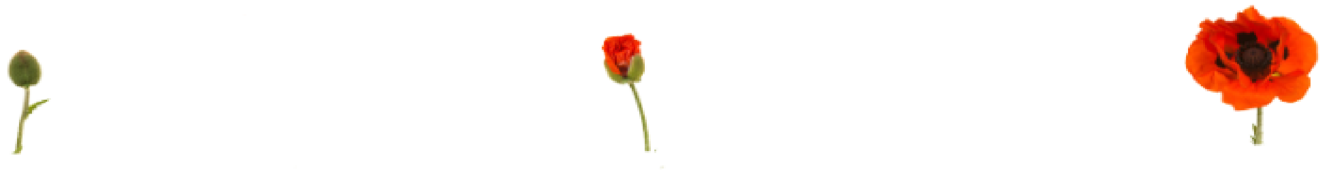


FIGURE 28 BLOOMING STAGES OF THE BUTTERCUP FLOWER

The design of the façade was inspired by the opening of the bud flower; this bud opening inspired the creation of the façade, which can look like a flower blooming. The flower taken inspiration is the Buttercup flower, which is a local species in India. The transformation of the flower from its bud stage to full bloom represents privacy, natural ventilation, and shading. By combining this design with architecture, we generated architectural elements which helped in sun screening and passive cooling strategies. The façade opening is categorized into three angles of opening, at 45° which is when the façade is fully opened; at

30° which is when the façade is partially opened; and at 0° which indicates that the façade is fully closed.

FIGURE 29 THE OPENING AND CLOSING STAGES OF THE FACADE SYSTEM AT DIFFERENT ANGLES.

FAÇADE DESIGN

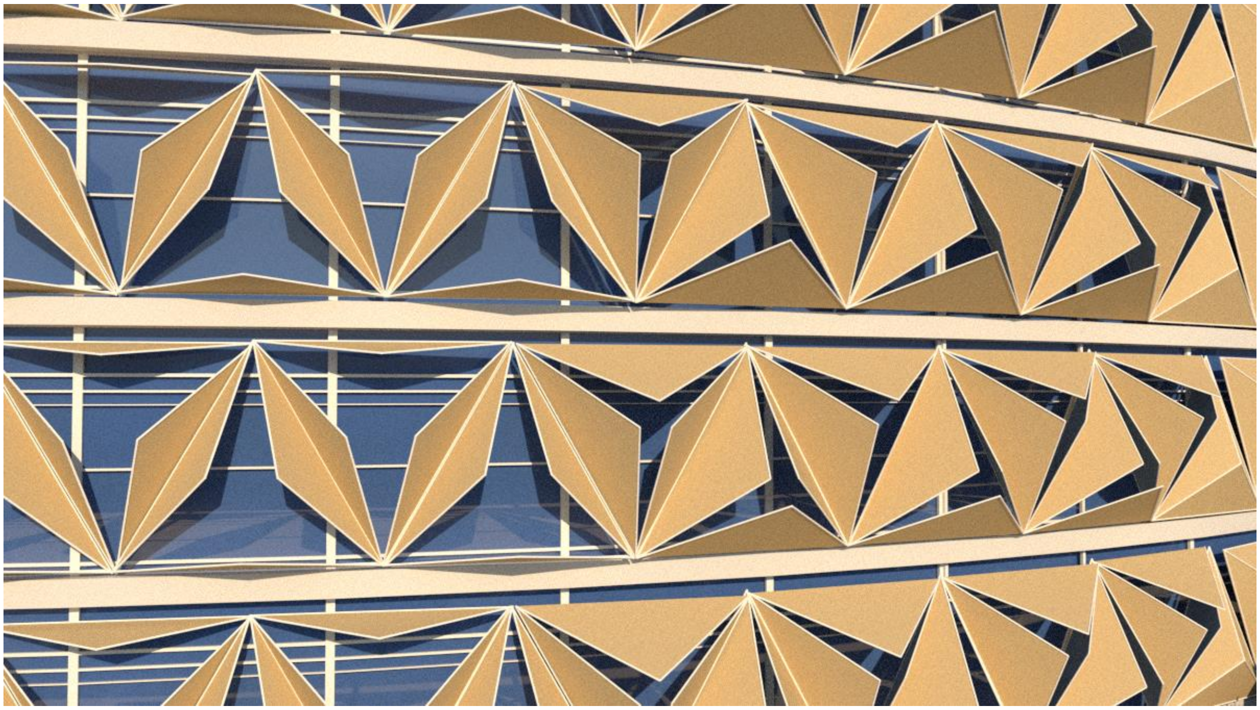


FIGURE 30 VIEW OF THE FACADE

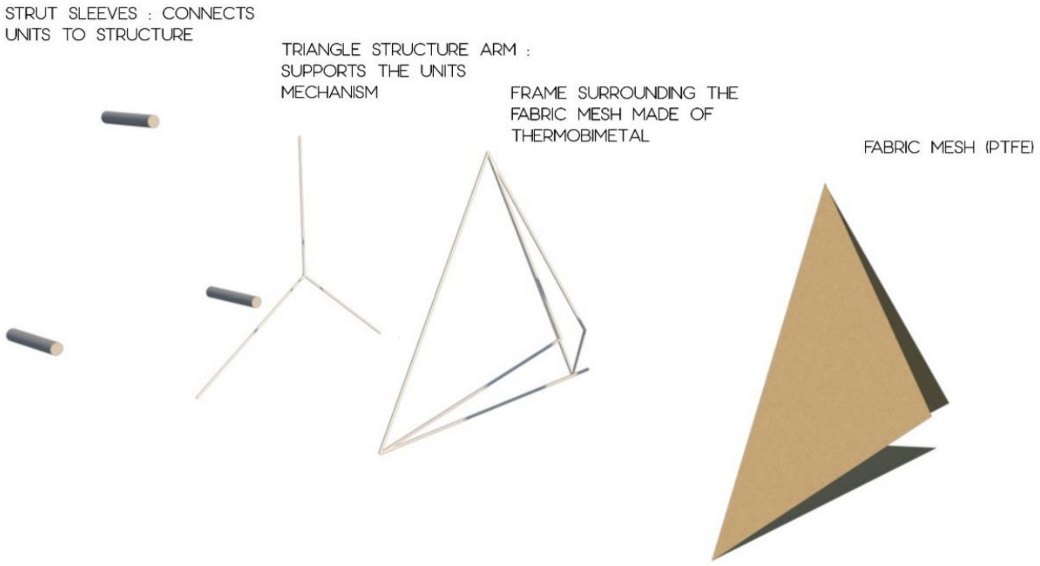


FIGURE 31 EXPLODED VIEW OF FACADE

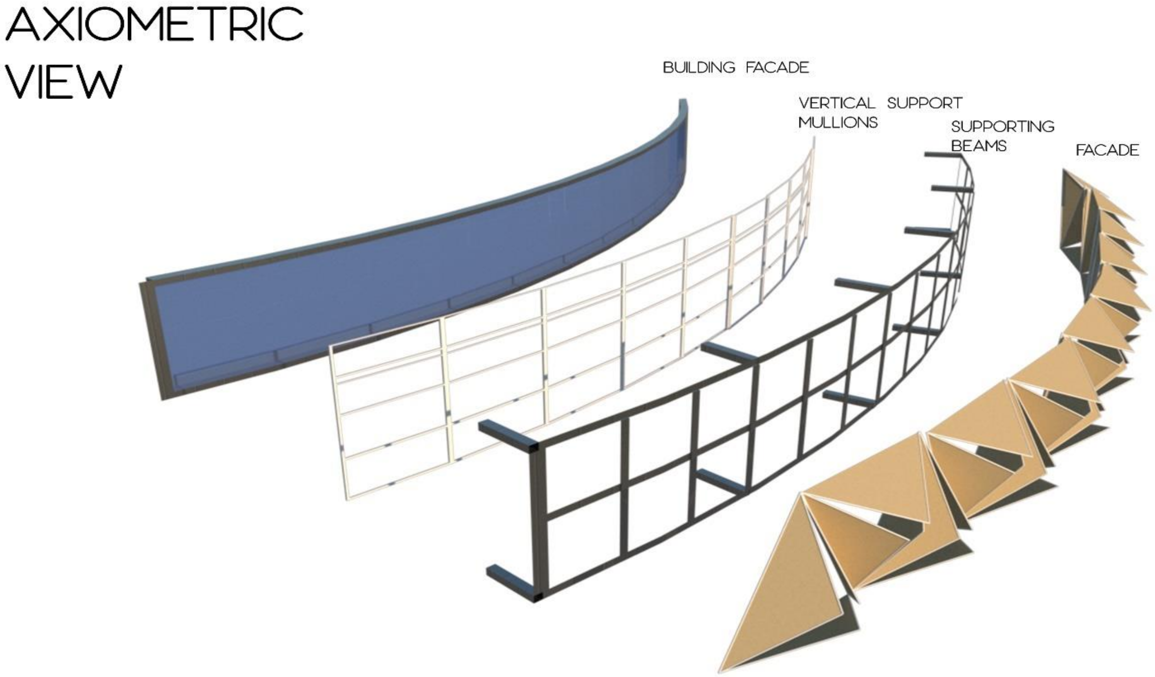


FIGURE 32 AXIOMETRIC VIEW OF FACADE INSTALLATION

The Façade is attached to the building using the supporting beams, which can be drilled into the existing conditions of the building. The façade is then connected to the vertical support, which is then attached directly to the façade. The opening and closing of the façade depend directly on the sun’s direction hitting it. By using energy analysis, we can predict the movement of the sun throughout the day and create a 3D view of how the building could approximately look with all the panels attached to it.

FIGURE 33 RENDERED VIEW OF THE BUILDING WITH THE FACADE ATTACHMENT

The arrangement of the façade on the building is correlated directly with the movement of the sunlight around the building. Since the building is located directly over the equator, the facade of the building is curved; this means that an unequal amount of sunlight hits the building. Since the sun passes directly over the building, when one part of the facade gets too hot, it automatically opens up dust, preventing the sunlight from hitting the face of the building. The panels open up, acting as a sunshade for the building since the facade is oriented in the north-south direction, and the sunlight is in the east–west direction.

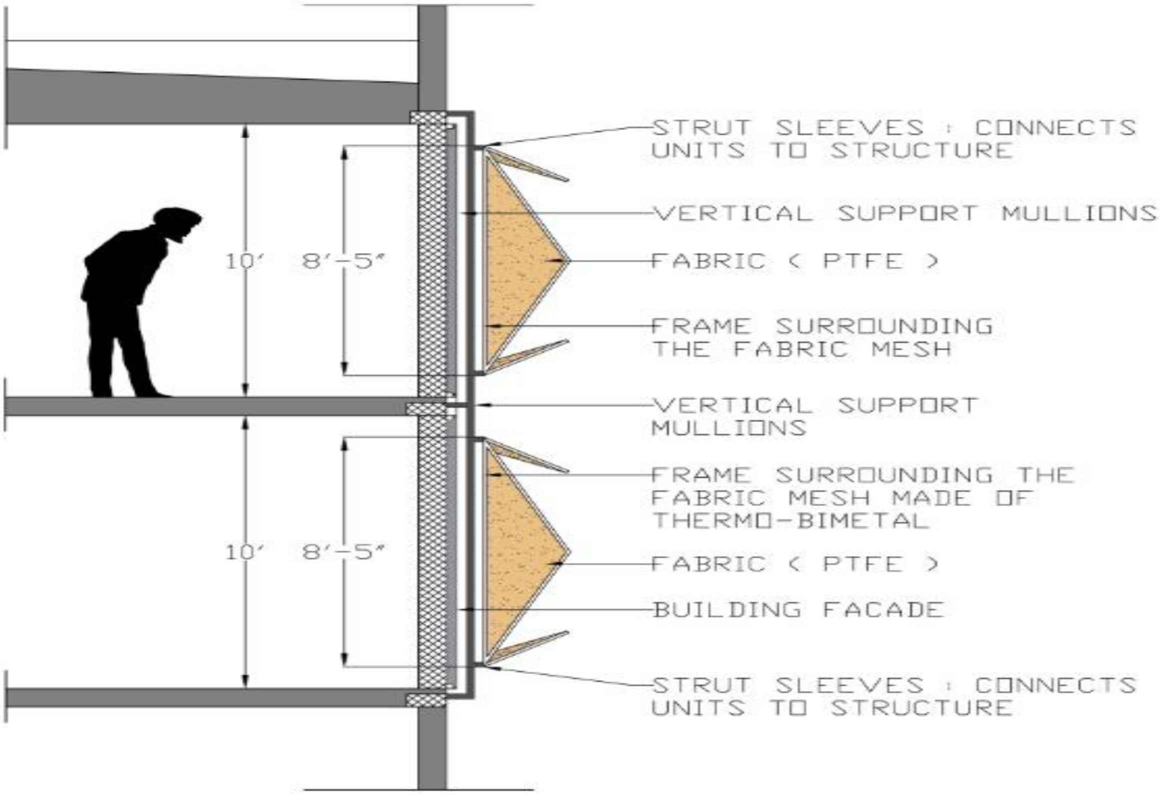


FIGURE 34 SECTION VIEW OF THE FACADE ATTACHMENT TO THE BUILDING

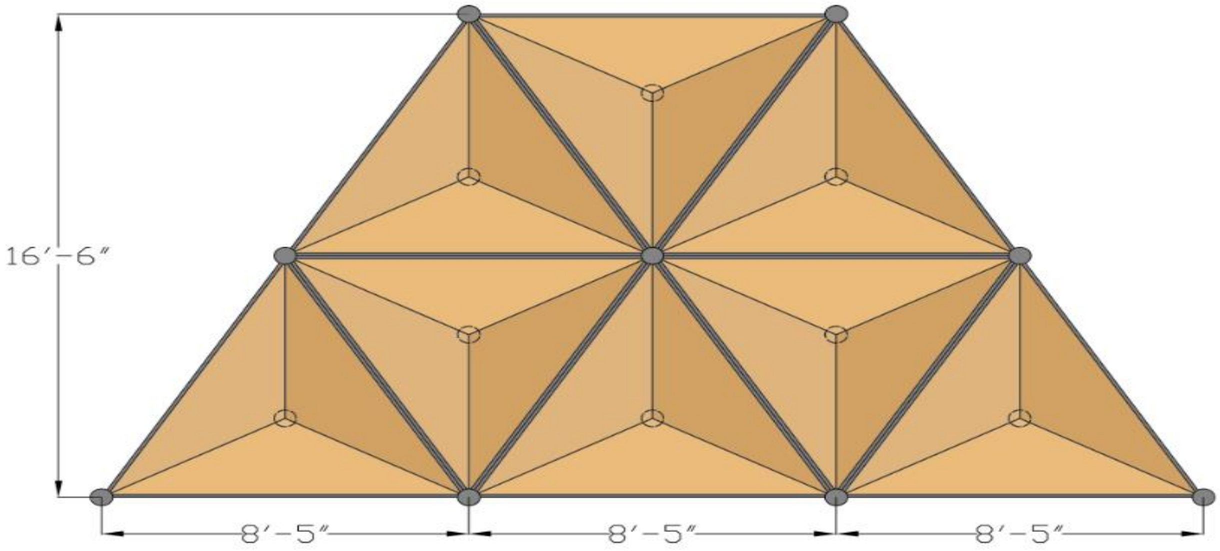


FIGURE 35 ELEVATION VIEW OF THE FACADE

MATERIALS USED

PTFE

PTFE (polytetrafluoroethylene), also known as Teflon, is a highly versatile and durable material that has a variety of applications in architectural facades. Structures such as roofs, façades, canopies, etc., can be made with the aid of these PTFE materials. These structures are lightweight, flexible, and can be customized to fit any building design. PTFE-coated fabrics also provide excellent weather resistance and can withstand extreme temperatures, making them ideal for outdoor use. It can also be used as a cladding material for building facades. The panels are highly durable, lightweight, and resistant to weathering and UV radiation and are also customized to different shapes and sizes and can be made in a variety of colors to match the building design. The façade shading element is made with the PTFE material, as it is perfectly suited for the climate of Chennai; it does not require any cleaning or maintenance, thus reducing the long-term maintenance of the façade.

THERMO BIMETAL

Thermo bimetal, also known as bi-metallic strips, is a material made of two different metals that have different thermal expansion coefficients. When heated or cooled, the two metals expand or contract at different rates, causing the strip to bend or warp.

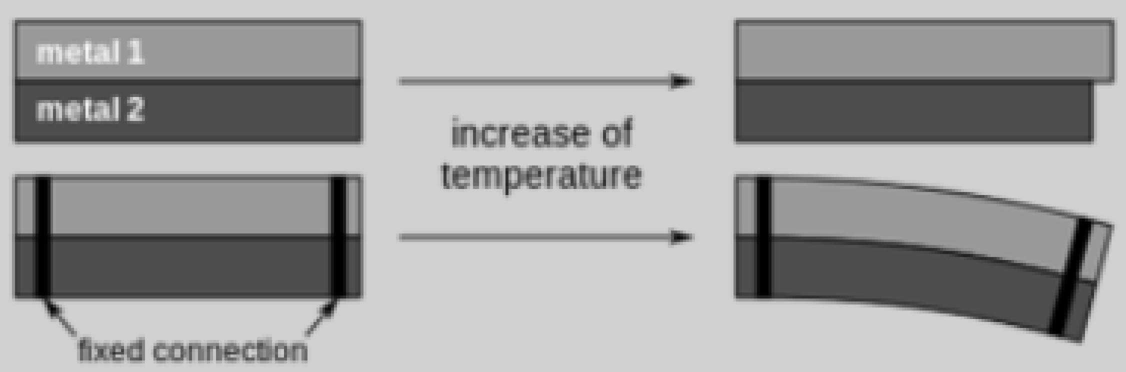


FIGURE 36 SECTION VIEW OF THE THERMO BIMETAL

Thermo bimetal strips can be used as thermal expansion joints in buildings to allow for the natural expansion and contraction of materials due to changes in temperature. This helps to prevent damage to the building and maintain structural integrity. The use of thermos bimetal in the façade is of prominent importance, as the opening and closing of the panels depend on this metal. This metal is used in the outer rims of the PTFE panels; thus, by using this material, we eliminate the use of an active motorized system to help with the opening and closing of the façade.

ENERGY MODELLING

The energy simulation demonstrates how much energy is absorbed and consumed by the surfaces of the model, considering factors such as solar radiation through the opening of shading devices or external site context to block energy. By utilizing Rhinoceros 3D and Grasshopper, information obtained from the simulation, such as the building, shading devices, and context, along with the EPW file (Chennai), can be used to assess the data. The energy analysis is based on specified materials or u-values, as well as an analysis period of one year. All of these parameters contribute to the energy analysis.

The energy simulation is conducted in three different ways: first, without the use of the dynamic/parametric façade, then with the façade at a certain static opening state, and finally, with a changing and dynamic façade.

Rhinoceros is a software tool commonly used in the architecture industry that is available for purchase. The Grasshopper plug-in, which is also used in architecture, can help analyze various aspects of a building's design and performance. Additionally, Grasshopper simplifies the design process by allowing for more complex modeling beyond traditional 3D modeling and can reference geometry objects in Rhino, like points, curves, and surfaces. The online resources associated with this software allow for the possibility of real-time updates to Python language scripts. Grasshopper can be used to make calculations for various aspects of building design, such as facade planning, optimization processes, energy use, and structural design. The complexity of the script is illustrated in the image, with each step linked to one another until the final results of the simulation are obtained. During the tool's use, errors can be identified immediately, enabling quick modifications to the script. The script shown in

Figure 33 helps us understand the complexity of the entire process and enables us to make changes in design in real-time.

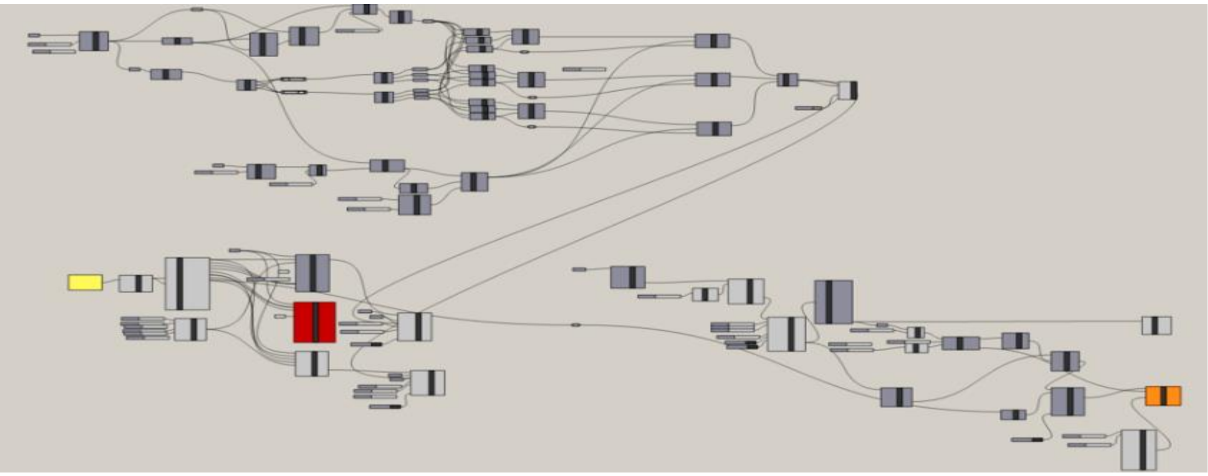


FIGURE 37 SCRIPT OF THE PARAMETRIC CODING

DIRECT SUNLIGHT ANALYSIS

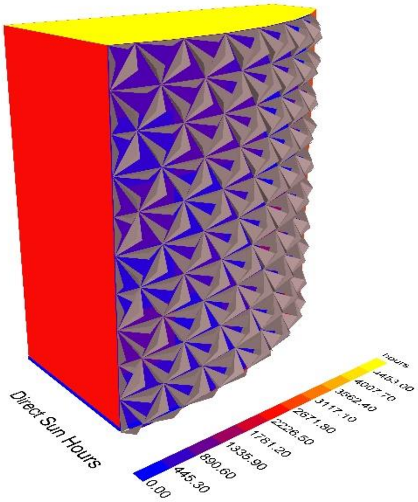


FIGURE 38 DIRECT SUNLIGHT HOURS

Direct sun hours refer to the number of hours during a day when the sun's rays are directly hitting the surface without being obstructed by any obstacles like buildings, trees, or shading devices. In energy simulation, the calculation of direct sun hours is important because it helps to determine the amount of solar radiation a building or a specific surface receives throughout the day. This information is used to assess the building's energy consumption and how much energy can be generated from solar panels or other renewable energy sources. By analyzing direct sun hours, architects and engineers can also optimize the design of shading devices and sunshades to block excessive solar radiation during peak hours, reducing the building's cooling load and improving energy efficiency. Overall, direct sun hours are a crucial parameter in energy simulation that helps to evaluate the energy performance of a building and optimize its design for maximum energy efficiency.

INCIDENT RADIATION ANALYSIS WITHOUT FAÇADE

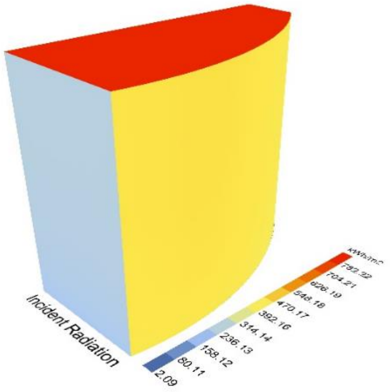


FIGURE 39 INCIDENT RADIATION ANALYSIS

Incident radiation analysis is a type of energy simulation that calculates the amount of solar radiation that falls on a building or a specific surface at different times of the day and year. This analysis considers the position of the sun in the sky, the orientation of the building, and any shading devices that may be present. The incident radiation analysis helps to determine how much solar energy a building or a surface is exposed to and how much energy can be generated from solar panels or other renewable energy sources. In incident radiation analysis, the simulation software calculates the intensity of solar radiation that falls on each surface of the building, including the roof, walls, and windows. This information is used to estimate the energy absorbed by the building and the amount of heat that needs to be dissipated through cooling systems. This analysis also helps to identify areas of the building that are exposed to excessive solar radiation, which can cause overheating and increase the cooling load.

INCIDENT RADIATION ANALYSIS WITH FAÇADE

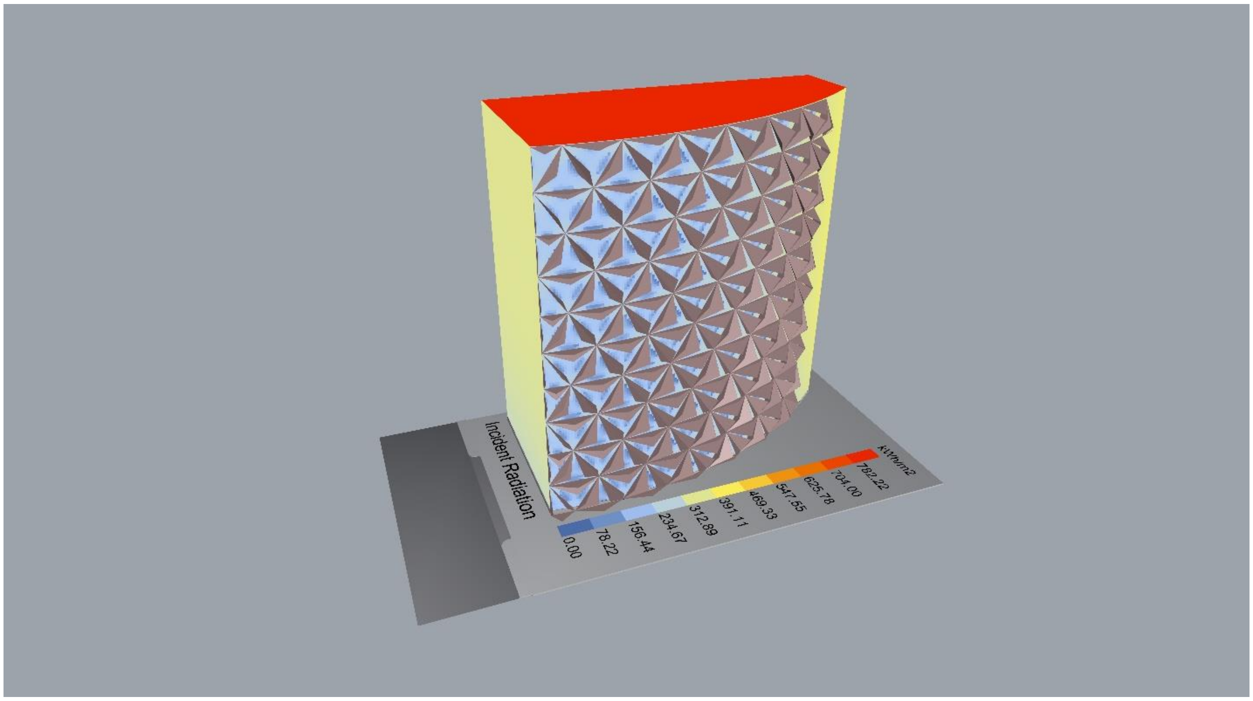
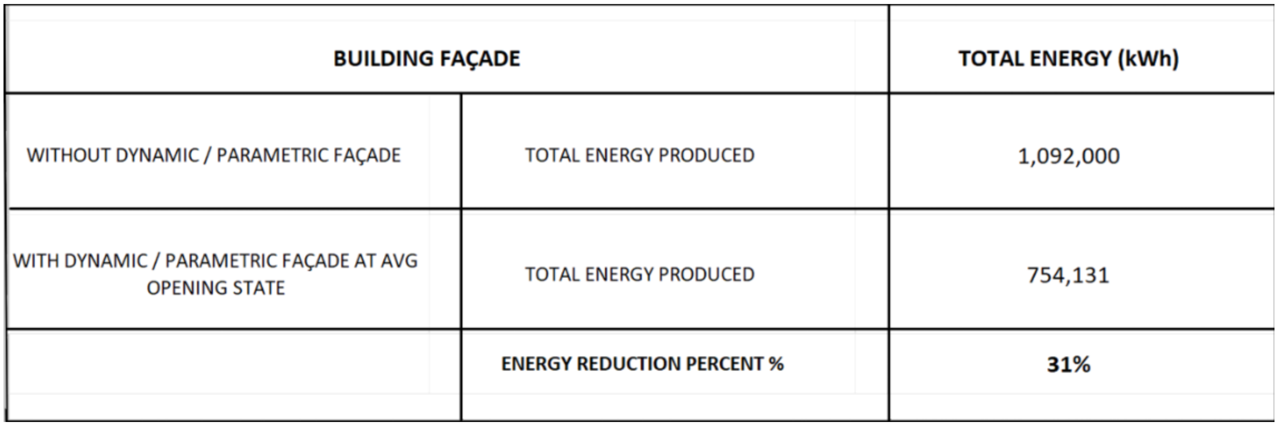


FIGURE 40 INCIDENT RADIATION ANALYSIS WITH FACADE

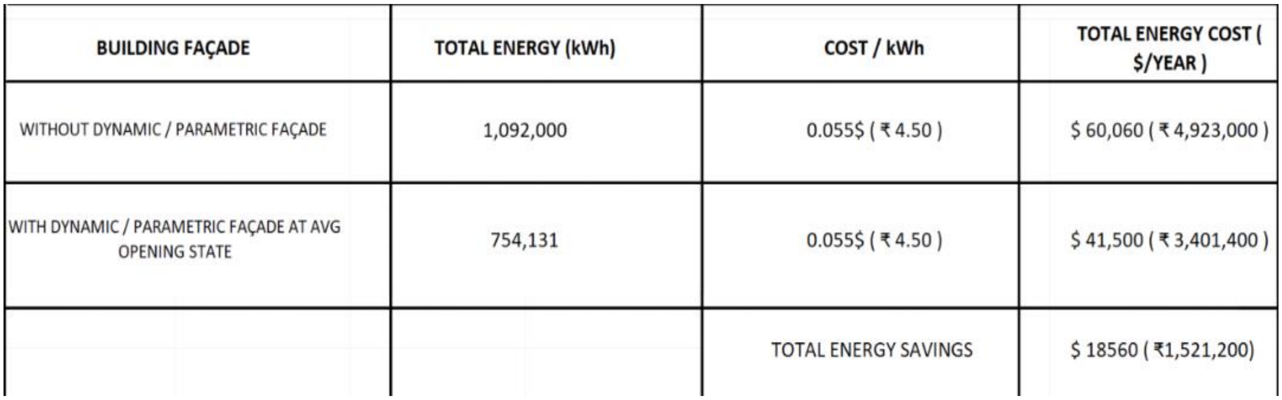
The results of the incident radiation analysis are used to optimize the design of the building, shading devices, and sunshades to block excessive solar radiation during peak hours, reducing the building's cooling load and improving energy efficiency. The analysis helps in determining good locations to place solar panels for future use as well; as we can see in Figure 19, the overall incident radiation is drastically reduced with the inclusion of the dynamic façade in the building.

ENERGY SIMULATION RESULTS

The simulation of energy consumption in the model assesses the amount of energy absorbed and utilized by its surfaces, considering the entry of solar radiation through openings and the use of shading devices or external site context to block energy. Rhinoceros 3D and Grasshopper are used to analyze the building, shading devices, and context, along with the location's EPW file, materials or u-values, and a whole year's analysis period. This information helps to conduct an energy analysis for the project. The simulation is run without and with the dynamic/parametric façade and also as a changing and dynamic façade. By running the first simulation using the data we gathered from the energy simulation results, we can calculate the total energy that Is produced with and without the use of the dynamic façade. This energy calculation below is the amount of energy needed to cool the building to optimum room temperature for comfort and work.



BUILDING FAÇADE		TOTAL ENERGY (kWh)
WITHOUT DYNAMIC / PARAMETRIC FAÇADE	TOTAL ENERGY PRODUCED	1,092,000
WITH DYNAMIC / PARAMETRIC FAÇADE AT AVG OPENING STATE	TOTAL ENERGY PRODUCED	754,131
	ENERGY REDUCTION PERCENT %	**31%**



BUILDING FAÇADE	TOTAL ENERGY (kWh)	COST / kWh	TOTAL ENERGY COST ($/YEAR)
WITHOUT DYNAMIC / PARAMETRIC FAÇADE	1,092,000	0.055$ (₹ 4.50)	$ 60,060 (₹ 4,923,000)
WITH DYNAMIC / PARAMETRIC FAÇADE AT AVG OPENING STATE	754,131	0.055$ (₹ 4.50)	$ 41,500 (₹ 3,401,400)
		TOTAL ENERGY SAVINGS	$ 18560 (₹1,521,200)

Based on the energy simulation results, there is a reduction of 31% in energy consumption in the building. There is a beneficial impact on the environment by using the dynamic façade and the glazing systems in the building that can be enhancing the sunlight entrance without the usual heat found in the Indian climate.

The analysis was done using the ladybug plug-in in Grasshopper. By plugging in the peak hours and the months, specifying the day. The dynamic façade was applied to help understand the energy savings and reduction of energy use in the building.

CONCLUSION

The aim of this thesis was to prove the importance of biomimicry in architectural design and the implementation of the latest technology in architecture computation. By applying the innovative façade, energy consumption was reduced by 31% in the overall building. By using the cost of 1 Kw/hr. in Chennai, which is approximately 0.005$, we were able to estimate the overall cost saving, which amounted to about 18,560$ / year. Furthermore, including PV panels on the roof of the structure would also increase the overall efficiency of the building. The study helps by using innovative software techniques from the initial stages to the final prototype stage and understanding which façade would be the most optimized for this structure. As India goes into its 2030 smart cities mission, we can utilize this innovation of façade and retrofit existing buildings to help improve their efficiency in the long run.

BIBLIOGRAPHY

“10 Stunning Examples of Biomimicry in Architecture.” 2020. *RTF | Rethinking The Future* (blog). June 4, 2020. https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a952-10-stunning- -of-biomimicry-in-architecture/.

“(18) The Impact examples of Tall Buildings in the UK | LinkedIn.” n.d. Accessed April 23, 2023. https://www.linkedin.com/pulse/impact-tall-buildings-uk-michael-grimwood/.

Aziz, Moheb Sabry, and Amr Y. El sherif. 2016. “Biomimicry as an Approach for Bio-Inspired Structure with the Aid of Computation.” *Alexandria Engineering Journal* 55 (1): 707–14. https://doi.org/10.1016/j.aej.2015.10.015.

Bhatnagar, Sampada. 2022. “Nature-Inspired Innovations: Applying Design Thinking to Biomimicry.” Medium. January 8, 2022. https://uxdesign.cc/nature-inspired-innovations-applying-design-thinking-to-biomimicry-56bc568ea063.

“BIOMIMETIC ARCHITECTURE: Green Building in Zimbabwe Modeled After Termite Mounds.” 2012. *Inhabitat - Green Design, Innovation, Architecture, Green Building | Green Design & Innovation for a Better World* (blog). November 29, 2012. https://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/.

“Biomimicry_ Innovation Inspired by Nature (PDFDrive).Pdf.” n.d.

“Brilliant Cement Making Technology Mimics Coral While Removing CO2 From the Atmosphere.” 2011. *Inhabitat - Green Design, Innovation, Architecture, Green Building | Green Design & Innovation for a Better World* (blog). December 15, 2011. https://inhabitat.com/brilliant-cement-making-technology-mimics-coral-while-removing-co2-from-the-atmosphere/.

“Building Material Inspired by Marine Sponges — Innovation — AskNature.” n.d. Accessed May 29, 2022. https://asknature.org/innovation/building-materials-inspired-by-marine-sponges/.

“Bullitt Center | WBDG - Whole Building Design Guide.” n.d. Accessed April 23, 2023. https://www.wbdg.org/additional-resources/case-studies/bullitt-center.

Chang, Soowon, Daniel Castro-Lacouture, Florina Dutt, and Perry Pei-Ju Yang. 2017. “Framework for Evaluating and Optimizing Algae Façades Using Closed-Loop Simulation Analysis Integrated with BIM.” *Energy Procedia*, Leveraging Energy Technologies and Policy Options for Low Carbon Cities, 143 (December): 237–44. https://doi.org/10.1016/j.egypro.2017.12.677.

Communications, Leah Burrows SEAS. 2019. “How Do Tiny Termites Make Such Massive Mounds?” *Harvard Gazette* (blog). February 12, 2019.

https://news.harvard.edu/gazette/story/2019/02/how-do-tiny-termites-make-such-massive-mounds/.

“Gaudí, Biomimicry, and Bonsai.” 2017. Bonsai Mirai. November 6, 2017. https://bonsaimirai.com/blog/gaud%C3%AD-biomimicry-and-bonsai.

Hanafi, Walaa Hussein Hussein. 2021. “Bio-Algae: A Study of an Interactive Facade for Commercial Buildings in Populated Cities.” *Journal of Engineering and Applied Science* 68 (1): 37. https://doi.org/10.1186/s44147-021-00037-5.

Jamei, Elmira, and Zora Vrcelj. 2021. “Biomimicry and the Built Environment, Learning from Nature’s Solutions.” *Applied Sciences* 11 (16): 7514. https://doi.org/10.3390/app11167514.

“Nature Does It Better: Biomimicry in Architecture and Engineering.” 2021. *Redshift EN* (blog). July 30, 2021. https://redshift.autodesk.com/biomimicry-in-architecture/.

“Passively Cooled Building Inspired by Termite Mounds — Innovation — AskNature.” n.d. Accessed May 29, 2022. https://asknature.org/innovation/passively-cooled-building-inspired-by-termite-mounds/.

Pawlyn, Michael. 2019. *Biomimicry in Architecture*. 2nd ed. RIBA Publishing. https://doi.org/10.4324/9780429346774.

Pohl, Göran, and Werner Nachtigall. 2015. *Biomimetics for Architecture & Design*. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-19120-1.

Talaei, Maryam, Mohammadjavad Mahdavinejad, and Rahman Azari. 2020. “Thermal and Energy Performance of Algae Bioreactive Façades: A Review.” *Journal of Building Engineering* 28 (March): 101011. https://doi.org/10.1016/j.jobe.2019.101011.

“The Animal House ~ The Incredible Termite Mound | Nature | PBS.” 2011. Nature. October 28, 2011. https://www.pbs.org/wnet/nature/the-animal-house-the-incredible-termite-mound/7222/.

“The History of Biomimicry and Architecture.” 2020. *RTF | Rethinking The Future* (blog). July 15, 2020. https://www.re-thinkingthefuture.com/rtf-fresh-perspectives/a1284-the-history-of-biomimicry-and-architecture/.

“The-Complete-Works-Leonardo-Da-Vinci.Pdf.” n.d. Accessed April 23, 2023. https://zelalemkibret.files.wordpress.com/2012/02/the-complete-works-leonardo-da-vinci.pdf.

Tokuç, Ayça, Feyzal Avcı Özkaban, and Özge Çakır. 2018. “Biomimetic Facade Applications for a More Sustainable Future.” In . https://doi.org/10.5772/intechopen.73021.

Tonn, Shara. n.d. “Think Like a Tree: A New Kind of Eco-Friendly Concrete Inspired by Coral.” *Wired*. Accessed May 30, 2022. https://www.wired.com/2015/09/think-like-tree-new-kind-eco-friendly-concrete-inspired-coral/.

“Venus Flower Basket Sea Sponge.” n.d. Issuu. Accessed May 29, 2022. https://issuu.com/tkoga/docs/koga_tessa_des116_process_manual-final-pretsolia-1/s/10471883.

"Why The Building Sector? – Architecture 2030." n.d. Accessed May 26, 2022. https://architecture2030.org/why-the-building-sector/.

world, STIR. n.d. "Remembering Richard Buckminster Fuller’s Principles of Empathy and 'Doing with Less.'" Accessed May 24, 2022. https://www.stirworld.com/inspire-people-remembering-richard-buckminster-fuller-s-principles-of-empathy-and-doing-with-less.

Wurm, Jan, and Martin Pauli. 2016. "SolarLeaf: The World's First Bioreactive Façade." *Arq: Architectural Research Quarterly* 20 (1): 73–79. https://doi.org/10.1017/S1359135516000245.