HOW DOES BIOLOGICALLY INFORMED DESIGN ALTER THE INTERIOR OF A BUILDING AND ITS POSITION WITHIN A CITY?

Exploring the environmental, social, and economic impacts biomimicry, biomorphism and biophilia have on an urban area.

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Interior Architecture BA(Hons)

Level 6

Word Count: 7626

Submission Date: February 1, 2023

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Lucy Whittall 03/01/23

ABSTRACT

A city stands as an amalgamation of the past and present, representing the development of each style, movement, and technology. Throughout all of these has been the influence of nature. Whether it has been used to manipulate and augment or been rejected and contradicted. Within architecture and design, nature' s influence is present throughout.

The modern bio-inspired design disciplines biomimicry, biomorphism, and biophilia each take influence from nature in different ways, some forms more abstract and functional, others more literal and imitational. The development of these branches of design all have impacts on environmental, social, and economic issues within a city, some even effecting mental and physical wellbeing. This thesis looks to explore whether these changes will be socially sustainable, questioning which side of society will benefit most from these developments, those who need it, or those who finance it?

Through this thesis, I will be exploring the relationship between biologically informed design and how it manipulates a cityscape; both physically and psychologically. This thesis investigates how this has been represented both within fiction and in reality, looking at the impacts of biomimetics from the structure to the materials themselves. By generating a link back to nature and reintroducing the living into our cities it asks the question; how blurred are the lines becoming between nature and man-made?

CONTENTS

INTRODUCTION

This thesis will explore the relationship between biomimicry and architecture, detailing the effects of integrating biologically informed systems into designs and how that can alter the temperature and light qualities of an interior. Whilst biomimicry as a discipline itself is relatively modern, the action of taking influence from nature is not. As far back as 6000 BC, during the Monolithic era, Buddhist temples and shrines were carved into the sides of mountains in India, taking influence from naturally forming caves.[1] Moving forward to the post-Industrial Revolution, Art Nouveau took a clear and literal influence from nature, filling designs with organic forms and motifs. In modern day design, biological systems influence the mechanics of environmentally conscious designs, using techniques which have been around forever in a contemporary context. Could these systems be the solution to monetary and environmental issues? Has nature had the solution in front of us all along?

The idea of using natural forms to create structures has been demonstrated within fictional contexts, initially being demonstrated as something alien and other worldly within The Swamp Thing comics of the 1980s. By introducing the concept of nature constructing buildings, did this bridge the gap between reality and fiction? Or did it split them further apart, making it seem futuristic and unrealistic?

Biophilia focuses on using natural forms and materials to alter the perception of an interior, bio-inspired design could positively impact mental health within cities through the use of shapes, patterns and forms found in nature. Biomimetic materials may also begin to transform how cityscapes are constructed, could future cities become environmentally conscious? Would reconnecting with nature within industrial spaces improve mental wellbeing?

[1] Wyatt Schreiner, "Biomimicry: A History," eHistory, last modified April 19, 2018, https://ehistory.osu.edu/exhibitions/biomimicry-a-history#:~:text=1950s%3A%20The%20term%20%E2%80%9Cbiomimetics%E2%80%9D,designers%20all%20over%20the%20world.

CHAPTER 1

1.1 THE HISTORY OF BIOMIMICRY

'Bioinspired design' is an umbrella term which encapsulates design that uses biology and nature as a resource to solve design and engineering problems.[2] Biomimicry and biomorphism are housed within this category and are often mistaken as the same thing and used interchangeably.[3] The Oxford English Dictionary defines biomimicry as, "the design and production of materials, structures and systems that are modelled on biological entities and processes."[4] Comparatively, biomorph, is defined as, "a decorative form or object based on or resembling a living organism."[5] The key differences between these two terms are that biomorphism simply looks like elements found in nature and may have no function relating to these forms; however, biomimicry uses systems found in nature to inspire the function. Biomimicry.org states it is important to recognise that "while biomimicry is a type of bioinspired design, not all bioinspired design is biomimicry."[6] For something to be defined as biomimetic it must perform a function which solves a design or engineering problem by using a system found within nature. During this thesis both biomorphism and biomimicry will be explored. There will be focus paid to the differences between how these branches of design appear within design, additionally looking at the future of biomimicry within architecture in particular.

Sagrada Familia, Barcelona, Spain (Incomplete)

The incomplete Roman Catholic church by Antoni Gaudi applies the function of natural forms to the structure of the building. The church, which started construction in 1882, is regarded as a pioneer to modern biomimetics. Gaudi believed form and function derived from nature solved structural engineering problems and could help to improve the lighting of the interior. As demonstrated in *Figure 1*, the most notable feature of biomimetics is branching columns in the nave of the church. These columns, inspired by trees, branch out and provide greater support for the vault and roof.

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[2] "What is biomimicry?" Biomimicry.org, accessed November 21, 2022. https://biomimicry.org/what-is-biomimicry/

[3] Biomimicry.org, "What is biomimicry?"

[4] "Biomimicry definition," Oxford Languages, accessed January 13, 2022, https://languages.oup.com/google-dictionary-en/.

[5] "Biomorph definition," Oxford Languages, accessed January 13, 2022, https://languages.oup.com/google-dictionary-en/ .

[6] "What is biomimicry?" Biomimcry.org, accessed November 21, 2022, https://biomimicry.org/what-is-biomimicry/ .

Using the technology behind the natural weight distribution of trees, this design allows the columns to bear greater weight than traditional columns.[7]

Figure 1 Sagrada Familia interior

Gaudi uses hyperboloids within the windows and the roof to diffuse natural light, this light reflects and diffuses through the spaces and gives the effect of sunlight filtering through the leaves of a forest.[8] This type of design is an example of biomorphism as it has no function other than visually mimicking something seen in nature. Throughout the church a combination of both biomorphism and biomimicry is used. Biomorphic columns reflect the forms seen within trees, their function works just as trees would, helping to bear greater weight and in turn reducing the amount of material needed for construction. This differs from the hyperboloids within the windows, which produce nothing more than a visual effect. However, this affects how the interior of the space is perceived by the user; giving the effect of being stood within a manmade forest.

The Sagrada Familia is a pioneer in the field of biomimetics, the term itself was not coined until the 1950's by, American inventor, Otto Schmitt. This highlights how progressive and ambitious Gaudi's work was, the hugely influential piece of design can be regarded as a catalyst to the evolution of this field.

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[7] "Biomimetic Architecture: Sagrada Familia," Steemit, accessed November 21, 2022, https://steemit.com/architecture/@snaves/biomimetic-architecture-sagrada-familia.

[8] "Biomimetic Architecture: Sagrada Familia," Steemit.

1.2 THE RELATIONSHIP BETWEEN ART NOUVEAU AND BIOMIMECTIC ARCHITECTURE

Between 1890 and 1914, the Art Nouveau movement gained popularity through its rejection of the aesthetic mass production generated during the Industrial Revolution. The style had particular popularity within Europe and the United States, a key feature was making designs look and feel alive through the use of asymmetric, curvilinear lines, and biomorphic iconography. [9]

Figure 2 The Tassel House by Victor Horta

Victor Horta is considered to be one of the fathers of Art Nouveau Architecture, with his Art Nouveau townhouses considered to be some of the most iconic and influential design works within the movement.[10] As seen in *Figure 2,* the staircase railings take forms inspired by vines and plant stems, their organic forms reject the rigid, straight lines of mass production. This style of architecture falls towards biomorphic architecture rather than biomimicry as the form is used as a decorative element rather than a structural one.

Antoni Gaudi was another influential and key figure within the Art Nouveau movement. Within the Sagrada Familia, Gaudi combines form and function, using biomorphic and biomimetic features

[9] "Art Nouveau Architecture- The Art and Architects of Art Nouveau Buildings," Art in Context, last modified December 16, 2021, https://artincontext.org/art-nouveau-architecture/ .

[10] Sam Parker, "Victor Horta: Belgium's Greatest Art Nouveau Architect," Culture Trip, last modified October 18, 2016, https://theculturetrip.com/belgium/articles/victor-horta-belgiums-greatest-art-nouveau-architect/ .

throughout the design. Differing from the work of Horta who uses biomorphic elements in a more decorative way, giving these elements no further function.

The influence of Art Nouveau on Biomimetic Architecture is present through the attitude of designers. Art Nouveau broke tradition and did not rely on a movement of the past to take inspiration from, it forged a new movement entirely that rejected the confines of mass production. Designers wanted to create something which called back to nature, much like Biomimetic Architecture, focusing on creating organic, ornate forms. This demonstrates the want to break from tradition and forge a new path, looking at forms and processes which had not been explored previously within design and architecture. The pioneering attitude is demonstrated within both stems of architecture. Gaudi' s both practical and decorative composition of the Sagrada Familia bridges the two movements, working as a catalyst influencing designers to take more ambitious inspirations from nature.

CHAPTER 2

BIOMIMICRY WITHIN FICTION

The concept of biomimicry has been something which has existed within both reality and fiction, by introducing biomimetics into the fictional world it presents the idea to a wider proportion of the population, not just those who specialise in the fields of interiors or architecture. It helps to make the idea of plant-made materials or structures a more fesiable innovation, by getting people used to the idea, even within a fictional context it makes it seem less alien of an concept.

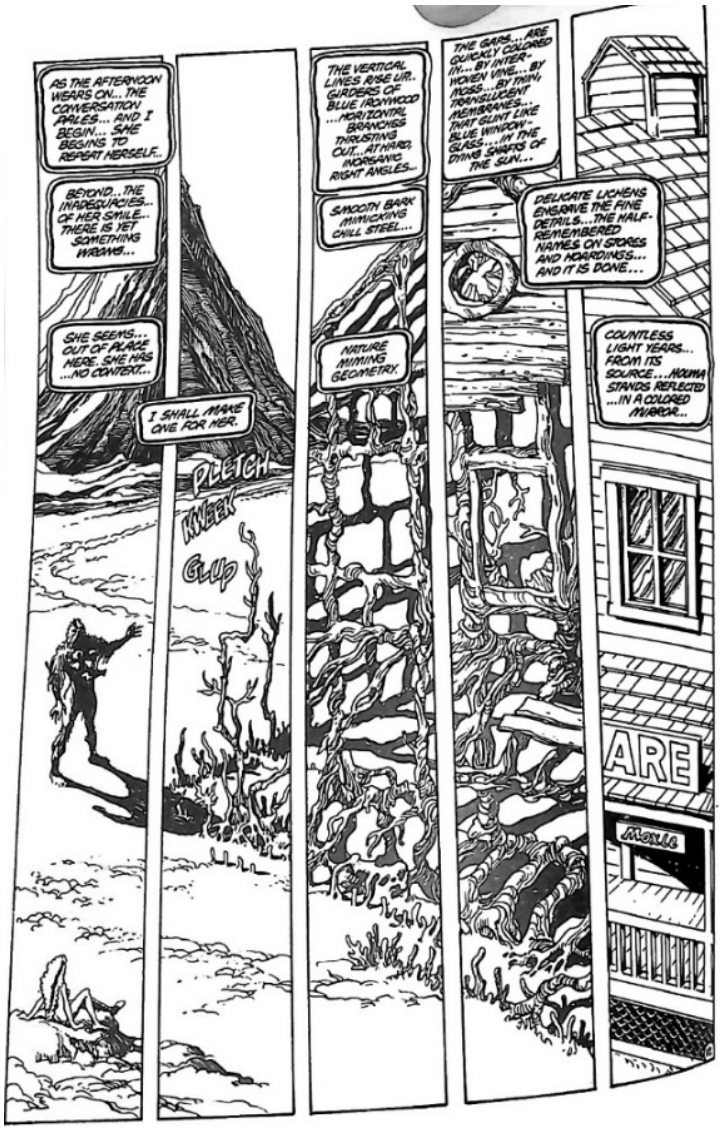

Figure 3 1980s Swamp Thing Comic

Volume 2, Issue 56 of The Swamp Thing comic book series depicts the creation of buildings through plant materials on an alien planet. Vines and bark replicate man-made materials, the opposite of biomimicry, taking place through "Nature miming geometry." [11]. *Figure 3* depicts Page 12 of Issue 56, showing Swamp Thing creating a building using plants following the rigid, inorganic shapes of human architecture. The comic describes the construction of the plant-made building, "The vertical lines rise up… girders of blue ironwood…horizontal branches thrusting out…at hard, inorganic right angles…" [12] The plants grow to mimic traditional building materials, replicating both their strength and visual qualities. This is emphasised further throughout the description, "thin, translucent membranes…that glint like blue window-glass…" [13] The translucent membranes would have created harmonious similarity to the blue glass they were created to replicate. Contrastingly, some materials used would not produce any similarity in reality as, "Smooth bark mimicking chill steel…" [14] was used by Swamp Thing. While bark and steel do not traditionally share many visual qualities, within a tree, bark is the exterior layer that protects the tree, steel can also be used as a protective and strengthening skin within architecture. The concept in this issue of the comic book depicts a city grown from just plants, with only organic materials used to create a cityscape, at the time this would have been such an unfamiliar concept that it could have only taken place on an alien planet.

The idea of using plant materials to replicate geometry, hard lines and inorganic forms is a very mathematical and almost strange way to approach using organic materials. The plants are forced to replicate traditional forms and morph to the lifeless and harsh shapes which stand in most conventional cities. The building was brought to life through this process in some ways, although it takes the harsh and mathematical form of industrial architecture, the living materials brought life and nature into the structure.

During the 1960s, the design movement Brutalism focused on the use of dramatic and overwhelming forms which used harsh lines and geometric shapes. The building materials themselves were dominated heavily by the use of concrete[15] and resulted in powerful structures which created intimidating and soulless designs. By the 1980s, many cityscapes would have been dominated by brutalist and industrial architecture, almost the polar opposite of bio-inspired design.

[11] Moore, Veitch, Alcala, 1987, p.12

[12] Moore, Veitch, Alcala, 1987, p.12

[13] Moore, Veitch, Alcala, 1987, p.12

[14] Moore, Veitch, Alcala, 1987, p.12

[15] "Brutalism," RIBA, accessed January 17, 2022, https://www.architecture.com/explore-architecture/brutalism#:~:text=Brutalism%20is%20a%20style%20with,construction%2C%20producing%20highly%20expressive%20forms.

When looking at the comic in the context of how a city would have looked during this period, it demonstrates how fictional the idea a biological city would be.

The idea of using plant materials on a large scale during this period would have been a fantasy, and even now still is. The narrative that the comic creates, the idea that a city could be completely plant made, is highly idealistic and still out of reach, however, there is now a push and desire to make this happen to some degree. With more of a focus on environmental issues, the idea of going back to nature, creating designs which use their technologies is becoming more prevalent. Plant systems have used the same technology for thousands of years, perfecting it, using techniques which enhance nature instead of destroying their surroundings. This is something humans can and should learn from, implementing this into our own design processes.

CHAPTER 3

3.1 COMPARING MODERN BIOMIMETIC ARCHITECTURE

Biomimetic structures look towards nature for inspiration, they humanise a natural process, turning something, which has always existed within nature into an innovative engineering feat. Biomimetic architecture uses technologies, much like the fictional ones demonstrated in Swamp Thing, to redesign a system we already have, looking back towards nature, creating a connection between humans and the natural world.

Eastgate Centre, Harare, Zimbabwe (1996)

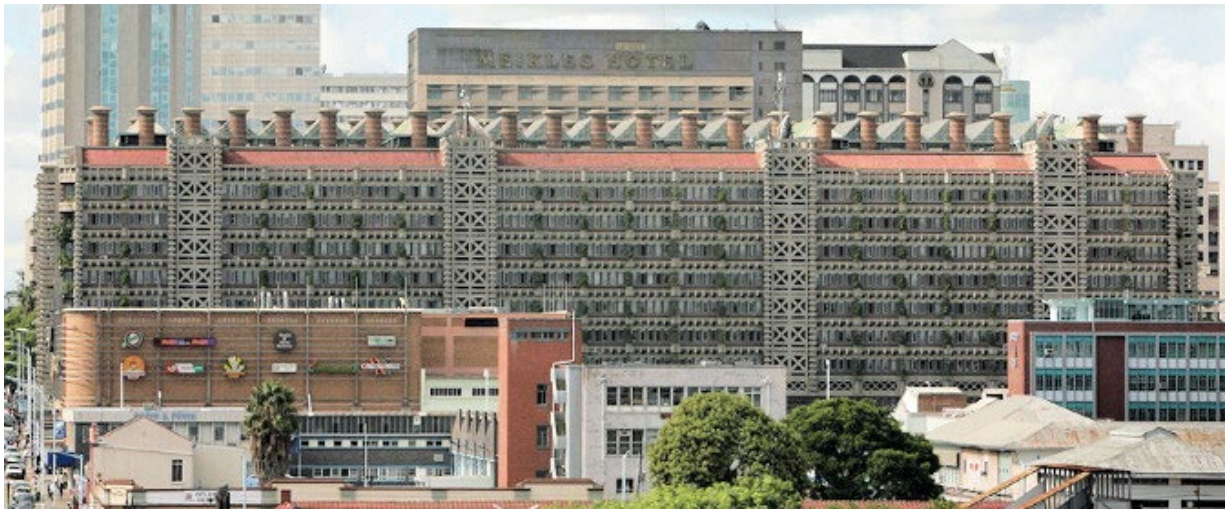

Figure 4 The Eastgate Centre

The Eastgate Centre is a nine-storey shopping complex and office building in Harare, Zimbabwe. Designed by architect Mick Pearce, the building has no conventional air-conditioning or heating, however, maintains regulated temperatures year-round due to a self-cooling/heating ventilation system. Pearce drew his inspiration from African termite mounds and indigenous Zimbabwean masonry.[16]

[16] "Eastgate Centre, Harare, Zimbabwe," Engineering for Change, accessed November 21, 2022, https://www.engineeringforchange.org/solutions/product/eastgate-centre-harare-zimbabwe/.

Constructed mainly of concrete, the Eastgate Centre has a ventilation system which operates in a similar way to a termite mound. Outside air is drawn in, and dependant on which is hotter, the air is then warmed or cooled by the building's mass. This air is then circulated into the building before exiting via chimneys at the top, these are visible in *Figure 4*.[17]

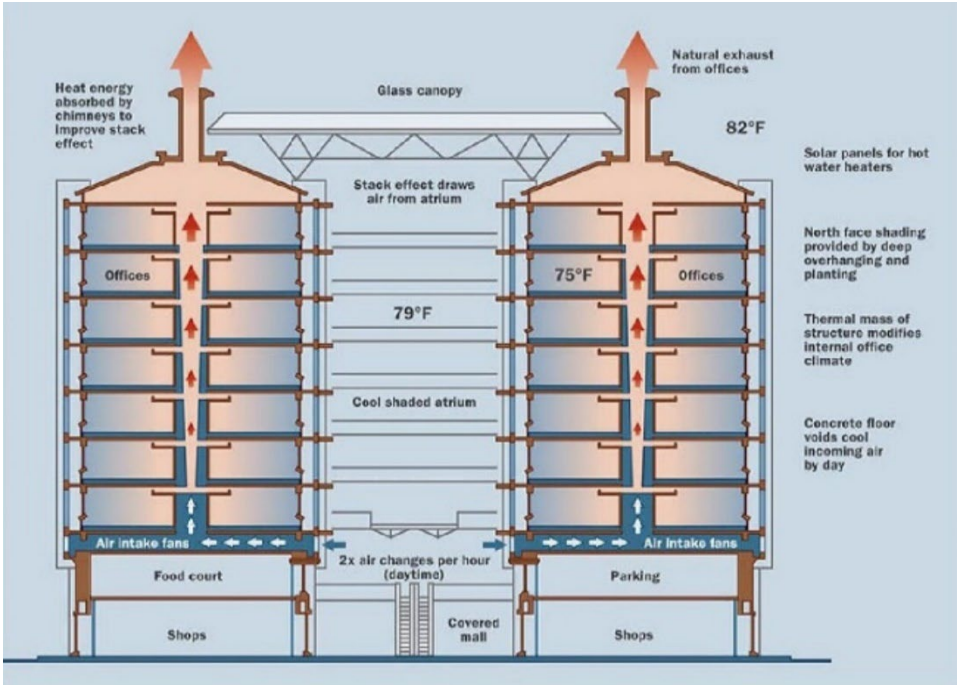

Figure 5 Ventilation system diagram of Eastgate Centre

Figure 5 depicts a diagram of how the Eastgate Centre's ventilation system works. A multi-height atrium covered by glass separates the complex's two buildings which stand side by side. This open area allows air to be drawn in continuously by fans on the first floor. The air is then pushed vertically towards the ventilation cores in each of the two buildings. Smaller vents branch out from the centre cores, much like within a termite mound, pulling cool air into the building. The hot air is pulled out of the building via a process known as the stack effect, finally exiting through chimneys at the top of the building. The speed at which the air moves through the building is dependent on the time of the day, fans help control air movement throughout the structure. [18]

In comparison to a conventional building of the same size, the Eastgate Centre uses less than 10% of the energy, this creates an eco-efficient system which keeps running costs low for the owners. This saving in costs also benefits the tenants, as they pay 20% lower rents than those in surrounding

[17] Engineering for Change, "Eastgate Centre, Harare, Zimbabwe."

[18] Engineering for Change, "Eastgate Centre, Harare, Zimbabwe."

properties. By not having to install an air-conditioning system, the owners saved $3.5 million alone.[19]

According to Global Finance, Zimbabwe is the world' s 17th poorest country of 2022.[20] To the general population of Zimbabwe, these kinds of technologies are incredibly out of reach, there is a huge disparity in wealth within the country. In 2018, unemployment rates were 90%.[21] These statistics demonstrate how sustainability is more than just an environmental issue, but rather a social, economic, and political one.

The termite mound inspired ventilation system works well within the building, however this technology could not just be applied to any building, it would require specially built properties. The technology itself saves money through its operation but the installation and construction process requires a lot of upfront funding. In this context sustainability becomes a privilege.

[19] Jill Fehrenbacher, "BIOMIMETIC ARCHITECTURE: Green Building in Zimbabwe Modelled After Termite Mounds," *Inhabitat*, November 29, 2012. https://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/.

[20] Luca Ventura, "Poorest Countries in the World 2022," *Global Finance,* August 5, 2022, https://www.gfmag.com/global-data/economic-data/the-poorest-countries-in-the-world .

[21] "Economic Crisis in Zimbabwe," Synergia Foundation, last modified October 18, 2018, https://www.synergiafoundation.org/insights/analyses-assessments/economic-crisis-zimbabwe.

BIQ House, Hamburg, Germany (2013)

Figure 6 Bio-reactive facade on BIQ House

BIQ House in Hamburg, Germany uses a bio-reactive façade on the southeast and southwest faces of the four-storey apartment building, as demonstrated in *Figure 6*. Renewable energy from algal biomass and solar thermal heat is generated through this façade. The Solar Leaf system, developed collaboratively between Strategic Science Consult of Germany (SSC), Colt International and Arup, can be applied to both new and existing buildings.[22]

BIQ House was the pilot project for this technology, installing 129 bioreactors, each measuring 2.5m x 0.7m, which formed a secondary façade on the building. Each bioreactor has four glass layers, the innermost two panes have a 24-litre cavity which circulates the growing medium, either side of these panes are argon filled cavities which minimise heat loss. The front glass panel is made from white antireflective glass.[23]

[22] "Solar Leaf," ARUP, accessed November 21, 2022, https://www.arup.com/projects/solar-leaf.

[23] ARUP, "Solar Leaf."

In intervals, compressed gas is introduced into the bottom of each bioreactor, creating air bubbles (seen in *Figure 7*), and allowing the water to circulate. This stimulates the algae to take in CO_2 and light. Biomass and heat is generated by the façade and is transported in a closed system to the building's energy management centre. Biomass is harvested through floatation and the heat is harvested via a heat exchanger. Excess heat from the photobioreactors can be used to help heat the building, can be stored for later use, or can be used to supply hot water to the building's fifteen apartments.[24]

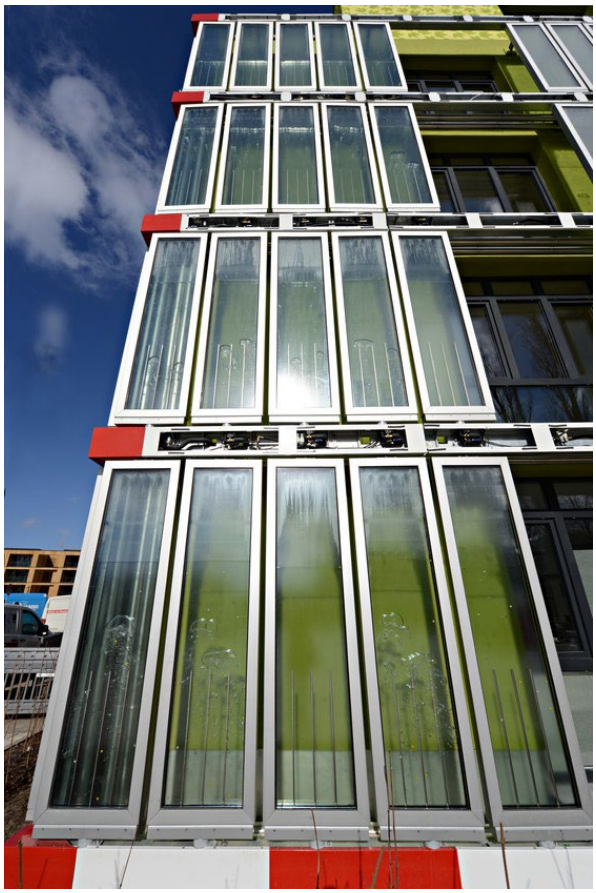

Figure 7 Panels in place on BIQ House

The photobioreactors require minimal maintenance and are highly efficient at producing algal growth. The biomass produced can be used for both power and heat generation and stored with minimal energy loss, this allows the bioreactors to provide one third of the total heat demand of the fifteen apartments. The photobioreactors do not require any further land and are minimally affected by weather conditions. They also employ a short carbon cycle as the algae feeds on CO_2, this therefore prevents emissions from entering the atmosphere.[25]

[24] ARUP, "Solar Leaf."

[25] ARUP, "Solar Leaf."

The bioreactors can also be used as shading devices, when more light is available more algae will grow, therefore providing more shade for the building. The panels will gradually turn greener as more algae grows. The technology is capable of being operated year-round, with temperatures of up to 40° C able to be extracted from the bioreactors without damaging the algae.[26] The bioreactors are like a skin to the building, this means they could be applied to more buildings if they have the appropriate conditions for the bioreactors. As they require minimal maintenance, they could be installed on high rise properties and help to power and heat flats or offices. As they do not require extra land they would work well within a city, possibly helping to offset carbon emissions that are generated within a city through their short carbon cycle, or at least contribute no further emissions.

A 2014 study explored the effects of city living on mental health in comparison to countryside living. The study found that living in cities raised the risk of anxiety and mood disorders by up to 39%[27] compared to those living outside cities. Through the photobioreactors production of algae, they turn to a green colour. The colour green is associated with evoking feelings of rest and security[28], the introduction of this colour would help aesthetically to cut up the grey scenery of a cityscape and help reduce feeling of anxiety. By implementing more of the colour which enhances countryside living into urban areas it may help to improve mental health within city dwellers. This would mean that the photobioreactors work not only to improve interior living conditions through light and heating but through aesthetics, potentially improving mental health.

Comparing the Eastgate Centre and BIQ House demonstrates two options of using biomimetic technologies to alter the interior temperature of a building. BIQ House' s system has the ability to generate heat and provide shade, this makes it applicable to a wide scale of uses as it can be used in both hotter and cooler environments. The energy produced by the bioreactors can be stored, this could mean that if an excess of energy is produced it could be used for more than the building the bioreactors are applied to. Another benefit of the bioreactors is that they can be used on both new and existing buildings, this makes them an accessible option to sustainable energy generation.

The Eastgate Centre works well to provide heating and cooling for the building, a downside however is that it requires a specially built property so it would be costly to install a similar system elsewhere

[26] ARUP, "Solar Leaf."

[27] Leo Benedictus, "Sick cities: why urban living can be bad for your mental health," *The Guardian,* February 25, 2014, https://www.theguardian.com/cities/2014/feb/25/city-stress-mental-health-rural-kind.

[28] Christi Wharton, "The Psychology of Design: The Color Green," Impact, last modified April 17, 2019, https://www.impactplus.com/blog/the-psychology-of-design-the-color-green#:~:text=Green%20evokes%20a%20feeling%20of,to%20put%20patients%20at%20ease.

and would require it to be a new build. The technology used is only suitable for larger scale projects too as in a residential property there would not be enough space for the chimneys or the air-cooling system, if they were able to make this smaller it could be an option for areas where a lot of costly air conditioning is used.

The gentrification of cities causes a number of implications socially and economically for those who are not wealthy. By introducing technologies which improve quality of life within poor urban areas, the character of the area is changed, therefore attracting investors and more affluent people to the area. In turn, outpricing and displacing businesses and people who already live there. While the idea of introducing these new technologies seems like a solution on the surface, it is important to acknowledge that it comes with social implications. While BIQ House and the Eastgate Centre both use technologies which in turn lower running costs, these rents are only lower in relevance to the surrounding area, which has likely been gentrified with the introduction of these new build technologies. The original dwellers of these areas are likely outpriced and displaced. These technologies are only accessible to people who are wealthy, supporting those who are not in as much need of the benefits they provide.

3.2 BIOPHILIC DESIGN

Biophilic design is a stem of "Bioinspired design" which differs from biomorphism and biomimicry, as it focuses on creating a connection between humans and nature through replicating experiences from nature within design. The purpose of this is in aid of improving mental health and wellbeing. While all these branches of design draw from nature, they each draw upon it in a different way. Biomorphism is where biomimicry and biophilic designs often overlap, however, this does not mean that every biomorphic design is biomimetic or biophilic. Biophilic designs take patterns or forms in nature which evoke a positive or safe feeling for humans, if the design is inspired by something which is perceived as dangerous, it cannot be considered biophilic as it does not conjure positive emotions.[29]

[29] Allison Bernett, "Biomimicry versus Biophilia: What's the difference?", Terrapin Bright Green, last modified February 14, 2017, https://www.terrapinbrightgreen.com/blog/2017/02/biomimicry-versus-biophilia/ .

COOKFOX Architecture Studio, New York, USA (2006)

Figure 8 Northeast wall looking over green roof

COOKFOX Architecture Studio renovated the penthouse of a former department store to create a biophilic office space in aid of improving employee and visitor wellbeing. The design includes a 3600 square foot green roof which is visible from 90% of individual desks to create a connection with nature.[30] As seen in *Figure 8*, the northeast wall contains twenty-four 9ft windows which both let in natural light and provide opportunity for small visual distractions which helps to decrease mental fatigue, increase productivity, and restore concentration. The drop ceiling was removed to increase ceiling heights and biophilic patterns incorporated into carpet tiles in order to give the illusion they are derived from nature. Desks have individual plants to create further connections to nature as well as OSB board used as dividing walls, this mimics the fractal patterns seen in wood. Many interior features were restored or retained, revealing biomorphic columns within the original 1921 structure as seen in *Figure 9.* The features have helped to reduce absences, improve occupant wellbeing and increased office productivity.[31]

[30] Joe Clancy, Cory Nestor, Terrapin Bright Green, "COOKFOX Architecture Studio", Terrapin Bright Green, accessed January 22, 2023, https://www.terrapinbrightgreen.com/wp-content/uploads/2015/11/641-Case-Study-Fall15.pdf

[31] Terrapin Bright Green, "COOKFOX Architecture Studio."

Figure 9 Original Biomorphic Forms in COOKFOX Architecture Studio

Statistics state that 14.7% of people experience mental health problems within the workplace, with women being nearly twice as likely.[32] In the UK, evidence suggests that 12.7% of sickness absences from the workplace are due to poor mental health.[33] Offices are renowned for feeling like soulless, monotonous, and cold workplaces for many people, by introducing biophilic features into an office, like COOKFOX have done, it helps to introduce light and life into the space. While their design features a huge variety of options, by introducing a small variety of the features COOKFOX have, such as biophilic patterns and plants, could help to improve mental wellbeing for workers by forging a connection back to nature.

BIQ House uses function to inform the shape of their panels, however, the green colour and movement within the panels as algae grows works in a biophilic way to evoke feelings of safety and security. As it creates more shade and grows, it is almost like a blanket grows around the facades of the building. Algae is not a dangerous or threatening medium to humans so evokes positive emotions rather than ones of claustrophobia. It creates a feeling of being surrounded by nature, albeit in an untraditional format, but by being surrounded by the colour green it helps to trigger the same feelings being surrounded by nature does. This similar feeling of being surrounded by nature is also present within the Sagrada Familia. As the columns are shaped similarly to trees and the windows produce lighting similar to that found within a forest, it almost gives the illusion to visitors

[32] "Mental health at work: statistics," Mental Health Foundation, accessed January 22, 2023, https://www.mentalhealth.org.uk/explore-mental-health/mental-health-statistics/mental-health-work-statistics .

[33] Mental Health Foundation, "Mental health at work: statistics."

of being within a forest. By mimicking nature in this way, it helps to bring the environment into interiors, meaning nature does not always have to be experienced in a traditional way.

3.3 COMBINING BIOMORPHISM AND BIOMIMICRY

Biomimicry and biomorphism are disciplines which work successfully separately, as seen in the Eastgate Centre and BIQ House, it is not obvious that these designs take influence from nature. Some more unusual and outlandish designs, more clearly demonstrate their atypical design inspiration, functioning as bioinspired designs, combining the disciplines of biomorphism and biomimicry.

Lotus Temple, New Delhi, India (1986)

The Baha'i House of Worship, also known as the Lotus Temple, takes its form from India's national flower. The lotus flower, considered sacred by many Indians, inspires the form of this temple as a way to represent the clarity and simplicity of the Baha'i faith. Light and water have been used within the structure in the place of religious idols, sculptures or carving which are normally found within places of religious worship. This not only represents the values of the religion however creates a place of worship open to all faiths and races, unifying mankind.[34]

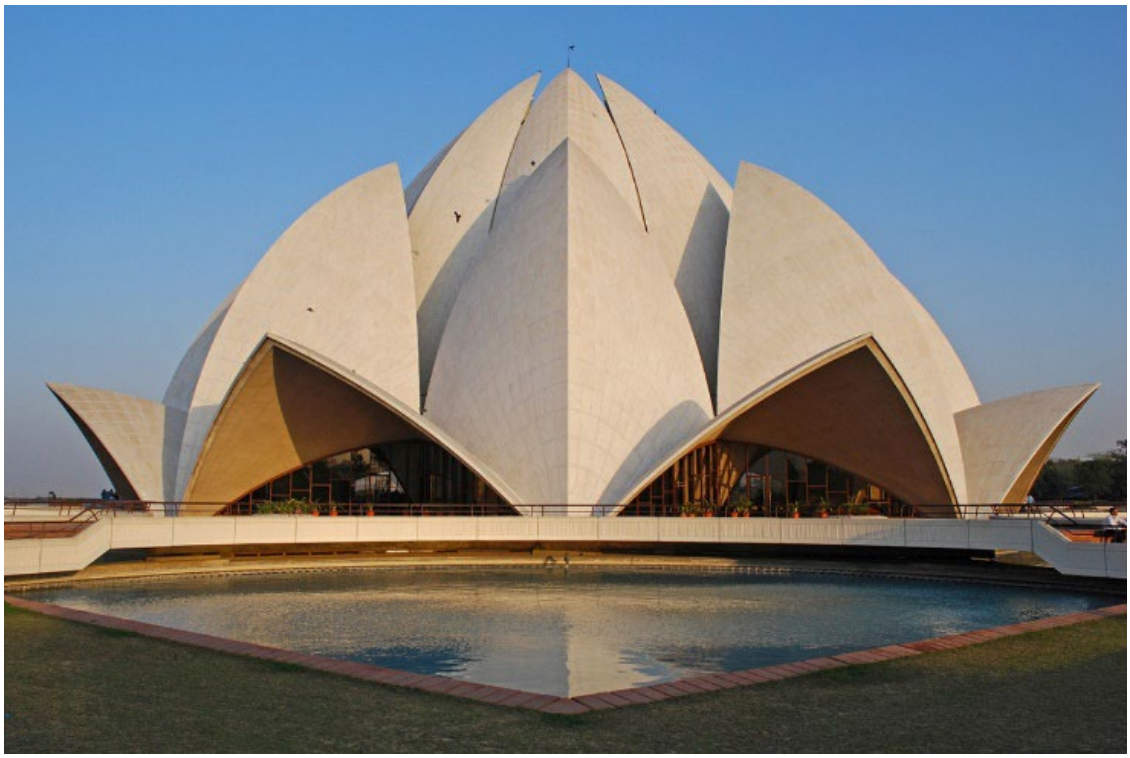

Figure 50 Exterior of Lotus Temple

[34] Sarbjit Bahga, "Lotus Temple: A Symbol Of Excellence In Modern Indian Architecture," World Architecture, last modified June 9, 2017, Lotus Temple: A Symbol Of Excellence In Modern Indian Architecture (worldarchitecture.org) .

Shown in *Figure 10*, Architect Fariborz Sahba designed the structure to be composed of 27 concrete petals, the first two layers curve inwards and the third layer curves outwards to form canopies over the nine entrances. The interior dome is modelled on the innermost part of the lotus, comprising of 54 ribs with concrete shells between them. Natural light is brought into the building through a series of skylights which filter the light into the structure in a similar way that sunlight passes through a lotus flower.[35]

The building is also self-cooling through ventilation openings in the basement which pull in fresh air that has cooled over the pools and fountains, this flows into the central hall and is then expelled through vents at the top of the building. The pools surrounding the base of the building are paired with external lighting to give the illusion of the lotus flower floating on water.[36]

The lighting of the structure' s interior uses biomimetic principals, taking reference from how light enters a real lotus flower and using this to create an evolving and atmospheric interior for the building' s users. The form itself, however, uses biomorphic design to create its shape, the building is simply meant to look like a lotus flower in reference to its cultural significance. While the structure uses a self-cooling air conditioning system, somewhat similar to that used in the Eastgate Centre, this does not come from the lotus flower itself, instead this process uses the structure like a host for this process.

The Quadracci Pavilion, Milwaukee Art Museum, Milwaukee, USA (2001)

The Burke Brise Soleil kinetic sculpture on The Quadracci Pavilion at Milwaukee Art Museum encompasses a 217-foot-wide wingspan. These wings function as a moveable sunscreen to help manage the amount of sunlight entering Windhover Hall and help control the interior temperature of the space. Inspired by the outstretched wings of a bird, the wings are made up of 72 steel fins of varying sizes. The kinetic sculpture was designed by Spanish architect and artist Santiago Calatrava.[37]

[35] World Architecture, "Lotus Temple: A Symbol Of Excellence In Modern Indian Architecture."

[36] World Architecture, "Lotus Temple: A Symbol Of Excellence In Modern Indian Architecture."

[37] Christophor Rick, "The Milwaukee Art Museum Burke Brise Soleil: Where Architecture Meets Art and Science," Milwaukee Area Science Advocates, last modified June 19, 2017, The Milwaukee Art Museum Burke Brise Soleil: Where Architecture Meets Art and Science – Milwaukee Area Science Advocates (milwaukeescience.org) .

Figure 11 The Quadracci Pavilion with closed wings

Figure 12 The Quadracci Pavilion with open wings

The wings move harmoniously; however, they give the illusion of moving separately as they all start at different angles. The fins move 90° over 3.5 minutes to open/ close the wings.[38] Wind is a weakness for the design, so built into the wings are two ultrasonic sensors which detect when the wind reaches 23MPH for 3 seconds.[39] This causes the wings to automatically close in order to maintain structural integrity.

Inspired by the form of bird wings, this structure works succinctly with the surrounding environment to provide protection from sunlight and keep control of the interior temperatures of the space. This structure works sculpturally in addition to functionally, with the design working as a combination of both biomorphic and biomimetic design.

Both The Quadracci Pavilion and Lotus Temple are highly sculptural architectural works, they are constructed with the intention of being memorable and individual. They both combine the disciplines of biomorphic and biomimetic architecture, creating spaces which are both designed with the intention of representing the natural world visually and functionally. While these designs are beautiful and individual, they are impractical to replicate and not functional within a wider context.

3.4 CONSTRAINTS OF BIOMIMETIC SYSTEMS

Pearl River Tower, Guangzhou, China (2013)

The 71-storey tower, Pearl River Tower, harvests wind and solar energy through its curvilinear form and orientation. Prevailing winds are directed into openings at each mechanical floor, these winds drive vertical turbines (seen in *Figure 13*) which generates the energy for the building to function.[40] The tower, which stands at 309 metres tall, takes inspiration for the system from sea sponges. Sea sponges harvest fuel from the sea by pumping thousands of gallons of water per day, designer, Roger Frechette, turned to sea sponges for inspiration as put by him, "we found it doing a lot of things we look to buildings to do but without mechanical energy or electricity." [41]

[38] "The Quadracci Pavilion," Milwaukee Art Museum, accessed December 14, 2022, Info | Milwaukee Art Museum (mam.org).

[39] "The Quadracci Pavilion," Milwaukee Art Museum.

[40] "Pearl River Tower, " Skidmore, Owings & Merrill, accessed January 4, 2023, https://www.som.com/projects/pearl-river-tower/#deep-dive-an-extra-sustainable-design .

[41] "Imitation of life," *The Architect's Newspaper*, September 5, 2007, https://www.archpaper.com/2007/09/imitation-of-life/ .

Figure 13 Vertical wind turbine within one of Pearl River Tower's envelopes

The east and west facades of tower are triple glazed with exterior blinds to control interior temperatures. The north and south facades have an internally ventilated double skin, both of which have automated blinds which respond to the sun exposure, allowing the most efficient shade and temperature control possible within the building. The cavity within the curtain wall is used to route return air through, the temperature of which increases as it travels upwards. This dehumidifies the outside air whilst serving as an energy source for the building.[42]

[42] Skidmore, Owings & Merrill, "Pearl River Tower."

Figure 14 Exterior of Pearl River Tower

The tower takes further measures to optimise its usage of the surrounding environment by using solar gain within the building to warm the hot water supply. Within each floor interior temperatures are further regulated through air-conditioning controlled by a chilled ceiling system and an underfloor air ventilation system. Additionally, rainwater is retained for grey-water usage.[43]

The tower uses its surrounding environment efficiently, being constructed in the optimal position for both the sun and prevailing winds to be exploited to their full capacity. The form of the building is shaped to capture the maximum amount of wind power, angling inwards towards the turbines to guide the winds into them. *Figure 14* demonstrates the two envelopes within the building' s exterior where the turbines are placed. Much like the design of the Eastgate Centre, the building is highly specialised and built for purpose, it is a largescale and costly project which cannot be applied

[43] Skidmore, Owings & Merrill, "Pearl River Tower."

to existing buildings. The constraints of these kind of structures are clear in the scale of the buildings, they require large empty plots of land, something unavailable in many cityscapes. The costs of building these structures is also something which would prevent them being a solution for many cities, they require years of research, design, and complicated, bespoke systems to be constructed. All of which puts time and monetary costs at an unobtainable level for the majority.

Looking at the Lotus Temple and Quadracci Pavillion, these buildings again are highly expensive structures, working more as pieces of art rather than commercially functional solutions which solve the problems posed. They are not something replicable, however, they were not designed to be, and they work well within their individual contexts creating one of a kind, memorable sculptured buildings. Creating these largescale, expensive structures works well in the context of a temple or museum as the revenue of visitors coming to see them, overtime will end up generating a lot more money than was used within the construction. A common theme within all these biomimetic designs is that they require a large upfront cost, something unaffordable to the majority of people. It also takes time to see a return on this investment within many of these designs, the benefits are seen years after the initial construction, but following this point they continue to be fruitful and worthy investments.

As mentioned earlier, the cost of sustainability is a privilege. The harsh reality of this is that the countries and cities which would benefit most from this, cannot afford such a privilege. By using biological systems to control temperature and lighting, energy costs would be minimal as it would make many properties self-sufficient to some degree. This could help improve people’ s mental and physical health in countries where temperatures are unbearable and air conditioning is unaffordable. After the initial investment, the upkeep costs are minimal and can with some systems end up making money back for the owners. The main issue with these systems is the initial cash injection which is required.

CHAPTER 4

4.1 BIOMIMETIC BUILDING MATERIALS

While biomimetic structures work well with their designed intention, not many are easily replicable or applicable to more than one highly specialised site. The exploration of biomimetic building materials could serve as a mainstream option for improving environmental impacts of the building industry, as it is a material, it is something that can be applied to a huge proportion of properties; both existing and newly built.

Blue Planet Systems Cement

Manufacturing cement and concrete generates between 7-8% of annual carbon dioxide emissions.[44] Concrete is formed through combining cement and aggregate; 44% of aggregate consists of carbon dioxide. As concrete is a very widely used building material, the carbon dioxide emissions from production are very high. In an effort to offset and neutralise these emissions Blue Planet Systems have pioneered a way to manufacture cement in a way inspired by the creation of reefs by coral.[45]

Both cement and coral reefs are made of limestone, within nature, the production of limestone is not a process which produces high carbon dioxide emissions, in contrast, human methods of limestone production generates high emission levels. Blue Planet Systems method uses carbon dioxide emissions captured from power plants to manufacture the aggregate. This process means that emissions are diverted from entering the atmosphere and are trapped within the concrete, as well as a reduction in emissions which would have happened as a result of traditional concrete production.[46]

This method of production is in its early stages, being trialled at a plant located in Pittsburg, California. If it proves successful, this method could revolutionise concrete production on a large scale, reducing carbon dioxide emissions within its own production, as well as trapping those released in other sectors. By creating a carbon neutral version of an already popular building material, this means that it can be applied to the same builds that concrete is currently being used for; making it an accessible way to reduce environmental impacts.

[44] Hersh Shefrin, "Blue Planet, and climate change: taking lemons and making lemonade," Santa Clara University, last modified April 4, 2022, https://www.scu.edu/illuminate/thought-leaders/hersh-shefrin/blue-planet-and-climate-change-taking-lemons-and-making-lemonade.html .

[45] Shefrin, "Blue Planet, and climate change: taking lemons and making lemonade."

[46] Shefrin, "Blue Planet, and climate change: taking lemons and making lemonade."

However, within the article, Shefrin makes the point that people may believe creating 'clean' concrete produces a "moral hazard" [47] as if "companies like Blue Planet are successful, then emitters will feel more comfortable increasing greenhouse gas emissions into the atmosphere." [48] This may mean that it works counterproductively. By producing such a material, it may be seen as a 'free pass' to pollute and stop worrying about the environment, when in fact, this technology, if successful, would need to be implemented alongside all current and future measures in order to combat climate change.

The use of these materials within a widescale context is still a fantasy, drawing back on the narrative created by the Swamp Thing comics, that a biomimetic city is idealistic and unrealistic. While Planet Earth is ready for it, humans are not. There are still many implications with using these materials on a large scale, creating moral and ethical dilemmas from production costs to people believing the environment is 'fixed' and no longer caring or paying attention to climate change in the way they would have and should have before.

4.2 BAUBOTANIK ARCHITECTURE

Baubotanik, or Living Plant Construction, is the practice of using living trees as load bearing, structural elements, harnessing their strength without cutting the trees down. As saplings are unable to bear the weight of a structure, initially a steel frame is installed to help support the weight. As the trees grow, and reach the strength and size required, the steel scaffolds are removed. For the structures to be viable, the type of tree must be able to thrive in the surrounding environment, tailoring the tree type to the location of the structure.[49]

Architects Oliver Storz and Hannes Schwertfeger started the company Bureau Baubotanik in 2010, as described by Schwertfeger; "Our projects are aimed at finding a way to use plants in high-tech environments and integrate living plants into buildings, offering a high quality of life." [50] Their most practical examples consist of bridges, pavilions, exhibition spaces and walkways, they are looking to integrate nature back into cityscapes. The company is most interested in bringing the qualities of the natural world back into high-density cities, eventually hoping to involve living materials within residential properties.[51]

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[47] Shefrin, "Blue Planet, and climate change: taking lemons and making lemonade."

[48] Shefrin, "Blue Planet, and climate change: taking lemons and making lemonade."

[49] Heike Lehmann, "Living plant construction: the vivification of architecture," *Bioeconomy BW,* October 18, 2016, https://www.biooekonomie-bw.de/en/articles/news/living-plant-construction-the-vivification-of-architecture.

[50] Lehmann, "Living plant construction: the vivification of architecture."

[51] Lehmann, "Living plant construction: the vivification of architecture."

Bureau Baubotanik believes this kind of technology could work innovatively as a way to replace green spaces which have been lost due to the construction of cities. By integrating living structures, the microclimate of an area could be improved.[52] However, there are uncontrollable factors which may prove problematic with this technology. The company notes that; "Trees do not grow at the same rate, some might be infested and damaged by pests." [53] Also stating, "…constructions involving living trees need to be pruned and inspected on a regular basis." [54] This highlights that this technology is high maintenance and must be monitored regularly. The issue of structural strength can be combated by reinforcing the trees with steel scaffolding, however, the need for consistent upkeep may prove problematic as it would become a constant expense to the owner.

Baubotanik architecture works practically as a way to reintroduce greenery into a cityscape where there may not be room for a greenspace like a park. By allowing the building itself to forge and demonstrate the connection to nature, the building could work as a park would, the trees replacing greenspaces which had been lost to urbanisation. Much like in the Swamp Thing comic, the trees are manipulated to maintain a very human and geometric form, manipulated in a way almost opposing biomimicry. While not ready for residential or widescale use, the technology demonstrates fantasy becoming reality, using the living structures to build what normally destroys them.

Platanenkubus Nagold, Nagold, Germany (2012)

Figure 15 Platanenkubus Nagold

[52] Lehmann, "Living plant construction: the vivification of architecture."
[53] Lehmann, "Living plant construction: the vivification of architecture."
[54] Lehmann, "Living plant construction: the vivification of architecture."

Platanenkubus Nagold (*Figure 15*) designed by Ludwig.Schoenle utilises six different levels of trees upon a steel structure, these trees will eventually grow into one through the "Plant Addition" technique.[55] The bottom layer of trees are planted directly into the soil, on the five further layers the trees are planted within containers which contain an automated system, constantly supplying them with nutrients and water.[56] Branches between the layers are initially artificially bonded and gradually through inosculation, a natural grafting process, the trees will fuse. This means that at a later stage, once the project is more established, the branches on the upper layers will be able to gain nutrients from the ground soil directly.[57] Once this has happened the roots on higher levels can be cut off and the living structure becomes self-sufficient. Once the trees themselves become stronger, the steel frame can also be removed, the structure then becomes self-supporting.[58]

The structure was developed for the Regional Horticultural Show in Nagold, now functioning as a "multifunctional vertical pocket park" [59] for the surrounding urban area. The idea of a self-supporting vertical pocket park is something which could be applied on a wider scale. These parks could be input into unused building plots as a way to bring greenery into urban areas; as they are vertical, they wouldn't require the same land a traditional park would. The issue with these structures is the maintenance they require. Regular health checks on the trees would be needed to make sure they can withstand the weight of the structure, don't have any pest infestations as well as general pruning and care needs. Before the structure is established the trees will also need to be tended to often to check their growth progression and stability. Whilst the constant upkeep is the same with any urban trees, to make sure they will not fall and damage people or property, the difference is that as the trees are relied on for their ability to form a structure rather than just surviving in an urban space. There are a lot of uncontrollable variables with this branch of architecture which may prove it to be inappropriate for use on a large scale.

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[55] "Platanenkubus Nagold/ Ludwig.Schoenle," ArchDaily, last modified November 28, 2016, https://www.archdaily.com/800294/platanenkubus-nagold-ludwichoenle .

[56] "Platanenkubus Nagold/ Ludwig.Schoenle."

[57] Tian Wang, "It's Alive! Architects Are Using Living Plants as Structural Building Components," *Architizer,* accessed January 28, 2023, https://architizer.com/blog/inspiration/industry/living-architecture-buildings-that-grow/ .

[58] "Platanenkubus Nagold/ Ludwig.Schoenle."

[59] "Platanenkubus Nagold/ Ludwig.Schoenle."

Figure 16 Close up of steel frame and trees intersecting

Forest bathing

Shinrin-yoku, or forest bathing, is a practice encouraging people to spend time within nature. The Japanese Ministry of Agriculture coined the term in 1982, with the practice linked with lowering blood pressure, heart rate and cortisol levels; a harmful hormone which is released when the body is stressed. Spending as little as 10-20 minutes a day outdoors is found to increase happiness and reduce stress.[60] The goal of this practice is mindfulness, spending 20 minutes immersed within nature, whether that be an urban park, beach, or forest, focussing on the surroundings and detaching from daily life. Providing a space for people to link themselves back to nature within cityscapes will enable them to experience the benefits of this practice. Baubotanik architecture could provide spaces where living trees are integrated to a cityscape, allowing people to immerse themselves with nature whilst in an urban area. Baubotanik buildings like Platanenkubus Nagold could allow people to feel as if they are in a pocket-sized forest and providing a sanctuary within a city. Green roofs could also have this affect, generating a link back to nature. The exploration of this practice highlights the importance of introducing biophilic, biomorphic and green spaces within a city in aid of both the mental and physical health of people.

[60] "Forest bathing: What it is and why you should try it," Kaiser Permanente. THRIVE, last modified April 8, 2022, https://thrive.kaiserpermanente.org/thrive-together/live-well/forest-bathing-try .

CONCLUSION

During this thesis, the modern disciplines of biomimicry, biomorphism and biophilia have been explored in the context of understanding their relationship between the natural world and human design. By delving into how each discipline' s benefits and drawbacks effect people within the context of a city, it demonstrates that no one branch is 'better', each has their own assortment of uses. By using them in collaboration, such as in the Sagrada Familia or Lotus Temple, the beauty biomorphism generates and the functionality of biomimicry, works succinctly to create functional works of art. This innovative branch of bio-inspired design works to not only improve physical feelings such as temperature within a space, but the emotions a space evokes, improving mental wellbeing for users and visitors.

It is important to note that these designs are costly, not only in an economic sense but also in a social and environmental context. While many of these designs benefit the environment post construction, the construction process itself would produce a large amount of pollution. From the creation of materials and systems; to the instillation process. The introduction of these biomimetic and biomorphic buildings into the cityscape could also cause the gentrification of poor urban areas. These buildings use innovative systems which would entice investors, inviting wealthier people into areas which would have been previously unattractive to them, pushing out the original dwellers.

While the narrative of an entirely biomimetic city is still a fantasy rooted in optimism, the introduction of biomimetic building materials, like the carbon neutral cement created by Blue Plant Systems, are a step closer to the possibly. They take one of the highest polluting and most common building materials and create an environmentally conscious alternative, a product which could revolutionise the building industry. It does not come without issues however, with the possibly it could cause people to become lazy with preventing carbon dioxide release, large polluters could see it as a free pass to pollute. With a different production process, the costs of this cement may also be higher, making it inaccessible to many people. The wealthy, again, become the beneficiaries of a product which would revolutionise the lives of those struggling economically.

Baubotanik architecture could help bridge the gap between nature and man-made, blurring the boundaries of each. The fantasy building technique depicted within the Swamp Thing comic has a likeness to Baubotanik architecture, using the living in a manipulated and artificial way; forcing nature to fit in with human ideals. With Baubotanik architecture it is important to realise that nature is still in control, there are variables within this discipline which humans cannot change. This may prove the discipline to be practically and economically unstainable. What is worth noting however is that what was once utter fiction is now becoming a reality.

The roots of Biophilia and Biomorphism are clearly linked to the Art Nouveau movement, taking the idea of bringing nature inside. With the negative impacts a detachment from nature causes on the body, both mentally and physically, the organic and decorative nature of these disciplines could revolutionise residential and commercial spaces, making them healthier environments for people to live and work within.

The majority of biomimetic systems are installed within large new builds, which have very specific requirements to be able to function. There is clear potential within the discipline of biomimetic architecture for a future where it can become an accessible and more widespread building option. Currently, the ability the to install the type of systems seen in the examples of the Eastgate Centre and Pearl River Tower require a specially built property and cannot be applied to the existing. The Solar Leaf Panels which provide the skin for BIQ House, are applicable to both the existing and new builds, they are a step towards accessible biomimetic systems. With all of these systems there may be unforeseen implications which minimise their benefits, whether it be social, economic, or environmental; highlighting the fact that within the industry of architecture, sustainability is often a privilege. This narrative poses the question, what will the future of biomimetic architecture look like?

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Figure 13 Vertical wind turbine within one of Pearl River Tower's envelopes - "The tower's envelope includes four inlets or ducts, each containing a vertical axis wind turbine." Griffith, Tim. [image online] Architectural Record. Available at: https://www.architecturalrecord.com/articles/7971-pearl-river-tower [Accessed January 31,2023]

Figure 14 Exterior of Pearl River Tower - "Currently, three towers are taller than the 1,020-foot PRT, including the immediately adjacent Pinnacle, a 1,181-foot skyscraper that resembles the Empire State Building." Griffith, Tim. [image online] Architectural Record. Available at: https://www.architecturalrecord.com/articles/7971-pearl-river-tower [Accessed January 31,2023]

Figure 15 Platanenkubus Nagold – "After Completion." Ludwig.Schoenle. [image online] ArchDaily. Available at : https://images.adsttc.com/media/images/583b/672b/e58e/cebc/9300/010e/slideshow/after_completion.jpg?1480288036 [Accessed January 31,2023]

Figure 16 Close up of steel frame and trees intersecting – "Adhesions" 2020. [image online] OfficeForLivingArchitecture. Available at: https://www.o-l-a.eu/projekt/platanenkubus-nagold Accessed January 31,2023]