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A MORPHOLOGICAL REVIEW OF FAÇADE PRECEDENTS EMPLOYING BIOMIMETIC DESIGN PRINCIPLES

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ABSTRACT

The façade functions to separate the interior and exterior spaces of a building. This separation supports the building in providing protection from weather conditions, especially sunlight, for its occupants, and plays a role in reducing the building's energy demand. At the same time, environmental issues pose distinct challenges for façade design, as environmental degradation increases the likelihood of rising global temperatures, which in turn leads to high energy use. Therefore, façade technology is required to be efficient and durable. One strategy to achieve this goal is the biomimetic approach. The research method uses a qualitative approach through the collection of secondary data in the form of façade precedents employing biomimetic principles. The sampling technique used is judgmental sampling, in which precedents are selected based on the architects' narratives and the morphological characteristics that represent biomimetic principles. Two precedents from tropical and subtropical regions, Nicolas San Juan (Mexico) and The Alpha (Australia), were selected as case studies. The research stages include a literature review on façades and biomimicry, the development of a biomimetic assessment matrix, and the analysis of both precedents using the matrix to identify the application of biomimetic principles in façade design. This study is a foundational research that can be further developed by increasing the number of precedents and expanding the scope of biomimetic aspects, considering that this study is limited to morphological aspects and relies on secondary data. From this process, the research shows that both precedents successfully apply biomimetic principles consistently in their façade structures and patterns, thereby providing references for the development of biomimetic façade design in future studies.

Keywords: façade; biomimetic; morphological; precedent study.

INTRODUCTION

The environment is an important aspect that must be considered in the architectural design process. Many buildings pay little attention to the environment, resulting in disasters that affect human activities and health. These disasters arise from the inability of humans to build a relationship between buildings and nature (Van der Ryn & Cowan, 2007). This phenomenon becomes a challenge for architects in creating a connection between buildings and nature as an effort to reduce the negative impacts of buildings on the environment. The objectives of establishing a relationship between buildings and nature include producing buildings with minimal impact on nature.

One of the strategies is to incorporate nature into the design process. Designs that incorporate nature aim to indirectly minimize the impacts of environmental degradation (Van der Ryn & Cowan, 2007).

One strategy to actualize the relationship between design and nature is by using nature as a source of learning and inspiration in the design process. This design strategy is known as biomimetic (Krivenko, 2021).

Biomimetic will generate principles derived from natural models and systems that operate in nature to be applied in architectural design. Nature that is used as inspiration in architectural design is studied from the natural elements present around the design context. The nature that exists around the design location serves as evidence that

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the natural model or system has successfully adapted to the environment. By incorporating these natural models or systems into the design process, design solutions that are superior will emerge (Dumanli, 2016).

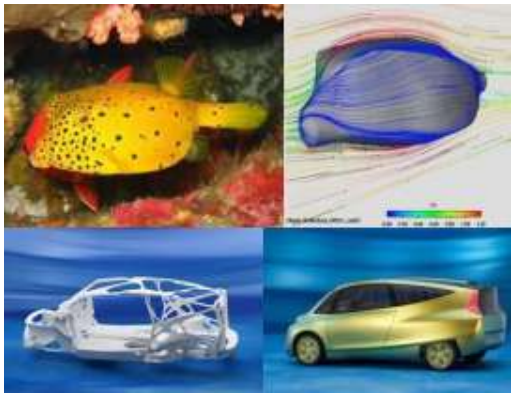

Figure 1. Implementation of biomimetics in car design
Source: (Xhexhi, 2020)

One of the elements that most influences a building's energy consumption is its façade element (Avinç, Koç, & Selçuk, 2024). The building façade is the intermediary medium between the exterior environment and the interior space. The following building components are included in the façade: exterior walls, exterior doors, windows, and façade openings (such as perforated blocks/roster) (Avinç, Koç, & Selçuk, 2024). There are several important parameters in façade design, namely solar gain control, natural ventilation, daylighting, visual comfort, heat control, moisture control, and noise control (Avinç, Koç, & Selçuk, 2024).

This paper emphasizes the benefits of façade design developed using a biomimetic approach. A design approach, such as the biomimetic approach, can be considered successful when the designer is able to apply design knowledge derived from a gradual process, starting from literature studies to the use of software in the design process (Geest, Tekinerdogan, & Catal, 2020).

Understanding the principles of a particular design approach provides a foundation for designing (Indrosaptono, Andadari, & Setiyawan, 2021), including the biomimetic approach. Therefore, this research aims to obtain the theoretical and practical principles of the biomimetic approach in façade design.

METHODOLOGY

The method used is qualitative, with data collection techniques carried out through secondary data in the form of façade precedents that use a biomimetic approach. This qualitative method is one of the methods that can be used to conduct architectural precedent studies (Kardina, Susetyarto, & Ischak, 2022).

The data collection was conducted using the judgmental sampling technique (Yaman, 2021), n which the precedents were selected based on the architect's narrative and their forms that apply the biomimetic approach. The number of precedents selected for the study is two, from Mexico and Australia, representing regions with tropical and subtropical climates.

The research stages begin with a literature study related to building façades and biomimetic, then the literature study was analyzed into a biomimetic fulfillment matrix. This matrix was used to assess two precedents, namely Nicolas San Juan in Mexico and The Alpha in Australia. Both precedents were analyzed using the biomimetic approach matrix to examine the manifestation of the approach in their façade designs. The results of the analysis can be used as a reference in designing façades with a biomimetic approach.

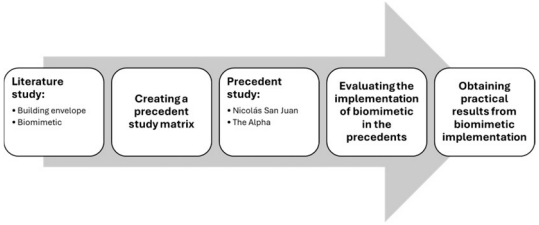

Figure 2. Research Flow

This study is a basic research that can be further developed in subsequent studies, particularly by increasing the number of precedents to enrich studies related to the application of façade design using a biomimetic approach. In addition, a more comprehensive biomimetic study can be conducted, as this research limits the biomimetic analysis to morphological aspects only. Another limitation of this study is the qualitative assessment technique, which is interpreted by the author based on available secondary data such as the architect's textual explanations and precedent photographs.

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RESULTS AND DISCUSSION

Facade

The buildings we inhabit today consist of various architectural elements. One of the architectural elements that make up a building is the building façade. A façade is the outermost part of a building, consisting of parts that are opaque and parts that are transparent (Pemerintah Provinsi DKI Jakarta, 2012). The façade provides protection for interior spaces because it separates these two types of spaces. Façade protection of interior spaces includes shielding from heat, radiation, wind, rain, noise, pollution, and other factors (Pemerintah Provinsi DKI Jakarta, 2012). The façade plays an important role in reducing energy loads for cooling and lighting as well as protecting building occupants from other outdoor climatic factors.

One of the roles of the building façade is to reduce energy use through strategies such as minimizing heat loss or gain, decreasing the demand for excessive cooling, heating, and lighting, and utilizing passive solar principles (Shan & Junghans, 2023). In addition, sustainable façade design aims to reduce negative environmental impacts by using low-emitting materials, implementing pollution control measures, and reducing greenhouse gas emissions (Shan & Junghans, 2023).

Beyond environmental roles, façades also contribute to improving the well-being of users, not only in measurable ways but also psychologically, with the goal that the façade design can enhance a person's sense of happiness and pride in their environment (Prieto & Oldenhave., 2021). This sense of pride refers to the façade as a symbolic expression of a building (Prieto & Oldenhave., 2021).

Façade designs that psychologically create a sense of pleasure, because they are aesthetically pleasing, typically employ theories of proportion and symmetry considered harmonious (Prieto & Oldenhave., 2021). This resonates with the concept of natural order. In his book, Christopher Alexander states that elements derived from nature are key to understanding architectural beauty. According to him, there are 15 design principles in his book The Nature of Order, namely: levels of scale, strong centers, boundaries, alternating repetition, positive space, good shape, local symmetries, deep interlock and ambiguity, contrast, gradients, roughness, echoes, the void, simplicity and inner calm, and not-separateness (Alexander, 2002).

Therefore, contemporary façade design has many objectives, not only quantitative but also qualitative. Multi-objective façade designs are mostly aimed at energy efficiency and human comfort, while the façade elements most frequently discussed are glazing and window dimensions (Shan & Junghans, 2023).

Biomimetic

The Earth is constantly evolving. This evolution leaves traces and evidence of the existence of strong and weak organisms. Weak organisms are vulnerable to extinction, whereas strong organisms will survive due to the dynamic nature of the universe. These strong organisms often inspire many scientists to develop certain technologies that facilitate human life. This phenomenon also influences the context of architectural design. Many architects, both in academia and in practice, adopt models or systems from nature in their designs (Xhexhi, 2020). This leads to the possibility that the resulting architectural products become sustainable. The term used to describe this behavior of architects is biomimetic.

Biomimetic in architectural design is a design process that guides the formation of design decisions through studies inspired by nature, thereby creating logical technologies to solve problems (Krivenko, 2021). Organisms used as learning models in the biomimetic process serve as prospective role models in building envelope design. Biomimetic can be summarized in this argument: fossils are failures, and the universe before us today represents successful learning (Xhexhi, 2020).

Biomimetic is an interdisciplinary science combining biology, technology, and design. Biomimetic does not only address how we imitate nature but also provides a full understanding of biological concepts to be developed into technological solutions (Avinç, Koç, & Selçuk, 2024).

There are three levels of the biomimetic approach: organism level, system level, and ecosystem level. The organism level studies specific organisms, such as certain animals or plants, either entirely or partially. The system level studies how certain organisms behave in relation to their external context. Finally, the ecosystem level replicates the ecosystem as a whole, examining how a system or specific

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functional principle contributes to the effective operation of the ecosystem (Avinç, Koç, & Selçuk, 2024).

Furthermore, the biomimetic approach is divided into two branches based on the initial stage of the approach: the problem-driven approach and the solution-driven practice (Faragalla & Asadi., 2022). The problem-driven biomimetic approach is characterized by studying the problem first, then developing solutions to it using relevant natural elements. In contrast, the solution-driven practice studies specific functions from nature first and then examines which contexts are relevant for implementing the design (Faragalla & Asadi., 2022).

From another perspective, biomimetic can be identified in three categories: physiological, morphological, and behavioral. This study focuses more on the morphological aspect of biomimetic. The morphological aspect consists of shape, pattern, and size (Avinç, Koç, & Selçuk, 2024).

Discussion

Based on the study above, it was found that façades have the primary functions of reducing energy consumption, minimizing negative environmental impacts, and enhancing the well-being of building users. On the other hand, the biomimetic approach can be examined through its morphological aspects. The discussion will be conducted to assess apartment precedents using the evaluation matrix in Table 1. The functions of the façades will be evaluated qualitatively through secondary data, such as photographs and textual explanations from architects, using the morphological aspects of the biomimetic approach. The following matrix was used in the discussion process of this study.

Table 1. Discussion Matrix

Façade Function			Shape	Pattern	Size
(SHAN & JUNGHANS, 2023)	Reducing energy consumptio	minimize heat loss or gain decrease the demand for excessive cooling, heating, and lighting utilize passive solar principle	Fulfillment through façade shape	Fulfillment through façade pattern	Fulfillment through façade dimension and scale
(SHAN & JUNGHANS, 2023)	Reducing negative environmental impacts	low-emitting materials implementing pollution control measures reducing greenhouse gas emission			
(YAMAN, 2021)	Enhancing building users' wellbeing	Symbolic expression of the building Proportion and harmonious symmetry Design that resonates with nature			

The table above presents the evaluation matrix of façade design using a biomimetic approach. This study examines two precedents. The precedents are assessed based on the ability of their façades to implement the biomimetic approach. Façades designed using the biomimetic approach are evaluated through three morphological elements: shape, pattern, and size. The following are the precedents analyzed in this study.

Nicolás San Juan, Taller 13, Mexico

Nicolás San Juan is an apartment building located in Colonia del Valle, Mexico. The building occupies a strategic location, which influenced the architects to create a distinctive structure (Taller 13, 2009). The uniqueness of this building can be observed in the standout character of its façade. This distinctive façade character was developed by the architectural consultant Taller 13, who drew inspiration from nature.

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Figure 3. Organic Façade Technology
Source: (Taller 13, 2009)

The consultant used the local trees around the site as inspiration during the design process (Taller 13, 2009). This influence is visually evident in the geometry of the structure, which gives the façade an organic appearance. According to the architects, tree-like forms in the design create stronger structures due to the even distribution of loads (Taller 13, 2009). The durability of the building's façade is enhanced through a structural design that features large columns at the base, branching upwards with gradually decreasing dimensions. The structural system is further reinforced by interlocking branches that connect with each other.

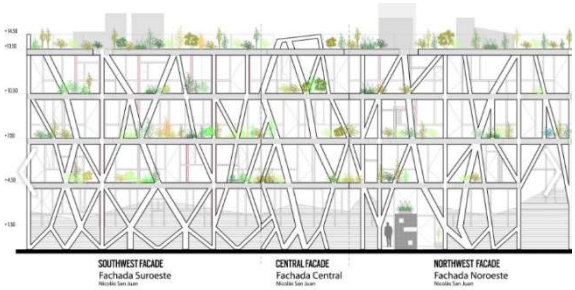

Figure 4. Facade technology detail
Source: (Taller 13, 2009)

The building's efficiency values can also be observed through the use of color and materials on the façade. Most of the colors applied are light shades (Taller 13, 2009). Light colors have a high albedo, which reduces heat absorption by the façade, thereby lowering the building's cooling load (Krivenko, 2021).

The building exhibits a proportional scale and a human-centered design, as the façade pattern dimensions are organized according to the floor heights. The façade patterns are arranged in a seemingly random configuration, creating a dynamic appearance, similar to the irregular forms of a tree.

The Alpha, Tony Owen Partners, Australia

The Alpha is a mixed-use building that accommodates residential, retail, and public spaces (Tony Owen and Partners, 2015). These three functions are realized in a building with a distinctive character. This unique character is evident in the organic façade design, which forms a hexagonal pattern.

Figure 5. Hexagonal pattern facade
Source: (Tony Owen and Partners, 2015)

The hexagonal façade was realized as an architectural strategy to create an efficient building envelope. As an efficient façade with an organic form, it is referred to by the architects as an environmental screen (Tony Owen and Partners, 2015). *This environmental screen functions to control sunlight while enhancing potential views out of the site by framing them through the hexagonal pattern formed on the façade* (Tony Owen and Partners, 2015).

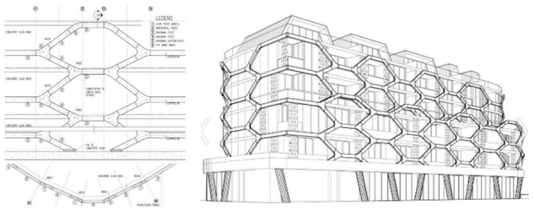

Figure 6. Detail of the hexagonal pattern on the façade (left), overall view of the building (right) Source: (Tony Owen and Partners, 2015)

To realize the hexagonal pattern in the construction process, the building utilized digital technology during the design phase. This digital technology quantified the benefits of the façade in terms of efficiency. As a result, the cost of designing this façade was 2.5% more efficient compared to a conventionally built façade (Tony Owen and Partners, 2015). The envelope's benefits are

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further supported by its ability to reduce radiation exposure into the interior, thereby lowering the building's energy consumption. The energy-reducing performance of the façade is also enhanced by the use of light colors on its surface (Tony Owen and Partners, 2015).

Observation Results

The summary of the precedent study results can be observed through the evaluation matrix below. The matrix illustrates the mechanism of fulfillment using indicators related to biomimetic principles, consisting of shape, pattern, and size.

The discussion is conducted by marking Y if the morphological aspect can be observed to fulfill the designated façade function based on secondary data. Conversely, X is marked if the morphological aspect cannot be identified as fulfilling the façade function in the matrix.

Tabel 2. Discussion Results Matrix

Nicolás San Juan, Taller 13, Mexico

Façade Function		Shape	Pattern	Size
Reduce energy consumption	minimize heat loss or gain	Y	Y	Y
	decrease the demand for excessive cooling, heating, and lighting	Y	Y	Y
	utilize passive solar principle	Y	Y	Y
Reduce negative environmental impact	low-emitting materials	X	X	X
	implementing pollution control measures	X	X	X
	reducing greenhouse gas emission	Y	Y	Y
Improve occupant wellbeing	symbolic expression of the building	Y	Y	Y
	harmonious proportion and symmetry	Y	Y	Y
	design resonating with nature	Y	Y	Y

The Alpha, Tony Owen Partners, Australia

Façade Function		Shape	Pattern	Size
Reduce energy consumption	minimize heat loss or gain	Y	Y	Y
	decrease the demand for excessive cooling, heating, and lighting	Y	Y	Y
	utilize passive solar principle	Y	Y	Y
Reduce negative environmental impact	low-emitting materials	X	X	X
	implementing pollution control measures	X	X	X
	reducing greenhouse gas emission	Y	Y	Y
Improve occupant wellbeing	symbolic expression of the building	Y	Y	Y
	harmonious proportion and symmetry	Y	Y	Y
	design resonating with nature	Y	Y	Y

The study of the two precedents, Nicolás San Juan and The Alpha, demonstrates that the role of façades within a biomimetic approach can be observed through three morphological elements: shape, pattern, and size. These three elements were analyzed to assess the extent to which the façades fulfill the main functions: reducing energy consumption, mitigating environmental impact, and enhancing occupant wellbeing.

In general, both precedents show a tendency for shape, pattern, and size to contribute significantly to energy efficiency. This is evident in the façade configurations, which minimize heat transfer, employ patterns that support natural daylight control, and regulate dimensions to create façade depth and shading variations consistent with passive design principles.

Regarding environmental functions, the precedents indicate that morphological aspects alone cannot fully capture the use of low-emitting materials or pollution control measures. These aspects were not detectable through visual and narrative secondary data and thus could not be confirmed in the matrix. However,

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morphological elements indirectly contribute to reducing greenhouse gas emissions by improving passive building performance and lowering operational energy needs.

In terms of enhancing wellbeing, both precedents consistently fulfill this function. Nicolás San Juan and The Alpha feature façades with strong symbolic expression, harmonious proportions, and pattern configurations that resonate with principles of natural order. This supports the argument that façades not only serve technical functions but also contribute to more emotional, aesthetic, and human-centered spatial experiences.

Overall, the observations indicate that the biomimetic approach, through morphological aspects, can serve as a tool to evaluate the effectiveness of façades in achieving multi-objective design goals. The analysis confirms that each element, shape, pattern, and size, contributes differently to façade performance, and all three are essential in realizing the integration of energy efficiency, environmental responsibility, and occupant wellbeing.

CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The precedent study shows that applying a biomimetic approach to façades provides benefits in energy efficiency, environmental impact reduction, and enhancement of occupant wellbeing. Both precedents exhibit several consistent similarities based on the analysis of morphological aspects.

The façade shape in both buildings demonstrates distinctive organic geometry, functioning as a passive strategy to respond to light and heat. The façade pattern shows repetition and configurations inspired by nature, supporting daylight performance and creating dynamic visual quality. Furthermore, the façade dimensions and scale are proportionally designed to promote efficiency and visual comfort. In addition, the use of bright colors in both precedents contributes to reducing heat absorption.

Overall, these similarities indicate that the biomimetic approach, through shape, pattern, and size, can serve as an effective foundation for creating façades that are both efficient and provide aesthetic and comfort value to occupants.

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