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INTEGRATION OF DIGITAL DESIGN AND NATURE: Using Hibiscus Leaf as a Model for Building Skin Fabrication

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ABSTRACT

Digitally fabricated facades are becoming seemingly popular in architecture. Digital manufacturing and its recent developments are helping towards a shift from geometry to process-centric design. In the natural world, the shape is structured through growth and adaptation, resulting in hierarchically structured constructs exhibiting complex morphological properties. This paper proposes an example of such process-centric practices with the integration of design and nature while utilizing the living and natural systems which become building blocks of the skin. Hibiscus Leaf, the subject of study, is analyzed concerning its processes, properties, and characteristics, which are used to derive a basic module for building envelope design.

Keywords: Nature-based designs, 3D modeling, Parametric design, Digital geometry, Building skin, Biomimetic

INTRODUCTION

Nature-based designs are becoming popular and their role as user interface interaction models is increasing rapidly. This expansive, constantly accessible surface allows for innate physical interactions and can even be successfully used without any visual cues (Ogata, et al.,2013; Weigel, et al.,2014). But nature-based input hasn't yet been discovered except in the context of mobile computing (Gannon, et al.,2015). In this research, nature is examined as a collaborative input surface for 3D modeling and fabrication. Parametric 3D modeling along with other various special advantages makes it possible for a wide range of users to take part in digital design. While requiring little prior knowledge for the majority of interactions, they enable expressive digital geometry. However, these systems struggle to generate expressive forms and permit high precision control. Therefore, the digital geometry produced is primarily restricted to abstract forms (Kim, et al.,2005; Zhang, et al.,2013).

Skin can help users naturally generate accurate forms around extremely complicated physical environments since it serves as an input surface as well as the primary canvas which is important for digital design (Gannon, et al.,2015). Additionally, individuals may design and create building skins when new technologies like 3D printing and digital fabrication are accessible to larger audiences. This study attempts to investigate workflows for design and manufacturing that employ the skin as an input medium. This article emphasizes the study of the biomimetic evolution of skin design. The strategy suggested in this study reveals possible applications of biomimicry for improving the built environment and its capacity for regeneration while also defining the many stages of biomimicry.

Biomimicry in Architecture

The necessity for sustainable building is growing in reducing human impact on the environment which is becoming more crucial with each passing day. Utilizing natural resources responsibly and managing the infrastructure will help conserve finite resources, cut down on energy use, and enhance the quality of the environment. A new type of sustainability, like biomimicry, has been advanced to realize a sustainable future as sustainable design gains widespread acceptance. (McLennan, 2004).

Since biomimicry was recognized as one of the most crucial sustainability principles, it has attracted the attention of environmental designers, where the architect is a prominent role. From biology, architects have drawn inspiration since the early 19th century. Architects have strived to develop ways in a design that are similar to the natural processes of growth, development, and evolution, rather than just copying natural shapes. (Russell, 2004)

Methods to Biomimicry

Approaches to using biomimicry in design often fall into one of two categories:

— Design looking to biology is the process where human needs or design challenges are defined and then we look in nature that how other organisms or ecosystems address it

— Design influenced by biology is the process to recognize a specific organism and analyze its distinctive properties, processes, and function for incorporating it into human designs (Biomimicry Guild, 2007).

Probably, the basic method to solving a given problem and the concern of how structures interact with one another as well as the ecosystems they are a part of will not be examined as a result of architectural design when natural analogs are matched with man-made design difficulties.

Biology influenced design

When biological knowledge affects human design, rather than focusing on identifying design difficulties, the combined design process depends on individuals possessing first-hand knowledge and understanding of pertinent biological and ecological research. Examples are Sto's Lotusan paint, which makes structures to be able to self-clean like the lotus flower since it possesses a hydrophobic surface which is helping it to rise spotless from muddy water, as described by (Baumeister, 2007).

A method for interpreting the applicability of biomimicry

Form, Process, and Ecosystem are the three levels of mimicking natural systems to solve a design problem for the above-mentioned methods (Biomimicry Guild, 2007). Form and process are elements of an organism or environment that can be imitated while studying it. However, the ecosystem is what may be investigated to find specific features which can be imitated. A method for interpreting the applicability of biomimicry is suggested in this study while highlighting biomimicry and its potential as a way to improve our built environment and its capacity for regeneration and identify various stages of biomimicry. This overview can help designers intending to utilize biomimicry to improve sustainability to identify some efficient and helpful courses of action by examining the degrees of biomimicry that have emerged. It is addressed in the framework of research which aspect is imitated. There are three stages of mimicry, which may be shown by looking at current biomimetic technologies: the organism, behavior, and ecology. (Biomimicry Guild, 2007). The detail of these three above-mentioned stages are as follows

First Stage, Organism

It concentrates on a particular living thing, like a plant or an animal, and can replicate the complete organism or only a specific aspect of it. The normal lifespan of a species of living thing is hundreds of years and these species have survived the constant changes on Earth. Knight (2001) discusses this particular biomimicry at the organism level. The surface of the beetle(insect) was examined and mimicked to use for other prospective uses like removing fog from airport runways and enhancing dehumidification equipment. Research and advancement have occurred (Baumeister, 2007). Human beings can, thus, draw from a large body of precedents to address societal issues that may have already been handled by organisms, typically in ways that are efficient in terms of energy and materials. According to Alberti et al. (2003), this is beneficial for people, especially as access to resources, the climate, and knowledge of the effects of present human activities' detrimental effects on many of the world's ecosystems grow.

Second Stage, Behavior

This stage involves imitation of behavior and may translate some specific aspect of an organism and its activity relating to a broader context. Numerous organisms experience the same environmental conditions that people do and must find solutions to related problems. As was mentioned, these creatures typically function within the environmental carrying capacity of a given location as well as the available energy and material restrictions. According to Reap et al. (2005), these margins and the limitations that result in the ecological role, and adaptations in ecosystems mean that not only do these organisms are well-adapted to their surroundings which continue to evolve, but also their behaviors and relationships with other different species or groups of organisms are playing a role. In this stage of biomimicry, the behavior of the creature is imitated rather than the organism itself. It could be able to simulate the interactions between different species or groups of animals in some ways. For behavior-level mimicry, moral judgments about the appropriateness of the replicated behavior for a human environment must be made. For instance, in the construction of passively regulated and thermally comfortable buildings, it might be acceptable to emulate the construction behavior (and results of that) of termites. However, if universal human rights are cherished, replicating the social organization of termite colonies would not be appropriate. Instead of imitating general building and survival behaviors that may be extended to social or economic sectors without careful study, it might be more acceptable to imitate specific behaviors that will boost the sustainability and regeneration potential of human-built environments. In this case, it might be more suitable to imitate complete systems as opposed to individual species (Zari,2007).

Third Stage, Ecosystem

It entails reproducing complete ecosystems as well as the fundamental principles that underlie them. According to Marshall (2007), Eco-mimicry is a sustainable kind of biomimicry when the goal is the well-being of people and ecosystems, as opposed to "power, prestige, or profit." The term has also been used to represent the replication of ecosystems for design (Russell, 2004). The importance of architectural design that is based on an understanding of ecology advocates a shift to regenerative design (Reed, 2006). Ecosystem-level biomimicry is widely used by researchers involved in industrial, construction, and building ecology (Kibert et al., 2002,). According to Reap et al. (2005), an ecosystem-based biomimetic design can be used at a variety of temporal and spatial scales and can act as a starting point for a sustainable or regenerative design approach for a particular location.

There are an additional five possible dimensions to the imitation inside each of these stages. The form, material, construction, function, or capability of the design and all could be biomimetic, like in terms of how it looks (form), feels (material), is manufactured (construction), operates (process), or what it can accomplish (function) (Zari,2007). The ecosystem level of biomimicry, for instance, might be represented by a collection of systems that can interact like an ecosystem. The specific design of such a system might be based on one organism or its behavioral system, but as a whole represents a biological ecosystem that is composed of the intricate interactions between a large number of different organisms.

CHANNELING DIGITAL DESIGN AND FABRICATION

We investigate how patterns develop in nature using coding and design. (Design, 2013). How can we apply the same growth principles to design? The rigid uniformity of mass production is liberated by digital manufacturing, and the natural world provides a new method of manufacturing that yields a range of results.

Skin Design: Inspiration from Hibiscus Leaf

The skin design which shall be discussed later in this paper has evolved using Hibiscus Leaf (Fig.1) as the basic model.

Figure 1 : Hibiscus leaf.
Source: Authors' compilation

Stages of biomimicry chosen for building skin design

The level of biomimicry that has been used in the building skin fabrication is a combination of Biomimicry at the first stage (Organism) and 2nd stage (Behavior). The basic design, in this article, has evolved from the first stage (Organism), while the function of the skin has evolved from the 2nd stage (Behavior).

Morphology (large-scale features)

An angiosperm's structurally complete leaf is made up of a petiole-the leaf stalk, a lamina which is the leaf blade, and stipules that are small structures on either side of the petiole. Some species do not generate leaves with all of these structural elements. For them, the blade can be laminar (flattened), with or without a petiole (Jasiwal,2022). For determining a plant's species, external leaf traits like form, edge, hairs, presence of stipules, and the petiole are crucial. Leaves grow predictably and they develop into a particular pattern and shape before stopping.

Divisions of the blade

Based on how the blade (lamina) is divided, there are different types of leaves. A straightforward leaf has a continuous blade. Even if the shape of a leaf is made up of lobes, the main vein is not visible in the spaces between the lobes (Jasiwal, 2022)

Leaf Venation

Veins frequently mimic the shape of leaves. They may break the margin and cause the leaf edges to end in little points, bristles, or spines. They may also curve along the leaf following the margin. The veins can give the leaf surfaces unique textures. This makes it easier to describe the plant and appreciate its beauty. Leaf veins can exhibit several traits, such as both impressed and reticulate veins, just like many other aspects of leaves (Fig. 2 & 3) (Manisha, n.d.).

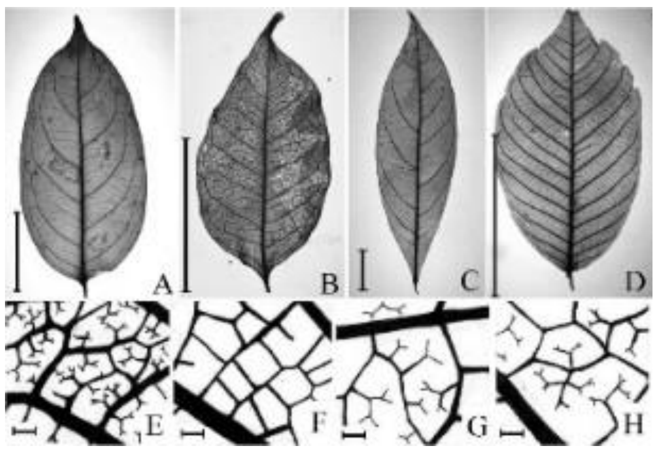

Figure 2: Leaf Venation.
Source: Correa et al., 2015

Characteristics of Hibiscus Leaf

Some of the identified characteristics of the hibiscus leaf are

- Hierarchy of leaf veins
  - Hibiscus leaf veins follow the hierarchy of patterns as Primary Veins, Secondary Veins, and Tertiary Veins (Fig. 4)
- Divergent Angles
- Variety in pattern
- Variety in shape
- Pattern generates interconnecting loops

Processes of Hibiscus Leaf

- Prone to resilience
- Water resistant
- Dirt-resistant
- Gathers Light from the sun

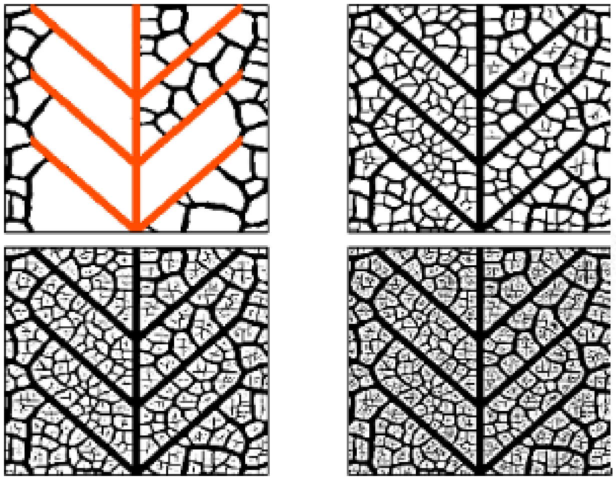

Figure 3: Hierarchy of veins
Source: (Laguna et al., 2008)

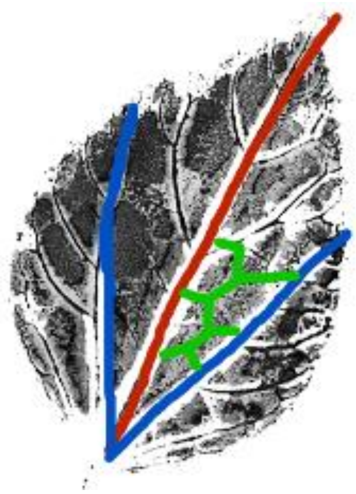

Figure 4: Hierarchy of veins in hibiscus leaf
Source: Authors' compilation

DEVELOPMENT OF MODULE: USING HIBISCUS LEAF AS INSPIRATION

Using the characteristics of the hibiscus leaf, a module has been developed, which will be further replicated and combined using digital design techniques to fabricate the skin.

Design Process:

The design of the module has been derived from the characteristics of the hibiscus leaf, its properties, and the processes that it follows. The resultant module mimics the properties of a leaf. The following sketches show the design process and stages of module development. (Fig. 5 & 6)

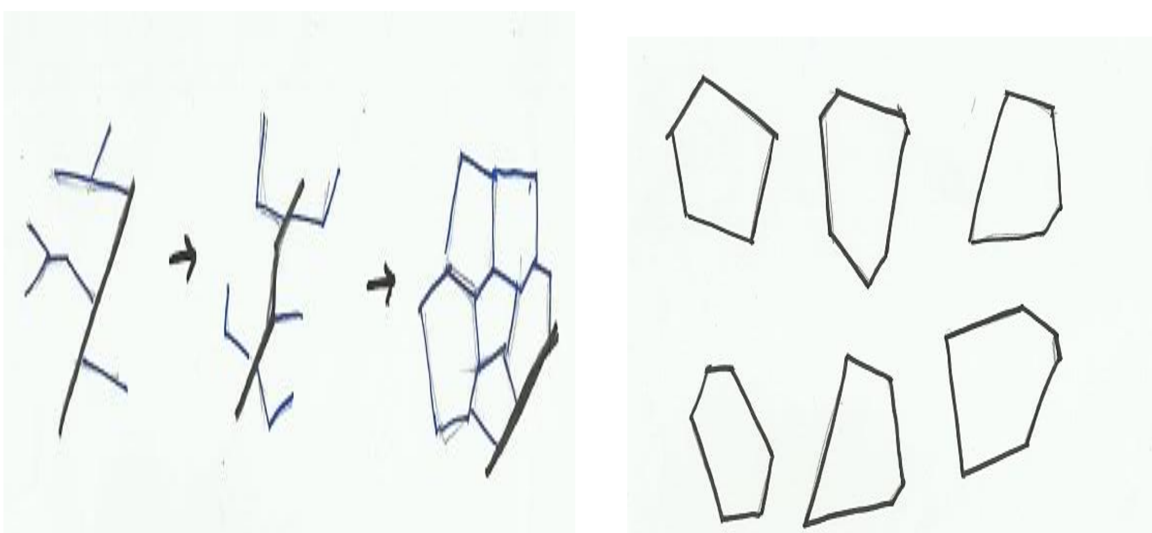

Figure 5: Initial sketches of pattern and shape
Source: Authors' compilation

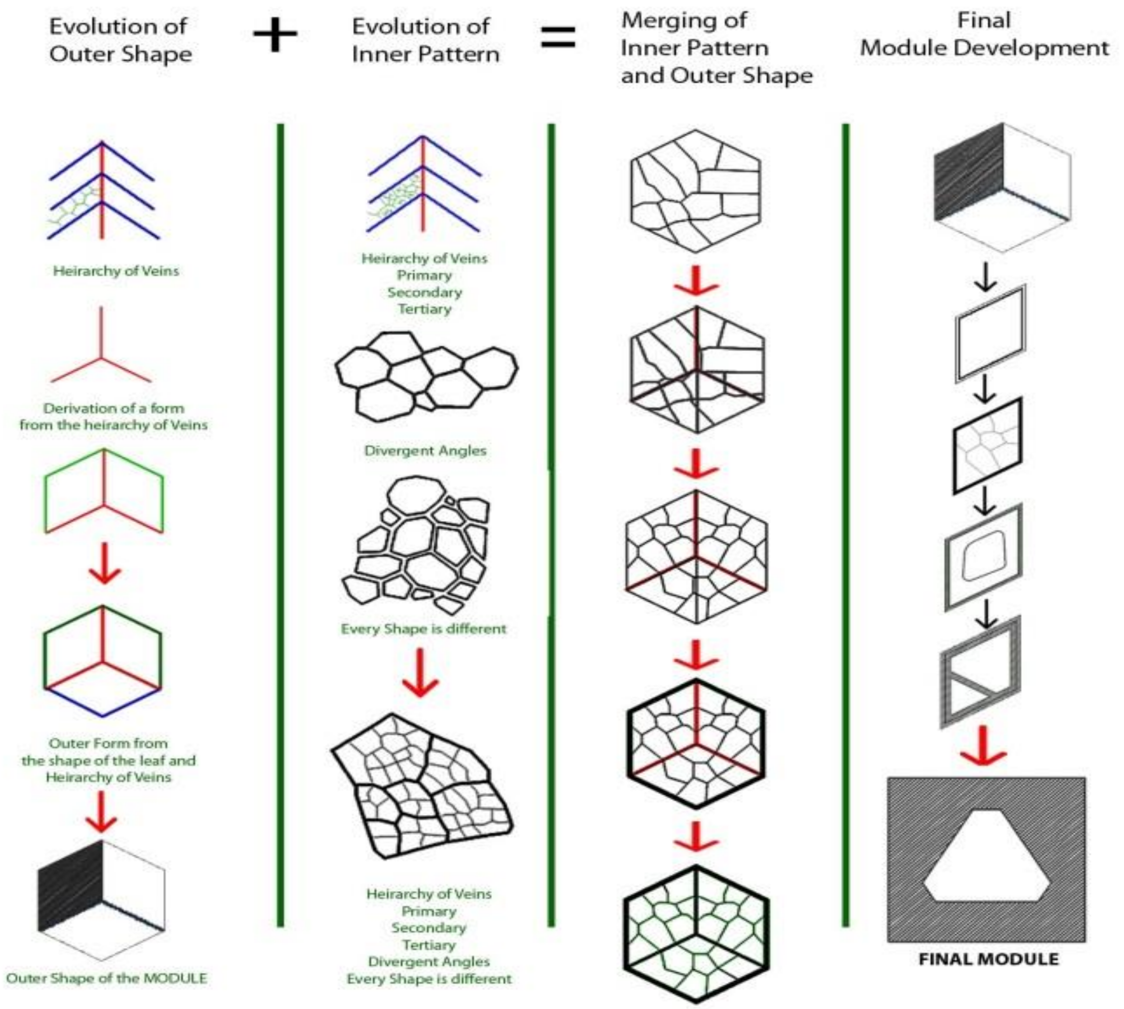

Figure 6: Chart showing the module evolution process
Source: Authors' compilation

Fabrication Design

Three requirements must be met by digital geometry: it must be formed of closed meshes, have a minimum thickness, and not have any faces that self-intersect. The plan is to only permit correctly formatted geometry to be developed, as opposed to fixing incorrect geometry to satisfy these requirements. First, a closed mesh with a minimum thickness is used to establish digital geometry. The spring-mass model is inflated with repellent particles to preserve this minimum thickness and avoid self-intersecting faces.

Parametric Analysis

In parametric mode, a pre-designed digital form's open parameters respond to the user's motions. This mode enables a non-expert to modify a base design created by an expert. An interactive parametric model is manipulated and stimulated using gestures like touch, poke, resize, flip, and reorient. Consequently, the module has been tested using these motions to transform it into a generative skin design module.

Skin Design

The use of digital design tools has established skin design. "Para cloud gem" is the main piece of software utilized for the mesh and skin design. Before completing the design, the software enables the designer to test out several variations of the fundamental module. (Fig. 7)

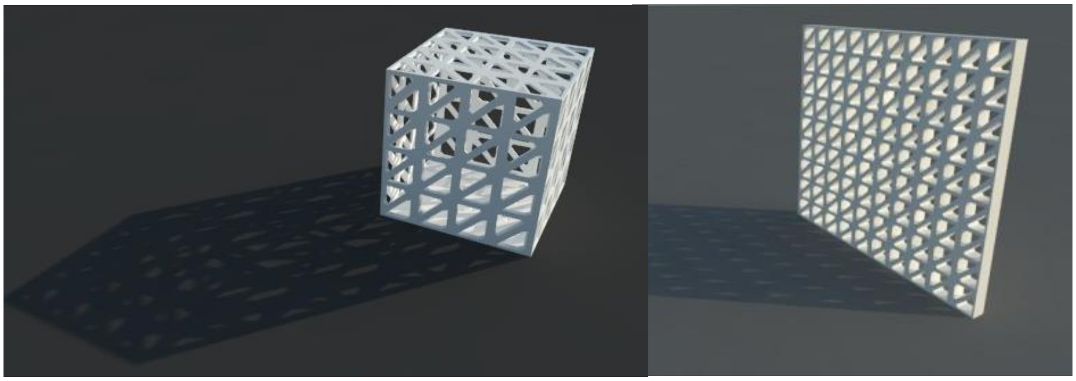

Figure 7: Skin experimentation using Paracloud Gem
Source: Authors' compilation

Building Profile

Built on a very tiny site, the MCB Tower is a sleek, contemporary landmark of its era. The 26-level building's exterior is sealed off by a carefully chosen combination of curtain walls and aluminum sheeting. The MCB Tower is a recognized landmark in Karachi. Regarding design and site layout, this building type offers a lot of potentials. An attractive and energy-efficient structure will be created by upgrading the facade. Due to the building's South orientation and glass façade, it is proposed to remodel the façade by utilizing digital architecture and a skin design that will regulate the amount of sunlight

Figure 8: MCB Building Karachi
Source: http://asa.com.pk/projects

that enters the building.

Procedure

The skin design was created utilizing para cloud gem from the module created using various 3-D tools. The skin was then altered using software and computer processes to create the building façade.

Regenerative Model: The concept of form follows the flow

The idea of generative architecture has been taken into mind when creating the skin design. The design was created in a way that allows the skin to morph and function in response to environmental changes.

Biotechniques: Dynamic Systems

Environmental designers are already aware of dynamic systems models because of the computer simulations used to assess energy consumption, airflow, and equipment interactions in buildings. The idea was applied to the creation of this skin to make it environment-friendly. When sunlight is required, the skin automatically opens up, and when too much sunlight needs to be blocked in a hot area, it automatically closes.

Figure 9: Façade Design on MCB Tower
Source: Authors' compilation

CONCLUSION

The skin design was made using several 3-D tools and the para cloud gem from the module. The building façade was then created by first altering the skin with software and computer techniques. The study demonstrates how skin may be used as an input surface for 3D modeling and fabrication systems, enabling users to design buildings that are both extremely complex and expressive. It is impossible to overstate how much the built environment contributes to the worldwide environmental and socioeconomic challenges. To improve the built environment's environmental performance, it is obvious that a change in how it is made and maintained is required. The study found that although the notion of biomimicry as a tool for sustainable architecture is well known and understood, its actual use in architectural design receives relatively little support. To ensure that all futuristic structures are sustainable and that the damaging effects of the built environment are kept to a minimum, architects and designers must develop a bio-inspired design adaption that mimics nature's best ideas.

This article also described the design factors for the next skin-centric systems. Since improved hardware systems have made 3D software more accessible, skin can serve as an interface between digital as well as physical environments, making it easier for both professionals and non-experts to use this technology. Additionally, this study touches on the concept of generative/adaptive architecture, which has to acquire prominence if we want to take a futuristic approach to architecture and create structures that evolve and adapt in response to environmental changes.

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