

Parametric Patterns Inspired by Nature for Responsive Building Façade

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ABSTRACT: Architects and designers developed in the past few years various methods of design; specially form generation techniques, inspiration and motivation sources were differed but most of them intended common goals such as achieve sustainability and utilize hi-tech and information technology.

In recent years generative systems in nature have become a source of inspiration for architects. Rather than viewing design as a top-down, linear, and goal-oriented procedure, they seek to understand underlying rules and principles of natural systems, which produce structural order and material organization of high complexity, efficiency, and beauty. This paper investigates how parametrically controlled systems can be applied to architectural design in order to achieve more responsive and adaptive modelling techniques.

KEYWORDS: Biomimicry, Parametric Design, Patterns, Responsive Architecture, Modulation.

I. INTRODUCTION

"Throughout history, architects have used nature for inspiration for their building form designs and approaches of decoration. From this point the emulation process of nature has begun and has been developed in many disciplines and recently recognized as "BIOMIMICRY".

With the innovation in the new architectural trend new methods of design needed to fulfil the complexity of nature geometries, shapes and form generation process, ways could apply the tools which could be used to emulate the algorithms of Nature. The appearance of digital tools applications specially "PARAMETRIC DESIGN TOOLS" and the huge development of computer aided design tools has been the answer to this quest.

Nature as an Inspiration Source: Nature allowed architects through biomimicry to emphasis their buildings with elements which are characterized by nature such as sustainability, survival, interaction, energy efficiency and structures and materials optimization, as well as interaction with the environment.

The need for powerful tools: This emulation from nature take evolves and expands to a large extent that made architect has the desire to mimic nature forms, aesthetic elements and smart solutions derived by nature. The computer appearance that helps architects to use mathematical aesthetics in nature was the reason of the continuation of inspiration from nature.

New Design Approach Potential: This design way is one of the methods used by nature for more interactive and more adapted to the environment. So buildings which are resulting from this process had the ability to interact and the ability

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to adapt with nature, more friendly and more sustainable, better at consumption energy reduction and construction structures and materials optimization.

A. Problem of the Study

Architecture passed in the last years great steps toward new trends in design and form generation methods. Biomimicry Architecture is one of the most emerging trends in the 21st century. Hence there is a need to develop new design methods matches with contemporary architecture and develop a new methodology and design thinking to reduce the complexity of nature form finding.

B. Objectives of the Study

The main aim of this research is to develop an innovative way in which to create new design thinking through a combination of the biomimetic principles of design that relate to and inform the process of digital and parametric design. The desire, in its realization, is to reduce the complexity of both design and construction.

C. Methodology of the Study

In order to achieve the above – mentioned objectives, the researcher adopts two basic methods of research:

- A Theoretical Review of the Biomimicry Utilities in Design and an Introduction of Parametric design.
- An Analytical Study for Parametric design tools and its applications of biomimicry architecture.
- Practical Studies of international and local experiments of biomimicry and parametric applications.

II. THE THEORETICAL ANALYTICAL METHODOLOGY

A. What is Biomimicry?

The term 'biomimicry' first appeared in scientific literature in 1962, and grew in usage particularly amongst materials scientists in the 1980s. There has been an enormous surge of interest during the last ten years, brought about to a large extent by individuals like biological-sciences writer Janine Benyus, Professor of Biology Steven Vogel and Professor of Biomimetics Julian Vincent, who have all written extensively in this subject area. Julian Vincent defines it as 'the abstraction of good design from nature'; while for Janine Benyus it is 'The conscious emulation of nature's genius. [1]

B. Nature Strategies and Targets

From wide observation to nature it's clearly obvious that nature concern about main objectives and basis to be achieved in formation, growth and during interaction with context which are:

1. Aesthetics
2. Efficiency
3. Ethics

[1] Aesthetics

Aesthetics have universal and personal appeal. Most people can agree on a beautiful proportion. But at the same time, one group can consider an item or a style to be beautiful while another is repulsed by it

[2] Efficiency

Being efficient is defined by the ratio of time and effort expended for the work being done, and nature is brilliant at balancing need with response. Nature equalizes design solutions that neither gain nor lose energy in the process of change.

[3] Ethics

In nature, ethics do not translate as "good" or "bad." Nature doesn't get caught up in judgments—its ethic is to simply do the "viable thing"—whatever is the most workable and sustainable

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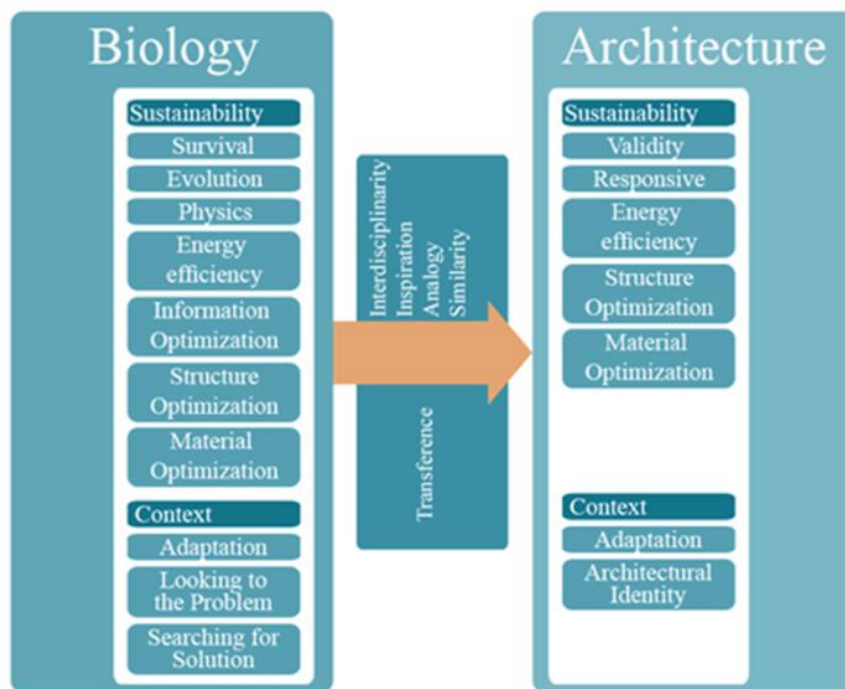


Fig. 1 Transference from Nature to Architecture (Source: Researcher)

Fig. 1 shows the transference methods of Nature Objectives to Architecture and what can architecture mimic from nature in order to solve architectural problems

C. Biomimicry Levels

Three levels of biomimicry that may be applied to a design problem are typically given as form, process and ecosystem. [2]

In studying an organism or ecosystem, form and process are aspects of an organism or ecosystem that could be mimicked. Ecosystem however is what could be studied to look for specific aspects to mimic.

There are three levels of mimicry;

1. Organism Level
2. Behaviour Level
3. Ecosystem Level

The organism level refers to a specific organism like a plant or animal and may involve mimicking part of or the whole organism.

The second level refers to mimicking behaviour, and may include translating an aspect of how an organism behaves, or relates to a larger context.

The third level is the mimicking of whole ecosystems and the common principles that allow them to successfully function.

1. Organism Level

Ravilious (2007)[3] and Knight (2001)[4] discuss a more specific material biomimicry at the organism level, where the surface of the beetle has been studied and mimicked to be used for other potential applications such as to clear fog from airport runways and improve dehumidification equipment for example.

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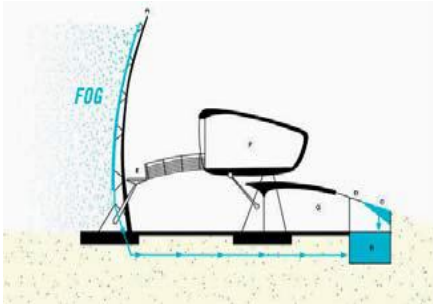


Fig. 3: Matthew Parkes' Hydrological Center for the University of Namibia and the stenocara beetle. (Source: Biomimetics in Architecture, Petra Gruber) (Source Biomimcry in Architecture)

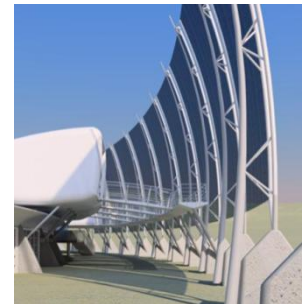


Fig. 2 Matthew Parkes' Hydrological Center for the University of Namibia

2. Behaviour Level

A great number of organisms encounter the same environmental conditions that humans do and need to solve similar issues that humans face. As discussed, these organisms tend to operate within environmental carrying capacity of a specific place and within limits of energy and material availability. These limits as well as pressures that create ecological niche adaptations in ecosystems mean not only well-adapted organisms continue to evolve, but also well-adapted organism behaviours and relationship patterns between organisms or species.[5]

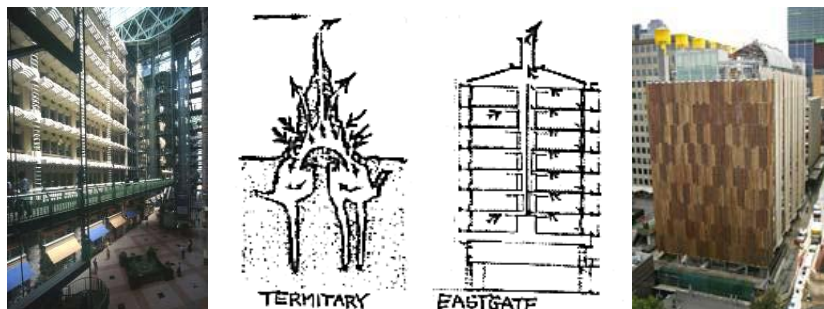


Fig. 4: Eastgate Building in Harare, Zimbabwe and CH2 Building in Melbourne, Australia

In behaviour level biomimicry, it is not the organism itself that is mimicked, but its behaviour. It may be possible to mimic the relationships between organisms or species in a similar way. An architectural example of process and function biomimicry at the behaviour level is demonstrated by Mick Pearce's Eastgate.

D. Digital Architecture

Digital architecture uses computer modeling, programming, simulation and imaging to create both virtual forms and physical structure. It relies on "sets of numbers stored in electromagnetic format" used to create representations and simulations that correspond to material performance and to map out built artifacts

Digital architecture allows complex calculations that delimit architects and allow a diverse range of complex forms to be created with great ease using computer algorithms

What is the parametric design?

Driven by new computer and digital fabrication tools, the architectural designs that are being built are pushing boundaries of form, customization and construction. Pushed by practices wanting and needing to produce novelty, computer-aided design systems are increasingly parametric – that is, they represent designs that change with their input data. Such systems give more control and capability to designers, but require much more comprehensive understanding if they are to be used effectively.

“Parametric design is such that it is the parameters of a design that are declared, not the shape.

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Equations are used to represent the relationships between objects. The ability to define, determine and reconfigure geometrical relationships is of particular value.”[6]

E. Design Principles in Nature

Watching nature and how form in nature is found and the variety in form finding clarify that design in nature rely on principles such as:

1. Shape and Patterns
2. Form generation process

A framework for understanding the application of biomimicry covers Design in nature, parametric potential, grasshopper applications and architectural applications if found. Following; algorithm in nature which related to research subject will be discussed.

1. Form and Unity

a. Voronoi Algorithms

The Voronoi geometry is an organizational phenomena that is sometimes referred to as “nature’s rule.” It re-occurs at a variety of scales, materials, and life forms. Different examples are found in biology, mineralogy of formation principles geometry, and construction such as foams, sponges, bone structures and crystals.[7]

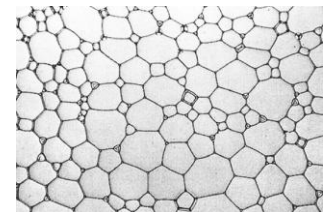


Fig. 5: Floating foam, two dimensional packing.

b. Parametric Potentials: Voronoi Algorithms

Voronoi diagram [8] is the partitioning of a plane with points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other. A Voronoi diagram is sometimes also known as a Dirichlet tessellation. The cells are called Dirichlet regions, Thiessenpolytopes, or Voronoi polygons. [9]

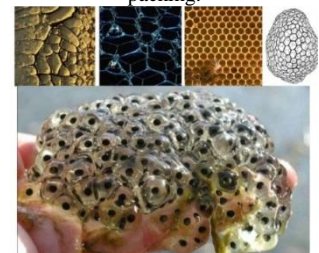


Fig 6 Voronoi diagrams in biology and mineralogy of formation principles.

c. Patterns

Pattern in Nature

Patterns organize and define relationships in nature and can be integrated into design to substantiate and support visual communication. Because design’s purpose is to create a relationship with the viewer, the language of pattern helps to frame what that relationship is before the message is read or even consciously processed.



Fig. 7 Patterns in living Organisms

Tessellation and Tiling in Architecture

The history of architecture has a broad range of tiling examples which are interesting to study and use for contemporary design applications. Tessellation and Tiling are among the possible design issues with Generative Algorithms and in Grasshopper.

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Fig. 8 Geometrical studies and extracting the logic of a pattern by simple geometries.(Source: Generative Algorithms, ZubinKhabazi)

2. *Responsive Modulation*

The idea for the next design experiment is to modulate a given surface with control over each module which means any module of this system, has to be responsible for some certain criteria. So even more than regional differentiation of the modules, here I want to have a more specific control over my system by given criteria which could be environmental, functional, visual or any other associative behaviour that we want our module be responsible for.

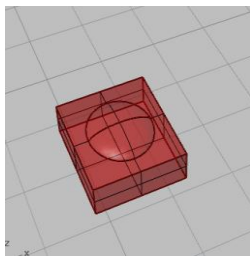


Fig. 9 Closed Geometry

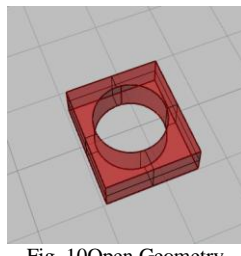


Fig. 10 Open Geometry

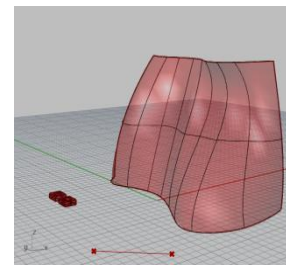


Fig. 11 Main Surface

Certify Units According to the angle between sun rays and each unit surface

Install the open and the closed geometries according to the Min and the Max angle needed (Source: Generative Algorithms, ZubinKhabazi)

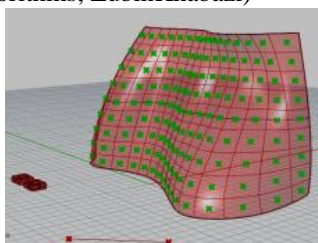


Fig. 12 Divide surface into U, V

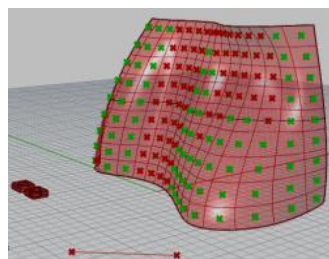


Fig. 13 Selected panel distribution

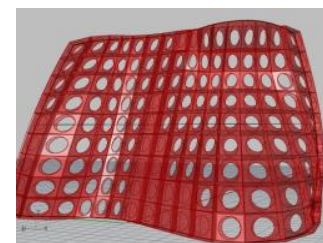


Fig. 14 Final result

The final result is separately controlled patterns could be used in architectural applications with different geometries and shapes. This concept is more efficient for sustainability targets of natural lighting and ventilation.

III. EXPERIMENTAL RESULTS

In this part architectural examples will be analysed, these examples will be simulated with the parametric tools in Rhino3D and Grasshopper in short steps without detailing showing only design techniques abstracted and developed by parametric tools.

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Al.Bahar Tower Abu Dhabi



Fig. 15 Al.Bahar Tower Abu Dhabi
Architect: Aedas

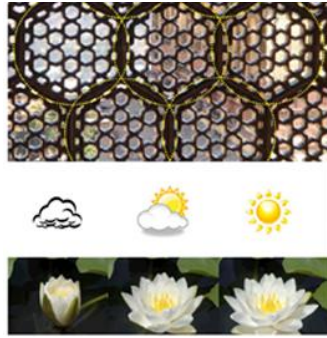


Fig 16 responded opened shape

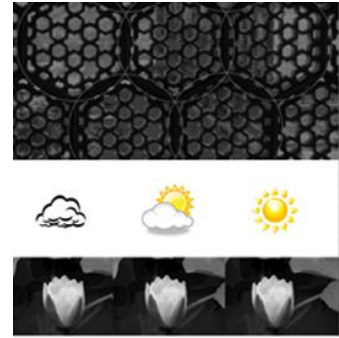


Fig 17 responded closed shape

Location: Abu Dhabi, UAE, 2012

The Design responded with two towers inspired by traditional vernacular architecture, oriented technology, and biomimicry.

Fig. 16- 17: The screen was developed following the principles and geometric composition of the ‘mashrabiya’ – a lattice shading screen common to the sunny regions of the Middle East – combined with the adaptive behaviour of natural organisms to the changing location of the sun and weather conditions

Grasshopper Application

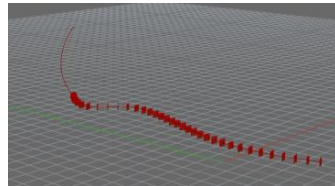


Fig. 18 Creating Surface Pattern

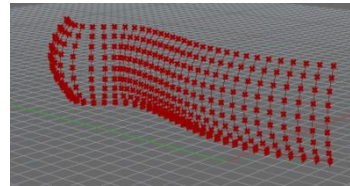


Fig. 19 Dividing Surface

Curves Import drawn curve to Grasshopper through Parma categories.

Divide Surface From Surface category divide them with required U&V Direction

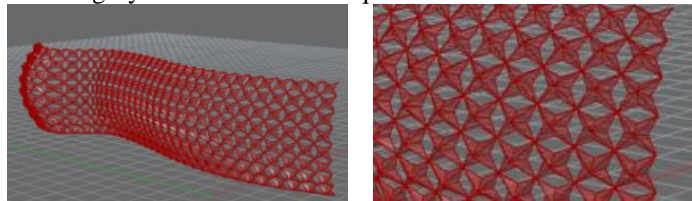


Fig. 20 Final result (Source: The researcher)

Lansdowne Road Stadium (Aviva Stadium)

Architect: Populous

Location: Dublin, Ireland 2010



Fig. 21 Lansdowne Road Stadium



Fig. 22 Lansdowne Road Stadium Panels

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Design Problem

Construct a huge roof attached with stadium walls which covered with kinetic glass panels rotating according to the sun ray angle.

Grasshopper Application

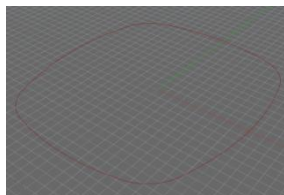


Fig. 23 Basic curve

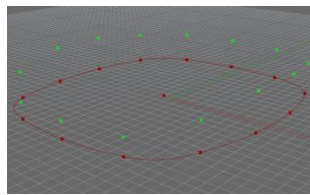


Fig. 24 duplicating curves

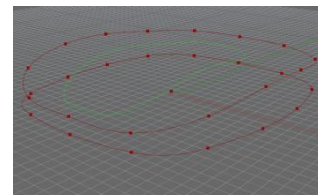


Fig. 25 dividing curves

Begin with primary element (closed shape) drafted in rhino or imported from other CAD software

Divide curve - Move - Copy
From Curve bar divide the shape to points, then move these points individually in the Z direction according to the desired design to have the other curves

Copy – Scale - Divide
From Curve category divide curves with constant points number

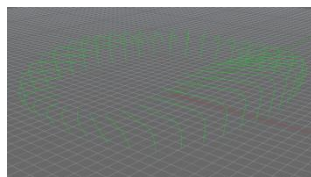


Fig. 26 creating cross section profiles

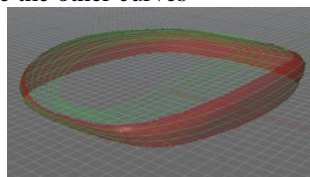


Fig. 27 creating the surface

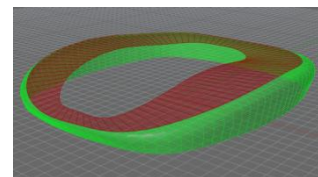


Fig. 28 Creating panels

Create Lines – Fillet
From Curve category Fillet curves and create polylines in order to create the surface

Loft
From Surface category loft curves with order

Divide surface – morph 3D geometry on surface
From surface category divide surface with U & V modules

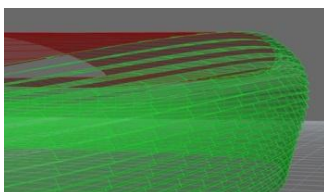


Fig. 29 Rotating panels with one angle value for each panel

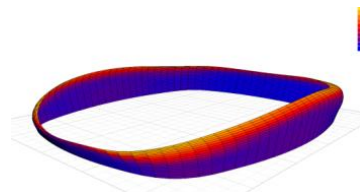


Fig. 30 Solar analysis output in Grasshopper.

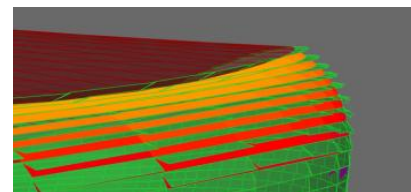


Fig. 31 Rotated Panels with different angle values(Source: The researcher)

Rotate – Constant angle
From surface category a divided surfaces could be installed according to the U & V modules with fixed axis to achieve the desired rotation angle.

With data transference between Grasshopper and Autodesk Ecotect analyzed values could be used with mathematical operations to calculate rotation angles required according to sun isolation to control day lighting and shades.

Rotated panels according to angle attached with sun insolation values

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King Abdullah Financial District Hotel Building

Architect: Norman Foster & Partners
Location: Riyadh, Saudi Arabia

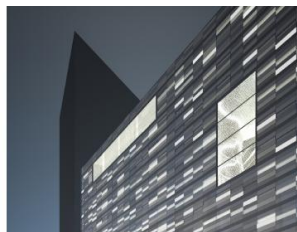


Fig 32 King Abdullah Financial District Hotel Building

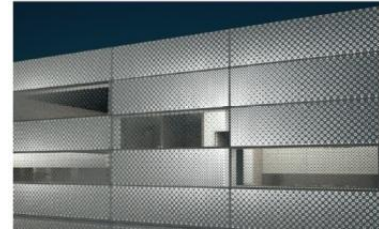


Fig 33 King Abdullah Financial District Hotel Building perforated panel

Design Problem

Construct high rise Building with perforated panel in elevation respond to the environment to control daylight.

Grasshopper Application

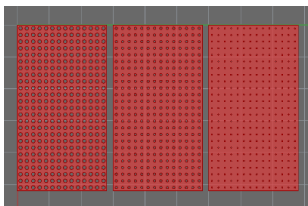


Fig 34 Three Perforated panels

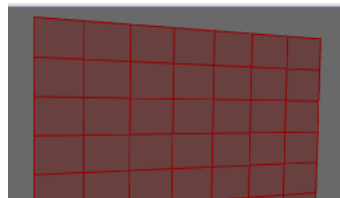


Fig. 35 Dividing Surface

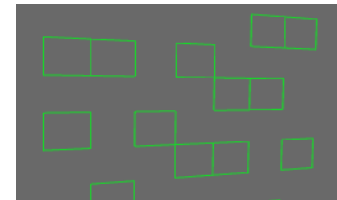


Fig. 36 Selected Surface panels

Creating Geometry

In Grasshopper geometries could be created to be base patterns in order to be morphed on the surface.

Divide Surface

From Surface category divide them with required U&V Direction

Selecting Modules

With a Repeated or random order panels could be selected from the set category with item selection components.

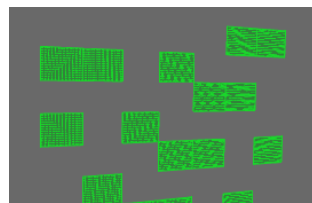


Fig. 37 Distributing panels according rooms use

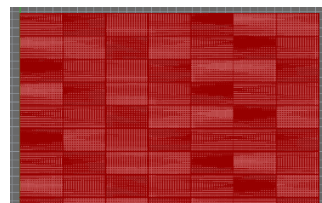


Fig. 38 Final Result (Source: The researcher)

Morphing Geometries

From transform category a divided surfaces could be morphed with geometry according to the U & V modules.

Morphing other Geometries

With the same previous technique other geometries could be morphed on the rest of surface panels.

IV. CONCLUSION

- Nature was the source of all that is and an infinitely creative and patient mentor.
- Through watching and investigating nature and organisms some principles could be extracted to create a nature mimicked design in art or architecture.
- Patterns organize and define relationships in nature and can be integrated into design to substantiate and support visual communication. Because design's purpose is to create a relationship with the viewer, the language of

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pattern helps to frame what that relationship is before the message is read or even consciously processed. be extracted to create a nature mimicked design in art or architecture.

- Responsive Modulation: To modulate a given surface with control over each module which means any module of this system, has to be responsible for some certain criteria.
- Biomimicry problem based approach is more appropriate for architectural applications
- Architects usually use all transfer methods between nature and architecture
- All biomimicry level could be used in the architectural process
- Local inspiration sources usually emphasis the architectural identity
- Local nature is more efficient in solving local problems
- Parametric design tools and mathematical methods in form finding help to get results more aesthetic, efficient, responsive and controllable.
- Parametric tools help to get more acceptable solutions for design problems

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8. In mathematics, a Voronoi diagram, named after Georgy Voronoi, also called a Voronoi tessellation, a Voronoi decomposition, or a Dirichlet tessellation (after Lejeune D irichlet), is a special kind of decomposition of a metric space determined by distances to a specified discrete set of objects in the space, e.g., by a discrete set of points.
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BIOGRAPHY



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