NAI-SIG: Natural And Ideal Studies In Geometry

Steven P. Kane
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NAI - SIG
Natural And Ideal Studies In Geometry
Natural And Ideal Studies In Geometry

Request for approval of Thesis Research
Project Book Presented to:

Dr. Tony Rizzuto Ph.D.

and to the
Faculty of the Department of Architecture
College of Architecture and Construction Management

by

Steven Patrick Kane

In partial fulfillment of the requirements for the Degree

Bachelor of Architecture

Kennesaw State University
Marietta, Georgia

July 23rd, 2020
I want to dedicate this thesis to my friends that I have gained over the years and to my family for their constant support in my college career. To my closest friends and my APX brothers, thank you for all the trips, journeys, all nighters, and memories that will last a life time. I truly couldn’t ask for a better experience throughout these past five years. Many of my friends have become my family, and I will always cherish the close friendships I have gained. To my family and my Parents, I am so grateful to have been blessed with the best in the world. There was never a time when you weren’t there for me, and without your constant support I wouldn’t be who I am today. Thank you for showing me how to be the best version of me and to never give up.
This thesis would not have been possible without the collaboration of my thesis Advisor Dr. Tony Rizzuto. Thank you for your dedication and passion to my collegiate education over the past five years at Kennesaw State University. Your constant display of Professionalism and engagement has showcased your true character, and I am truly happy I have gotten the chance to call you my Chair, Advisor and friend. Your countless hours of discussions and passion for architecture has inspired me throughout this whole thesis to keep me motivated and thrilled to think and design critically. I have been fortunate enough to be taught by someone like you, and I want to thank you for your belief in me and for encouraging me all these semesters.
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Relationships between understanding our place in time and space has led to the discovery that it is too difficult
to change a person; therefore, we must change our environment. Natural Form and what we conceive to be
Ideal Form, structures an idealistic coordinate system for design. Designed throughout an enclosure there is a
strand of rules, nature uses to design within its time and space. Natural Forms and Ideal Forms are never able
to be created by Man, yet we are able to design structures that originate from geometrical patterns. Through
understanding and researching the Geometrical shape of the Hexagon, guidelines will be constructed for the
design process. This thesis seeks to design a structure using Natural Forms and Ideal Forms to make an enclosure
where the two sides meet an equilibrium. The Hexagonal formation is used both in Nature and Architecture, as
a tool for designing that can be seen from a multitude of Disciplines. Structuring an Enclosure around these ideas
of forces will create a place mixing Natural rules and Ideal rules into a representation of Balance.
ABSTRACT

Architecture through historical evidence seeks to find a straightforward development strategy for designing a place around Phenomenological views. Humans are one moment in time and space, seeking interactions between our senses and our environment. We are able to shape our reality over time, utilizing the characteristics given to us by history and nature. The Geometric Discipline assessed, explores how natural forces seen as vectors are applied in Different rational and irrational numbers. Natural structures and forms are looked at in a sensible fashion to give logic to our environment for design. The divide of design analysis for the hexagon form in different variables, looks at parametric design and where rules stem from. Mimics of Nature, systems for Nature and Mans representation of Nature will probe the ideas supplied by our surroundings. The Hexagon is seen as an Ideal form for Nature and Man to use to design some of the most beautiful structure seen from the Sagrada Familia to the Redwood forest. The ability for us to design is based around rules and regulations that allow us to design vectors into structures. With modern technology the Coordinate system used by nature can be replicated to create elaborate structures and systems very simply Designed. Fabrication will follow Natural Form and Ideal Form to design a structure built from the Hexagons variables. Looking at the Hexagon as a sixth strand of design, an enclosure will be produced that investigates Nature, Ideal Forms, Space, Human Interaction and the underlining strategies from the hexagon. Application of the Structure will appeal to how the hexagon is made in nature and how simple vectors create forms. The mix media of biological structure and architectural language will develop a new interaction to stand as an example of a natural structure reacting to its origin.
NATURAL REALM
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The Balance between Nature & Geometry

Harmony is the balance that we search for in life as it gives a tranquil stitching to the conception of our environment. It can be found in Music, as in Beethoven’s masterpieces and a driving force to find a peaceful state. It can be found in Nature as a vast valley comes to life in the Sunrise and whistling winds. It can be found throughout history as philosophers such as Leon Battista Alberti dissect the meaning and creation of life to find “The Answer”. From Alberti, “When I investigate and when I discover that the forces of the heavens and the planets are within ourselves, then truly I seem to be living among the gods.”

There is a harmonious strand that seems to link every living and non-living object together, and through micro and macro scales of different formations, patterns and geometries we are then able to open the vale of creation. Through patterns and geometry, a systematic rubric can appear to showcase the interconnections of how and why objects become the way they are. In fact, it is no coincidence that speculations of The Golden Section, Pythagorean theorem and Darwinism can be seen all the way from a molecular level to an entire solar system. Patterns in Nature shows an evolution that goes long beyond the Western World and is encrypted in the fabric and methods of everyday life and culture.

As literature, life and experimentation start to take form we are able to utilize methods found in nature and apply them to the built environment. Patterns can come in the form of fractals, spirals, chaos, dunes, bubbles, tessellations, cracks, stripes, spots and many other variations creating both a work of beauty but more importantly a structural system that has become seamlessly undetectable by the naked eye.

History and mythologies have existed for centuries, but the question is always linked to finding the meaning of life and the connection between man and the heavens. In religions such as Judaism, Christianity, Islam, and many others, there is a foundation that Man was made on the sixth day. A stipulation that the number six is entangled with the perfect geometric form both for spiritual and structural origins.

When looking into Nature one of the most influential designs to look at is the formation of the hexagonal honeybee dwelling. Through the theory of Darwinism, the structure of the honeycomb is seen to create a visual and structural method of creating a perfect form for the honeybees. If you are able to stack single shapes together to create a seamless plane there is only three shapes you can use, a triangle, square and hexagon. Although all shapes can configure together to create a flat slate, the hexagon is ideal for the honeybees by being the most efficient form to increase productivity and decrease area usage.

[Figure_1.01] COLLAGE_1: The harmonious relationship of pattern and geometry are represented by a molecular level and solar-system interacting with the Vitruvian Man by: Leonardo da Vinci and The Golden Section. Portrayed on The Birth of Venus by: Sandro Botticelli, this Collage is meant to represent the way Relationships and Geometry are able to be traced from Nature and used.
When comparing the triangle, square and hexagon on a flat plane, the area of the walls to create the form are less than that of the triangle and square. Dissecting further into a hexagon, it is six equally placed triangles or dissecting a square, it is two equally placed triangles. Hexagons are said to have an isotropic foundation and set a stage for an insight to creation. The hexagon however repeated in a cylindrical form will never be able to enclose itself without the help of another geometrical form. “Thompson realized, there must be pentagonal or square facets in such a polyhedron to allow it to form a closed shell.” (Ball, P.19) One could say the hexagon is the ideal shape for a two-dimensional surface, but as an entity into the third dimension it cannot perform the structural foundation for all life.

When looking at a major foundation to life mono hydrogen dioxide better known as water, a droplet is set by a series of forces to give shape that minimizes its surface area and energy. When applied to different solutions such as soap, this mixture can create foam and looking at a closer spectrum creates bubbles. Why these bubbles are important, is to look at the connections they create when they interact with one another. If you are able to interconnect three bubbles together you will find the angular connection to be 120 degrees, if you are able to put four bubbles together you will see a transformation of 90 degrees to 120 degrees and so forth as you add more bubbles. 120 degrees is the perfect angle at which a hexagon is based off of and the connection is clear that this angle in relation to the hexagon and life is expressed further. Hexagons set a network where they create a standard for minimal surface value and therefore minimal energy loss. Nature can be seen as prodigal in structure, she “meanwhile, forms her patterns in very impure, messy chemical mixtures under the mildest of conditions and with profligate abundance.” (Ball, P.21) This fluidly to nature protrudes through geometric forms and patterns to show that every structure is not perfectly constructed with every shape and form being exactly the same. Life intertwined with patterns in Nature leaves us to learn that the crucial element to the built environment, is that objects are not constructed in identical, equal sided and equal angled cells, yet they are organically formed by forces. “They emerge spontaneously from a delicate interplay of forces and can often be altered in scale or in structure by a small shift in the balance of this interplay.” (Ball, P.22) This foundation results from pattern and geometric connections to nature and the innateness of why forms take their shape naturally in different environments.
**Bubbles**

*Most Efficient Shape: Sphere*

Maximun Volume: \( V = \frac{4}{3} \pi r^3 \)

*Least Surface Area: \( A = 4 \pi r^2 \)*

[Figure_1.03] Bubbles: A bubble is one of many way to show how force meets at an equilibrium. The idea of a sphere is natures way of Maximizing the most Volume while Minimizing the Surface area. Shown as the most efficient shape, when Combined together the Bubbles connect at a 120 Degree angle. This creates the shape with the fewest edges, a hexagon, and to make the most mechanically stabilized structure.
Chapter 1: Natural Realm
CRACKS

Giant’s Causeway

Location: County Antrim on the north coast of Northern Ireland

What: Natural area of 40,000 interlocking basalt columns

Shape: Most of the columns are hexagonal, some are four, five, seven, and eight sided

Height: Tallest column is around 39 feet

[Figure 1.04] Cracks: This rock formation occurs when magma heat temperature rises from underground to the atmosphere. The heat is rapidly cooling from the surface downward. The cooling temperature pulls the direction of cracks to fill less space. The direction of vectors forms to release tension to reach mechanical stability with the 120 Degree angle. Forming together over time the stress as lava cools, makes these hexagon columns scene at Giant’s Causeway.
Cooling points stay Central

Heat pushes force in hexagon formation

Crack release tension
FLY EYE

[Figure 1.05] Fly eye: A fly eye is an evolution of nature adapting to give a fly the maximum light sensing area. This formation creates a hexagonal grid for the lens to sit, giving a view to detect everything to the left, right, front and above. The facet of the fly eye is based off of the 120 Degree angle to give the most structural and useful pattern.
Fly eye Structure

Maximize light sensing area

Minimal cell wall material

Rhabdom

Crystalline cone

Lens
Earth: 3rd Planet from the Sun

Saturn: 6th Planet from the Sun

Saturn’s Hexagon

Location: Saturn’s Hexagon, North Pole of the Planet Saturn

What: Persisting hexagonal cloud pattern

Shape: 200 mph jet stream moves between three sides to eight sides, mainly staying in a hexagon formation.

Height: 190 miles

[Figure 1.06] Saturn’s Hexagon: This Pattern and cloud formation shows the hexagon appearing within the solar system. A possible function of the universe, the Hexagon on Saturn happens to be the 6th planet in the Solar System. These massive amounts of force from the Planets core set off Eruptive Events countered by Convention Currents and Outward Sound Energy.
Continuous Eruptive Events

Convection Currents & Sound Energy release back towards Center

Hexagon shaped Cloud

Helium Clouds
Methane Clouds
Ice Particles

Eruptive Event

Outward Sound Energy

Convection Currents

31,070 Miles
15,535 Miles

Continuous Eruptive Events push in six directions

Chapter 1: Natural Realm
TESSELLATIONS

[Figure 1.07] Honeycomb: Hexagons are the most efficient shape for the site of bees to come together. Maxing out the area of wax, the structure cools to a tessellated hexagonal pattern. Round wax pockets are warmed up by the friction of the hive moving through the structure, and is pulled by surface tension. The Collage represents the structure of the honeycomb coming from its architect the bee, representing the balance of force and creation.

Spit from bees

Spit from bees pressure against each other

Mechanical stability is reached in hexagon grid

Forces Balanced

120° 120° 120°
Fractal Snowflakes: Base their structure from a Hexagon

Chapter 1: Natural Realm
Helge Von Koch discovered an explanation for a mathematical code that could represent ideal patterns for fractals. Combined and diagrammed over Dan Komarechka Images of snowflakes, hexagon structure and curves start to form in a fractal concept.

Koch snowflake: Infinite Mathematical Curve
[Figure_1.09] Turtle Shell: The protective structure on a Turtle Shell bases its design from hexagons connecting to other geometrical shapes. The horned-looking design comes from time, as the shell gets bigger another hexagonal layer appears. Intended to role on its feet, the dome structure offsets its balance to rollover when set on its back. From the Center hexagons, the Geometry follows along the skin of the turtle to ensure the most protection.
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[Figure 1.10] Radiolaria: Marine skeletons are formed from shapes that represent the platonic solids. Morphed into dome pulled structures, these micro-organisms create forms around the hexagon.
“The Significance of the Skeleton.-The skeleton of the Radiolaria is developed in such exceedingly manifold and various shapes, and exhibits at the same time such wonderful regularity and delicacy in its adjustments, that in both these respects the present group of Protista excels all other classes of the organic world. For, in spite of the fact that the Radiolarian organism always remains merely a single cell, it shows the potentiality of the highest complexity to which the process of skeleton formation can be brought by a single cell. All that has been brought to pass in this direction by single tissue-cells of animals and plants does not attain the extremely high stage of development of the Radiolaria.”

Ernst Haeckel

Ernst Haeckel

German philosopher

Chapter 1: Natural Realm
Chapter 2: Idealogical Realm

IDEALOGICAL REALM
Patterns in Geometry

Geometric proportions and patterns don’t stop in nature as shown in Islamic design, patterns and geometric relationships link a diversity of forms to create patterns. The Islamic patterns and designs are derived from different armatures of circles repeating in different points to start to create the design used by the Islamic artisans. “These findings support the argument that geometry was independently discovered and applied by Islamic culture as a universal language, constituting one of the most important multicultural symbols in design.” (Dabbour, P. 1) This language of pattern sets an aesthetic level of language that has parameters and boundaries that allows the pattern to change slightly based on the separation of geometries. Geometries come to life as points, lines, surfaces and solids start to connect and set the boundaries for which we are able to visualize and conceive a form.

The Greek Philosopher Plato developed a system of dividing and analyzing structure by aesthetic, static and functional categories known as stereotomy. Allowing this relationship of ratios and proportions to take on spatial measurements and starts a framework where the x-axis, y-axis and z-axis, frame standards for design. Taking away the organic form of nature and to abstract it into a systematic design standard for the built environment.

Through Ancient Civilizations and structures that still stand such as Stonehenge or The Great Pyramids of Giza, we can tell that these systems were set in place before Plato described and analyzed his theory of stereotomy. History shows that geometry has both qualitative and quantitative qualities, separates and structures systems into standards that can be manipulated and forever furthered into subdivisions of this field. Dabbour describes geometry standards as, “It’s quantitative dimension regulates the order and construction of design forms. Its qualitative nature sets the proportions of design forms and represents an expression of the order of the universe as a visual representation of the truth.” (Dabbour, P.2)

Looking at geometries in an arithmetic form, design can take place in three separate categories numbers in space, numbers in time and numbers in space and time.

Stereotomy

The technique of cutting solids, as stones, to specified forms and dimensions.

“qualitative nature sets the proportions of design forms and represents an expression of the order of the universe as a visual representation of the truth.”

“quantitative dimension regulates the order and construction of design forms.”

Plato: Athenian philosopher

numbers in space
numbers in time
numbers in space and time
Numbers in Space
Coordinate system
Numbers in Space and Time
Numbers in Time
"qualitative nature sets the proportions of design forms."

Stereotomy
The technique of cutting solids, as stones, to specified forms and dimensions.

Vitruvian Man by Leonardo da Vinci - est. 1490

Islamic Design

Islamic architecture uses this method of extracting points and geometries in a circular stage based off different points, number of circles and armatures. By creating a base axis for the design to tessellate itself out of, the circles are able to follow a harmonious rhythm and set a standard for design that allows a pattern to emerge and create its own tectonic language. The first stage of design sets an initial boundary where the circles are taken into a unity or proportions choosing the number of circles to set up a framework for how the circles will interact with each other. The second stage is the division phase, where basic geometries are discovered in an overlapping fashion to reveal a series of isotropic geometries. The third stage structures and orders the parameters for design to create a standard for how the geometries will interact with each other in order to hone in on distinctive overlay of geometrical pattern. Utilizing a methodical structure gives the Islamic pattern its distinctive and systematic outcome, that allows the ratio and proportions to become visually undetectable as geometries travel through a tectonic language and seek to scout out a tuneful pattern. This system of circular geometries in Islamic design sets a rhythm of creation, seen as fourfold to eightfold, fivefold to tenfold and sixfold to twelve-fold patterns. Allowing organizational design systems to communicate a structured system that is easily able to change based on different parameters set for pattern revealing. Geometries furthered into the future yearn for boundaries to break away from isotropic definitions, in order to return to their organic nature.
Throughout Civilization many people have looked towards religion for answers, and as religion has some answers that link people to a higher meaning, we still don’t know “The Answer”. Many symbols from the Cross, Star of David, Khanda, Pentagram, Crescent and Star, and many others, have been used before to link simple geometry to a greater feeling. Moving through the boundary of knowledge known by man, we acknowledge the Ancient world for its lack of clarity through writings and human records. Analyzing that major religions only resembles text that go back 6,000 years ago, therefore any formation or links that are found to be older help us to understand acceptable knowledge. Among late antiquity the Greeks, Romans, and Sasanian in Iran had possessed this understanding of proportion and how to manipulate and understand nature to make many art forms including structure. This refinement of classical styles played its part in the Islamic style of design to give beauty, harmony, intricacy and complexity to a Brand that is arabesque. This design made and styled by Islamic Architects, Mathematicians, Astronomers and scientist created a system that represent the second biggest religion in the world. “Islamic artists appropriated key elements from classical traditions, then complicated and elaborated upon them in order to invent a new form of decoration that stressed the importance of unity and order.” (P.8, Metropolitan) From understanding and utilizing what others had before them the Islamic pattern stands as a perfection of dissection form Nature. The Islamic pattern, Materials tend to stand out as artifacts of Calligraphy, Textiles, Ceramics, Metal Works, Architectural Elements, Manuscripts and Vegetal Patterns; all exemplify the representation of the natural world. Sometimes, scripted as “The Code”, without any representation of human or animal made, it creates “Idolatry” a worship of imagery. The Qur’an published the Islamic Religion when the sayings of Muhammad recognized, Muhammad was the last prophet of Allah. Structured in the beginning of the religion Calligraphy and the message of Allah was structured and choreographed to be imprinted in your mind. The designs of patterning a never-ending pattern seems to be so mesmerizing and so delicately made. Adjusting and manipulating into an ornamentation design they lack religious symbolism, in return the sophisticated approach lets people know what Islamic geometry looks like. Calligraphy, Islamic art and Vegetal Patterns; symbolized a design that both created intricate combinations and a way to spread the word of the Qur’an. The Qur’an, “The principles and teachings of Islam as a way of life, a religious code, and a legal system were promulgated by Muhammad, an Arab merchant from Mecca.” (P.10, Metropolitan).
Seen as a legal system, five pillars of Islam were created to share an equal view of the world, where everyone preaching the word of a single God “Allah” will be saved, as many Monotheisms. The First Pillar States Shahada, that Allah is the singularly God, and Muhammad is God one last true Prophet. The Second Pillar states Salat, one must do ritual pray five times a day: Dawn, Noon, Afternoon, Sunset & Late evening. The Third Pillar states Sawm, A month long Fasting during the Religious time period Ramadan; regarding no eating, drinking, smoking or indulgences be performed during daylight hours. The Fourth Pillar states Zakat, this means to fancy the poor and treat people equal, as so a percentage of your income is to go to the lower class and misfortunate; man helps fellow man. The Fifth Pillar states Haji, the religious Icon in Mecca is the home and Birthright of the Islamic culture, and in one lifetime one must pilgrimage to Mecca. Designing this religion to be Symbolic based on a geometric system of design, made a religious and political movement. The spread of pattern to the reach of people was very vital to the influence of Islamic Patterns raising the Islamic Religion to be the Second biggest Religion.

Regular Tessellation of points created structures that embody, at a glance an image that imprints Islamic pattern in your mind. Religion pronounced, “spends his substance however much he himself may cherish it upon his near of kin, and the orphans, and the needy, and the wayfarer, and the beggars, and for the freeing of human beings from bondage.” (P.12, Metropolitan). The invited growth of the pattern overlaid with the invited growth as a person made this pattern so harmonious to Islam, that when faced with any of these patterns today one’s mind goes straight to the Islamic Religion. Numbers of arrangements and diverse shapes, were necessary in creating simple systems to make Tombstones, Bowls, Manuscripts, Textiles, Screens, Incense burners, Doors, Fountains, Panels, Rooms and anything that you could imagine. The reach and power of Pure Geometry lead to one of the reasons the Islamic religion became so abundant. By replacing Imagery with an image less system a submissive arrangement stated that only God is pure, and Humans are meant to serve. As a Human we will try to represent God, but we will never reach equality with God, nothing we make will be ideal. For freedom of design and its time period Islamic Patterns have showcased the complexity and mapped out the proportions of limitless geometry. As the Geometric Code in Pattern is never ending, these points in design can be manipulated and scaled to be different variables used in today’s world of Scientific Thinking.
Humanism Influence

Understanding the linkage and harmonic resilience of geometric shapes and forms have always had a role in human designs. Nature has shown that it can set an aesthetic Vail so beautifully designed that it is undetectable by the naked eye. Around the 15th Century Western civilization saw a re-examination of thought that reached a tipping point and gave birth to Humanism, and the rise of Renaissance philosophy. With this can a rebirth of the primacy of geometry and mathematical order in aesthetics.

Investigations of the Truth during this rebirth lead to two categories of inquiry. First, the continuation from scholasticism that Man was the apex of creation existing between the divine and nature. Second, that knowledge accessible to man was only part of the truth of the world, some aspects of the universe were only accessible to the divine. From Art Historian Rudolf Wittkower, “echoed and at the same time revealed the perfection, omnipotence, truth and goodness of God.” (B10, Faught) These two ideas lead to the Renaissance pursue of all knowledge accessible to mankind.

Renaissance philosophy, following the writings of Plato, began to understand the world as derived from mathematical relationships and proportions. This driving concept lead theorists to see a continuity between the microcosm and macrocosm based on proportion and ratio. “The study of Greek mathematicians led to the view that the entire universe is a system of rational harmonies which adhere in its totality to the rules of mathematics.” (B4, Faught) The Renaissance was about finding a higher meaning in God’s construction of the universe and translating that into philosophy and art. The result was an increased interest in human proportions, or anthropomorphism, and underlying geometric orders. In architecture the latter were often visually identified by the use and application of classical ornamentation. Dimensions, symmetry, proportions and many other mathematical fundamentals were now seen as vehicles to truth and the necessary underlying structure in all art forms.
The Human Body is seen as a focal point and the perfect center of the Universe.

Grid layered over perfect human proportions.

Francesco de Giorgio da Martini
Vitruvian Man, 1492

[Figure 2.07] COLLAGE_2: The Polymath of Mans Knowledge of place and space during the Renaissance Era lead to the discovery of Microcosm and Macrocosm. The humanism understanding lead to an euphoric yearning of Logos (Logic/Reason/Proof), Ethos (Credibility/Trust) and Pathos (Emotions/Values). Influencing studies of Fine Arts, Architecture, Dance, Literature, Music, Philosophy, Science, Technology, Humanism, Age of Discovery, and Warfare into the world we see today. Through different medians Mans place in the universe became more clear, feats of capturing sunlight, engineering, structure and overall Architecture gave an enlightenment to every Human.

In Alberti’s books of architecture, “I shall define beauty to be a harmony of all the part, in whatever subject it appears, fitted together with such proportion and connection, that nothing could be added, diminished or altered but for the worse.” (B8, Faught) Filippo Brunelleschi’s Pazzi Chapel in Santa Croce, Florence; was one of the first representations using these methods; from English Architect Banister Fletcher, “Byzantine in conception, Gothic in Construction, and Classical in decorative detail.” (B14, Faught) A polymath of design, set the standard of churches to follow. Here a rigorous geometrical order underlies the entire design in plan and section, with that order revealed by the application of the classical orders. Alberti’s nine plans for Renaissance churches, including the circle, square, hexagon, Octagon, Decagon, dodocaon, the square plus half, the square plus one third, and the square doubled, were intended to capture the higher meaning of the universe and truth in a building typology. Centralized in plan many also reinforce the centrality of man in the universe. Utilizing Geometry and the fundamentals of design, Alberti’s book on architecture De Re Aedificatoria dove into the single strand to employ pure forms and abstract them into church plans. Geometry injected with human influence and these nine shapes of Alberti, lead to the connection that any form of shapes translated into the z-axis in architecture, must use a square facet if you wish to acquire architecture of the Renaissance. Represented as a portal the rectangular form is represented as the first translation from an ideal form to a corrupted one. In fact, the Idealization of our world will never be perfected as long as we have space and time. Therefore, the Renaissance stands as one of the most influential movements in architecture, literature and documentation for the realization that salvation has no true purpose but the purpose of our reality.

Leonardo Da Vinci and Donato Bramante’s later ideal forms for churches took this idea into three dimensional mass forms. This idea would culminate in Palladio’s use of mathematical proportions taken from music, specifically the harmonic cords (believed to be reflective of the cosmology) in the design of individual rooms and buildings.
"I shall define beauty to be a harmony of all the parts, in whatever subject it appears, fitted together with such proportion and connection, that nothing could be added, diminished or altered but for the worse."
- Alberti’s definition of Beauty
Santa Maria delle Carceri a Prato, Giuliano da Sangallo, 1484-1495

Santa Maria in Campagna, Piacenza, 1522-1528

Santa Maria della Consolazione, Todi, 1508

Tempietto, San Pietro in Montorio, Rome, Bramante, 1502
City
“The Ideal City” The panel of Urbino
Painting Attributed to Fra Carnevale
Location: The Ideal city of Urbino, Baltimore, and Berlin.
Created: 1480

Ideal House
Ideal House: fundamental needs
Architect: Claude-Nicolas LEDOUX
Bi-lateral symmetry giving clear order to forms and spaces
Created: 1770

Cemetery
Cemetery of ideal city of Chaux, Arc-et-Senans
Section and plan: Drawn by Le Doux,
Location: Chaux, Arc-et-Senans, France
Created: 1874
**Suspended Living**

**Dymaxion House: suspended living space**

Architect: R. Buckminster Fuller

The Dymaxion House never went into production

Created: 1927

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**Glass House**

**Glass House: light and transparency of the future**

Architect: Bruno Taut

Location: Pavilion at the Cologne Deutscher Werkbund Exhibition

Created: 1914

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**Uncanny**

**House of the Suicide**

Architect: John Hejduk

deeply personal feelings and experiences

Created: 1985

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Chapter 2: Ideological Realm
**MIMICKING ARCHITECTURE**

**Forest**

*La Sagrada Familia*

Architect: Antoni Gaudi, Francisco de Paula del Villar y Lozano  
Location: Basilica in Barcelona, Spain  
Start: March 19th, 1882  
End: In progress  
Style: Spanish Gothic, Modernism, & Art Nouveau

**Microscopic Sea Creature**

*Kunsthau Graz*

Architect: Peter Cook, Colin Fournier  
Location: Graz, Austria  
Start: 2001  
End: 2003  
Style: Blobitecture, Digital Facade

**Soap Bubbles**

*Eden Project*

Architect: Nicholas Grimshaw  
Location: Bodelva, United Kingdom  
Start: 1998  
Open: March 17, 2001  
Style: High-tech architecture
**Honeycomb Flower**

*Orchideorama*

Architect: Plan B Architects + JPRCR Architects
Location: Medellín, Antioquia, Colombia
Style: Installation and structure

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**Wood**

*The Tippet Rise Art Center: Xylem*

Group: Francis Kéré Architecture
Location: Stillwater County, Montana
Installed: 2016-2019
Style: Sacred wooden and straw loguna structures

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**Rock-caves**

*National Taichung Theater*

Architect: Toyo Ito, Cecil Balmond
Location: Taichung, Taiwan
Start: 2006
End: September 30, 2016
Style: Modern

---

Chapter 2: Ideological Realm
BIO-MIMETIC ARCHITECTURE

Sustainable Urban space

AIA Pavilion
Group: Gernot Riether and 11 students
Location: New Orleans
Installed: 2010
Style: CNC routing, thermoforming parametric forms in grasshopper

Algae
Algae House
Architect: Splitterwerk Austrian Firm & ARUP
Location: Hamburg, Germany
Start: December 2011
End: April 2013
Style: bio-adaptive facade

Silkworms
Silk Pavilion
Group: MIT Media Lab’s Mediated Matters research group
Location: MIT Lab Cambridge, Massachusetts
Installed: 2013
Style: 6,500 Silkworms with 26 polygon panels for primary structure
2014

Spiders Web
ICD/ITKE Research Pavilion
Group: (ICD) and (ITKE) of the University of Stuttgart
Location: Stuttgart, Germany
Installed: 2014
Style: Custom Made Robot

2016

Beetle wings
The BUGA Fibre Pavilion
Group: The University of Stuttgart
Pavilion was on display until October 6th, 2019
Installed: 2016
Style: fibre-composite pavilion

2018

3D-printed exoskeleton
Aguahoja
Group: MIT Media Lab’s Mediated Matters research group
Location: traveling art instalation
Installed: 2018
Style: Programmable Bio-composites for Digital Fabrication

[Figure_2.13]
ARTIFACTS.1
The Cube

The Dome

The Sphere

The Web
The Cube Artifact’s intent was to use the Geometry of the hexagon to create a shape, that questioned to what extent is the Geometry lost? With the style design of Gothic Architecture, I saw to manipulate the Hexagon pattern into a Geometric Pattern of Spheres. The sphere is seen as the Most efficient shape, but in Cathedral Architecture you never see a sphere, you see an ellipse. The Sphere is too perfect for man to manipulate. Second, I abstracted the construction lines, to create a waffle grid structure. After voiding the patterned ellipses out of the waffle structure, the Cube space was created. With Uncanny edges, mirror views, a play of light and shadow, Monumental-ism and manipulated geometry; this design shows how a simple geometry, can become easily organic, structural and still stay true to its Geometry.
Hexagon Geometry Selection

2-D Hexagon transformed into 3-D Sphere Pattern

Spheres coded to Ellipse heights
The Dome Artifact took a look at Geometry as a tool to be wrapped around a sphere. Understanding that we have a unique view of a domed space as representing something higher or optimal for light and space manipulation; a Dome was chosen as a shape representing a Humanist Ideal form. The chosen pattern comes from the hexagon, choosing points and nodes for how to manipulate the dome. Playing with the idea of views and focusing out words, Seven view ports were selected and represent the seven sphere’s of force to make the hexagon. After extracting the Hexagon view ports, the Dome was made. Symmetrical views made the space feel more calm, as well as focusing the light and shadows. The sphere and Hexagon shaped views of the Dome, allow for a remembrance of figures, drawing attention towards the balance and placement of the Geometry.
Geometric Pattern wrapped around Sphere
The Sphere Artifacts looked at a Truncated Icosahedron, and what simple shape deforming would do to the view of the Spheres. Subtraction of pieces allowed the first sphere to open up and be able to have an inhabitant. A wire dome was added to study models, to see the shadows and views seen from deformation and a screening system. The second iteration took the Truncated Icosahedron, to push and pull the form as a whole. The Geometric pattern is represented in hexagons and polygons, which can still be seen intact with the morphing. The last Sphere was deformed by the individual panels of the hexagons and polygons, transitioning the points of force to interlace and create triangles. The natural movement of the shapes is to bow and become a curved surface, but with the manipulation of flat panels the surfaces called for more support or less support material, for the panels.
Deformation Spheres
The Web Artifact used a Geometric pattern as a means to turn a 2-Dimensional Drawing into a 3-Dimensional organic form. The intersections of the nodes were replaced by long pointed pipes to act as 360 Degree pivoting points. The lines of the Geometry were coded to different lengths decided upon the scale of the pattern. Together this system allowed for an Organic form that could be manipulated to compress and expand. The balance of the geometry the hexagon gave, allows the compression of geometries to natural dome when the points are closer together. Each joint and geometry is free to move affecting its neighboring partner creating a type of screen and fabric. The scalability and hexagonal geometry allowed light and shadows to change imprinting its geometry on the surface around.
Color coded Patterning system

Geometric Pattern Manipulated into Organic form
STRUCTURAL ANATOMY
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Cosmogonist Theorem

Richard Buckminster Fuller was an engineer, inventor, mathematician, architect, cartographer, philosopher, poet, cosmogonist and comprehensive designer. Known for Synergetic Geometry, he mixes in that man has legs that make us have mobility, while vegetation has roots making them more docile. When investigating structure, and specifically the Geodesic Dome Buckminster Fuller was able to find nature’s geometry. His Geodesic Dome structure in 1926 was seen as the strongest, lightest and most efficient means of enclosed space yet devised by man. This design reinforced the idea that the underline key to structure is based in Nature. “Molecular biologists have now established that his mathematical formula for the design of the geodesic dome applies perfectly to the structure of the protein shell that surrounds every known virus.” (Tomkins)

In the end Fuller was seen as a visionary, he concluded that nature uses a coordinate system and eventually analyzing nature would reunite all the scientific disciplines. Ensuring that Man is able to be a complete success in his environment.

Underlining the formula E = mc^2, Einstein’s concept of Energy explained the basis of the universe and the theory of special relationship. Explaining and being able to adapt to our environment should be a primary factor to life, but everything in Nature is constantly changing and we as man have the ability to shape our environment. Newton’s Three Laws state first, objects at rest remain at rest and objects in motion remain in motion in a straight line unless acted upon by an unbalanced force. Second, Force is equal to mass times Acceleration seen as f = ma. Third, for every action there is an equal or opposite reaction. Modern Science and technology proved that nature has a dynamic norm instead of a static norm with inertia.

Fuller stated,” If nature can accomplish all those associations in beautiful whole numbers to make all her basic structures, I thought, then the system will turn out to be a coordinate system and it will be very, very simple.”, (Tomkins) Natures geometry in Fuller’s mind was known as Synergy an invisible realm that’s unpredictable by individual behaviors of sub-systems. Seeking to make more and more from less and less, his investigations based around looking at nature’s basic pattern to link the gap between science and humanities. If we create existence from a point to a line to a plane to a form, we cannot create the perfect ideal forms. Looking at a sphere V= 4/3 π r^3, this ideal form uses π an irrational number, but nature doesn’t use it uses an arithmetical-geometrical coordinate system.

1609 - Galileo di Vincenzo Bonaulti de Galilei

Principle of Inertia

1666 - Sir Issac Newton Three Laws of Motion

1st - “Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by force impressed on it.”

2nd - “Force is Equal to the change in momentum (mV) per change in time. For a constant mass, force equals mass times acceleration.” F = ma

3rd - “For every action, there is an equal and opposite re-action.”

1686 - Sir Issac Newton Theories of Gravitation

1686 - Sir Issac Newton Three Laws of Motion

1st - “Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by force impressed on it.”

2nd - “Force is Equal to the change in momentum (mV) per change in time. For a constant mass, force equals mass times acceleration.” F = ma

3rd - “For every action, there is an equal and opposite re-action.”

1863 - Josiah Willard Gibbs and Oliver Heaviside

Vectors : has Magnitude and direction

Cartesian coordinate (x,y)—the x,y components of a vector.

Polar coordinate (r,θ)—the magnitude (length) and direction (angle) of a vector.
Therefore, nothing in nature is truly perfect, nothing physically conceived will be an ideal form, we just seek like nature to represent the pure forms. After understanding how nature designs and analyzing different geometries in nature, it's not about points in nature but vectors in nature.

Galileo’s diagrams of forces showed the bases for how objects move in nature and how forces are affected. A Vector is an object that has both magnitude and direction. The length of the vector is known as the magnitude, while the arrow points in the direction. Connecting to a coordinate system polar coordinates, (r,θ), and cartesian coordinates, (x,y); this relationship known as vectors is formed between point A and point B seen as \( \mathbf{a} = \overrightarrow{AB} \). Analyzing Galileo’s theorem looked at how things moved instead of why things moved. Experimenting with dissecting the rules to inertia and the movement of objects vectors in numbers in space, numbers in time and numbers in space and time, Galileo found answers to nature’s structure. Galileo stated, “It is not the nature of objects to come to rest. It is natural for objects that are moving to keep moving. The property of objects to resist change in motion is called inertia.” (Galileo)

The motion of a form in space can be separated into two types of motion and we start to see how Natural Motion and Violent motion affect the structural integrity of an object.

Fuller’s understanding of what a vector wants to do led him to the design of the Geodesic dome to state; Fuller stated, “I think all nature’s structuring, associating, and patterning must be based on triangles, because there is no structural validity otherwise.” This is nature’s basic structure, and it is modelable.” (Tomkins)

Fuller’s studies showed that four triangles together created the ideal structure of nature and that the Tetrahedron was the simplest and most efficient way to replicate nature. In Buckminster’s theories he believed that earth is a spaceship since it's an object in space. To manipulate a person is too hard therefore we manipulate our environment to get us moving in a prepared way. “He once told his friend and biographer Robert W. Marks, “I did not set out to design a house that hung from a pole, or to manufacture a new type of automobile, invent a new system of map projection, develop geodesic domes or Energetic Geometry. I started with the universe—as an organization of regenerative principles frequently manifest as energy systems of which all our experiences, and possible experiences, are only local instances. My objective was humanity’s comprehensive success in the universe. I could have ended up with a pair of flying slippers.”” (Tomkins) Utilizing different methods though the ideal geometry lead to many futuristic ideas of how nature can be used as a functioning design of structure and support, a tension and a compression balancing off one another. Today there are many structures built off of the Geodesic dome to push the form of an object around how its manipulated.

1905 - Albert Einstein Theory of Special Relativity \( E=mc^2 \)

E = energy
m = mass
c = the speed of light

Not a Static Norm

Synergetic Architecture
Synergetic: Common purpose or benefit

Nature uses a arithmetical-geometrical Coordinate system.

"Nature is rational, a sphere uses π, π is irrational, Nature does not use π."

"Earth is an object in space, Earth is a Spaceship."

"Man has Mobility, Nature has roots, Man must be a success in his environment."

MOBILITY

Nature has a Dynamic Norm
Not a Static Norm
PLATONIC SOLIDS / POLYHEDRONS

Tetrahedron
Cube
Octahedron
Icosahedron

4
6
8
20

Chapter 3: Structural Anatomy
Chapter 3: Structural Anatomy
The Geodesic dome is known as one of the most influential pieces of architecture. Its structure allows it to be the most efficient and strongest structure to date. The design allows for the structure to sit as a space frame with equally distributed forces as tension and compression are met at an equilibrium. Designed around the sphere it has the most volume with the least amount of surface area. The spherical form allows wind to slide smoothly over the surface, helping to maintain a constant temperature inside the structure, eliminating the necessity of heating and cooling. The interchangeable parts allows for an easy manufacturing and constant built design. This dome uses the geometrical patterns of triangles, and when blown up you can see the hexagons appear with pentagon facets.
Wooden Geodesic Dome Construction

Study drawings from Richard Buckminster Fuller’s Geodesic Dome
Chapter 3: Structural Anatomy
The Tensegrity structure is based off of simple geometric patterns that combine together to utilize compression and tension to make it stand. It is supported as a whole by tension and compression making the structure very fragile and reliant on its cables. The load transfers allow the cables to be in tension, to maintain structural integrity. As stress increases on the structure, forces are transferred throughout becoming stiffer as the cable’s tension increases. The pattern allows for all structural members to have no shearing or bending and creates a strong and rigid structure. With this floating compression it allows for many structures to pop into place based off of the geometry next to it.
PVC Pipes and Umbrellas in the Dandelion-esque Dome in Singapore

Study drawings from Richard Buckminster Fuller’s Tensegrity
Chapter 3: Structural Anatomy

T3-Prism: Simplest Tensegrity Structure

Icosahedron

Tensegrity Icosahedron
Merging two Tensegrity Icosahedron together
The Fly Eye Dome was constructed of lightweight fiberglass and circular opening to design a space with the most light. The Oculi represent the way in which a fly’s eye works, allowing for maximum light sensitivity and minimal structure. The integrity of the structure allows for light and air to flow through the space without compromising the geometry. As an affordable and portable home for the future, each opening is able to support different functions. Such as photovoltaics, water collection, windows, shading and many others, the design allows for an infinite selection of programs on the structure to support the needs of anyone. This sufficient dome is able to be easily assembled and hand built stemming from the same ideas as the geodesic dome.
Fuller Dome - Traveling Exhibition

Study drawing’s from Richard Buckminster Fuller’s Fly Eye Dome
Digital Soap and Bubble studies

[Figure_3.05] Frei Otto’s soap films took structure into a physical representation of how the forces become harmonized within the curvatures of soap films. This method has an efficient use of materials with and creates a lightweight structure. This lightweight sculptural structure uses cabled nets, lattice shells and other tensile materials to represent the films at an architectural language. Spacial composition utilizes fusion between the landscape and architectural pieces to blur the lines between the interior, exterior, walls, ceilings and floors. This design allows for a lightness and stable structure that has been utilized today for many objects from Stadiums to camping tents.
NAI - SIG
Natural And Ideal Studies In Geometry
## NAI-SIG Building Components

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Through Natural and Ideal studies in Geometry, Nature shows us how to design, and is the true creator. We can learn how to design simple structures and forms that mimic how nature teaches us. The hexagon has been proven as the most mechanically stable shape with its 120 Degree angle, and has been proven to use the least amount of material. In the Ideal realm, Geometry has been proven to be the greatest design strategy to gain a higher power and feeling when encompassed by perfected forms of shapes. By utilizing what we have learned from Nature and the utilization of human history; we are able to push new boundaries and create the world around us. Architecture is meant to be designed around the human body a person’s experience. Our senses; Proprioception, Vestibular, Taste, Hearing, Touch, Sight and Smell allow us as humans to see the world in a certain way. Unlike a fly, bee or any other animal known we attempt to capture moments in time that reflect our understanding and our version of the world.

NAI-SIG is a Pavilion space that is designed around the Geometric Studies done on Nature and the Ideal Geometry we have come to know and understand. This investigation will explore the way in which Geometry can consume the space around a person, and create a meditation space without representation of preconceived notions. The form will take on the appearance of a Natural and Ideal form mixed together to meet in the middle. NAI-SIG will be a piece of architecture that sparks questions of what a space can become by utilizing simple geometric forms that are familiar to us. Keeping in mind that Nature is never Ideal, and we will never be able to live in an Ideal world, I will be distorting and creating a form that links the hexagon to an Organic Natural form that moves around the human perception of our world.
Following the Amoeboid process and many shapes distorted from geometric forms, I let NAI-SIG follow the same Vectors nature had shown. The Ideal Geometry I used was the Hexagon, and by choosing the Dual Truncated Icosahedron to Distort it gave NAI-SIG a significant meaning. Acknowledging the circle as what nature uses and the square is what humans use, NAI-SIG distorts and gets pulled based upon Natural vectors and Human space. A simple form was made for the outer shell by moving the Dual Truncated Icosahedron vectors around in an inscribed Hexagon. For the inner shell I wanted the space to have a curving effect as if the space was moving around you. A simple curve derived from a Hexagon within a Hexagon was used as the base of how the inner shell would follow the curve. Similar to an organic form the Dual Truncated Icosahedron had to be pulled around the curve to ensure the geometry would be continuous throughout.
Dual Truncated Icosahedron distortion of inner shell
With the Geometry distorting around the space created, the inner shell sits within the outer shell to express the interior and exterior. Combined together the two shells are set into the ground and cut at the ground to transfer this organic form into the built world. After designing the skin, they were manipulated to work at the scale of a person and to allow for the skins to work together.
NAI-SIG PAVILION COMPONENTS

NAI-SIG Overall

White Concrete Base

Reflection Pond

Hexagon Oculus

Truncated Icosahedron Bench

Truncated Octahedron Podium
Silver Enameled Aluminum Outer Shell

White Enameled Aluminum Inner Shell

Wooden X-Axis Waffle Grid Structure

Entrance Gateway

Black Carpeted Flooring

Wooden Y-Axis Waffle Grid Structure
NAI-SIG FURNITURE

NAI-SIG has white Corian furniture to adapt to the curvatures of the distorted Truncated Octahedron and Truncated Icosahedron. The Podium is directly positioned under the Hexagonal Oculus, giving the space a direct object that draws attention to the hexagon derived polyhedrons. Following the inside space the bench follows the curve of the wall from the chair to create a space to rest and reflect. Lastly in the public space the chairs are placed around the pavilion to draw focus to the main structure, and to connect the inscribed hexagon to the rest of the plaza.
Truncated Icosahedron Bench
The Entry to the pavilion follows the square shape that represents what humans use. In a square fashion the form was distorted to allow the entrance to move around the door, as well as draw people towards the opening. This is the most distorted area of the outer shell, and cuts through the skin, as to not take away from the organic form. The Oculus is a Hexagon shape to represent a higher meaning and serves as the only window to the outside. When moving through the structure the Oculus illuminates the bigger space, leaving the corridor to be darker and only lit by the floor lights.
TECHNICAL DRAWINGS
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Section 1.1: 1’=1/8”
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South Elevation: 1'=1/4”
Southwest Elevation: 1’=1/4”
Northwest Elevation: 1’=1/4”
North Elevation: 1’=1/4″
Northeast Elevation: 1’=1/4”
Chapter 5: Technical Drawings
Section 2:1:1’=1/4”
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Section 2.5: 1' = 1/4"
Section 2.6: 1’=1/4”
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Section_3.4:1’=1/4”
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Through this thesis the NAI-SIG Pavilion shows how simple Geometries can be utilized to create a space that holds a sense of meaning. The hexagon form is shown by Nature to be an Ideal form and have the most mechanically stable angle. By taking what Nature shows us and the historical significance of how we use geometries, the distortion and rules learned can help to bring out the true meaning of architecture. A space should encompass all the human senses and the enclosure around you. Allowing NAI-SIG to have an organic form and inscribed geometries combined the Natural Realm with the Ideal Realm. The built world is designed for us to experience and architecture should always yearn to move and distort around our perception. Architecture can create a sense of familiarity and sensibility that gives a person a feeling of wonder. Through the discipline and focus of the hexagon, Nature and Ideal Forms hold such importance to every aspect of life.
The intention of this thesis was to look at the Hexagon to utilize its geometry to create a built installation. The research and involvement through the thesis at the beginning was very strong with the goal of making models each week and hopefully producing prototypes. Half way through the process the Pandemic changed those goals from being face to face to being online. The thesis had to adapt and change from its original intention as a built installation to a Pavilion design. The knowledge and constant collaboration with my Advisor helped to transfer the project to its final design, while keeping the integrity of the work. Overall this experience has been one of the most challenging and mind opening subjects I have gotten to study. By studying the history behind the hexagon, it has shown me the important role geometry plays behind the veil of creation.


**ILLUSTRATION CREDITS**

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*Figure_1.01*: The Beautiful background of the masterpiece _The Birth of Venus_ with the shell in the foreground. https://www.pinterest.com/pin/414894184393718345/  

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*Figure_1.05*: r/OddlySatisfying - The Way That the Basalt Columns in the Giant’s Causeway Fit Together. Reddit, www.reddit.com/r/oddlysatisfying/comments/6yaq4h/the_way_that_the_basalt_columns_in_the_giants/.  

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*Figure_1.06*: Eye of a Fruit Fly: Microscopic Images, Microscopic Photography, Scanning Electron Microscope Images. Pinterest, www.pinterest.com/pin/304063412311607033/  

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*Figure_1.06*: Choi, Charles Q. “Bizarre Giant Hexagon on Saturn May Finally Be Explained.” Space.com, Space, 22 Sept. 2015, www.space.com/30068-mysterious-saturn-hexagon-explained.html.  

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*Figure_1.09*: “Turtle Texture.” Aaron Lynton, aaronlynton.com/product/turtle-texture/.  

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*Figure_2.02*: “Radiolaria: More on Morphology.” Morphology of the Radiolaria, ucmp.berkeley.edu/prostata/radiolaria/radmm.html.  

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*Figure_2.02*: “Radiolaria: More on Morphology.” Morphology of the Radiolaria, ucmp.berkeley.edu/prostata/radiolaria/radmm.html.
Notes

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Flyeye,Https://I.pinimg.com/Originals/78/45/c4/7845c42e73d0efcb0c233a4e12688a4.jpg. i.pinimg.com/ originals/78/45/c4/7845c42e73d0efcb0c233a4e12688a4.jpg.

[Figure 3.63]: Frei Otto: Spanning the Future, www.freiottofilm.com/.


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