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Bio-Inspired Design Approach Analysis: A Case Study of Antoni Gaudi and Santiago Calatrava

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Abstract*—Antoni Gaudi* and *Santiago Calatrava* have reputation for designing bio-inspired creative and technical buildings. Even though they have followed different independent approaches towards design, the source of bio-inspiration seems to be common. Taking a closer look at their projects reveals that *Calatrava* has been influenced by *Gaudi* in terms of interpreting nature and applying natural principles into the design process. This research firstly discusses the dialogue between Biomimicry and architecture. This review also explores human/nature discourse during the history by focusing on how nature revealed itself to the fine arts. This is explained by introducing *naturalism* and r*omantic* style in architecture as the outcome of designers' inclination towards nature. Reviewing the literature, theoretical background and practical illustration of nature have been included. The most dominant practical aspects of imitating nature are form and function. Nature has been reflected in architectural science resulted in shaping different architectural styles such as organic, green, sustainable, bionic, and biomorphic. By defining a set of common aspects of Gaudi and *Calatrava*'s design approach and by considering biomimetic design categories (organism, ecosystem, and behaviour as the main division and form, function, process, material, and construction as subdivisions), *Gaudi's* and *Calatrava*'s project have been analysed. This analysis explores if their design approaches are equivalent or different. Based on this analysis, *Gaudi*'s architecture can be recognised as *biomorphic* while *Calatrava*'s projects are literally biomimetic. Referring to these architects, this review suggests a new set of principles by which a bio-inspired project can be determined either biomorphic or biomimetic.

***Keywords*—**Biomimicry, Calatrava, Gaudi, nature.

I. Introduction

NATURE plays a central role in humans' life specifically when it comes to imitation and metaphor. Nature's trace can be seen in any types of investigation and discovery [1]. Very first human being has been in close relationship with nature but they started to turn away from that and finally were expelled from heaven [2]. Natural wisdom includes billion years of experiences, systems and structures motivating architects, engineers and scientists to look for innovations and technologies [2].

Biomimicry was first used in scientific literature in 1962 [3] and is the study of emulating nature for solving human problems [4]. It also means "the imitation of natural biological designs or processes in engineering or invention. *Julian Vincent* notes that Biomimicry is "the abstraction of good design from nature", and *Janine Benyus* identifies that as "the conscious emulation of nature's genius" [5]. As reference [5] states there is an obvious distinction between Biomimicry and Biomorphism. [5] declares that Biomimicry is used when imitating natural forms is accompanied with relevant functions and processes found in nature whereas Biomorphism applies to conditions when merely natural forms are emulated. The translation of nature in Greek is Physis which in English means something that grows [6], [7].

Biomimicry can assist humans in changing their perceptions towards nature since nature is not a barrier but the source of innovation and inspiration[6]. Reference [8] Suggest three main categories of mimicry according to the existing biomimetic technologies. They are the *"organism"*, *"behaviour"* and *"ecosystem"*. Each category consists of five subcategories: form, material, construction, process and function. Organism level includes mimicking organisms in part or in whole. Behaviour level is referred to imitating organism's behavioural aspects in a large context and in the ecosystem level, the whole ecosystem is emulated in architectural design [8].

TABLE I
LEVELS OF MIMICRY [8]

Three Levels of Mimicry				
Organism		Behavior		Ecosystem
Form	Function	Material	Process	Construction

II. Inspiration from Nature

A. Historical Background

Reviewing the literature there is a classification by which human and nature relationship during the history is defined. According to this classification, there are three types of relationships between human and the environment: "*religious* or *cosmologic"*, "*symbiotic"*, and "*exploitative"* [9]. Natural environment used to play a dominant role through religious-oriented times when humans were considered less valuable than nature. This relationship evolved gradually until humans-nature relationship came back into a balance. This relationship went out of balance again when humans became firstly modifiers, then creators, and finally destroyers of nature [9], [10]. Reference [11] also refers to these three stages as: "*theological"*, "*metaphysical"* and "*positive stage"*.

Considering this gradual development in humans' perception towards nature, natural forms were initially imitated metaphorically in historical architecture [6]. For example, temples and houses in ancient times were built in a way to symbolise the universe [12] and form did not follow function.

Ornaments were known as indirect imitations of nature and mostly used in "*Victorian architecture"* [13]. For instance,

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"*Mycenaean palaces"* were decorated with marine motifs [14] and "*Corinthian columns*" were carved to resemble leaves and floral patterns. "*Egyptian"* column capitals had also lotus and palm motifs. In other words, there has always been a strong link between trees and architecture which can be seen even in contemporary architecture [15].

Form and function were finally reconciled. Human body became a source of inspiration, and measurements in architecture were derived from *Vitruvius*'s man. For example, during the age of discovery, *Da Vinci* illustrated how proportionate human body fits into geometric shapes such as circle and rectangle.

B. Nature in Fine Arts

Art movements occurred due to artists' tendency towards nature and natural phenomena. For instance, nature was the driving force for "*Romanticism"* and "*Medieval period* "recognised humans as the creators of art in the same way that God has created the earth [16]. Later, due to the technological developments, a shift occurred in the reflection of nature in the fine arts and 20th century witnessed the new type of approaches towards nature.

Basically, there is a relationship between naturalism in art and romanticism in architecture [17] and as [18] states they both have the same root. *"Naturalism"* in philosophy means the "idea or belief that only natural forces operate in the world." whereas in the "*religious nationalism*" there is an emotional connection between humans and nature. *Jules-Antoine Castagnary*, the French art critic, declares that the ultimate aim of naturalist school was to reproduce and revitalise nature at its highest power [19], [20]. *Arno Holz*'s theory suggests a mathematical equation for art, "Art = Nature - X," meaning that nature should be imitated in the art as much as possible. *Johann Ludwig Tieck*, the German romantic poet, refers to nature and art as languages for God and humans respectively [21]. *Tieck* believes that the illustration of nature in a religious context empowers art.

In overall, the perception of nature takes place in artists' mind based on their views towards nature and as *William Carlos* states, copying the exact nature does not produce creative art since imitating nature requires the imagination of the creator in the highest sense [22].

Artists and architects have been always inspired by nature. For instance, *Leonardo Da Vinci* was a profound observer of nature and *Wassily Kandinsky* used to create nature rather than solely imitating that. Picasso notes that "Through art, we express our conception of what nature is not." and *Goethe* believed that artist copies nature by creating its image in the real world [23]. Philosophers such as *Plato*, *Derrida* and *Kant* have also defined the concept of mimesis in different ways.

III. Biomimicry in Theory and Practice

Looking deep into nature and imitating natural forms and processes have brought about new theories in architecture and design [24]. For instance: *Plato* and *Aristotle* refer to the qualities of integrity, unity, and wholeness in living beings as the central concept in any type of artworks. *"Romanticism"* and "*Renaissance"* also took shape to oppose mechanical characteristic of "*classism"*.

Elizabeth Lawrence claims that natural organisms (especially animals) are the main source of inspiration for metaphoric expressions and symbolizations [25], [26]. Reference [24] States that organisational constituents of natural shapes such as pattern, symmetry, proportion, and unity; make a basis for creating artworks. *D'Archy Thompson* compares animals skeleton and plant stems with mechanical structure [27]. *Horatio Greenough* declares that animals and insects' skeleton and skin form the principles of construction [28], [24]. Reference [29] refers to the *"indirect experience"* of nature as the interventions made to the architectural forms in order to make them more natural and reference [30] suggests that tree-like forms used in the built environment have a positive effect on human beings.

From a practical point of view, nature and architecture relationship has been defined in various ways during the history of art and architecture. This relation has taken on different meanings such as: bringing nature into design (direct use), sculpture design, designing structural compositions inspired by natural structures, imitating natural forms for the purpose of producing morphological concepts, the concept of wholeness, symbolism and metaphor, to name a few. "*Baroque"* as the dominant style in Europe and "*art nouveau"* as the international style of art and architecture had floral and plant-inspired motifs. *John Ruskin* mimicked nature through close and accurate observation [31] and *Louis Kahn* was interested in the spiritual aspect of nature.

A few years later, during the period of "*modern* "architecture, natural growth and evolutionary processes were described by *Frank Lloyd Wright* who was inspired by his precedent: *Louis Sullivan*. *Wright* introduced *"organic "*architecture in which form and function were just one aspect [32].

Organic by definition means produced by or derived from living organisms and is borrowed from biology in architecture enabling designers to compare inorganic forms, structures and functions to those found in living organisms [33] and as [34] states organic's root can be traced back to the aesthetics of "*classicism"*. In the recent years *"Bionic"* architecture as" the study of mechanical systems that function as living things" [35] has become popular worldwide.

A large number of structural systems are inspired by natural organisms. For example, tree branches show flexibility and deformability motivating column and beam structure in architectural design. Shell of insects and molluscs have inspired light and sturdy structures and spider webs and animals cells are the source of inspiration for tension and "*pneumatic"* structures respectively [36]. While natural organisms inspire a wide range of structures, a considerable amount of nature-inspired designs are decorative and known as *"biomorphic"* or *"zoomorphic"* representing shapes in nature [37]. These two types of design have got their own proponents as *Eugen Tsui* who is reputed for his animal architecture and their own opponents as *Aldersey-Williams* who notes that literal imitation of animals' form in

architecture might lead to ridiculous result [24].

Another type of imitating nature in symbolic form is "*Biophobic"* pattern which resembles humans' eyes and provokes stress and agitation. "*Biophobic"* patterns can be seen in *Imre Makovecz'*s architecture [38] however *Aiken* refers to one of *Picasso*'s painting arguing that eye features are more deployed in art rather than architecture.

Contemporary architecture suggests a new type of design approach called "*morphogenesis"* following biological process within which an organism takes shape and develops. In "*Parametric"* design architects use algorithmic parameters to produce complex geometries and develop parametric façade and structures.

IV. Extraction of Biomimicry Parameters from *Gaudi* and *Calatrava*'s Design

Reviewing the literature, a set of parameters can be derived and an analysis can be made based on those parameters to compare "*Bio-inspired"* design of *Gaudi* and *Calatrava*. These parameters are divided into two parts: theoretical and practical.

The first row of Table II introduces a number of biomimetic design aspects in the practical part. The second row suggests if either organism, behaviour, or ecosystem levels correspond to these aspects. The third row shows levels of form, function, construction, material, and process (Pedersen Zari's subcategories of Biomimicry) which apply to those design aspects in any architectural design process.

TABLE II
Practical Parameters in Correspondence with Biomimetic Levels Scope: Architectural Design in General

Biomimetic design aspects	Three levels of mimicry	Sub-levels of mimicry
Metaphor	Organism	Form, Function, Construction, Material, Process
Proportion	Organism	Form
Form	Organism, Behaviour, Ecosystem	Form
Function	Organism, Behaviour, Ecosystem	Function
Movement and Growth	Organism, Behaviour	Form, Function, Process
Material	Organism, Behaviour, Ecosystem	Material
Pattern	Organism, Behaviour	Form
Sustainability	Ecosystem	Function, Process
Geometry	Organism	Form
Technology	Organism, Behaviour, Ecosystem	Form, Function, Construction, Material, Process

A. Practical Parameters

1) **Metaphor/ Analogy:** metaphor is defined as "illustration of an idea by means of another familiar idea that is similar or parallel to it in some significant features. Reference [39] Clarify a distinction between analogy and metaphor. They refer to the former as a tool for generating concept in the early design stage, however, both of them are used by designers through the design process. As reference [40] suggest there are three types of metaphor: *"structural"*, *"textural"*, and *"isolated pictorial"* dealing with intellectual, poetic, and visual sensitivities respectively [41]. Reference [1] classifies metaphors into another three categories: tangible, intangible and combined. Tangible and intangible metaphors are defined as abstract ideas and visual/material representations respectively.
2) **Proportion:** *Vitruvius* believed that human body is the source of proportion for humans' design and recognized the nature as the source of harmony. Famous architects such as *Maillart, Nervi, Wright,* and *Otto* have designed tree-inspired structures considering proportions found in trees[15].
3) **Form and function:** "form follows function" was first discussed in the 20th century associating with "*modernist"* architecture but references [2] and [42] state that "there is no form without function and no function without form". From another point of view, physical external forces (function) acting within an organic body (form), facilitates better expression of architecture [43].
4) **Movement and growth:** Growth and movements are two characteristics of living things [44]. Movements are mainly attributed to animals however plants show slow movement during the growth process. Reference [45] notes that" Architecture can be used as a tool to motivate growth and progress through movement". This type of architecture has the ability to create spaces that enlighten and motivate, creating an instrument to breathe life into people and communities.
5) **Material:** Material itself is one of the five sublevels of mimicry proposed by Pedersen Zari.
6) **Pattern:** Natural patterns can be recognised at the core of bio-inspiration. These patterns appear in various scales and the main characteristic they represent is self-similarities mostly found in trees, blood vessels, shells, seeds, and etc. Reference [46] notes that "Nature uses patterns and gradients to optimise interactions and benefits".
7) **Sustainability:** Reference [6] states that Biomimicry is a way of merging environment into the design projects in order to achieve principles of sustainability and reference [47] note that "Biomimicry has been defined as mimicking the functional basis of biological forms, process and systems to produce sustainable solutions".
8) **Geometry:** As reference [48] states geometries found in nature are both quantitative and qualitative. [48] adds that quantitative aspect of natural geometry represents order and regulation of shapes and forms.
9) **Technology:** learning from nature has made a big change in today's structural industry. Computer-aided designs are getting popular among architects enabling them to design complex structural morphology initially inspired by natural structures [36]. These nature-originated structures exhibit high performance and show unique characteristics in terms of load bearing capacity contributing to technological development in architecture and construction design.

B. Theoretical Parameters

Theoretical background observed in *Gaudi's* and *Calatrava*'s early life and academic period can be divided into four parts: being influenced by natural environment, family and religion, industry and culture, and architectural inclinations. These parameters are explained in detail in Section V.

V. Comparison of Practical Biomimetic Parameters in *Gaudi* and *Calatrava*'s Architecture

A. Metaphor

Metaphors are classified into three categories: metaphors referring to animals, plants, and natural phenomena.

1.Plant-Inspired Metaphors

Tree-like column structure of "*Sagrada Familia"* is recognised as one of the great samples of bio-inspired architecture. Interior architecture of "*Casa Calvet"* and "*Casa Mila"* reflects *"Baroque"* style decorated with floral motifs [49], [50]. "*Casa Vicens"* has sinuous ironwork balconies and palm tree motifs on the garden fence and "*Parc Guell*" is consisting of 86 Doric columns representing trees.

Calatrava's projects also contain plant and animal morphologies [36] formed both deep down in the oceans and his imagination. His architecture is associated with leaves' patterns and animals and birds' skeletons allowing them to become symbols and urban monuments. A number of structural elements in *Calatrava*'s projects such as "*Valencia Science Centre"*, "*Heritage Square"*, and "*Kuwait Pavilio*n" replicate trees but as reference [25] states this type of imitation are not literal but symbolic. Tree-like structure of the "*Cathedral of Saint John"* reminds one of the tree-inspired columns of "*Sagrada Familia"* [51].

2.Natural Phenomena as Metaphors

Gaudi's architecture borrows from natural phenomena, for instance, there is a terrace in "*Parc Guell"* surrounded by a colourful wave-like serpentine bench and "*Casa Mila"* looks like sandy hills around Barcelona [2].

Calatrava frequently used waveforms in his projects. This waveform application evolved gradually from early experimental models to mid-sized installations as *"Winery for Bodega& Bebidas"* and finally to the fully developed structure of *"the national Wall"* [52].

3.Animal-Inspired Metaphors

Gaudi rigorously studied human body gestures and figures and used them as a basis for making sculptures [53]. In "*Parc Guell"* serpentine bench is designed in accordance to human body shape[2]. *Gaudi* has also designed "*Casa Mila"*'s chimneys in the shape of surrealistic creatures and has used animal-like models numerously in his projects such as dragon gate of "*Guell Pavilion"*, beetle-shaped door knocker of "*Casa Calvet"*, climbing animals on "*Sagrada Familia"*'s Walls, "*Casa Batllo"*'s fish scale facade, dragon scale roof tile, and skull-shaped balconies and etc. One can notice the resemblance of "*Parc Guell"*'s walls and serpentine bench to snakes.

Calatrava follows the same approach towards "*bio-inspired* "design. "*Lyon Satolas TGV Station"* design resembles a giant bird with spread out wings [54], [55] however *Calatrava* denies this biomorphic inspiration [56]. "*Quadracci Pavilion*" is a building with the wing-like structure used as movable sunscreen making equilibrium of sun and shadow. *Calatrava*'s early sketches of "*Montjuïc Communications Tower"* depict a man kneeling on the ground with extended arms to make an offering. The building itself represents an athlete holding the Olympic flame in his hands. Moreover, structural elements of some of his buildings resemble human spine [57]. "*Turning Torso"* was built upon studies of human body motions [57], transparent atrium in the "*Milwaukee Art Museum"* is similar to two hands in prayer [58] and "*Kuwait pavilion"*'s structure looks like interlaced fingers of clasped hands. *Calatrava*'s "*Planetarium*" and "*Opera House"* are inspired by the shape of an eye which is one of the main concepts *Calatrava* used in "*L' Hemispheric"* [59].

B. Proportion

Gaudi knows propriety [60] and in his projects, bio-inspired architectural elements appear nearly the same size as the literal ones while *Calatrava*'s designs are far huger than the real world samples.

C. Form and Function

As references [53], [15] note two inseparable aspects of *Gaudi*'s design are form and function. In other words, *Gaudi* made a great a combination of practical functions with the aesthetic forms and during his life, showed commitment to *Vitruvius*' idea saying that "architecture is form, function and beauty". For instance, "*Sagrada Familia"* is a symbol for combining structural appearance and structural load bearing concept of tree branches (form and function) [15] through irregular shapes[61].

Calatrava, on the opposite side, does not imitate literal organic forms however in his architecture; structural forces (function) determine physical shapes [25] as this happens sometimes in *Gaudi*'s designs. For instance, the descending pointed arch in "*TGV station"* is design to fulfil functional requirements and "*Stadelhofen"*'s detailing implies structural actions accompanied with anthropomorphic forms [62]. Considering form and function, *Calatrava*'s work is frequently cited in the literature to be inspired by *Gaudi* since both illustrate structural and formal audacity in their architecture [63].

D. Movement and Growth

Gaudi believed that buildings should look like alive and animated. *Gaudi* said that growth as a living organism' characteristic should be visible through architecture [64]. As a practical implementation of this idea, in either the "*Parc Guell* "or the "*Sagrada Familia Cathedral"*, structures are derived from growing trees.

Calatrava refers to growth and movement as two outstanding aspects of living things. *Calatrava*'s projects take their meaning from movement [45], [65]. *Calatrava* is

intrigued with moving structures in nature. For instance, *Milwaukee Art Museum* represents movement [52].

E. Material

Gaudi used traditional materials such as mortar, stone, ceramic and glass and rarely used artificial finishes on natural materials.

Calatrava believed that materials should be formed in a way to be able to match themselves with and respond to different functions. *Calatrava*'s use of material is confined to concrete and glass mostly appeared in white, grey or black. *Calatrava* and *Gaudi*'s choice of material is different as *Gaudi*'s choice is ebullient and warm while *Calatrava*'s choice is abstracted and homogenised [59]. *Calatrava* used ceramic tiles at the base of *Montjuic Tower* in a similar way that *Gaudi* used those in *La Pedrera*'s chimney.

F. Pattern

Most of *Gaudi*'s buildings are made of coloured tiles as well as mosaic patterns while *Calatrava*'s architecture is simple and plain.

G. Geometry

Observing nature, *Gaudi* learnt that nature does not include any straight line but internal geometries enabling organic forms to evolve and continue. *Gaudi* designed ruled surfaces such as hyperbolic paraboloids, hyperboloids, helicoids and conoids using formulas in geometry [66].

Calatrava recognised geometry as the foundation of architecture. *Calatrava* claimed that the language of the structure is built upon geometrical rules [67].

H. Sustainability

Some researchers believe that *Gaudi*'s architecture can be known as sustainable design [68]. For instance reference [69] acknowledges that sustainability criteria's of *Gaudi*'s design include the following items: awareness of natural lighting principles, integrated design, the importance of public green spaces, and borrowing from nature's own.

Calatrava's buildings are not isolated but emerged from the urban context and as reference [69] state are equipped with sustainable technologies. However, his designs are awarded for environmental measures such as energy consumption and waste disposal other researchers as [70] blame his architecture for not being environmentally friendly.

VI. Comparison of Theoretical Background of Gaudi and Calatrava

A. Geographical Influence

Gaudi was a good observer of nature and Barcelona had a great impact on his architectural mindset. Barcelona's surrealist landscape inspired most of *Gaudi*'s design. *Gaudi* had several trips to Spain, France, and the Balearic Island to get inspiration for design [71].

As a student, *Calatrava* Travelled around *Mediterranean* and explored vernacular architecture. *Calatrava* was affected by the huge monuments built in France, Germany, and Belgium as successful technical constructions rooted in *Mediterranean* architecture.

B. Ideological Influence

Gaudi grew up in a family with an artistic background. *Gaudi's* father had a copper making workshop where he learnt how to deal with metal turning them into curved forms. Being familiar with 3D dimensional forms and volumes *Gaudi* used these techniques years later in his buildings. *Gaudi* lived a Christian life and his religious beliefs became gradually intensified in his architecture.

Calatrava did not have either religion-oriented life or artistic background.

C. Influence of the Industry and Culture

Gaudi was born during the industrial revolution which served as a catalyst for *Gaudi*'s work. "*Modernist"* movement also coincided with the period when *Gaudi* was a student and influenced a large number of artists and architects including him.

Calatrava's architecture followed high-tech *Biomorphic* language in which technology was used as a material for modernists.

D. Architectural Inclinations

Gaudi's design inherits some aspects of "*avant-garde"* architecture such as dynamic forms and undulant surfaces [72]. A number of his contemporary historians relate *Gaudi*'s art with "*Cubism"*, "*Surrealism"*, and "E*xpressionism"*. *Fernando Chueca* introduces *Gaudi* as the "the greatest Spanish artist between *Goya* and *Picasso* and *Alexandre Cirici* refers to him as an abstract painter whose work anticipated plastic art and architecture. *Gaudi* as a "*Romantic"* artist [64] was inspired by architectural theoreticians such as *Walter Pater*, *John Ruskin* and *William Morris* and also impressed by *Viollet Le Duc and Ruskin'* thoughts regarding the analysis of "*Gothic"* architecture [64]. *Gaudi* followed *Le Duc*'s rational approach to architecture while was interested in *Ruskin* and *Morris*'s principles of art and crafts.Besides being influenced by other artists, *Gaudi*'s design of "*Parc Guell* "inspired many "*Catalonian"* artists such as *Salvador Dali* and *Joan Miro* who remained connected to their homeland during their carrier lifetime [72]. Moreover, *Eduardo Torroja*, *Felix Candela*, and *Pier Luigi Nervi* as engineer-architects were professional in using reinforced concrete and initially influenced by *Gaudi*'s construction technique.

Calatrava known as the creator of abstract images was influenced by *Paul Cezanne* and *Rodin* and had a huge admiration for *Brancusi*'s sculptures. His architecture in terms of use of mathematics was also similar to that of *Robert Maillart*, *Pier Luigi Nervi* and *Felix Candela* [73].

VII. Conclusion

Calatrava's architecture is organic and simpler than *Gaudi's* complex forms. *Calatrava's* works are more metaphorical in terms of following forms and functions in nature where *Gaudi's* approach seems to be more objective

and direct. We witness more dynamics and function in *Calatrava's* works which is a result of having access to a more modern technology. *Calatrava* is inspired by *Gaudi's* works and works of those who followed *Gaudi's* approach.

TABLE III
PRACTICAL PARAMETERS IN CORRESPONDENCE WITH BIOMIMETIC LEVELS, SCOPE: ARCHITECTURAL DESIGNS OF GAUDI AND CALATRAVA

Parameters	Architect	How	Main levels	Secondary levels
Metaphor	Gaudi	Natural: Waves Plants: Ornaments Animals/Human: Ribs, body	Organism	Form and Function
	Calatrava	Natural: Waves Plants: Structure Animals/Human: Hands, eyes, ribs, body	Organism and Behaviour	Form and Function
Proportion	Gaudi	Trees	Organism	Form and Structure
	Calatrava	Trees and Human body	Organism	Form
Technology	Gaudi	Limitations in Construction	Organism and Behaviour	Form, Structure, Function and Process
	Calatrava	Exhibition of construction technologies	Organism and Behaviour	Form, Structure, Function and Process
Pattern	Gaudi	A lot of texture	Organism	Form
	Calatrava	Less texture	-	-
Growth & Movement	Gaudi	Dynamic building aesthetics: Reflections of movement	Organism	Form
	Calatrava	Dynamic building elements: Controlled movement, mechanical movement	Organism and Behaviour	Form and Process
Material	Gaudi	Concrete, brick, stone, colourful tiles, Warm colours	-	-
	Calatrava	Concrete, Steel, Glass, White/Cold colours	-	-
Sustainability	Gaudi	Attention to site characteristics: harmony with nature	Organism and Ecosystem	Form and Function
	Calatrava	Attention to climate. Ignored sustainability. Ignored site characteristics.	Organism and Ecosystem	Form and Function
Geometry	Gaudi	Organic geometry: Inspired by Curves, Mountains Caves, Plants	Form	Organism
	Calatrava	Simple organic geometry: Conical and Cubical forms	Form	Organism

The environment, academic education, Hi-tech movement, constructivism and structuralism had a great impact on *Calatrava's* works resulting in creating industrial formalism and abstract formal geometry. *Calatrava* uses the innovative technology to take a step forward in the modern context of his time, while *Gaudi's* architecture is influenced by historical and cultural symbols of Spain neoclassicism as well as family, religion, industrial revolution and form/structure-oriented architecture. *Gaudi* not only brought his artistic genius to its utmost but influenced many architects after his time. Both of these architects had an eye on form and function in nature, but functionalism is bolder in *Calatrava's* works. We can say that Gaudi was a biomorphic architect, while *Calatrava* is a biomimetic architect. Table III compares Biomimicry design principles of Gaudi and Calatrava with mimicry levels suggested by Pedersen Zari.

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