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ARTIGO

EXPLORING BIO-PARAMETRIC SOLUTION-BASED DESIGN PROCESS FOR AN EPHEMERAL PAVILION

EXPLORAÇÃO DO PROCESSO DE PROJETO BIO-PARAMÉTRICO BASEADO NA SOLUÇÃO PARA UM PAVILHÃO EFÊMERO

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ABSTRACT:

This research proposes an experimental approach to develop an ephemeral pavilion located at the Serpentine Gallery in London. The Serpentine Pavilions Program functions as an experimentation laboratory and, at the same time, as public and event spaces, enabling architects to expose their projects and work methodologies. Thus, the methods of Biomimicry and Parametric Design were combined to develop the pavilion. While the first one was used to create an ephemeral pavilion based on the Sartorius muscle, the second one was responsible for generating the parametric model from a fast and intuitive manipulation code capable of exploring shape variations. This work explores the solution-based method approached by Badarnah (2012) based on a natural inspiration to solve a problem defined afterwards. Firstly, the anatomy of the Sartorius muscle was investigated. Subsequently, with the domain of the solution, the parametric insertion of the shape was computationally performed. The anatomical study of the Sartorius muscle revealed functions such as flexion, abduction, lateral rotation of the thigh, and medial rotation of the knee. Thus, the architectural choices reflect both its narrow and elongated morphology of the muscle and flexibility and rotation aspects. The pavilion also considered the previous Serpentine Pavilions regarding attributes such as area, height, and materials, which with other parameters may be changed using the code implemented in Grasshopper.

KEYWORDS: bio-inspired architecture; sartorius muscle; Serpentine Gallery; parametric pavilion.

RESUMO:

Esta pesquisa propõe uma abordagem de projeto experimental para desenvolver um pavilhão efêmero localizado na Serpentine Gallery, em Londres. O Programa Serpentine Pavilions funciona como um laboratório de experimentação e, ao mesmo tempo, como espaço público e de eventos, permitindo aos arquitetos exporem seus projetos e métodos de trabalho. Assim, os métodos da Biomimética e Design Paramétrico foram combinados para o desenvolvimento do pavilhão. Enquanto a primeira foi utilizada para criar um pavilhão efêmero baseado no músculo Sartório, a segunda foi responsável por gerar o modelo paramétrico a partir de um código de manipulação rápida e intuitiva capaz de explorar variações morfológicas. Este trabalho explora o método solution-based abordado por Badarnah (2012), que se baseia em um problema pré-definido (o projeto do pavilhão) e só depois busca a inspiração natural. Primeiramente, foi investigada a anatomia do músculo Sartório e apenas posteriormente, com o domínio da solução, a inserção paramétrica da forma foi realizada computacionalmente. O estudo anatômico do músculo Sartório revelou funções como flexão, abdução, rotação lateral da coxa e rotação medial do joelho. Assim, as escolhas arquitetônicas refletiram a morfologia estreita e alongada do músculo e os aspectos de flexibilidade e rotação. O pavilhão também considerou as edições anteriores dos Pavilhões Serpentine quanto aos aspectos de área, altura e materiais, que juntamente com outros parâmetros podem ser alterados através do código implementado no Grasshopper.

PALAVRAS-CHAVE: *arquitetura bio-inspirada; músculo sartório; Serpentine Gallery; pavilhão paramétrico.*

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INTRODUCTION

This paper's primary goal is to document the creation process for an ephemeral pavilion in which the biomimicry and parametric design were used as design methodologies to create real-time shape simulations that may help architects during the decision-making process.

Since its creation, the evolutionary history of nature has shown us that it regulates itself and selects the best solutions, aiming at the continuity of living beings on Earth. Animals, plants, and microbes are genuinely the natural environment architects and engineers (RAO, 2014).

Thus, the ephemeral pavilion project is an experiment that starts from the observation of the human anatomy to find architectural solutions. Currently, this approach is related to the biomimicry study field (also known as bio-inspired design), but the term only had its prominence throughout Janine Benyus' publications in 1997. Previously, in 2006, Benyus has defined biomimicry as a study field that investigates pre-existing solutions in the natural environment, to inspire processes and solve humankind's problems, aiming the sustainability and optimization of natural resources. According to Badarnah (2012), the development of morphology and shape in architecture is commonly inspired and copied from biological systems' solutions and rules. Therefore, the present paper explores biomimicry as a guiding principle of the investigation of the ephemeral pavilion.

Biomimicry is a broad study field, but this method can be adapted for many different areas of knowledge such as engineering, medicine, aviation, and the cosmetic industry. For instance, in architecture history, it is possible to mention several examples of biomimicry applications as aesthetic inspiration, which is the case of Joseph Paxton, who designed the Crystal Palace in London in 1851, by observing the leaf structure of the Giant Water Lily. (RADWAN; OSAMA, 2016).

According to Vattam *et al*. (2007) and Badarnah (2012), when studying biomimicry, two approaches are commonly used when applying the bio-inspired design: the problem-based method and the solution-based method. The first one is known for looking for a biological inspiration after identifying a particular and well-defined problem. The second technique starts from the research of a natural element to solve a problem defined afterward. In this paper, the experimental pavilion project has explored the solution-based method, and the tridimensional solution was generated by using a parametric plug-in tool called Grasshopper[i] inside the 3D modeling software Rhinoceros.

Oxman (2006) claims that the recent architectural production has experienced a revolution supported by five paradigmatic models: the generation of shape in the digital environment, the CAD/BIM transition, the concept of a project considering variables of performance, the use of algorithms to create shapes and the architectural project applying, by association, all the methods cited previously. Recently, these paradigms are being found in the Architecture, Engineering, Construction, and Operation fields. However, project techniques such as the integrated project are already being applied and incorporated in the practice of the automotive, aeronautics and naval industries (AsBEA, 2013).

Therefore, it is possible to affirm that the parametric design has been receiving attention due to its possibility of refining the development process and manipulating shapes in the architecture field. Moreover, this resource amplifies the range of experimentation and application of concepts and methods which are not commonly explored in architecture.

According to Tedeschi (2014), more recent academic research is looking for alternatives to overcome the editing limitations of the most popular CAD tools, and throughout the programming bases, the researchers focus efforts creating new opportunities to control the pre-existing CAD software. Tedeschi also mentions:

> *Many designers soon realized that more sophisticated programs could manage complexity beyond human capabilities by structuring routines and procedures. This type of modeling relies on programming languages which express instructions in a form that the computer can execute through a step-by-step procedure: the algorithm. (TEDESCHI, 2014. P. 22)*

The algorithm allows to direct the solution for a question or to implement a specific task by using a finite list of well-defined and straightforward instructions (TEDESCHI, 2014). Thus, the algorithms mirror the human ability to break a problem into simpler and specific steps, making the information processing and execution easier to be done.

A clear consequence of technological development is the reformulation of project process that incorporates algorithmic logic and computational tools. Nowadays, the methodologies of parametric design can adjust the project to the context variables, feature granted by the influences of parametric languages and generative processes (WOODBURY, 2010)

Dino (2012) argues that the generative process requires four elements. The input is responsible for data entry, in other words, the initial conditions, and parameters. The output is where the data exits and flows to generate new variants. Aside from them, a generative mechanism (rules, algorithms, for example) and the selection of the best variant is also necessary. Therefore, generative systems are known as production systems, and they are not merely a representation of the building in which the architect is an active operator in the project process and editing.

Therefore, the Parametric method consists of defining topological relations between an architectural object's parts before determining their measurements. Generally, the dimensions are not fixed values, but they are numeric intervals related to constructive components' measures resulting in more flexibility and shape variations (MONEDERO, 2000). A well-defined Parametric design optimizes the time spent in a project, and it is relevant in the project management area due to its possibility to change the features of an object interactively. (MONEDERO, 2000).

As a result, the shape of the architectural object is generated by manipulating the rules and numeric intervals with the assistance of programming throughout rules and well-defined restrictions that are coherent with the previously established parameters incorporated into digital drawing tools. (TEDESCHI, 2014)

The Biomimicry, united to the parametric project applied in architecture, is an emergent methodology nowadays. It has been manipulated by architects and laboratories that intend to discuss and test new materials, shapes, and project techniques. The expositions, such as the Serpentine Gallery Pavilion, are the perfect construction site for architects to materialize ideas and explore the limits of their experiments in architecture, including applying new creative processes, materials, and alternative or less popular construction methods. (TUNÇBILEK, 2013). The temporal and displaceable characteristics prevent the pavilion from creating roots in a specific location and facilitate the dismount and installation in different contexts.

Aware of the international relevance of the Serpentine Gallery Pavilion exposition, this location was chosen as place for the insertion of the experiment developed in this research, mainly because it has a proper structure for this type of construction (Figures 1 and 2).

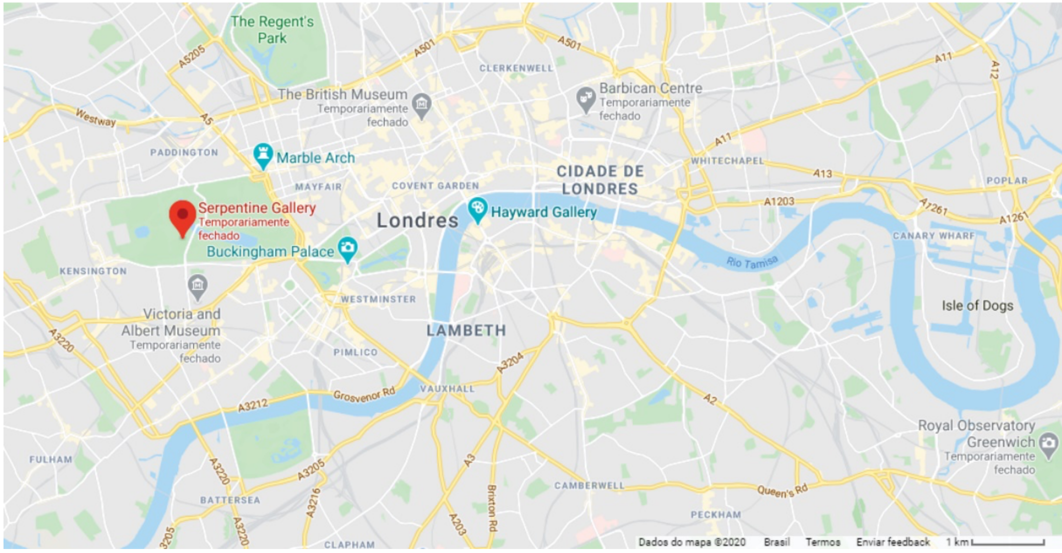


Figure 1. Map locating the Serpentine Gallery in central London city, in England.

Source: Google Maps, 2020.

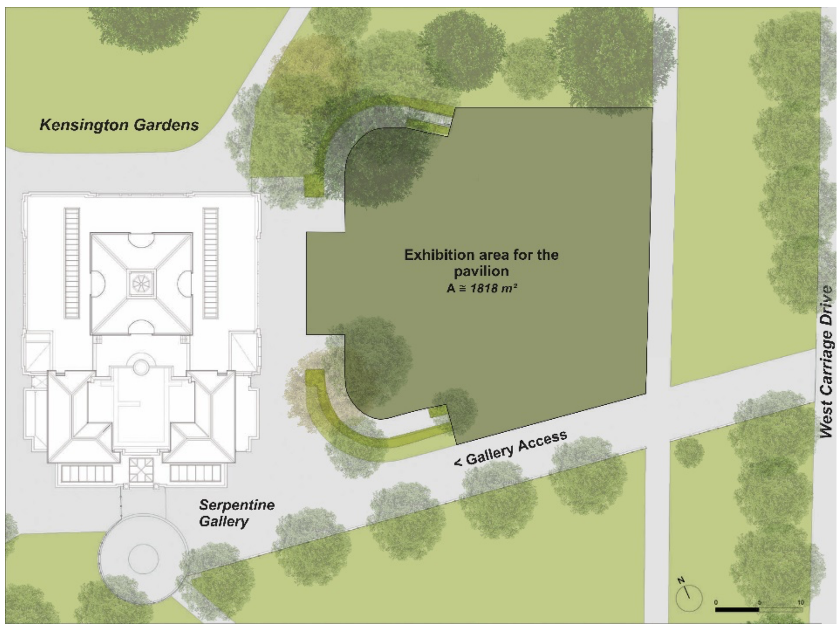


Figure 2. Position of the site where the pavilions are built in the Serpentine Gallery garden in Kensington Gardens.

Source: Adpated from EUMIESAWARD, 2005.

The pavilion project developed in this research focuses on testing and understanding the approaches in discussion for didactic purposes and was not built on a real scale.

METHODOLOGY

To guide the bio-inspired design practice rationally, it is essential to understand the analogies and strategies previously discussed to a better clarify about the design process.

In the architecture, analogies can be related to design references already proposed. This approach is quite common among students to compose a mental portfolio of design solutions. In biomimicry, it is possible to mention the morphological and functional analogies.

The morphological analogy would be an experimental search for references developed from the interpretation of shape and structural attributes to transform into a project (BONSIEPE; YAMADA, 1982). On the other hand, the functional analogy considers functional attributes and specific qualities based on the study of the physical and mechanical systems of biological materials. Thus, once an element's natural characteristics are inferred, it is possible to apply the strategy developed in several objects. Therefore, while the morphological analogy is limited, the functional analogy is more extensive (SOARES; ARRUDA, 2017).

To propose sustainable solutions to human challenges, it has been sought to emulate nature. To direct the research thinking for this purpose, the literature addresses some strategies, such as solution-based and problem-based.

The problem-based strategy (BADARNAH, 2012; VATTAM *et al.,* 2007) requires that the researcher first find a process in nature, an inspiring natural element that can solve human needs problems. On the other hand, the solution-based process (BADARNAH, 2012) works with a predefined problem and then seeks inspiration from nature. It is developed from 3 phases known as: (1) definition of the problem, (2) exploration and investigation, and (3) solution domain.

Finding an inspiring element is not always easy, it may happen as a quick insight or may require some research time. In this case, due to the wide range of possibilities in nature, the research started from the premise of exploring human anatomy. Thus, by understanding that human being is also part of nature, so all the elements that make up the body are subject to study to discover properties capable of inspiring or guiding a project. From tiny cells to the most prominent bones and organs, human anatomy is rich in details visible and invisible to the naked eyes that can be inspiring elements for the use of biomimicry.

From a thorough search of human anatomy, the Sartorius muscle was defined as the inspiring element. The muscle is also called the tailor's muscle, as a reference to the cross-legged position in which tailors used to sit. It is the longest muscle in the human body, usually exceeding 50cm in length, moving the hip and knee joints. For this reason, it is considered a biarticular muscle (GRAY, 1918). The Sartorius muscle is narrow, ribbon-shaped, runs obliquely across the upper and anterior part of the thigh, from lateral to the medial side of the leg, descends vertically to the medial side of the knee, passing behind the femur and ending at the tendon (GRAY, 1918).

The muscle acts by flexing, abducting (movement in the frontal plane, when a limb moves away from the midline of the body) weakly and rotating the thigh laterally; already in the knee, the muscle is responsible for flexing and rotating the leg medially (DZIEDZIC; BOGACKA; CISZEK, 2014) (Figure 3).

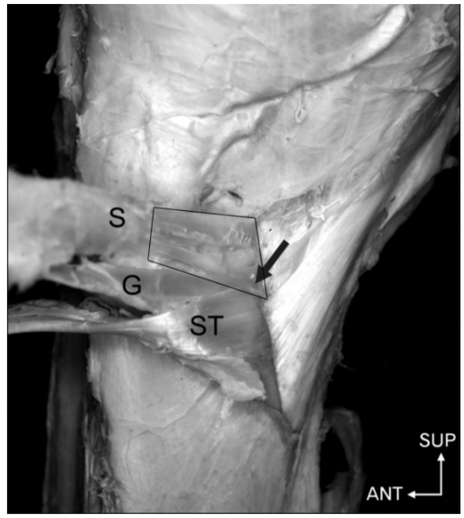
Figure 3. Frontal view of the Sartorius muscle.

Source: ISTOCK, 2016.

Another relevant attribute for the pavilion's proposal was the relationship between the muscle and the Sartorius tendon. There is a variation in shape at the insertion site of the Sartorius tendon; the fixation occurs with a wider 'base' and narrows, resembling the shape of a trapezoid facing upwards. Part of the Sartorius tendon is in the layer below other tendons, and the hidden part is longer (DZIEDZIC; BOGACKA; CISZEK, 2014) (Figure 4).

Figure 4. Variation of the sartorius tendon at the insertion site. A wider 'base' fixation is perceived that narrows, resembling a trapezoidal shape that gives continuity to the tendon. Part of the sartorius tendon is in the layer below the gracilis and semitendinosus tendons (arrow). Subtitles: ANT, anterior; G, gracilis tendon; S, sartorius tendon; ST, semitendinosus tendon; SUP, superior.

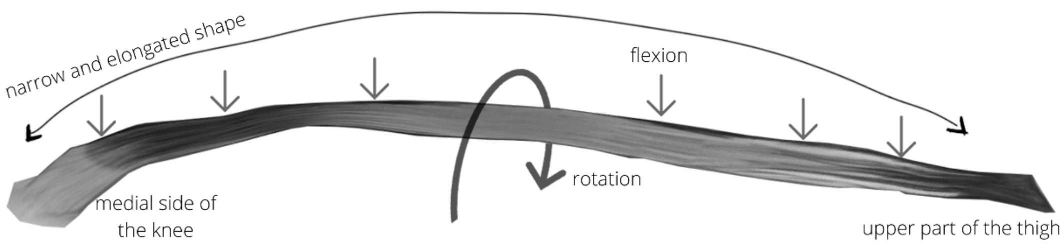
Source: LEE, Je-Hun et al.; 2014



After the anatomical study of the Sartorius muscle, it was possible to establish a morphofunctional analogy. Thus, both the formal and structural attributes of the Sartorius muscle, as its narrow and elongated shape and its position of insertion were explored, as well as the specific functions and qualities such as flexion and rotation actions (Figure 5).

Figure 5. Schema of inferred muscle characteristics.

Source: Author



In the face of all the relevant characteristics analyzed from the Sartorius muscle, it was possible to advance to the parametric modeling phase through a computational implementation using the Grasshopper plug-in. A visual script tool made it possible to perform morphological and conditioning tests to respect parameters established by previous pavilions, such as area and height, for example. From changes made to the implemented code parameters, it was possible to obtain several morphological results respecting the bio-inspired characteristics.

EXPERIMENT

From the Sartorius muscle's anatomical research, it was sought to develop a pavilion with two types of structures that reflected the elongated morphology and the aspects of flexibility and rotation (Figures 6 to 9).

The central and main structure has an elongated trapezoid shape, it is supported by glued laminated timber (glulam) arches, covered with elongated pieces. Also, glulam, in ribbon format that rotate in different degrees, and they are arranged along the arches (Figure 6 and 7). This kind of material is constituted by layers of wood placed so that their fibers are parallel to each other and bonded with high-strength adhesives, which gives the structural aspect.

The glued laminated timber was chosen because it is easily malleable, resistant, provides flexibility with curvatures, arched and folded shapes, as well as allowing a great wingspan (MIGLIANI, 2019). It is noticeable that the choice of material also allows the association with the anatomical characteristics of the Sartorius muscle.

The lateral and secondary structures are metallic, composed of flat trusses, covered by glass panels, and supported by elongated arches arranged – in most experiments – in an inclination that allows most of them to be under the main structure (Figures 6 and 8).

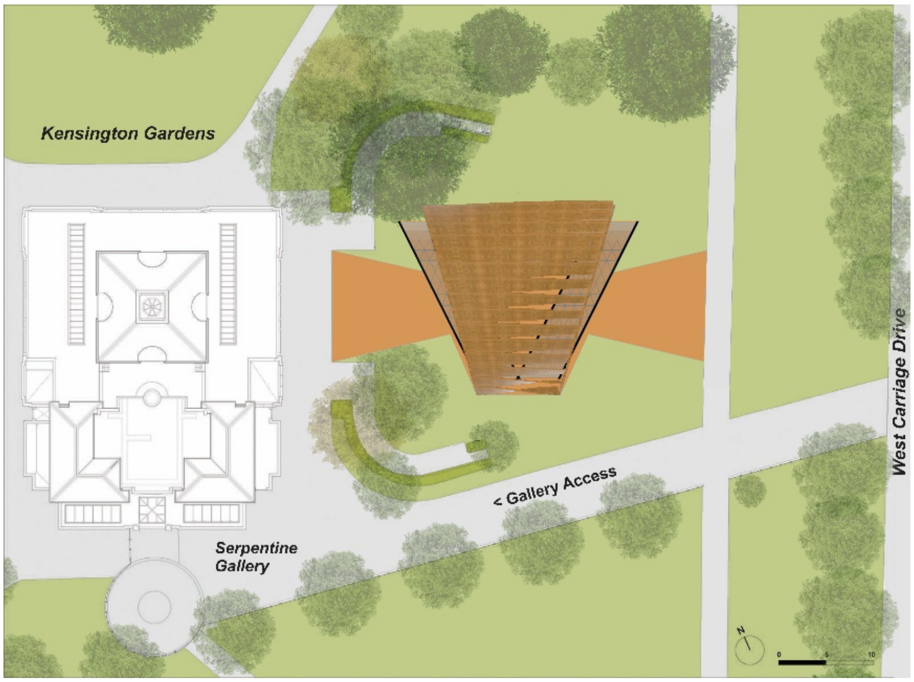


Figure 6. Site plan of Sartorius Pavilion in the gallery garden.

Source: Adapted from EUMIESAWARD, 2016

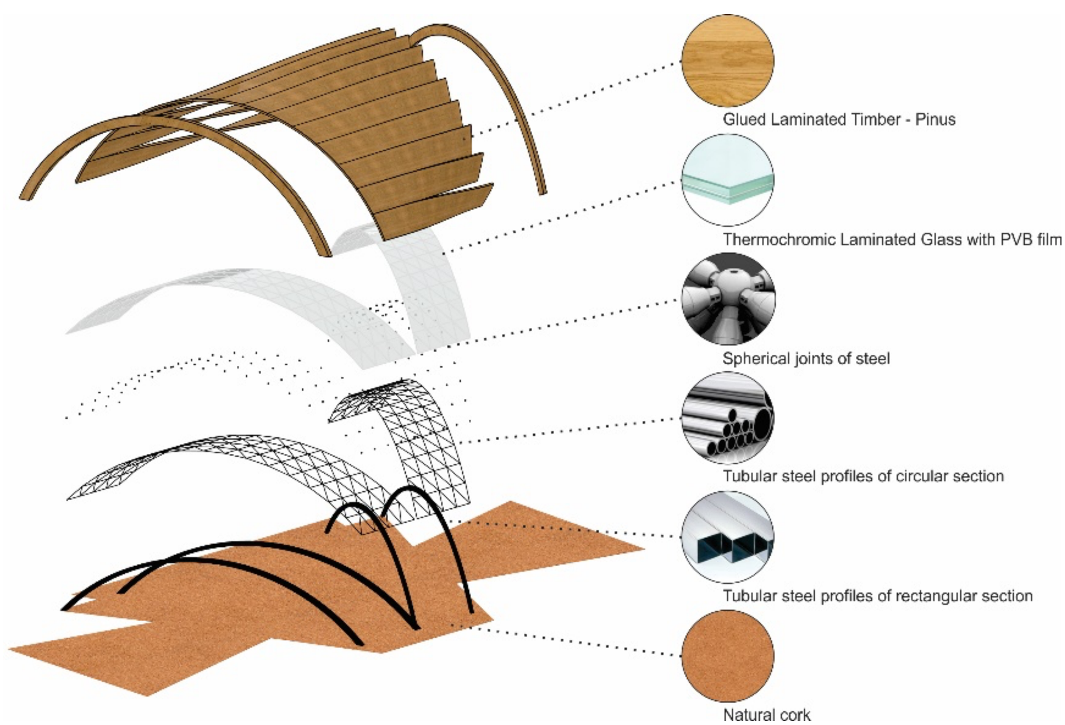


Figure 7. The exploded perspective of the structure of the Sartorius Pavilion and material specifications.

Source: author

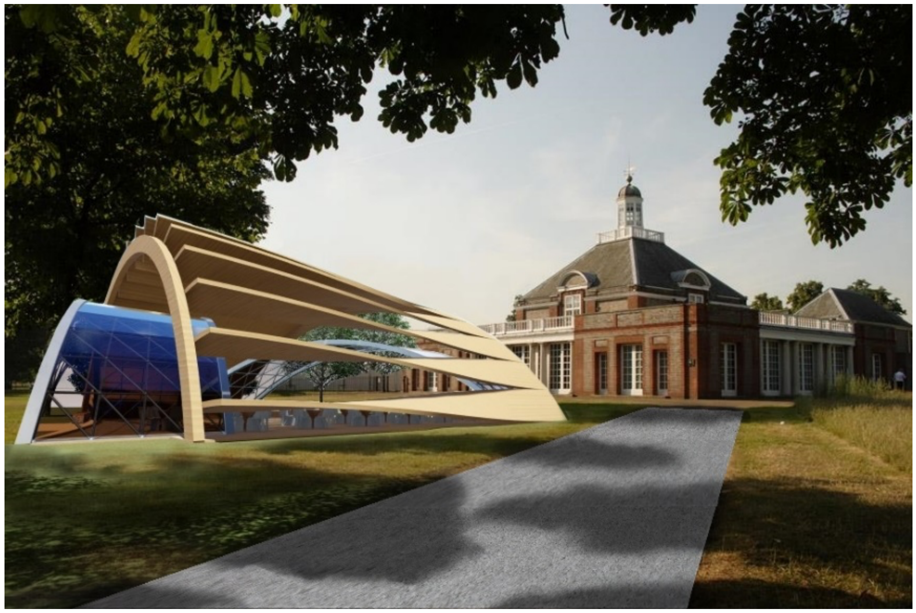


Figure 8. The outside perspective of the Sartorius Pavilion..

Source: author

Figure 9. The interior perspective of the Sartorius Pavilion.

Source: author

The development of the pavilion design considered the previous editions of the exhibition at the Serpentine Gallery regarding aspects of the area, height, and materials, making it possible to modify these parameters in computational implementation, aiming at promoting variability of design solutions, as well as meeting the imposed limitations. Thereby, through the same code, it was possible to explore the shape, maintaining the proposed design logic, considering the same context.

The developed code allowed to parametrize the entire design process such as thickness and height of the structures, dimensioning of panels, degree of rotation of the wood boards that cover the main structure, among other technical details. However, to generate several solutions, it is essential to note that accurate structural calculations were not considered, requiring for that an evaluation by a specialist team, as it occurs typically for Serpentine pavilions designs. The code developed for this experiment could be divided into six parts, as illustrated through the diagram bellow, that structure the entire pavilion project (Figure 10).

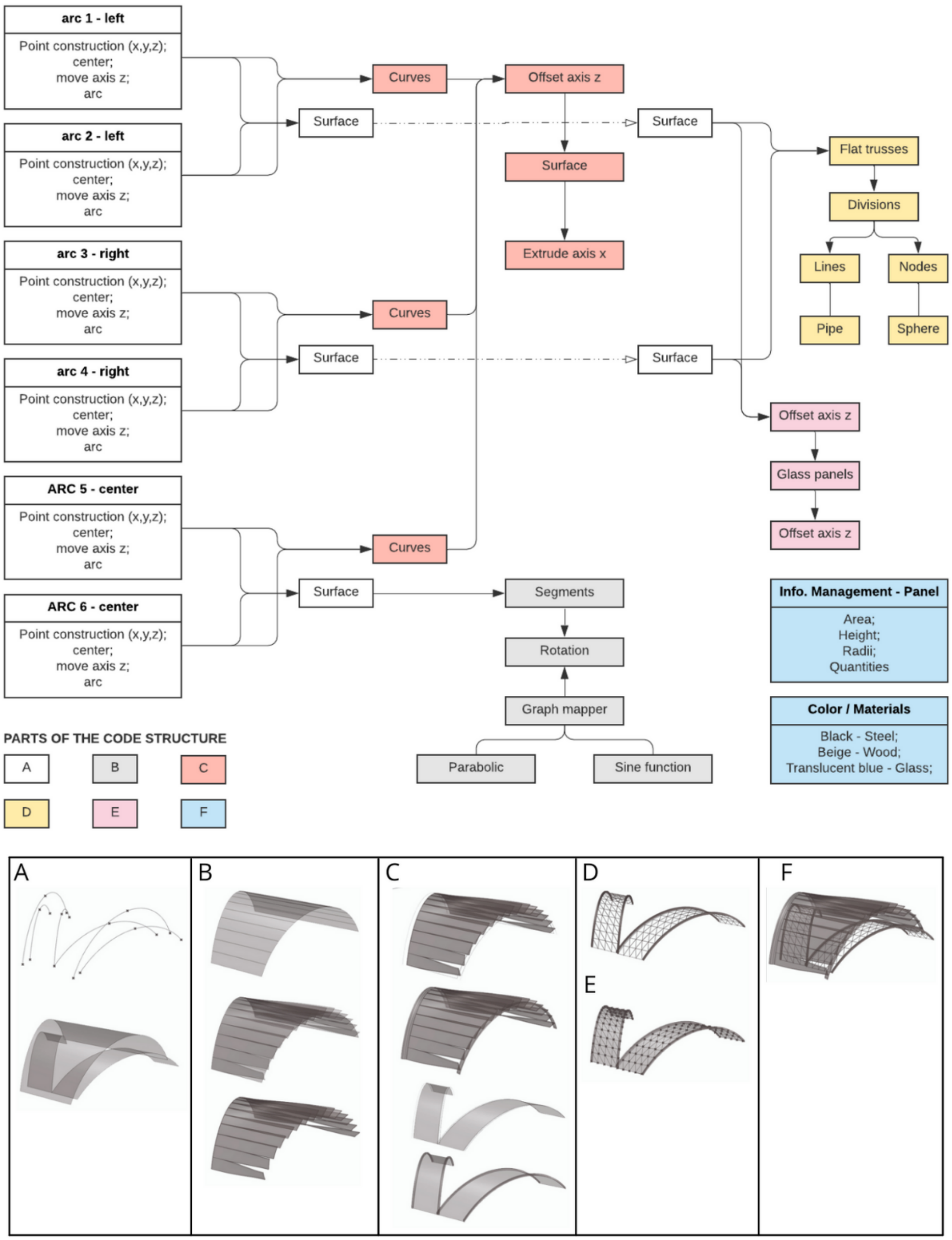


Figure 10. Synthetic diagram of the developed algorithm.

Source: author

In part A, control points are inserted, from which the shapes of the 3 structures are developed and can be manipulated in terms of location, dimension, and height.

Then, in B, it is possible to insert the cover of the trapezoidal structure with oblique profiles. In this section, there is the possibility to control the number of divisions, the degree and positioning of the rotations through graphs of parabola and sine function.

Later, in C, the lateral arches of the structures are inserted considering the position defined in A. It is also possible to control the thickness and heights of the arches.

In section D, the metal structure of the flat truss and the spherical joints are inserted, making it possible to control radii and spacing.

In E, the components responsible for inserting the glass panels of the roofs of the smaller structures are added, being able to control the thickness, quantity, and types of panels.

Finally, in F, components capable of generating information for documentation are added, serving as a control panel. In these panels, information such as radii, quantities, areas, and heights can be found. In addition, the structures are grouped in terms of materials to facilitate visualization and manipulation of the model in Rhinoceros, when it is necessary to make the code in Grasshopper.

From this, it was possible to simulate different shapes within the predefined parameters, of which five will be documented in this paper and stood out for portraying extreme variations of the shape within the imposed restrictions (Figure 11).

All items listed in the technical sheet (Figure 11) are subject to variation and the parameters were considered when implementing the code in Grasshopper. The table summarizes this variability and shows five morphological options of the Sartorius Pavilion that were generated interactively, since the code is responsive and allows several possibilities to be tested quickly.

Changes in parameters such as the inclination of the arches of the wooden structure or positioning of the metal structure can generate different results, such as pavilions 1, 3, and 4, for example.

Experiment 1 is a model that does not have the largest area and heights, balancing horizontality, and verticality. It was the model used for detailing the perspectives (Figures 6 to 9).

Experiment 2 is distinguished from others by its greater horizontality and by having more compact lateral metal structures. In contrast, experiment 3 presents a more rectilinear shape, both lateral structures and the central wooden structure.

Experiment 4 stands out for the more robust dimensioning of the arches and for having the structures inclined on the z-axis.

Experiment 5 has the highest occupancy rate of the terrain and demands more wood and glass panels than the other pavilions. Despite the large size of the pavilion, it is still within the limits of the pavilions' height and area already presented by the gallery.

Experiments 4 and 5, compared to the others, are large pavilions and occupy a large part of the area available for the installation of Serpentine Pavilions.

As for the height and area of implantation, it is noticed that pavilions 1 and 5 are quite divergent. This difference occurs due to the positioning of each structure's insertion points, directly affecting both the number of wooden boards that cover them and in the structuring of the glass panels, for example.

The height variability in the Sartorius Pavilion was important to assist in the study of the relationship between the pavilion and the Serpentine Gallery, as well as in the definition of the most interesting sights at the height of the observer. Changes in parameters such as the inclination of the arches of the wooden structure or the metal structure's positioning can generate different results, such as experiments 2 and 3.

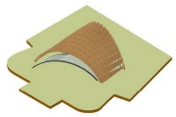
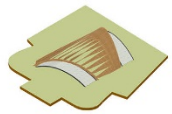
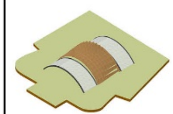
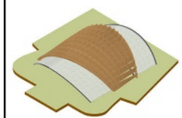
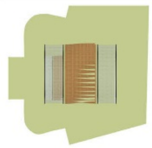
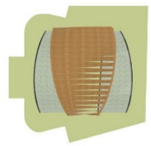
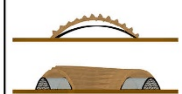
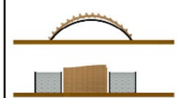
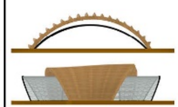
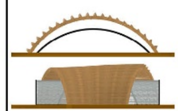
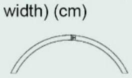
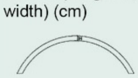
Sartorious Pavilion - Table of Parameters and Restrictions					
	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Experiment 5
Perspective					
Top view					
Elevations					
Area (m²)	469,64	545,91	440	814	469,64
Height (m) Large Structure	8 (min 6 – 9 máx)	7 (min 6 – 9 max)	9 (min 6 – 9 max)	8 (min 6 – 9 max)	8 (min 6 – 9 max)
Height (m) Minor Structure	5 (min 3 – 6 max)	5 (min 3 – 6 max)	6 (min 3 – 6 max)	6 (min 3 – 6 max)	5 (min 3 – 6 max)
Wooden boards Quantity	15	12	16	18	15
Wooden boards thickness (cm)	15	15	15	15	15
Lateral Arcs - Wood (Height H, width) (cm) 	70, 30	70, 30	50, 30	90, 30	70,30
Lateral Arc - Metalic (Height H, width) (cm) 	30, 30	30, 20	40, 30	40, 30	30,30
Steel Structure (the circular section can be swapped for rectangular sections)					
Divisions (x, y) 	(4, 15)	(4, 15)	(4, 16)	(5, 18)	(4,15)
Ø Steel structure section (cm)	6	6	6	6	6
Glass Panels (each panel has a singular dimension, map of components needed)					
Division (x, y) 	(4, 15)	(4, 15)	(4, 16)	(5, 18)	(4,15)
Quantity of Glass (m²)	226,5	204,06	271,74	611	226,5

Figure 11. Technical sheet of the parameters implemented in the parametric modeling phase.

Source: author

DISCUSSION

The biomimicry behind the construction justifies the project decision and enriches the final project with a conceptual base inspired by nature. It also refers to an area of science that is not commonly associated with architecture and civil construction.

In this paper, human anatomy was the field of knowledge in which the methodology of biomimicry was inspired, because it considered humankind a fragment of nature. For this reason, the human body components could also be studied and result in favorable findings that might inspire a project. Badarnah (2012) recognizes that one of the main challenges that the bio-inspired design faces is selecting the natural element and adjusting it to a proper detail scale. The investigation might happen, for instance, on a microscopic scale or even by the human eye. It is a process that have a multidisciplinary potential in the architecture project context (VATTAM *et al.*, 2007) that might count with the cooperation of professionals from different study fields, such as programmers to assist in the generative design and expand it to researchers from biology, the science area that would help to incorporate alternative archives of reference into the work of designers and architects as was already done by Vattam (2007).

To generate the Sartorius Pavilion morphology, the parametric modeling required the use of additional tools called plug-ins, available for common usage in Grasshopper. The Pufferfish[ii] helped simplify the manipulation of curves, created, and controlled the thickness of the wooden structure in a ribbon shape that supports the trapezoidal shape roof. Another important plugin-in was Lunchbox[iii], which allowed creating a grid of steel truss and triangular panels connecting it to the secondary roof structure made by minor arcs. Human[iv] simplified the manipulation of lists and made it possible to select specific objects rapidly. The last of the plug-ins used was Heteroptera[v] which was fundamental in creating geometric shapes throughout simple mathematical components.

The creation of a variational geometry is directed related to the concept of parametric models that allows the interaction and edition of the model in any stage of implementation, which is necessary to modify some parameters such as dimension and restriction. This process dismisses the manual edition of the shape and allows the addition of new parameters without compromising the architectural object's instantaneous visualization.

It is relevant to point out that the architectural shape's variability is directly related to the parameter's definitions implemented parametrically and to the complexity between these parameters. The experiment of Sartorius Pavilion has as restrictive parameters the Sartorius muscle features. Additionally, the distinct attributes of the materials chosen, and the dimensions variation of the constructive elements incorporate its restrictive premises that impact the resulting tridimensional model's overall variability. In Sartorius Pavilion's experiment, the variability follows a formal language but, it helps the architect in the decision-making process.

Furthermore, the Parametric Project optimizes the process by increasing the possibilities for architects to innovate, explore and test several shapes, once the model achieves different results instantaneously.

CONCLUSION

Inspired by the motivation to find possibilities, reduce the rework, and explore the tridimensional parametric model interactivity by applying biomimicry and parametric design methods, the Sartorius Pavilion project was developed.

During the experiments, the viability of integration between biomimicry and parametric modeling was analyzed. While the first method is composed of concepts and abstractions, in this part of the study, the project's guiding idea arouses through the inference of data and patterns found in nature. The second method allows to materialize the concepts and provides final shape visualization rapidly according to the pre-established parameters' changes.

To restrict the research for inspiration, the human body became an element of study, in which the human anatomy is seen as a vast field and presents a huge potential of application in the project process. In this investigation, it was found out that the Sartorius muscle features expressive morphological and functional attributes. The Sartorius muscle twists itself to fit in properly in the thigh's anatomy. Therefore, the object of study has shown a possibility of imitation that might be represented by mathematical formulas that are materialized to the architecture field through a structure with similar features, but inside a digital model.

The Solution-based method was only applied after the definition of the natural element. Thus, it was possible to achieve the variability for the parametric shape which corroborates to the visualization of the final solution and speed up evaluating the shape by who is projecting. In the traditional project process, the evaluation to define a specific solution generated excessive work in remodeling and reconstructing geometry to test diverse variables. In the parametric project, as proposed in this paper, some of these variables, such as minimum and maximum height, distribution, and thickness of the pavilion structure, are related to variable values and rules that allow the model to become dynamic and responsive. This is a sign of a change in the paradigm which architects are used to focus more their efforts on the process of design in relation to the result.

Looking forward in time for the Sartorius Pavilion (figure 12) as an experiment, it is attractive to considerate as a future development the application of plug-ins such as Karamba[vi] and Kangaroo[vii] for structural analysis and evaluation, as much as the test using Ladybug[viii] for climatic performance simulation. Associated with those plug-ins, the application of evolutionary algorithms as Galapagos[ix] would help to combine the best results of other analyses considering the most relevant information during the decision-making process and would help to optimize the project concept phase even more. Finally, it would also be interesting as a future development, the incorporation of more subjective analysis parameter, for instance, visual orientation value or ideal height related to the surrounding buildings.

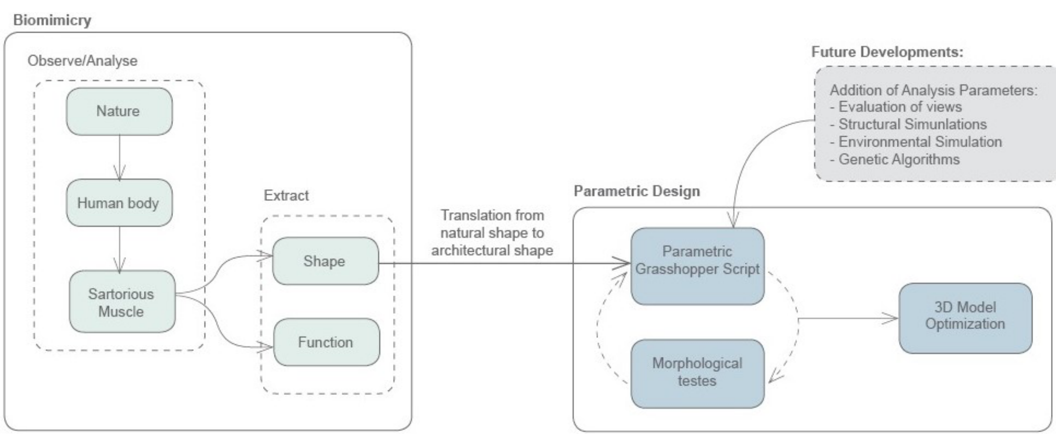


Figure 12. Design process summary in the visual scheme and the possibilities of model optimization for futures studies.

Source: author

The limitation in the usual project process in the professional architecture practice was one of the major motivations for this paper. Both approaches, biomimicry, and parametric design, are alternative methods to achieve more expressive shape design and reduce rework during the project concept and decision-making process. From what was developed in this paper, it is possible to observe that the project approaches explored complement each other, and the complexity of the conceptual architecture process is likely to increase. In contrast, other disciplines such as biology or programming are being used as input or tools for project development.

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Notas

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[i] Grasshopper is a tool that operates with generative algorithms of associative modeling of the visual script, that is, it uses components and parameters to obtain a geometric result that can be visualized in Rhinoceros software (BROOD; PIRES; BORBA, 2012).
[ii] Pufferfish is a plug-in focused on shapeshifting operations. It has components that focus on interpolations, tweens, averages, blends, transformations, and morphs (FOOD4RHINO, 2020).
[iii] Lunchbox is a plug-in that explores mathematical shapes, structures, panels, workflow, rationalization, and interoperability. In addition, it has components that manage data and geometries in the process of creating generative shapes (PROVING GROUND, 2019).
[iv] The Human plug-in is used to create and reference geometries, including lights, blocks, and text objects (TEER, 2016).
[v] Heteroptera works as a toolbox, added to the Grasshopper interface, including animation, mathematics, networks, and probability components (BAHRAMI, 2017).
[vi] Karamba is a plug-in that develops accurate structural analyzes, works with load calculations, and allows working with space trusses and shells (MAKE BIM, 2017).
[vii] The Kangaroo tool consists of a set of components useful for making physical simulations, finding shapes, and solving geometric constraints (MEIER, 2020).
[viii] Ladybug is an open-source plug-in used for environmental analysis of solar incidence on an object. Express its results through interactive graphics that show the sun's path, compass rose, and shadow studies (MAKE BIM, 2017).
[ix] Galapagos is a standard Grasshopper plug-in linked to analysis tools to optimize complex design issues with many variables (NADIRI; MAHDAVINEJAD; PILECHIHA, 2019).