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Projetos de design bioinspirado: Estudos sobre Algoritmos Generativos e Morfologias Naturais

Resumo Bioinspirações são processos nos quais a natureza é observada com o objetivo de extrair dela elementos que possam ser tomados como referência para o desenvolvimento de soluções eficientes para as necessidades humanas. O objetivo deste artigo é investigar como as informações dos sistemas naturais podem ser representadas em processos de design generativo. Para isso, três projetos foram analisados em momentos diferentes utilizando a metodologia de pesquisa-ação. Os projetos foram desenvolvidos com o apoio do software Rhinoceros e do plugin Grasshopper. Optamos por técnicas colaborativas com a formação de grupos de trabalho em todos os casos. Como resultado, as equipes desenvolveram processos generativos para uma lâmpada, um pavilhão e um berço, resolvendo os desafios propostos. A conclusão é que os processos generativos bioinspirados permitem criar múltiplas formas parametrizadas a partir do mesmo código, enriquecendo projetos interdisciplinares e aproximando o design da natureza.

Palavras-chave Algoritmo bioinspirado, Processo generativo, Bioinspiração, Biodesign.

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Bio-inspired design projects: Studies on Generative algorithms and natural morphologies

Abstract *Bioinspirations are processes in which nature is observed in order to extract from it elements that can be taken as a reference for the development of efficient solutions to human needs. The aim of this article is to investigate how information from natural systems can be represented in generative design processes. To this end, three projects were analyzed at different times using the action research methodology. The projects were developed with the support of Rhinoceros software and the Grasshopper plugin. We opted for collaborative techniques with the formation of working groups in all cases. As a result, the teams developed generative processes for a lamp, a pavilion and a cradle, solving the proposed challenges. The conclusion is that bio-inspired generative processes make it possible to create multiple parameterized forms from the same code, enriching interdisciplinary projects, bringing design closer to nature.*

Keywords *Bio-inpired algorithm, Generative process, Bioinspiration, Biodesign.*

Una mirada cartográfica a sitios web de museos de arte en Brasil

Resumen *Las bioinspiraciones son procesos en los que se observa la naturaleza con el fin de extraer de ella elementos que puedan servir de referencia para el desarrollo de soluciones eficientes a las necesidades humanas. El objetivo de este artículo es investigar cómo se puede representar la información de los sistemas naturales en los procesos de diseño generativo. Para ello, se analizaron tres proyectos en diferentes momentos utilizando la metodología de la investigación-acción. Los proyectos se desarrollaron con el apoyo del software Rhinoceros y el plugin Grasshopper. En todos los casos se optó por técnicas colaborativas con la formación de grupos de trabajo. Como resultado, los equipos desarrollaron procesos generativos para una lámpara, un pabellón y una cuna, resolviendo los retos propuestos. La conclusión es que los procesos generativos bioinspirados permiten crear múltiples formas parametrizadas a partir del mismo código, enriqueciendo los proyectos interdisciplinarios y acercando el diseño a la naturaleza.*

Palabras clave *Algoritmo bioinspirado, proceso generativo, bioinspiración, biodesign.*

Introduction

The following article is an investigation about project-oriented experiences with multifaceted conceptions, based on biologically-informed design. Each experience described is guided by project strands that have their roots in the learning process of nature-derived systems.

It is important to emphasize that, throughout the complex history of humankind, learning from nature has inspired a series of inventions that have enabled a great number of innovations and resources in the course of time (Arruda, 2018).

When we utilize inspiration from nature in the design processes, the most adequate term to use is biodesign (Broeck, 1989). In the words of the author referenced, the fundamental activities of biodesign are concentrated in the investigation and basic experimentation from the observation of nature-derived events, whose fundamental idea is to create a database that feeds the project, not only in regards to technical solutions, but also to methodological aspects.

Nevertheless, for Arruda (2018), the terms biodesign, bionic, biomimetics, among others, are related to the biotechniques or bioinspirations easily confounded, as their origins, concepts, methods and bases of investigation are truly very similar, although there are some differences.

Still in this discussion, it is important to mention American researcher Janine Benyus (1997), cofounder of Biomimicry Institute and responsible for the popularization and spread of the term biomimetics. Benyus defines Biomimetics through the delimitation of three approaches: nature as model, nature as mediator and nature as mentor. Such approaches go beyond the imitation of biological shapes, also instigating the imitation of behaviors and the organization of nature-derived systems in order to solve human issues. According to the researcher, Biomimetics unveils an era whose bases are not settled on what we can extract from nature, but on what we can learn from it.

That being said, we will present in this article three approaches of generative project conception based on nature-derived systems. In this work, we adopt the term generative as a computational system that enables to produce families or generations of products through parametric manipulation (Saruhashi, 2018; Vettoretti, 2011).

The results of these different ways of thinking about the conception of an artifact were compiled from a series of lived experiences, throughout the sensu post-graduation course in Parametric Design in Architecture, offered by the Pontifícia Universidade Católica de Minas Gerais (PUC Minas), and by the workshop entitled BIO.CODES (bio-inspired algorithms in design artifacts), offered by the DigitalFUTURES platform, ministered by the pernambucano office SELVAGEN.

The projects developed at PUC Minas aimed to solve the design of a table lamp (project 01) and a pavilion (project 02) for a music festival, which were, respectively, challenges proposed in the disciplines of Introduction to Digital Fabrication and Parametric Systems. From the third project developed through a workshop came out a crib as the final product (project 03).

In this way, our goal resides in the presentation of three different bioinformed project conceptions, describing their generative processes for the attainment of diverse solutions.

Methods

The different project conceptions reveal an empirical-analytical approach through the methodology matrix research-action channeled to biodesign, using collaborative tools through a planned action of educational character (Freitas, 2020; Gil, 2002).

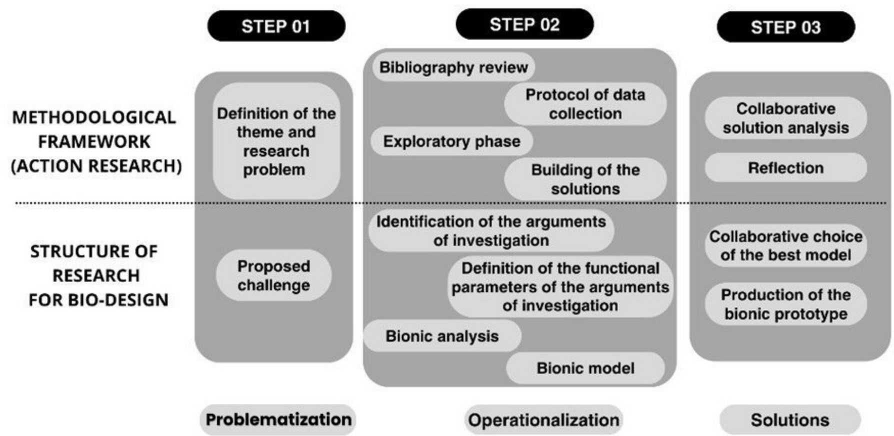
According to Santos (2018), the planning of the collaborative research-action differs from other research types within the academic field, due to its flexibility and the active participation of researchers and groups of interest.

The models of project conceptions approached are based on the biologically informed design and use strategies that explore specific situations of a problem, intending to build ways for new solutions with a bio-inspired profile.

The project tools are attached to a parametric methodology and are executed in the Rhinoceros 3D software (Mcneel, 2022), with the aid of the plugin Grasshopper (Davidson, 2022). In this method, the generative system is a computational system in which principles of shape are defined, which enables to generate drawing alternatives and variations, reaching a level of complexity compared to that of the nature-derived system (Torreblanca-Díaz et al., 2017).

Therefore, a methodological sequence in three steps was outlined, tracing a parallel with the structure of research for bio-design (Arruda, 2018)

Figure 1. Methodological steps
Source: The authors, 2024



The research structure asserts a sequence that initiates with a problem (step 01) through the definition of the theme, the research problem or proposed challenge. Next, the operationalization (step 02) is conceived in four axes followed by the duality: bibliography review - identification of the arguments of investigation; protocol of data collection – definition of the functional parameters of the arguments of investigation; exploratory phase – bionic analysis; building of the bionic model solutions. Lastly, the presentation of the solutions (step 03) follows the collaborative slant of choice, solution analysis and its feasible prototyping.

The groups formed were composed of, at most, three participants with basic knowledge of Rhinoceros and Grasshopper, from different locations in Brazil and active in architecture and design projects. In all steps, collaborative techniques with the participants were opted for, in other words, the decisions needed to integrate the characteristics of each member. In the first step, work groups were formed to observe the problem. Right after, these groups defined the elements of project composition, taking into account the operationalization of such projects and, lastly, the groups presented the systematization of the solution stemming from the gathering of collective ideas.

Research results

In this portion of the article, the results will be presented in sections, contextualizing with the different project conceptions, describing the processes of shape codification and, at last, the diversity of solutions found in the interaction with the generative process developed.

Project 01: Vorogiro Table Lamp

The systematic ideas for the development of this project stemmed from the engagement of participants in attempting to solve a design for a table lamp, which would involve elements from animal and vegetation domains.

Therefore, it was opted for a team for utilizing the Vonoroi diagram as a reference, since it is a very common pattern in nature and noticeable in diverse elements of nature.

For another compositional element of the lamp (the base), the team was inspired by the roots from mangrove forests in order to develop a bio-support according to the references in figure 2.

Figure 2. Project references

Source: Bellelli, 2026

The choice of such bioreferences initially stemmed from the exploratory character of the Vonoroi pattern on the Grasshopper software. For the base, the reference was founded on the vegetation pattern that is present in great part of the city's territory of one of the participants, and has the potential to act as a natural support.

Consequently, the table lamp was divided into two main components: the optical set and the base, according to figure 3. In regards to the optical set, located on the upper part of the lamp, it was developed a code that utilized the Vonoroi component, which is a bio-inspired algorithm.

In the figure below, it is possible to notice in the sequence of items 1, 2, 3 and 4 that, initially, an anchoring strategic surface of the pattern was used for later being transported to the other petals of the optical set composition.

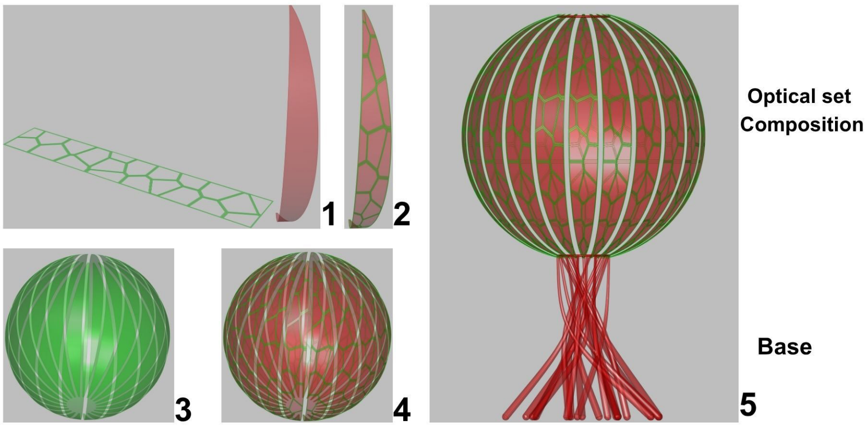


Figure 3. Parameterization process of the lamp
Source: The Authors, 2024

In addition to the optical set, the association among different variables of the generative system contributed to the definition of a parameterized system that generated various solutions, aiding in the generation of shape results and in the attainment of optimized solutions, according to the differentiation of the pattern among the Vonoroi cells.

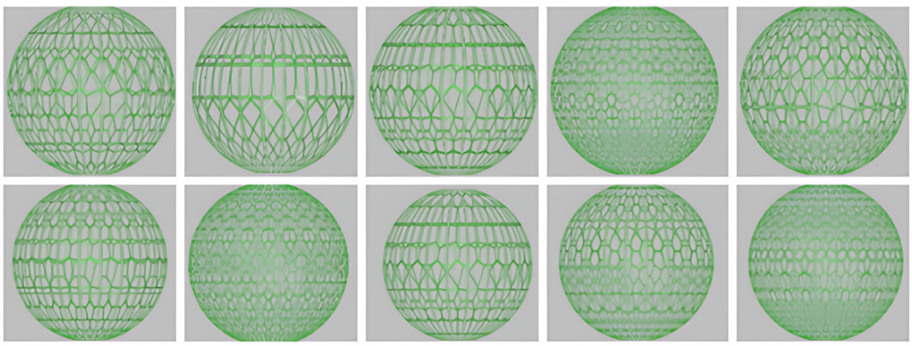


Figure 4. Generative design of the optical set
Source: The Authors, 2024

The main events of parametric manipulation of the code that generated various conceptions of the optical set and the base are concentrated in the Voronoi algorithm and in its inputs, according to the figure 5-6.

Figure 5. Variation algorithm of the optical set
Source: The Authors, 2024

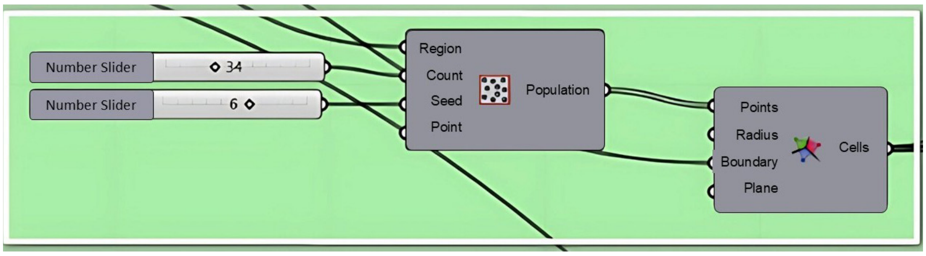
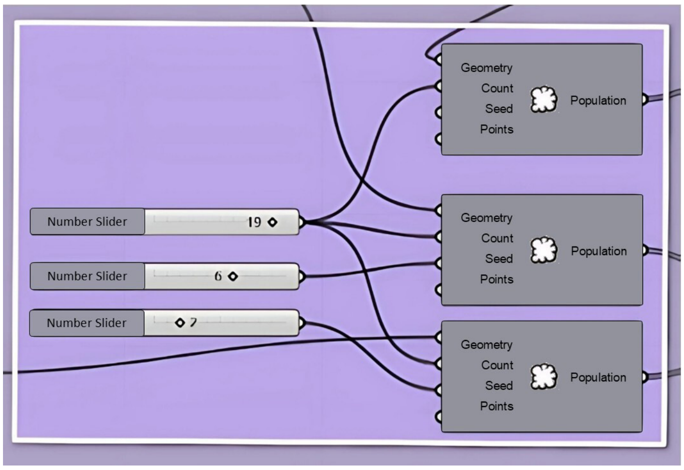
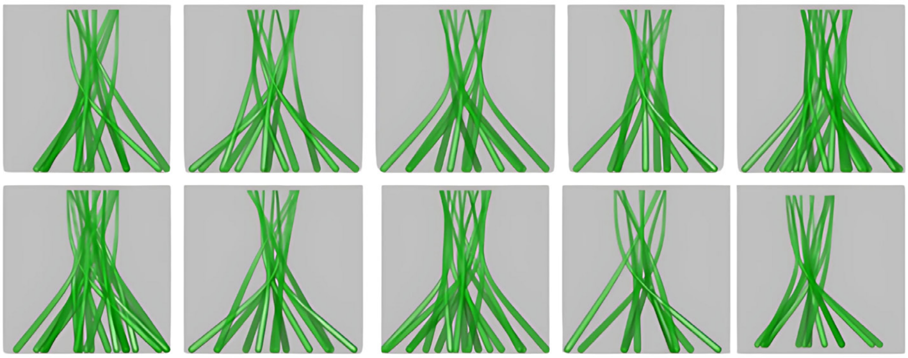


Figure 6. Variation algorithm of the optical set
Source: The Authors, 2024



For the experiments carried out with the lamp base, the rules used took into consideration three point populations that concentrated in the substrate, the intermediate axis and the optical set. In this case, the randomization of the seed parameter provided product variables close to our defined goal in the references according to the analysis below.

Figure 7. Variation algorithm of the base
Source: The Authors, 2024



Project 02: Trilobite Pavilion

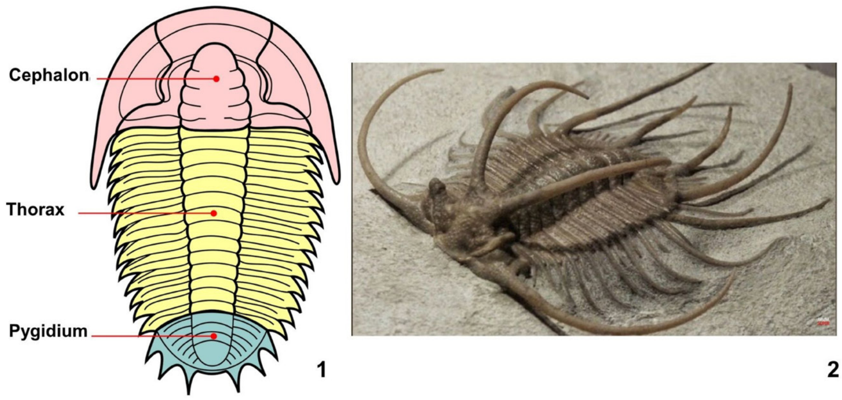
The goal of this project was to develop a pavilion for the Burning Man Festival, taking into account the characteristics of the festival, the programs and themes for each pavilion.

For the operationalization, the project should generate the experience of being inside a living atmosphere, as though it were possible to accompany the emergence of a living being from the desert sands according to the drafts produced below in the ideation step.

Figure 8. Pavilion draft
Source: The Authors, 2024

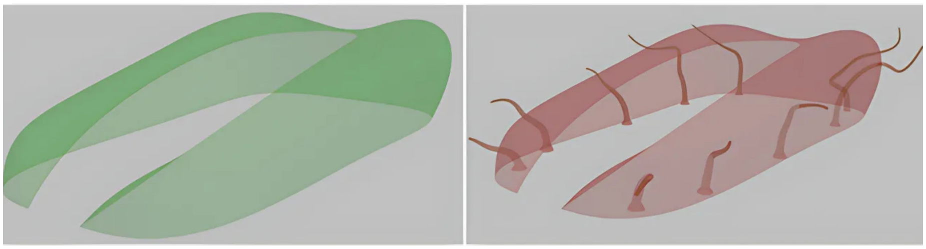
Therefore, it was defined as a bioreference, aligned with the concept and the utilization of the morphological structure of the trilobite arthropod. According to Silva (2004), the arthropod went completely extinct by the end of the Permian period, and had diverse eating habits and its body divided basically into three parts (cephalon, thorax, pygidium), according to the figure below. Other researches demonstrate variants of the species present in the desert, more precisely in the place of the Burning Man festival. Hence the concept.

Figure 9. Bioreferences for the pavilion
Source: Bampi, 2026



In order to obtain the pavilion shell, we manipulated a base surface on Rhinoceros with the aid of two curves that were internalized on Grasshopper, and then, we proceeded to parameterizing it stemming from the hegaxon cells algorithm. As for the tentacles, we used the same strategy with the aid of the pipe algorithm.

Figure 10. Surface base
Source: The authors, 2023



In this process, it was possible to present a solution with an expressive number of shape elements according to the figure 12. In this shape generation system, the emphasized rule created an encompassing grid that, according to its subdivisions through an algorithm system, provided a varied cellular arrangement.

As it was previously cited, our defining programming of the pavilion linked together graphic elements that explored structural variables, broadening our shape library. The main generative algorithm in this process was the hegaxon cells (Figure 11), which allowed the development of a range of solutions through the manipulation of two parameters, the divisions U and the divisions V of the model, according to the figure below.

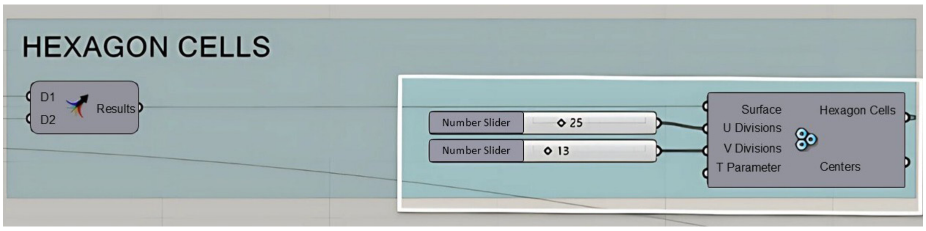


Figure 11. Variation segment (algorithm) of the exoskeleton
Source: The authors, 2024

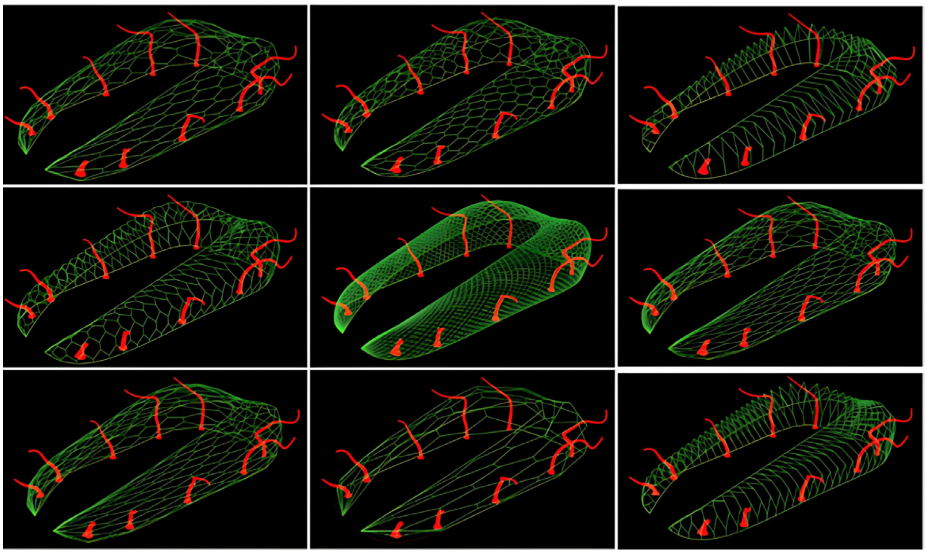


Figure 12. Generative design of the pavilion
Source: The authors, 2024

Project 03: Ever-Living crib

The participants involved in this project were challenged to find a solution for the design of a crib stemming from two big steps: the problem via nature-related and technologic context, and the operationalization through the description of the references, concept, ideation and parameterization.

Starting from this, on the collaborative platform Miro, it was selected the Cerrado biome, the ever-living flower (inflorescence – Xerochrysum bracteatum) and its harvest process. As materiality-related references, wooden profiles were selected with the utilization of natural fibers.

All the references were founded in the workshop where some choices had already been brought up, ushering the participants to choose the information and gather in similar bioreferences. Below there is an figure of a piece of the banner created in the workshop BIO.CODES (Figure 13) with the information aligned by the team.

Figure 13. Piece of the banner created in the workshop
Source: The authors, 2024

The generative code of this work was developed from the geometrical ellipsis figure, which was parameterized taking into consideration the width and length of the ellipsoidal rays (Figure 14). Consequently, for the lateral protections of the crib (Figure 15), interpolated curves followed a wave dynamic that reflected the edge of the ever-living flower, paired with the crib support according to the sequence of figure below.

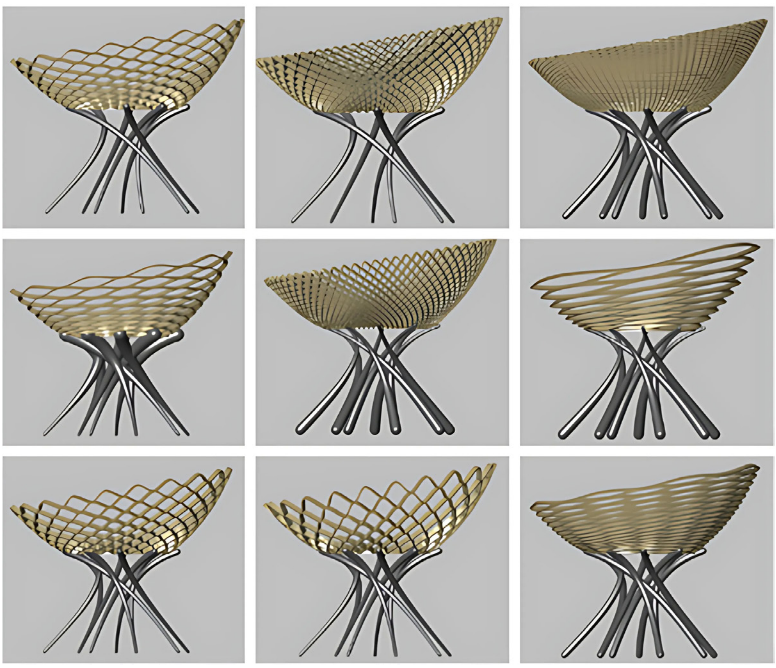


Figure 14. Piece of the banner created in the workshop
Source: The authors, 2024

The demonstrated possibilities of design for the crib reveal the parameterized simulations both in the crib support (Figure 16) and in the lateral protections. To that end, transformations in the number of U and V curves were made in the algorithm input net on surface. In the support, pipe variable algorithm inputs were consecutively transformed, enabling a generative presentation of the model.

Right below, there are segments of the generative code, demonstrating the inputs and the components on Grasshopper that were used for the visualization of the aforementioned variables.

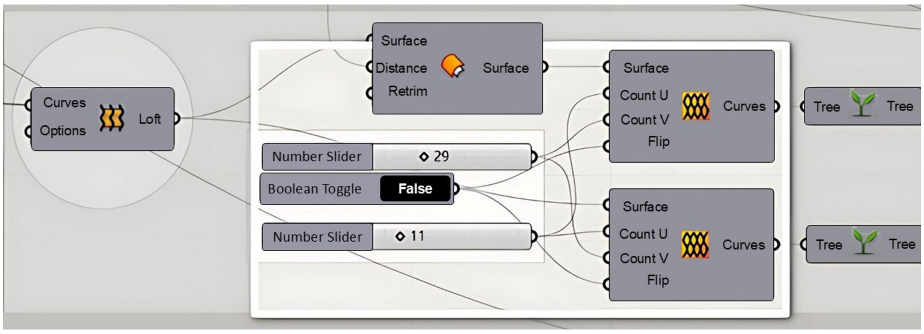


Figure 15. Variation script of the protection grid
Source: The authors, 2024

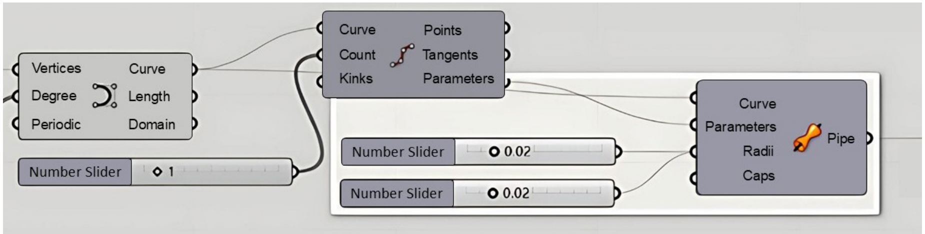


Figure 16. Variation segment (algorithm) of the crib support
Source: The authors, 2024

Discussion of results

The different bio-informed project conceptions in the three projects were incorporated from the different data entries in the generative system, enabling a multitude of results. For the Vorogiro Table Lamp, the root of the project concept is the voronoi and population algorithms defined as bio-inspired elements. For the Trilobite Pavilion, the core of the project concept concentrated in the Trilobite paleontological arthropod. As for the Ever-living Crib, the native project bioreference gathered around the nature-related context and its social references.

Therefore, for the Vorogiro Table Lamp we have a different project nature than the other projects for we selected algorithms as investigation arguments, analyzing and exploring the functional parameters of its inputs to generate solution models.

Nevertheless, for the Trilobite Pavilion the data collection protocol was different. By identifying the extinct species (trilobite arthropod) as a project argument of investigation, we directed the functional parameters towards the morphological analysis of the animal, exploring the possibilities of bionic models and subsequently solution proposals.

Another different way of thinking of bio-informed project concepts involved specific characteristics of the Cerrado biome and its range of biotic, abiotic and social factors in the protocol of the data collection. In this case, the analysis of the solution models explored abstract links within the generative code.

The solution models found in each project presented geometric repetitions and transformations that left the lamp and crib supports symmetrically different, whereas the optical set and the lateral protections of the crib presented radial symmetry. As for the pavilion, it displayed a different behavior than the previous ones, revealing a bilateral symmetry.

The human collaboration in the generative processes is another important point within our discussion, when we compare the different designs of project solution to the theory of the evolution of things. In each meeting with the participants from each project, the developing products were continuously remade towards an improved version, sometimes modifying the parameters, sometimes adding/removing algorithms.

The generative code of the projects exhibited a much higher dynamism than expected. In regards to the scales, we could have attained a significant variety by altering some parameters of the basic geometric shapes. However, it is important to highlight that, in the building of the three codes used, the population algorithm increased the possibilities of solution as demonstrated by the experiments with the lamp base.

Final considerations

The bio-inspired generative processes become a promising field of work by enabling the development of ideas based on algorithms, morphological patterns of species and nature-related contexts within a logically founded system.

Therefore, the possibility of manipulating parameters by generating multiple shapes from the same implemented code provides us with selecting diverse project typologies.

The works developed were relevant due to the interdisciplinary thinking produced in the work steps with participants from different locations and social contexts. In the academic scope, the information exchange, mainly related to the project parameterization, contributed towards the enrichment of knowledge about the theme.

The generative code oriented by software was a tool of great aid for the generation of basic and complex shapes in the design project of artifacts. The Grasshopper plugin allowed us to develop codes that can be parameterized by generating 3D models on Rhinoceros. The tool turned up to be potentially feasible in the development of bio-inspired projects.

Deepening the knowledge about the generative logic and introducing the algorithm thinking into the project exercise can indicate incorporating into the project discussion a more reliable approach of nature as a model, measure and mentor.

Final considerations

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