BIO-FADEN 2.0 Pavilion: experimental study of algorithmic-generative design and digital fabrication with 3D printing of a bionic pavilion prototype in the Midwest Region of Brazil

BIO-FADEN 2.0 Pavilhão: estudo experimental de projeto algorítmico-gerativo e fabricação digital com impressão 3D de um protótipo de pavilhão biônico na Região Centro-Oeste do Brasil

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ABSTRACT
This research has as main objective to determine the possibilities and limitations of digital design and digital fabrication by 3D printing of a prototype of bionic pavilion with non-Euclidean geometric shapes in reduced size inspired by fruits present in the MidWest Region of Brazil. The work was structured in 3 stages: Rationale, Materials and Logistic, and Experimentation. The Rationale consisted of a literature review on the concepts of: bionics, generative-algorithmic design, digital fabrication, 3D printing and prototyping. The Materials and Logistics stage consisted of the presentation and classification into categories of materials and the logistics that were usedTthe experiment consisted of 4 phases: Graphic code and 3D digital modeling of the bionic pavilion; operationalization of digital fabrication; selection of 3D printing digital fabrication technology and; digital fabrication by 3D printing. The main result of the research is that digital technologies - rhinoceros 5.0 software, grasshopper software - allow to design a prototype of a pavilion of complex shape or of small size inspired by natural structures.

Keywords: bionic, generative design, digital fabrication, 3D printing, pavilion.

RESUMO
Esta pesquisa tem como objetivo principal determinar as possibilidades e limitações do projeto digital e da fabricação digital através da impressão em 3D de um protótipo de pavilhão biônico com formas geométricas não euclidianas em tamanho reduzido, inspirado em frutas presentes na Região Centro-Oeste do Brasil. O trabalho foi estruturado em 3 etapas: Fundamentação, Materiais e Logística, e Experimentação. A Rationale consistiu em uma revisão bibliográfica sobre os conceitos de: biônica, design generativo-algorítmico, fabricação digital, impressão 3D e prototipagem. A etapa de Materiais e Logística consistiu na apresentação e classificação em categorias de materiais e a logística que foi utilizada. A experiência consistiu em 4 fases: Código gráfico e modelagem digital 3D do pavilhão biônico; operacionalização da fabricação digital; seleção da tecnologia de fabricação digital de impressão 3D e; fabricação digital por impressão 3D. O principal resultado da pesquisa é que as tecnologias digitais - software rinoceronte 5.0, software gafanhoto - permitem projetar um protótipo de um pavilhão de forma complexa ou de pequeno tamanho inspirado em estruturas naturais.

Palavras-chave: biônico, design generativo, fabricação digital, impressão 3D, pavilhão.

1 INTRODUCTION

This article deals with the second experiment of a group of 7 experiments carried out in the doctoral thesis entitled “Design and Fabrication of a Complex, Cellular and Responsive Biomimetic Pavilion with Digital Technologies and Robotics in Brasília - DF”. Within the research project of “Parametric Modeling, Digital Fabrication and Mass Customization”. Line of research on “Production Technology for the Built Environment”. Area of concentration of “Technology, Environment and Sustainability”. Postgraduate Program of the Faculty of Architecture and Urbanism - PPGFAU - of the University of Brasília - UnB - Campus Darcy Ribeiro.

The advancement of 3D modeling and digital fabrication by addition technologies have allowed the design and fabrication of prototypes of artifacts with complex shapes or non-Euclidean geometries in the field of architecture; but there are few experiences that show the possibilities and limitations of these technologies for the production of building components.

In such sense, the problem of this research was to determine the possibilities and limitations of digital design and digital fabrication by adding of reduced size Bionic Pavilion.

The guiding hypothesis of the research was that digital addition fabrication technology using cast filament fabrication is a rapid production process that presents little deformation in objects of complex shapes or non-Euclidean geometries..

The main objective was to determine the possibilities and limitations of digital design and digital fabrication by adding a Bionic Pavilion of non-Euclidean geometries in reduced size. Through the specific objectives presented below: 1) Establish a theoretical framework; 2) Establish a materials and logistics benchmark; 3) Determine the Pavilion's graphic code and digital 3D modeling; 4) Determine the operationalization of the Pavilion's digital fabrication phases; 5) Select Digital Fabrication Technology by 3D Printing; 6) Determine the phases of digital fabrication by 3D printing.

2 METHODOLOGY

The methodological process was structured in 3 stages: Rationale, Materials and Logistics, and Experimentation.

2.1 RATIONALE

The foundation consisted of reviewing and systematizing the literature on the concepts of: Pavilion, Bionics, Generative Design, Digital Fabrication and 3D Printing.

2.1.1 Pavilion

The authors have designed Pavilions to study digital design methodologies, material properties, and digital fabrication methods.

Henriques (2012) designed the TetraScript Pavilion; Dorstelmann et al. (2014) designed the ICD/ITKE Research Pavilion 2013-14; Oxman et al. (2014) designed the Silk Pavilion; Reichert, Menges and Correa (2015) designed the Meteorosensitive Pavilion; Mogas-Soldelila et al. (2015) designed the Ocean Pavilion; Dambrosio et al. (2019) designed the Buga Fibra Pavilion; Alvarez et al. (2019) designed the Buga Wood Pavilion; Guillen (2020) and Guillen, Silva and Kallas (2020) designed the BIO-FADEN 1.0 Pavilion.

Thus, in this article, the term “Pavilion” will be understood as a temporary installation to study digital design methodologies, material properties and digital fabrication methodologies.

2.1.2 Bionics

The term “bionics” comes from the words “biology” and “technology” and was coined by Jack Ellwood Steele in the 1950s (Guillen Salas, 2020, cited by Guillen-Salas;

Silva; Kallas, 2020). The “bionics” is the study of natural ways to transfer them to technology (Guillen Salas, 2020, cited by Guillen-Salas; Silva; Kallas, 2020).

2.1.3 Generative Design

The authors agree to point to "generative design" as a design method through rules and algorithms.

Agkathidis (2015) defined generative design as a design method where shape generation is the result of applying rules and computational algorithms. ASSESS (cited by INTRINSIM, 2019) pointed out that generative design is the use of algorithmic methods to generate viable designs from a set of performance goals and constraints. Darja Moskvina (2020) pointed out that generative design is a process of a production system where the generation of a solution corresponds to design logic or algorithms. Buonamici et al. (2020) considered generative design as a series of tools, of artificial intelligence methods and algorithms, applied to solve design problems. Westerveld (2021) defines generative design as a method that allows users to give various information and constraints to a system rather than providing a complete geometric model.

Thus, in this article, “generative design” will be considered as a design method where rules and computational algorithms are established to obtain multiple solutions to a design problem.

2.1.4 Digital Fabrication

Digital fabrication is the process of fabrication using computer numerically controlled (CNC) machines of an object with a customized material (Guillen Salas, 2020, cited by Guillen-Salas; Silva; Kallas, 2020).

2.1.5 3D Printing

In the literature, the authors present more comprehensive definitions than others.

Gedhardt and Fateri (2013) and Al-maliki and Al-maliki (2015) agree to define 3D printing or additive fabrication as a process of constructing of solid object from a digital file. The fabrication consists of placing layers in successive form until completing the created object. Crucible (2014) and Ramya and Vanapalli (2016) agree to define 3D printing as a set of technologies capable of creating or reproducing three-dimensional objects or structures. 3D printing (2016), Panda et al. (2016), Erasmus 3D+ (2017), The 3D printing (2017) and Shahrubudin and Ramlan (2019) agree to define 3D printing as a technology that allows the fabrication of an object from a computer-assisted designed model.

Thus, in this article, 3D printing will be understood as an additive fabrication technology that is capable of producing three-dimensional objects or structures from a model designed with computer assistance. In such process the manufacturing material is placed in successive layers until completing the model.

2.2 MATERIALS AND LOGÍSTICS

The materials and logistics used were classified into 8 categories.

1) Physical space: Digital Fabrication and Mass Customization Laboratory/FAU/UnB, Residence. 2) Furniture: Tables and Chairs. 3) Equipment: SONY brand notebook VAIO model, Intel(R) Core(TM) i5-3210M CPU @ 2.50GHz 2.5GHz, RAM 12GB; 64-bit Operating System, Windows 8.1; ZCorp Printer 310; RepRap Uberblock Printer; RepRap Anet A8 Printer. 4) Softwares: Rhinoceros versão 5.0; Grasshopper; ZPrinter; Cura 15.04.6. 5) Office Supplies: Scissors; stiletto. 6) Material for 3D Printing: Powder ZCast 500; Plaster-maltodextrin-sugar powder; Acrylonitrile Butadiene Styrene Filament – ABS; Polylactic acid filament - PLA. 7) Construction Material: Double sided adhesive tape. 8) Electric Tooling: Pliers.

2.3 EXPERIMENTATION

The Experimentation stage was structured in 4 phases: Graphic code and digital 3D modeling of the Bionic Pavilion, Operationalization of the digital fabrication of the Pavilion, Selection of digital fabrication technology by 3D printing and, Digital fabrication by 3D printing.

2.3.1 Graphic Code and Digital 3D Modeling of the Bionic Pavilion

This phase was structured in 4 steps: Graphical surface code, Graphical module code, Graphical code of the Pavilion surface divided into modules, and 3D Modeling of the Pavilion.

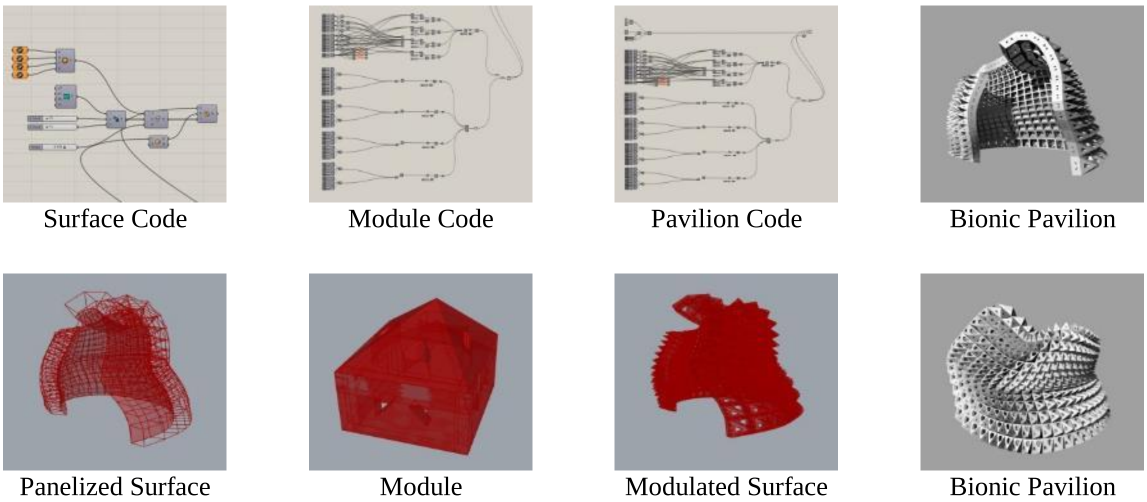
Surface graphic code. The Pavilion surface was generated from a process of 4 tasks: Definition of three-dimensional NURBS curves, Surface subdivision, Surface paneling and Module twisting.

Graphical code of the module. The pavilion module was generated from a process of 6 tasks: Definition of points, Generation of lines, Generation of surfaces, Generation of extrusions, Execution of subtractions, and Definition of solid form.

Graphic code of the Pavilion surface divided into modules. The pavilion code consisted of two graphic codes: a surface programming code and another module programming code.

3D modeling of the Pavilion. The Pavilion in 1:1 scale was designed in the dimensions of 2.5m x 2.5m x 2.5m and three-dimensionally modeled with 450 modules distributed in 15 rows and 30 columns.

Figure 1. Graphic Code and 3D Modeling of the Bionic Pavilion.



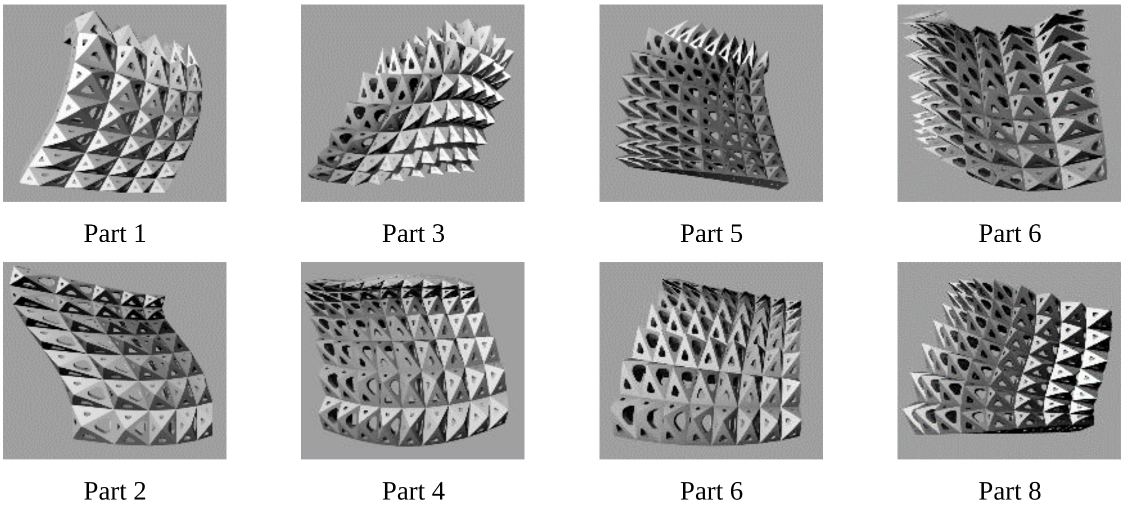
Source: Guillen Salas, (2020), Guillen-Salas; Silva; Kallas (2020) and Guillen-Salas; Silva (2021).

2.3.2 Operationalization of the digital fabrication of the Pavilion

The Operationalization of the digital fabrication of the Bionic Pavilion was structured in 2 tasks: Division of the Pavilion into cloths and, Division of the cloths into blocks.

Division of the Pavilion into parts. The 3D digital model of the Pavilion was divided into 8 panels to enable the digital fabrication and organization of the modules.

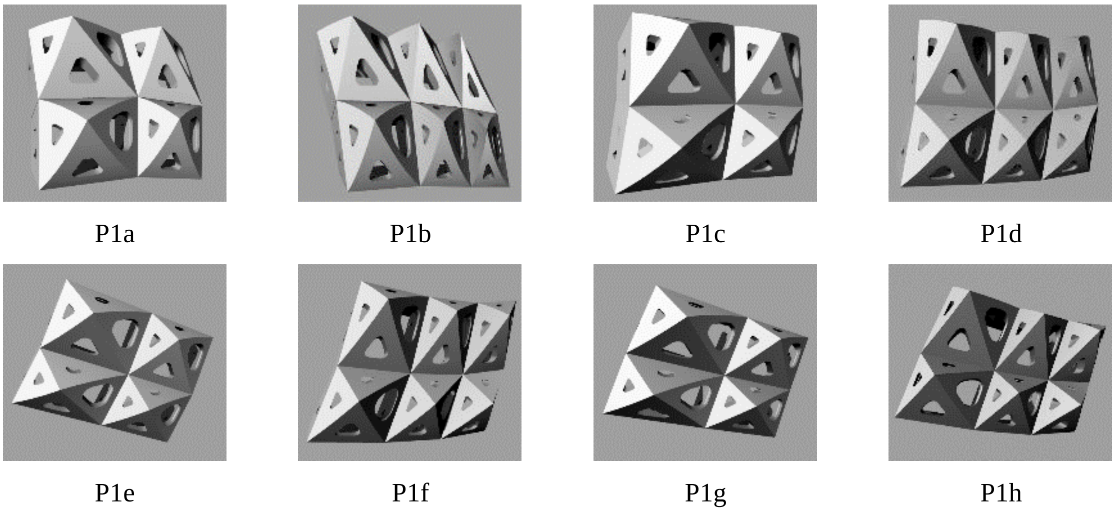
Figure 2. Division of the Pavilion into Parts.



Source: Guillen Salas, (2020), Guillen-Salas; Silva; Kallas (2020) and Guillen-Salas; Silva (2021).

Division of parts into blocks. The parts were divided into blocks based on the largest size that could be printed on the available printer and the average printing time of 4 hours per piece. After the creation of the blocks, the identification of the block with the largest size was carried out, among all the parts, to determine the maximum proportion for printing the blocks.

Figure 3. Division of Part 1 into Coded Blocks.



Source: Guillen Salas, (2020) and Guillen-Salas; Silva; Kallas (2020).

2.3.3 Selection of Digital Fabrication Technology by 3D Printing

The selection of digital fabrication technology by addition has passed the testing of 2 3D printing technologies. The powder casting fabrication technology and the cast filament fabrication technology.

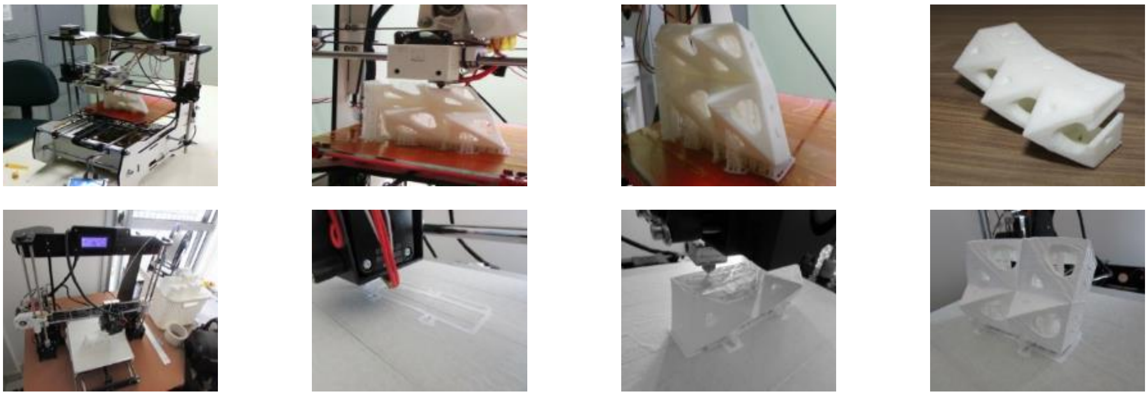
Powder Casting Fabrication Technology - 3DP. Fabrication by powder casting is a 3D printing process that consists of adhering powder layers by applying a binder.

Figure 4. Fabrication by Powder Casting. 3D Printing with Zcast 500 Powder (top row of photographs). 3D Printing with Maltodextrin/plaster/sugar (lower row).

Source: Guillen Salas, (2020).

Cast filament fabrication technology (FFF). Cast filament fabrication is a fabrication process by adhesion of layers of a plastic filament. In the experiment, ABS and PLA filaments were used.

Figure 5. Cast Filament Fabrication. 3D Printing on ABS filament (top row of photographs). PLA filament 3D printing (bottom row).



Source: Guillen Salas, (2020).

2.3.4 Digital Fabrication by 3D Printing

Digital fabrication by addition was performed in 3 tasks: 3D printing of parts 1-2-3-4, 3D printing of parts 5-6-7-8 and assembly of the reduced size 3D model of the Bionic Pavilion.

The 3D printing of parts 1-2-3-4 was performed on the RepRap Uberblock printer using PLA. After 3D printing, the blocks of each part were cleaned, organized and joined using double-sided tape.

Figure 6. Parts 1-2-3-4.

Part 1 Part 2 Part 3 Part 4

Source: Guillen Salas, (2020).

The printing of parts 3-5-7-9 was performed on the RepRap Anet A8 printer using PLA. After printing, the blocks of each part were cleaned, organized and joined using double-sided tape.

Figure 7. Partes 5-6-7-8.

Part 5 Part 6 Part 7 Part 8

Source: Guillen Salas, (2020).

The assembly of the reduced size 3D model was performed by joining the parts with double-sided tape. See Figure 8

3 RESULTS

The Pavilion surface code allowed for quick modification of the shape and to determine the number of modules that would be distributed along the surface.

The module code allowed to determine the size of the modules, the size of the module, the shape of the module, the module faces and the size of the module perforations.

The Pavilion code allowed the transformation from Euclidean module geometry to non-Euclidean surface geometry.

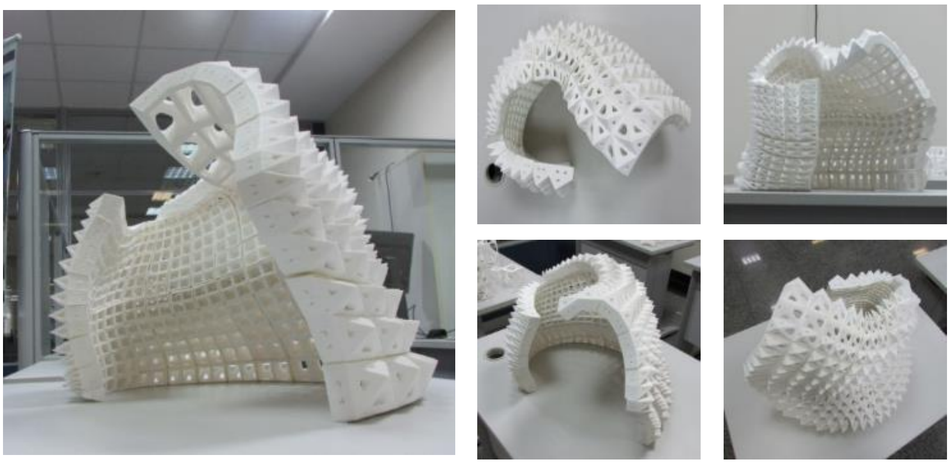
The Pavilion code allowed to preserve the proportion of the thickness of the faces as a function of the size of the same faces.

The maximum print size of the parts depends on the choice of module or block (set of modules) that can be printed on the 3D printer used.

Fabrication with PLA on a RepRap printer is a fast fabrication process with good print resolution and adhesion continuity between the layers of the produced object. When compared to ABS printing.

The reduced size 3D model of the Pavilion is necessary to study and analyze the phases of assembly operationalization.

Figure 8. Prototype of the Bionic Pavilion.



Source: Guillen Salas (2020) and Guillen-Salas; Silva (2021).

4 DISCUSSION

The graphic code presented itself as a versatile tool for the control of the non-Euclidean geometry of the Pavilion surface and the Euclidean geometry of the module.

The graphic code allowed modifying the shape of the Pavilion surface and the module geometry, but when modifying the module geometry it did not modify the Pavilion surface geometry.

The graphic code allowed preserving the thickness of the module faces in proportion to the size of the faces as established in the project.

The printing of the modules or blocks (sets of modules) allowed us to observe the need to code the parts to be organized in the respective parts and in the Pavilion.

The 3D printing process by powder casting provided a good printing resolution depending on the particle size of the material used, but it is a time-consuming process that demands great care in handling the produced part until it reaches the desired hardness.

The 3D printing of the blocks made it possible to verify the need for a coding in the block to identify the printer on which it was fabricated.

5 CONCLUSION

The guiding hypothesis of the experiment was confirmed. Digital addition fabrication technology using cast filament fabrication is a rapid production process that presents little deformation in objects with complex shapes or non-Euclidean geometries. From the observations listed below:

The digital design process using a graphic code allows the customization of non-Euclidean and Euclidean geometric shapes in bulk automatically and saving the proportions established in the design of the components.

The maximum size of the part and module directly depends on the size of the 3D printer printing table available to carry out the fabrication.

Fabrication with PLA on a RepRap printer is a fast fabrication process, with good print resolution and continuity of adhesion between the layers of the produced object.

The 3D model of the Pavilion in reduced size is necessary to study and analyze the operationalization of the assembly.

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