Experimental Study of Digital Design and Digital Fabrication with 3D Printing of Bionic Cell Prototype for Pavilion Design in the Midwest Region of Brazil

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Abstract. The main objective of the research was to determine the possibilities and limitations of digital design and digital fabrication with 3D printing of a cell prototype. The work was structured in 3 stages: Rationale, Materials and Logistics, and Experimentation. The Rationale stage consisted of reviewing the literature on the concepts: Prototype, Bionics, Parametric Design, Digital Fabrication and 3D Printing. The Materials and Logistics stage consisted of the presentation and classification into categories of materials and the logistics that were used. The Experimentation stage consisted of 3 phases: determination of the structural characteristics of the fruit peels; determination of the shape of the cell from the structural characteristics of the fruit peels and; choice of 3D printing digital manufacturing technology. The main result of the research was that digital technologies - MEV Jeol JSM-7000F microscope, Rhinoceros 5.0 software, Grasshopper software - allow to observe and design a cell in a complex way inspired by the natural structures found in the peels of fruit species of Annona Cherimola, Mill with Annona Squamosa, L; Mauritia Flexuosa; Babassu Coconut, Soursop and Pine Cone or fruit of the Earl.

Keywords: Bionic, Parametric Design, Digital Fabrication, 3D printing, Prototype

1 Introduction

This article deals with the third experiment of a group of 7 experiments carried out in the doctoral thesis entitled "Design and Manufacturing 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 have tried to point out the possibilities and limitations of these technologies for the production of components inspired by nature's structures for the construction sector.

In this sense, the problem of this research was to determine the possibilities and limitations of digital design and digital fabrication by additive technology of prototype of structural cell inspired by the natural structures found in the fruit peels of some fruit species present in the midwest region of Brazil.

It is hypothesized that the digital addition technology, using direct light processing in resin, is a fast production process that presents a good print resolution on objects with complex shapes or non-Euclidean geometries.

The main objective was to determine the possibilities and limitations of digital design and digital fabrication by additive technology of prototype of structural cell inspired by the natural structures found in the fruit peels of the fruit species of atemoya (Annona cherimola, Mill - Annona Squamosa, L.), buriti (Mauritia flexuosa), babassu coconut, soursop and pine cone or earl fruit, present in the Midwest Region of Brazil.

The specific objectives were: 1) Determine the structural characteristics of the fruit peels of the fruit species of atemoya, buriti, babaçu coconut, soursop and pine cone or earl fruit; 2) Determine the shape of the structural cell from the structural characteristics of the fruit peels of fruit species; 3) Determine digital addition fabrication technology for structural cell production.

2 Methodology

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

2.1 Rationale

The rationale consisted of the review and systematization of the literature related to the concepts: Prototype, Bionics, Parametric Design, Digital Fabrication and 3D Printing.

Prototype

In the literature, the authors refer to the "prototype" as an artifact or a process of solving design problems.

Kim (1990 cited by Houde; Hill, 1997) pointed out that the prototype is an interactive design system which demands collaboration between designers from different disciplines. Bardram, Christensen and Hansen (2004) defined the prototype as the design, construction and evaluation process. Otto and Wood (2001, cited by Camburn et al., 2017) reported that the prototype is an artifact that approximates a resource or several resources of a product, service or system. Papamanolis (2018) pointed out that the prototype is an original model in which something is standardized. Lauff, Kotys-Schwartz and Rentschler (2018) related the prototype to a tool that serves to communicate, learn and make informed decisions in the design process. Kim (2019) indicated that the prototype is the beginning of the design or the process of resolving assumptions in design.

Thus, in this article, the “prototype” will be understood as an initial model of a design process.

Bionics

The term “bionics” comes from two areas of human knowledge, “biology” and “technology” and was first used by Jack Ellwood Steele in the 1950s. Steele defined “bionics” as the study of the forms of nature to reproduce them with technology. (Guillen Salas, 2020, cited by Guillen-Salas; Silva; Kallas, 2020).

Parametric Design

In the literature, the authors present an evolution in the definition of parametric design.

Monedero (2000), Woodbury (2010), Zarei (2012), Burry and Murray (1997 cited by Minh, 2009, cited by Abdullah; Kamara, 2013) and Monedero (1998, cited by Abdullah; Kamara, 2013) defined the parametric design as modeling a shape through relationships between its different parts.

Hernandez (2006), Hudson (2010) and Schnabel (2012) defined parametric design as computational modeling in a way through controlled relationships between its different parts.

Woodbury (2010, cited by Lee, 2015), Sárközi (2019), Lee and Oswald (2020) and Tedeschi (2020) defined parametric design or algorithmic generative design as a computational modeling process in a way through controllable relationships between its different parts by parameters and rules.

Thus, in this article, it will be assumed that parametric design is a computational modeling of a shape through generative algorithms, where the relationships of the different parts of the shape are controlled by parameters and rules.

Digital Fabrication

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

3D printing

The authors point out that "3D printing" in three ways. 1) which is a manufacturing process from a digital file (Gedhardt; Fateri, 2013) (Al-maliki; Al-maliki, 2015), 2) which is a set of technologies to create or reproduce three-dimensional artifacts (Crucible, 2014) (Ramya; Vanapalli, 2016), 3) which is a technology for manufacturing artifacts from a CAD model (3D printing, 2016) (Panda, et al., 2016) (Erasmus 3D+, 2017) (The 3D printing, 2017) (Shahrubudin; Ramlan, 2019). In this article, "3D printing" will be considered as a layered additive manufacturing technology for producing three-dimensional artifacts with computer assistance.

2.2. Materials and Logístic

The materials and logistics used were classified into 10 categories.

1) Physical space: Laboratory of Ideas, Prototyping and Entrepreneurship - IPELab - of the Technological Park of the Federal University of Goiás – Campus Samambaia; Residence. 2) Furniture: Tables; Chairs. 3) Equipments: SONY brand notebook VAIO model, Processador Intel(R) Core(TM) i5-3210M CPU @ 2.50GHz 2.5 GHz, RAM 12 GB, 64-bit Operating System, Windows 8.1; Metallizer Belzier SCD 050; Microscope MEV Jeol JSM-7000F; 3D Printer RepRap Anet A8; 3D Printer Moonray S. 4) Softwares: Rhinoceros v. 5.0; Grasshopper; Cura v. 15.04.6; Sprintray Rayware 1.4.6. 5) Office supplies: Pen; Paper A4 format 75 gr. 6) Craft Material: Colored flexible plastic putty; spatulas. 7) Material for 3D Printing: Polylactic acid filament – PLA; Moonray Gray Resin. 8) Personal Protection Material: Mask; Gloves. 9) Cleaning Material: Isopropyl Alcohol; Drying Cloth. 10) Electric Tool: Pliers.

2.3. Experimentation

The experimentation stage was structured in 3 phases: Structural characteristics of the fruit peels of the fruit species of atemoya, buriti, babassu coconut, soursop and, pine cone or fruit of the Earl; Structural cell shape and; Digital fabrication technology by addition.

Structural Characteristics of Fruit Peels

The determination of the characteristics of the peels was carried out with a 3-steps: 1) Selection of fruit peels, 2) Drying of peels samples and, 3) Peels sample analysis.

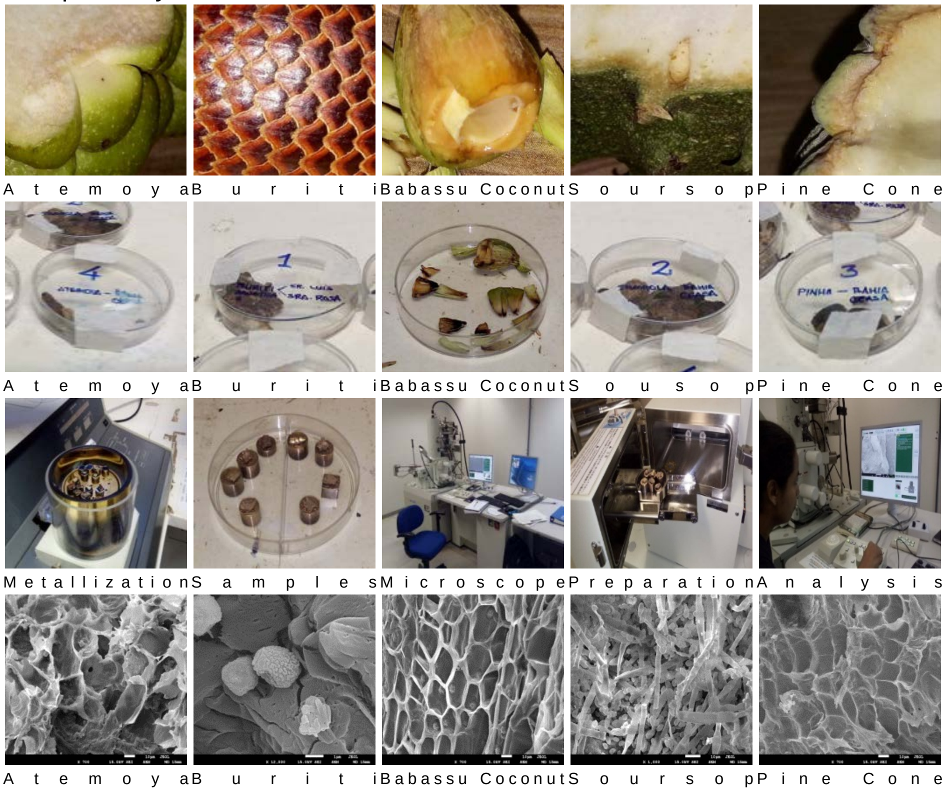


Figure 1. Structural Characteristics of Shells. Peel Selection (first row), Sample Drying (second row), Sample Analysis (third row), Microscopic Images (fourth row). Source: Guillén Salas (2020).

Structural cell shape

The determination of the shape of the structural cell from the structural characteristics of the peels was carried out following a process consisting of 3 steps: 1) Traces of the structural cell, 2) Manual modeling of the structural cell, 3) Digital 3D modeling of the structural cell.

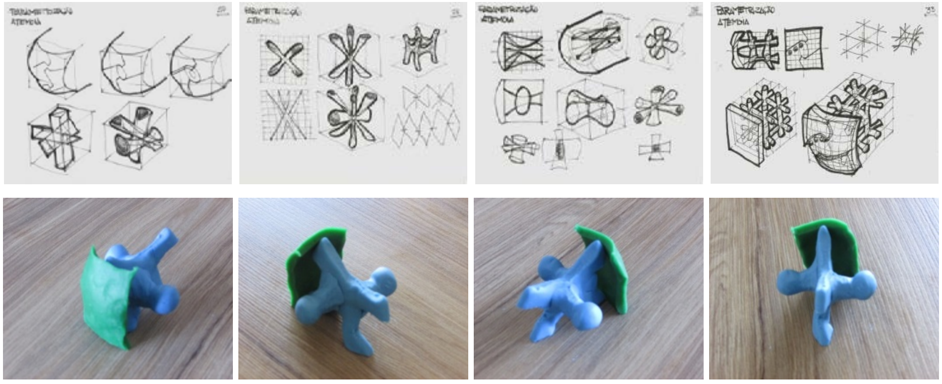
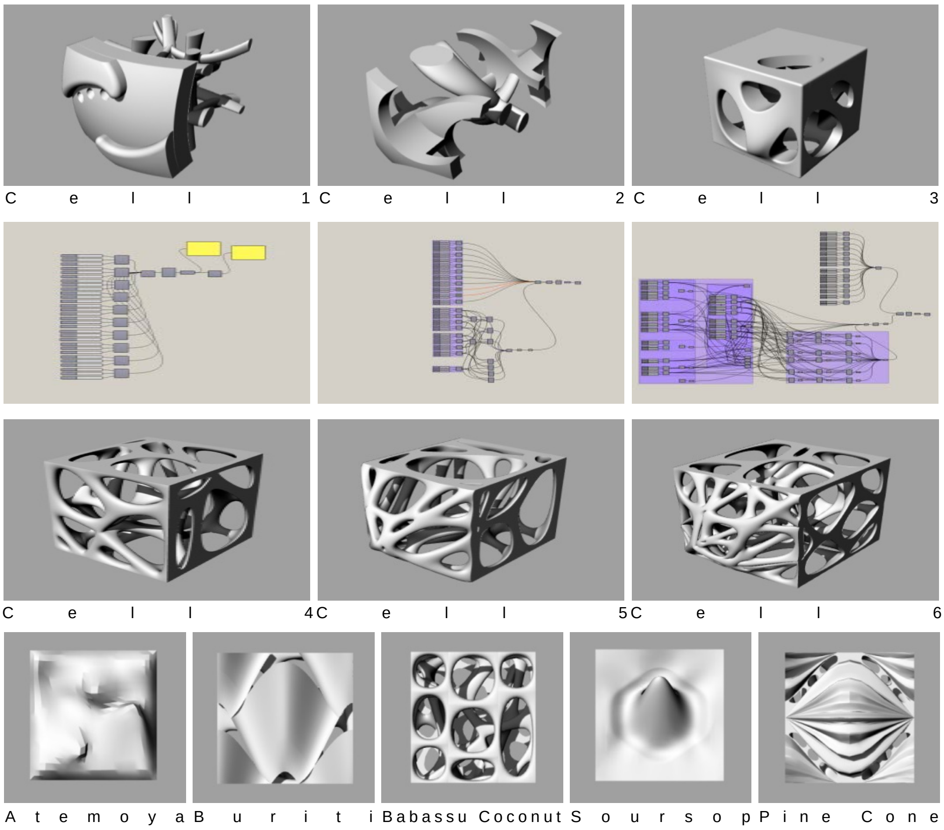


Figure 2: Traces of the Structural Cell and Manual Modeling of the Structural Cell. Source: Guillen Salas (2020).



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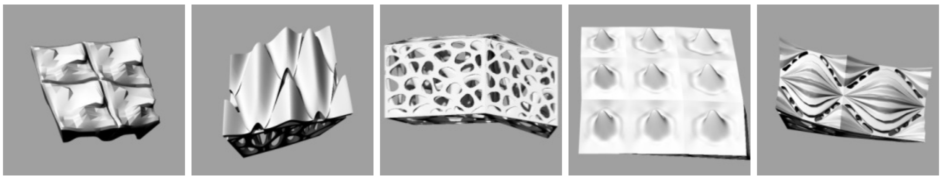

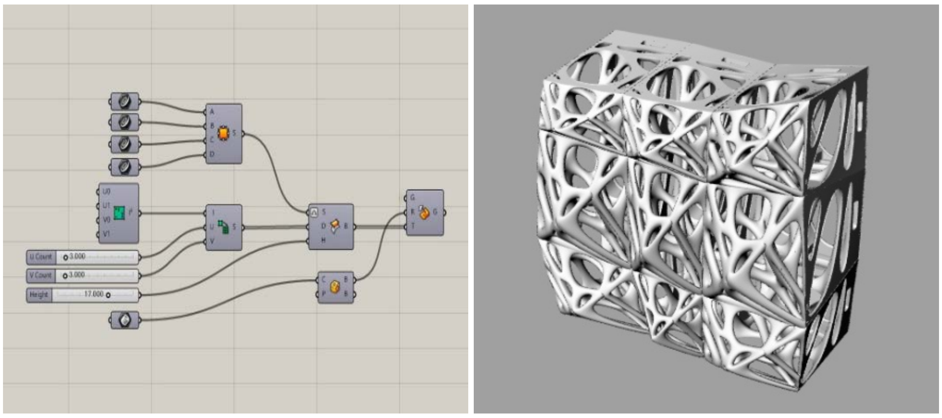

Figure 3. Digital 3D Modeling of the Structural Cell. Source: Guillen Salas (2020).

Digital fabrication technology by addition

The choice of digital fabrication technology by addition for the production of the structural cell was carried out in a process consisting of 2 steps: 1) Fabrication by cast filament, 2) Fabrication by direct light processing in resin.

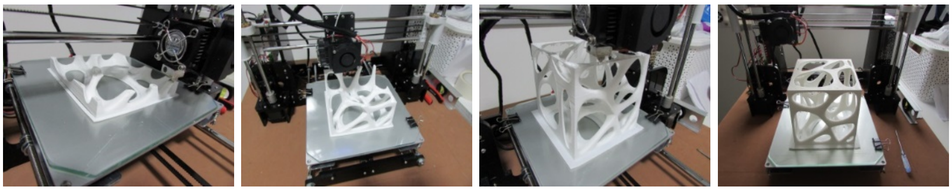

Figure 4: Cast Filament Fabrication. Source: Source: Modified from Guillen-Salas e Silva (2021) and Guillen Salas (2020).

To be continued…

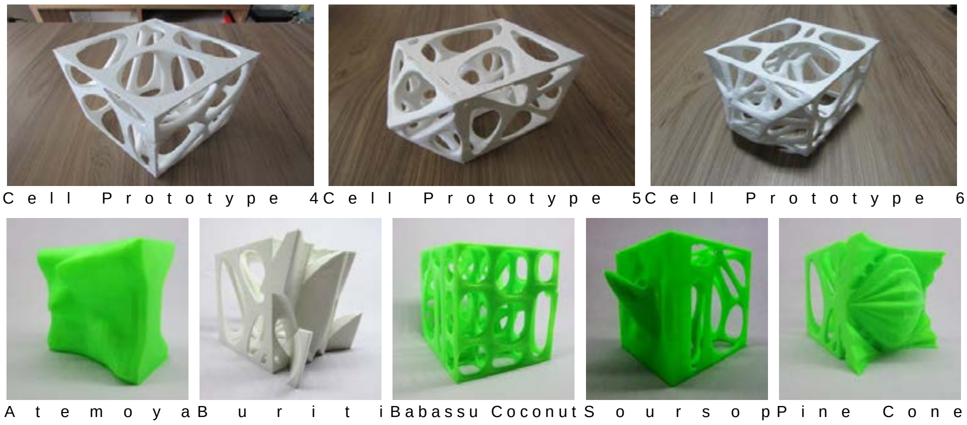

Figure 5: Cells Prototypes. Source: Source: Modified from Guillen-Salas e Silva (2021) and Guillen Salas (2020).

Figura 6: Cells Panels Prototypes. Source: Modified from Guillen-Salas e Silva (2021) and Guillen Salas (2020).

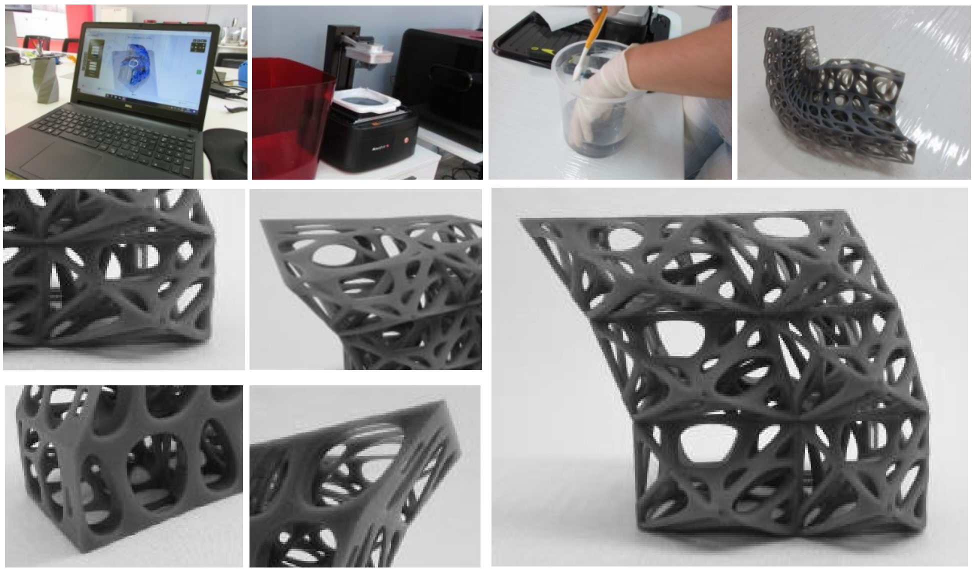

Figura 7: Fabrication by Direct Light on Resin (Stereolithography. Source: Modified from Guillen-Salas e Silva (2021) and Guillen Salas (2020).

3 Results

Predominantly the peels of the fruit species observed are composed of an outer surface, continuous, wrinkled and waxed, and an inner surface composed of interconnected bubble structures of different shapes and sizes in various layers.

Digital 3D modeling technologies, in the mix of direct modeling and programmatic modeling, are tools that allow the modeling and manipulation of complex shapes inspired by the structure of the fruit peels.

Digital addition fabrication using direct light-on-resin processing technology enables the production of complex shapes inspired by natural structures with high print quality, speed, strength and ready to use.

4 Discussion

The bubbles that make up the shell structures reduce in size the closer they are to the outer surface.

Digital 3D modeling, parametric design and generative design technologies allow the creation and manipulation of complex shapes through rules and parameters.

3D printing technology using direct light on resin has greater resistance in the thin parts than 3D printing using PLA.

5 Conclusion

The guiding hypothesis of the experiment was confirmed. Digital addition fabrication technology using direct light resin processing is a fast production process that presents good print resolution on objects with complex shapes or non-Euclidean geometries.

The structure of interconnected bubbles of varying sizes is a strategy that can be applied in the development of architectural envelopes to reduce direct sunlight and preserve ventilation in building facades.

Architectural components emulating interconnected bubble structures ranging in size from small to larger can be designed and fabricated with the aid of digital technologies and digital additive fabrication. 3D printing by direct light technology on resin.

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