Experimental Study of Prototyping of Autonomous Responsive Cell Panels for Pavilion Design in the Midwest Region of Brazil

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Abstract. There is little research on the possibilities and limitations of digital design, prototyping and manufacturing of architectural components inspired by microscopic plant structures. The hypothesis was that "prototypes of autonomous responsive cell panels can be produced using digital manufacturing by addition and robotics. The objective was to determine the possibilities and limitations of the design, prototyping and manufacture of a responsive cell prototype inspired by the microscopic plant structures of the peel of fruits of Annona Cherimola, Mill and Annona Squamosa, L. (atemoia), Mauritia Flexuosa (buriti), Attalea ssp (babassu coconut), Annona Muricata (soursop) and Annona Squamosa (pine cone or conde fruit). Autonomous responsive cells inspired in plant structures can be produced. But the autonomous responsive cell controlled for sensor-presents itself as an alternative to automatic orientation toward a natural (sun) or artificial lighting source.

Keywords: Robotics, Biomimetic, Responsive Architecture, Arduino, Digital Fabrication.

1 Introdução

This article is about the fifth experiment of seven carried out in the doctoral thesis entitled “Design and Manufacture 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”. Research line of “Production Technology of the Built Environment”. Concentration area of “Technology, Environment and

Sustainability". Graduate Program at the Faculty of Architecture and Urbanism - PPGFAU - University of Brasilia - UnB - Campus Darcy Ribeiro.

The advancement of 3D modeling and digital fabrication by addition technologies has allowed the design and manufacture of prototypes of artifacts with complex shapes in the area of architecture; but there are few experiences that have pointed out the possibilities and limitations of these technologies for the production of components inspired by the structures of nature for the construction sector. In this sense, in this experiment, the possibilities and limitations of digital design and digital fabrication were observed by adding a responsive cell prototype inspired by the natural structures found in the fruit peels of some fruit species present in the Central-West Region of Brazil.

The guiding hypothesis of the research was that prototypes of autonomous responsive cell panels can be produced by mixing digital addition fabrication and robotics.

The general objective was to determine the possibilities and limitations of the design and manufacture of a prototype of a responsive cell inspired by the natural structures found in the fruit peels of the fruit species of atemoia, buriti, babassu coconut, soursop and pine cone or fruit of the count, present in the region. Midwest of Brazil. And the specific objectives were: 1) Determine the possibilities and limitations of retractable surfaces and the type of triggering for responsive cells; 2) Determine the possibilities and limitations of responsive devices by electromechanical actuation; 3) Determine the possibilities and limitations of fabrication of responsive cell panels on double curvature surfaces.

From the specific objectives, the methodological process of the experimental study was organized in 2 stages.

2 Methodology

The study was organized in 2 stages: Rationale and Experimentation.

2.1 Rationale

This step consisted of reviewing the following concepts:

Bionics is seen as the study of the forms of nature to transfer them to technology (Guillen-Salas & Silva & Kallas, 2021a, 2021b) (Guillen Salas & Silva & Kallas, 2020) (Guillen Salas, 2020).

Biomimicry is defined as the science that studies and reproduces the methods, designs and processes of nature (Guillen Salas, 2020) (Badarnah, 2017) Cohen & Reich, 2016) (Chung, 2011) (Santos, 2010). Biomimicry was understood as the conscious imitation of nature in search of making the planet sustainable (Benyus, 1997, citada por Guillen Salas, 2020) (Al-Obaidi, & Ismail & Hussein & Rahman, 2017) (López & Rubio & Martín & Croxford, 2017) (Pawling, 2016).

Responsive architecture is marked as a dynamic architecture that implies physical and autonomous change through computational-electromechanical or natural devices. From the reception of a signal by a sensor, signal processing by a microcontroller and the actuation of motors to regulate the impact of external environmental factors on the internal environment. (Guillen Salas, 2020) (Kolarevic & Parlac, 2015) (Henriques, 2015) (Menges & Reichert & Kieg, 2014).

Generative-algorithmic design is understood as a design method that uses computational rules and algorithms to obtain multiple solutions to resolve a design problem (Guillen Salas & Silva & Kallas, 2020).

Arduino is defined as an open source hardware and software microcontroller (minicomputer) platform for electronic prototyping (Banzi citado por Guillen Salas, 2020).

Digital fabrication is understood as the computer numerically controlled (CNC) manufacturing process of an artifact with customized material. It can also be understood as the preparation of a digital file to be sent to the factory (Guillen-Salas & Silva & Kallas, 2021a, 2021b) (Guillén-Salas & Silva, 2021c) (Guillen Salas & Silva & Kallas, 2020) (Guillen Salas, 2020) (Kolarevic & Klinger, 2008) (Kolarevic, 2003, 2001).

3D printing is defined as a computer-aided additive manufacturing technology by layering three-dimensional artifacts (Guillen-Salas & Silva & Kallas, 2021b).

The prototype is marked as the initial model of a design process (Guillen-Salas & Silva & Kallas, 2021b).

Thus, from the literature review on these concepts, the experimentation stage was structured.

2.2 Experimentation

This stage was organized in 2 phases: Materials and Logistics and Experiment.

The Materials and Logistics phase consisted of 14 categories: 1) Physical space: Residence. 2) Furniture: Tables; Chairs. 3) Equipment: Notebook SONY model VAIO Processor Intel(R) Core (TM) i5-3210M CPU @ 2.50GHz 2.5 GHz RAM 12 GB, Metallizer Belzier SCD 050, Microscope MEV Jeol JSM-7000F, Operacional System 64 bits Windows 8.1, Moonray Printer, RepRap Anet A8 Printer. 4) Softwares: Rhinoceros 5.0, Grasshopper, Autodesk T-Spline for Rhinoceros, Cura 15.04.6, Sprintray Rayware 1.4.6, Arduino software IDE. 5) Office supplies: Pen, White Chamex Paper A4 75gr, Metal Rulers, White Glue, Scissors, Stylus. 6) Sewing material: thread. 7) Cardboard material: Simple wave cardboard 1.40 m x 1.00 m, plastic spatula, wooden sticks. 8) Hospital supplies: Disposable syringes, Silicone hoses. 9) Construction material: Bolts, Wing nuts, Metal washers, Rubber washers. 10) Robotics Material: Arduino Uno Board, USB Cable, Breadboard, Jumpers, Micro Servo 9g SG90 TowerPro, Servo Motor MG996R, Potentiometer 100k, Luminosity Sensors

LDR 5mm, Temperature Sensors LM35DZ, Ultrasonic Sensors HC-SR04, Pan/Tilt Support with 9G Servo Motor, AtMega328P Controller - Standalone Configuration, 12V 3W Solar Panel, 40 cm² Phenolite Board, 9V 240mAh Rechargeable Battery, 1Ω Resistors, 2.2 K Ω Resistors, 10 K Ω Resistor, 150 Ω Resistor, Oscillator Crystal 16 MHz, 2n2222A transistors, reset/push button, 7805 voltage regulator, 220 uF electrolytic capacitor, 100 nF capacitors, 22nF capacitors, 1N4007 diode, LEDs, 9V battery clip. 11) Material for 3D printing: Polylactic acid filament - PLA, Moonray Gray Resin. 12) Material for personal protection: Safety glasses. 13) Electrical tooling: Photovoltaic cell, Nose pliers. 14) Transport: Private car.

The experiment phase consisted of 5 subphases:

1) Characterization of the microscopic structures of fruit peels. The microscopic images were obtained using a scanning electron microscope brand MEV Jeol JSM-7000F from the Laboratory of Microscopy and Microanalysis (LMM) of the Institute of Biological Sciences (IB) of the University of Brasília (UnB) with the support of the laboratory technique.

In the images, the presence of bubbles that are interconnected in layers of different thicknesses was observed. The bubbles appear in smaller sizes when they are located in areas of sharper curvature and closer to the outside of the shell.

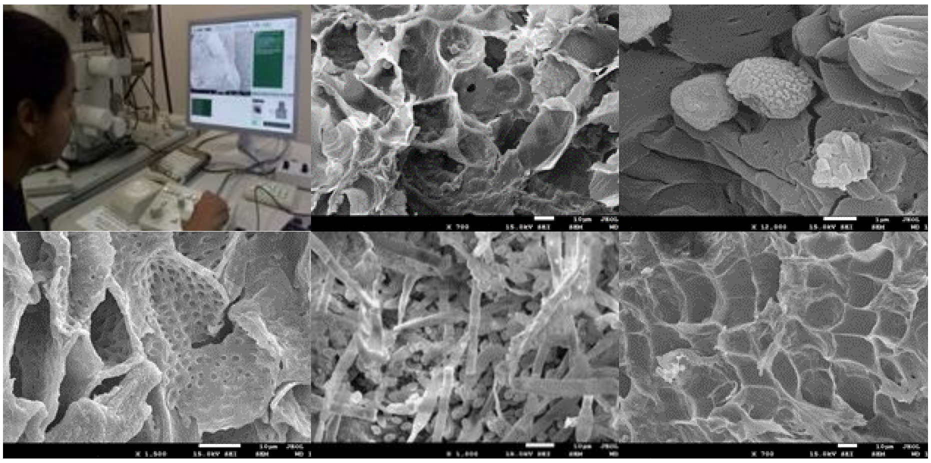

Figure 1. Microscope observation and image capture of atemoya, buriti, babassu coconut, soursop and pine cones. Source: Guillén Salas (2020).

2) 3D Modeling, Simulation and Prototyping of cells. Cells were modeled using rhinoceros 5.0 and the grasshopper and t-spline plugins. The simulation was performed with Autodesk's flow design software. And the fabrication was carried out with PLA on an Anet A8 brand RepRap 3D printer.

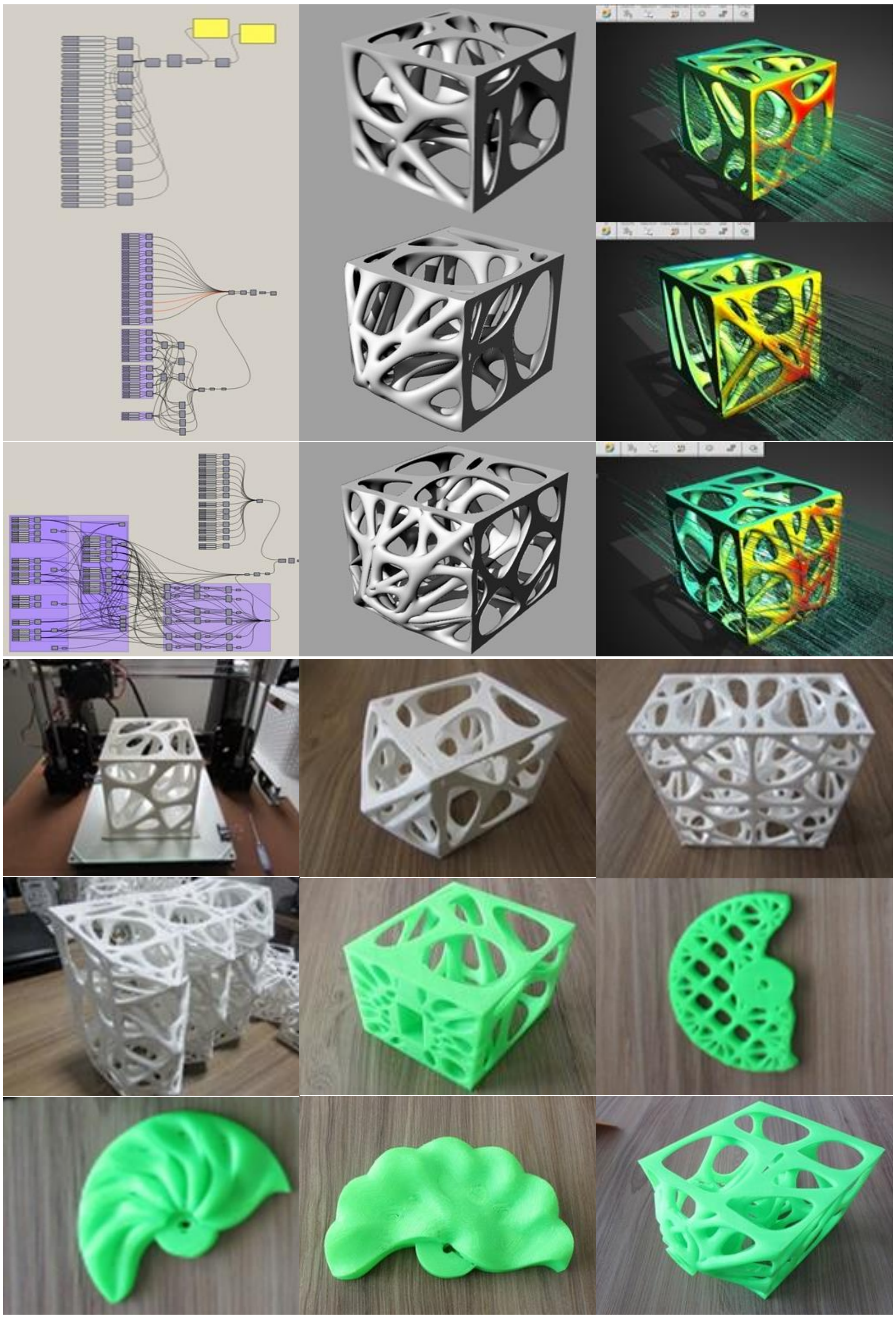

Figure 2. 3D cell modeling and aerodynamic simulation (1st, 2nd 3rd rows). Cell prototypes (3rd, 4th, 5th, 6th Rows). Source: Guillén Salas (2020).

3) Preliminary studies of responsive mechanisms for cells. These studies were carried out in 3 steps:

a) Study of folding surfaces. The mobile part of the cell is intended to be a surface that can be retracted or extended. For this purpose, 4 folds were studied for the device. The folds were made on 75gr paper measuring 21cm x 21cm.

After testing the folding surfaces, a single-direction folding was chosen to facilitate the design of the rail-based system.

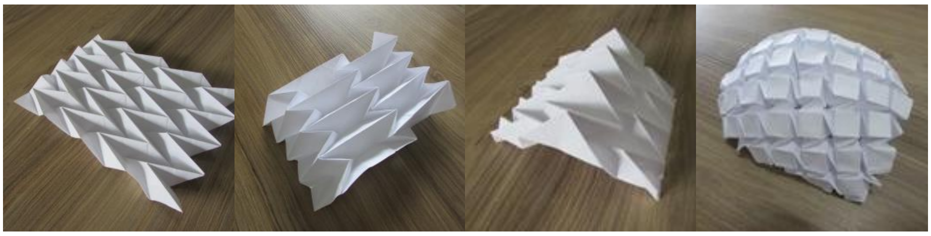

Figure 3. Study of the mobile part of the cell on 75 gr paper. Source: Guillén Salas (2020).

b) Study of unidirectional mechanical drive device. After defining the type of folding of the mobile part of the cell, the drive system was studied. The drive was proposed using guides for the unidirectional sliding of the folding surface when it is retracted or extended.

In the study, it was observed that this type of system demands more space due to the different components necessary for its operation. In view of this observation, the combination of two axes for rotation was chosen, which would occupy less space.

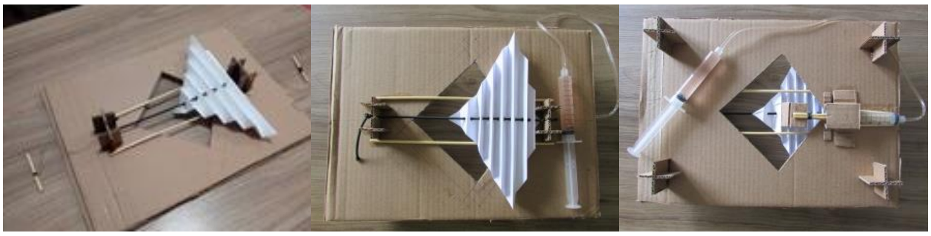

Figure 4. Unidirectional sliding device system of the mobile part of the cell. Source: Guillén Salas (2020).

c) Study of a rotating mechanical drive device. After observing the need that the device should be able to be directed according to a user's requirement. The device was thought to have a horizontal and a vertical axis to allow its direction. The device operation was simulated by manually rotating the axes.

Figure 5. Rotating device of the mobile part of the cell. Source: Guillén Salas (2020).

4) Prototyping of responsive cells. Prototyping was carried out in 4 steps:

a) Prototype driven by potentiometer. The cell was produced with PLA in an Anet A8 3D printer. The fabrication took 28 hours, divided into 24 hours on the fixed part and 4 hours on the mobile part. The dimensions of the fixed part were 12cm x 12cm x 12cm and the mobile part was 11cm x 6cm x 0.5cm.

Figure 6. Cell triggered by potentiometer manually using arduino. Source: Guillén Salas (2020).

b) Prototype driven by ultrasonic sensor. The cell was produced with PLA in an Anet A8 3D printer. The fabrication took 29 hours, divided into 24 hours on the fixed part and 5 hours on the mobile part. The dimensions of the fixed part were 12cm x 12cm x 12cm and the mobile part was 11cm x 6cm x 1cm.

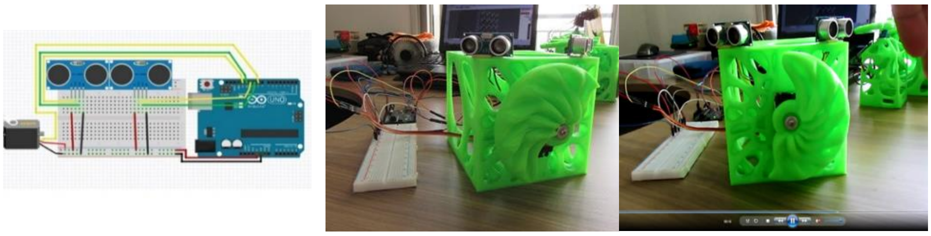

Figure 7. Cell driven by ultrasonic sensors using arduino. Source: Guillén Salas (2020).

c) Prototype driven by temperature sensor. The cell was produced with PLA in an Anet A8 3D printer. The fabrication took 29 hours, divided into 24 hours on the fixed part and 5 hours on the mobile part. The dimensions of the fixed and mobile parts were 12cm x 12cm x 12cm and 11cm x 6cm x 1cm, respectively.

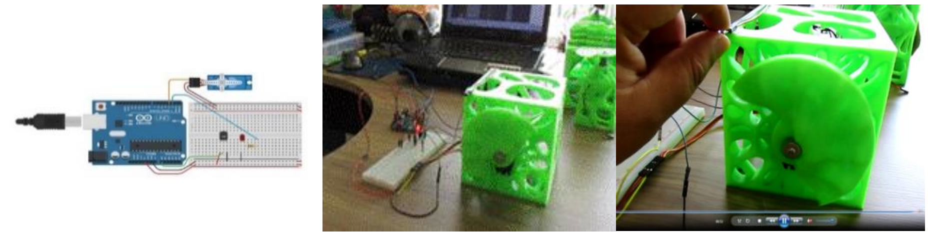

Figure 8. Cell driven by temperature sensor using arduino. Source: Guillén Salas (2020).

d) Prototype activated by light sensor. The cell was produced with PLA in an Anet A8 3D printer. Manufacturing took 36 hours. The cell dimensions were 12cm x 12cm x 12cm.

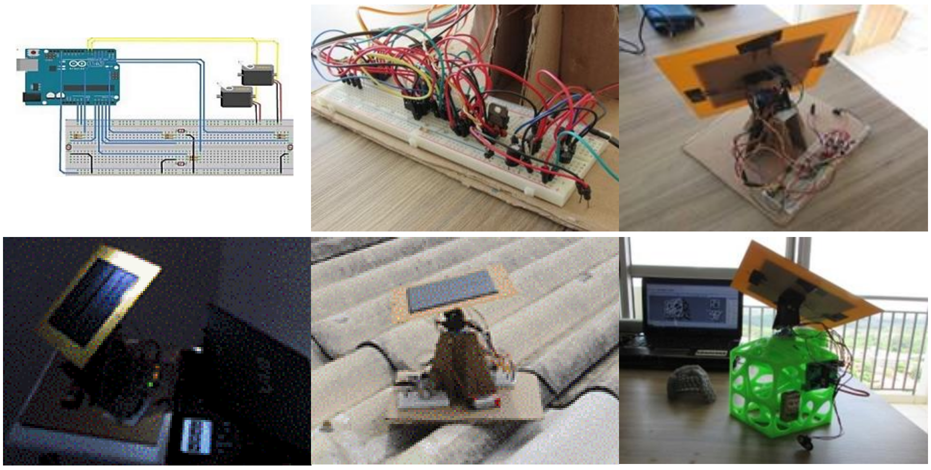

Figure 9. Cell triggered by light sensors using arduino. Source: Guillén Salas (2020).

5) Prototyping panels with responsive cells. Prototyping was performed in 2 steps:

a) Prototype with Type A structural cell driven by an ultrasonic sensor. The panel prototype was produced with 9 cells of different sizes and shapes. The panel was composed of cells organized in 3 rows and 3 columns. Where, in the center, an autonomous responsive cell was implemented. The panel dimensions were 21cm x 21cm x 12cm. And, fabrication by PLA cast filament took 93 hours.

The panel was tested twice with variation in obstacle detection distance and sound wave emission angle. In the first test with a detection distance of 1m and a sound wave emission angle of 120 degrees, interference between the sensors was observed. In the second test with a detection distance of 25 cm and a sound wave emission angle of 80 degrees, better performance was observed.

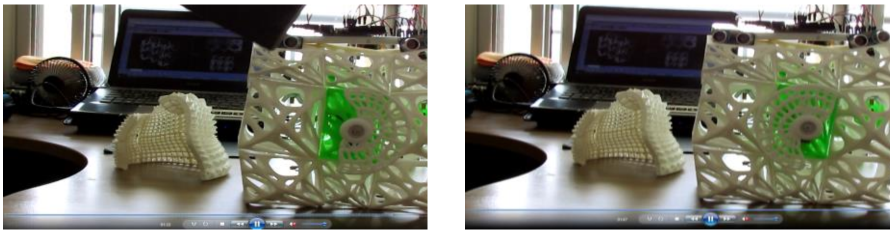

Figure 10. Panel prototype with responsive cell driven with ultrasonic sensors. Source: Guillén Salas (2020).

b) Prototype with Type B structural cell driven by ultrasonic and temperature sensors. The prototype was produced with 32 cells of different sizes and shapes. The panel was composed of cells organized in 4 rows and 8 columns. Where, starting from the left side of the panel, the third cell of column 2 and the second cell of column 7 were implemented with autonomous responsive cells controlled by ultrasonic distance and temperature sensors. The panel dimensions were 60cm x 46cm x 9cm. Manufacturing by cast PLA filament took 384 hours.

Figure 11. Panel prototype with responsive cell driven with ultrasonic sensors (Top row). Panel prototype with responsive cell driven with temperature sensor (Lower row). Source: Guillén Salas (2020).

The panel was tested with the ultrasonic distance and temperature sensors. In the test with the ultrasonic distance sensors, the obstacle detection distance and the sound wave emission angle were set to 1m and 80cm, respectively. In the test the two cells were connected to work with the same sensor. In this way, the cells reacted at the same time when an obstacle approached any of the sensors.

In the test with the temperature sensor, one sensor triggered two cells. In the test, it was observed that the activation of the mobile device took a long time because the ambient temperature was stable. But to check the functioning of the system, the sensor was manually touched for 2 seconds and the mobile device of the two cells rotated 180 degrees.

3 Result

The main result of the research was the confirmation of the guiding hypothesis of the study, that "Prototypes of autonomous responsive bioinspired cell panels can be produced by combining digital manufacturing technology by addition (3D printing) and robotics (electronic prototyping with Arduino).

And, that the autonomous responsive cell triggered by light sensors presents itself as an alternative to automatic guidance.

4 Discussão

Four prototypes of responsive bioinspired cells were developed, from the electronic activation by a potentiometer to the activation by light sensors with a solar cell for self-generation of energy.

In the first prototype, the system was manually activated by a potentiometer. In this prototype, the need for the mobile part of the system to react automatically to an external stimulus was observed.

In the second prototype, the system was automatically activated by ultrasonic sensors when an object or person approached. Although the system reacted to an external stimulus, it was still necessary to react to a stimulus from an environmental factor, such as temperature or luminosity.

In the third prototype, the system was automatically activated by a temperature sensor. But the need for the system to reorient itself to the position of the sun and at the same time to feed itself from the sunlight was pointed out.

In the fourth prototype, the system was automatically activated by light sensors that followed the movement of the artificial light source or natural light. And feed itself from the sunlight.

Thus, the first prototype showed the possibility of being electronically controlled, the second prototype was controlled by ultrasonic sensors, the third prototype was controlled by a temperature sensor, and the fourth prototype was controlled by light sensors and powered by a solar cell; In this work, the possibility of producing autonomous responsive cells was confirmed from the combination of digital fabrication technology by addition and robotics.

Based on this confirmation, the possibility of producing bio-inspired responsive panels controlled by proximity, temperature, luminosity or other sensors was also pointed out. And that these panels can have different applications in external and internal environments. And need further research.

Acknowledgements. Coordination for the Improvement of Higher Education Personnel (CAPES) through the scholarship provided for a period of 18 months. Department of Postgraduate Studies at the University of Brasília (DPG/UnB) for financial assistance for the development of the experiments. Digital Fabrication and Mass Customization Laboratory at the University of Brasília (LFDC/UnB). Microscopy and Microanalysis Laboratory (LMM/IB/UnB). Laboratory of Ideas. Mecajun (ENM/UnB).

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