embryo-project | Architecture

Poster 1/2

Biomodule Bimetal Façade

Adaptive bimetal façade prototype with kinetic modules for self-shading, self-actuated by temperature variation and operates without using an electromechanical device

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Partner Institutions
Universidade Federal de Pernambuco (Biodesign Group)

Expected Future Partner Institutions
BioLab of Lisbon (Rafael Calado)

Penn State University (Benay Gürsoy Toykoç)

OBJECTIVES

The project's primary goal is to deepen recent research by developing a 1:1 prototype of an adaptable façade that responds to environmental temperature variation. The prototype will be composed of seventy-two 'Bimetallic Biomodules', which are kinetic modules for façade self-shading, self-actuated without electrical power or any electromechanical device. To reach our main objective we need to complete a set of complementary objectives, listed below:

OBJ1: Make a technical solution for an adaptive façade with the bimetallic biomodules.

OBJ2: Develop a 1.00x1.00x0.08m adaptive façade physical prototype frame.

OBJ3: Evaluate the kinetic modules' self-shading, considering the influence of the two layers of glass present in the frame.

OBJ4: To disseminate the results in indexed publications and plan a future research proposal to develop a ventilated façade with bimetallic biomodules controlled by smart materials.

ABSTRACT + IMAGES

Coordinating construction with solar exposure and shading systems is fundamental to planning and developing sustainable architectural solutions. The current state of knowledge demonstrates the intensification of proposals for adaptive and kinetic façades that unite bio-inspiration with material research and computational algorithms. The solutions result from abstraction processes on biological systems in association with the inherent responsiveness of the material; it is possible to reduce mechanical system usage and energy consumption and further extend responsiveness to environmental conditions.

The main objective of the 'Biomodule Bimetal Façade' Embryo project is to execute a 1:1 scale prototype of a previous concept resulting from studies where a bio-inspired self-actuating shading device was designed and validate it on real application scenario expecting to obtain an architectural nZEB façade component capable of improving inner building environment without the use of electromechanical devices.

Previous studies resulted in the creation of the 'Bimetal Biomodule', a kinetic module by bio-inspiration on the sophisticated leaf morphology of the *Ammophila arenaria* [1] (Figure 1). Such an organism allows reversible leaf movement through osmotic control when exposed to water and salt stress [3]. At the bottom of the leaf veins are bulliform cells [3] that determine the pattern of leaf opening and closing [1].

To develop the kinetic module for façades, we selected a smart material, the bimetal, because it bends when heated [4,5] and exhibits reversible behaviour in the same way the plant moves [1]. The explanation for the material's behaviour lies in its composition, which consists of at least two metal layers with different thermal expansion coefficients (the active layer and the passive layer) [4]. In the last twenty years, the use of bimetal has gained relevance in architecture [5]. Sung's work [4] is probably the most advanced example [5], carrying out studies that relate shape to performance and present numerous exploratory experiments [4]. We highlight the *InVert Auto-Shading Windows* as it features patents, awards, and commercial products.

At the 'Design Computation Group' [DCG], we conducted promising studies with a bimetallic strip with a width of 10cm and a thickness of 0.06mm. The active layer is composed of $Mn_{75}Ni_{15}Cu_{10}$ and the passive Ni_{36}. Thermal tests showed potential for using creases on the active layer of the bimetal. The arrangement of the creases can invert the bimetal behaviour to open when heated and close when cooling (Figure 2**b**, Figure 2**a**).

Applying the creases on the bimetal corresponds to the bioinspiration in the morphology of *Ammophila arenaria* [1] and improves control over the performance. The creases along the height extension provide resistance to the material's closing when subjected to temperature elevation. We tested prototypes of creased Bimetals Biomodules by stamping the material using a 3D printed matrix. Thermal tests were conducted to evaluate the self-actuation of the modules between 18°C and 32°C (Figure 3). By stamping the creases onto the bimetal's active layer, we could couple characteristics of the plant movement and control the behaviour of the bimetal.

The next experiment, exposed 5 material samples in an open environment, on a day close to the summer solstice, during a heat wave and the autumn equinox (Figure 4). The objective was to identify the equations triggering the behaviour of the biomodules in face of environmental temperature variation. In Figure 4, the two samples on the left were installed outdoors, exposed to the weather, while the other three were in an enclosed environment. The statistical treatment of the collected data resulted in equations explaining at least 73.2% of the biomodules' behaviour. It proved they are adaptable to different climatic conditions and work regardless of electromechanical devices. Then an algorithm was developed to generate parametric variations of the biomodules integrating the equations and simulating the solar protection of the biomodules on façades (Figure 5). The simulations used the climatic context of Lisbon as a reference.

The Embryo project 'Biomodule Bimetal Façade' aims to deepen the previous studies. We propose to validate the implementation of the biomodules through an application specifically for façades. We will develop the technical details of a solution and a 1:1 adaptable façade physical prototype (Figure 6). 72 biomodules will be installed between two translucent glass layers. Next, we intended to evaluate the prototype's performance under the influence of the glass properties in an open environment.

The Embryo Project corresponds to applied research for façade self-shading, in the architecture field, in close correlation with design, and experimentation with materials. The proposal is structured in three stages: a) technical detailing; b) prototype development; c) future developments, and dissemination. The expected results are (1) a working prototype; (2) to disseminate the study in an international indexed publication, (3) develop a research project proposal and (4) the final report. The team members collaborating on this research bring together expertise in biomimetic, design, and architecture in order to bring multiple viewpoints and contributions. Furthermore, we expect to validate a solution for near-zero energy adaptable façade in an innovative and bio-inspired way.

FIGURE 1. Bioinspiration in plant movements and abstraction for the smart material: bimetal.

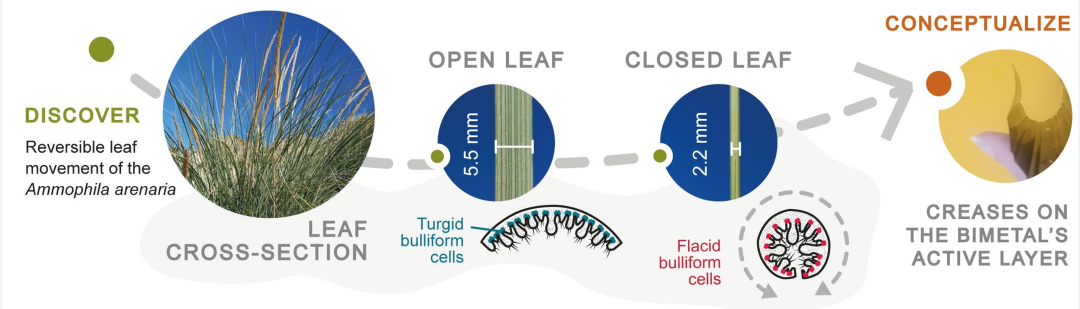

FIGURE 2. Experiment with 10 x 15 cm samples of the bimetal. a) Natural bimetal behavior; b) Creased bimetal. Adapted with permission from [1].

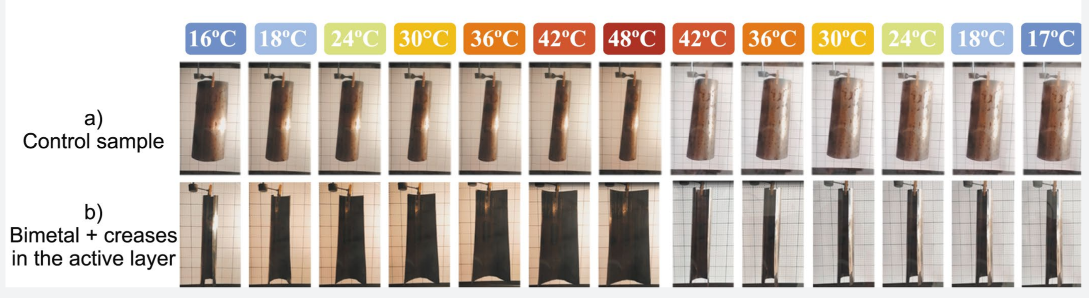

FIGURE 3. Qualitative thermal test synthesis of the samples of the Bimetal Biomodule.

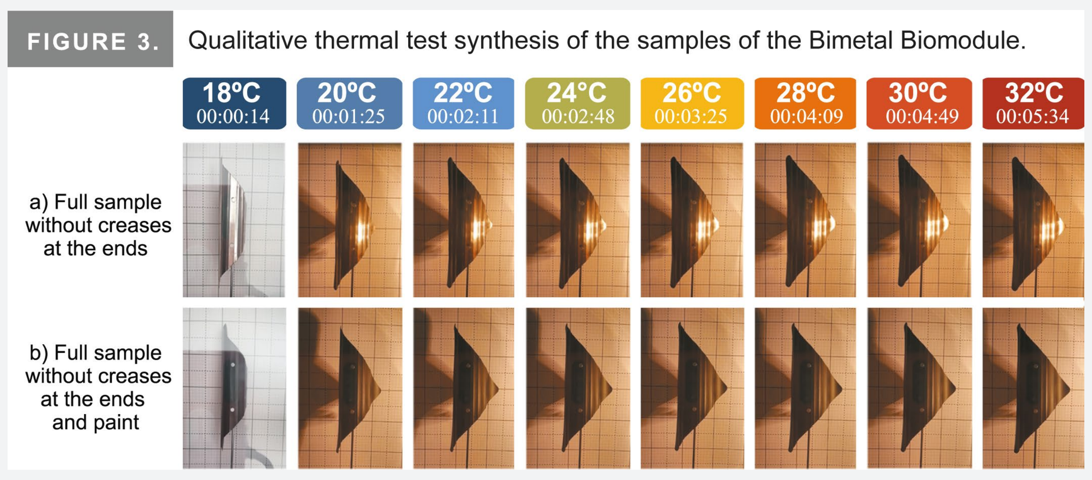

FIGURE 4. Minimum and maximum variation of the biomodules in the three days of the experiment in an open environment.

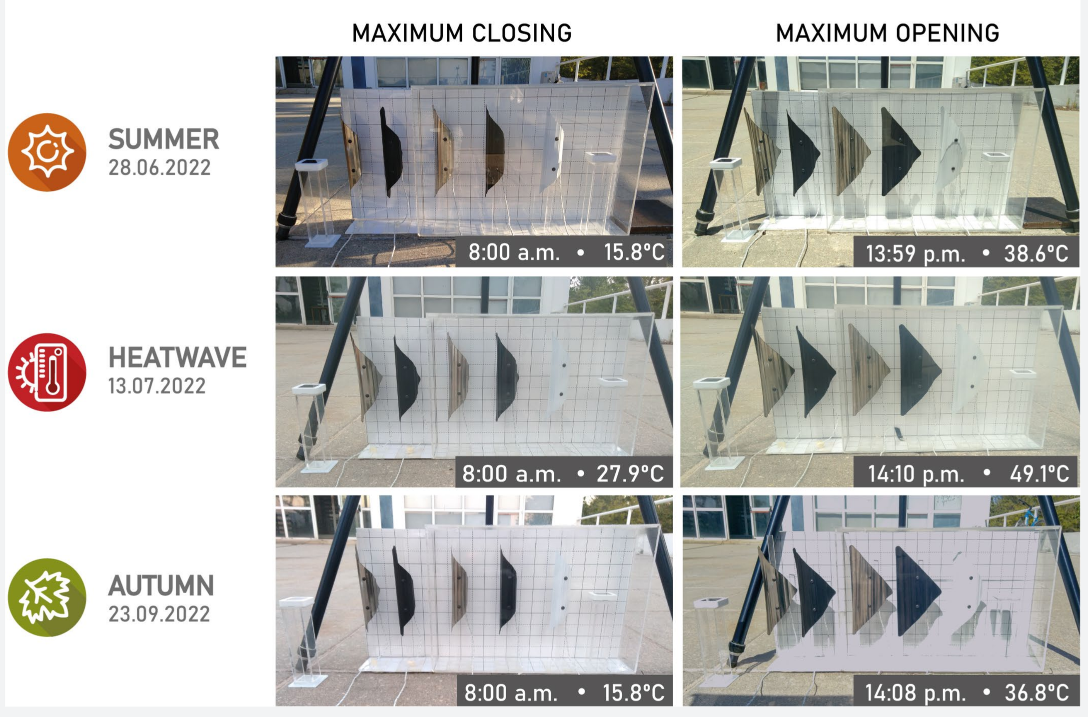

FIGURE 5. Sun protection simulation through computational algorithm.

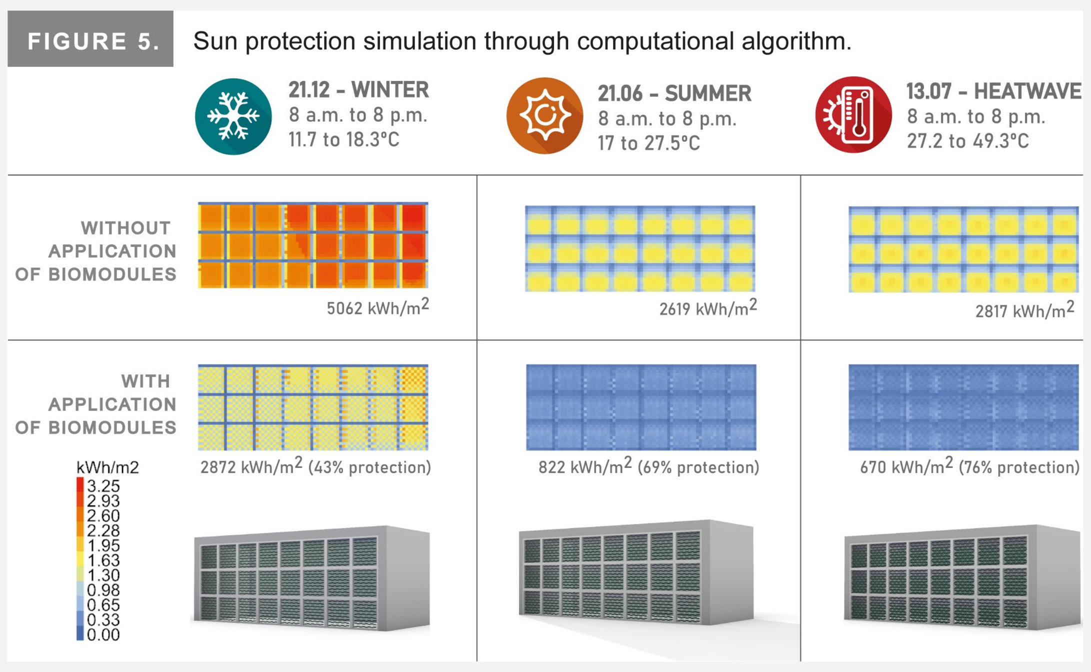

FIGURE 6. Rendering of module for façades (1 x 1 x 0.08 m) with 72 biomodules.

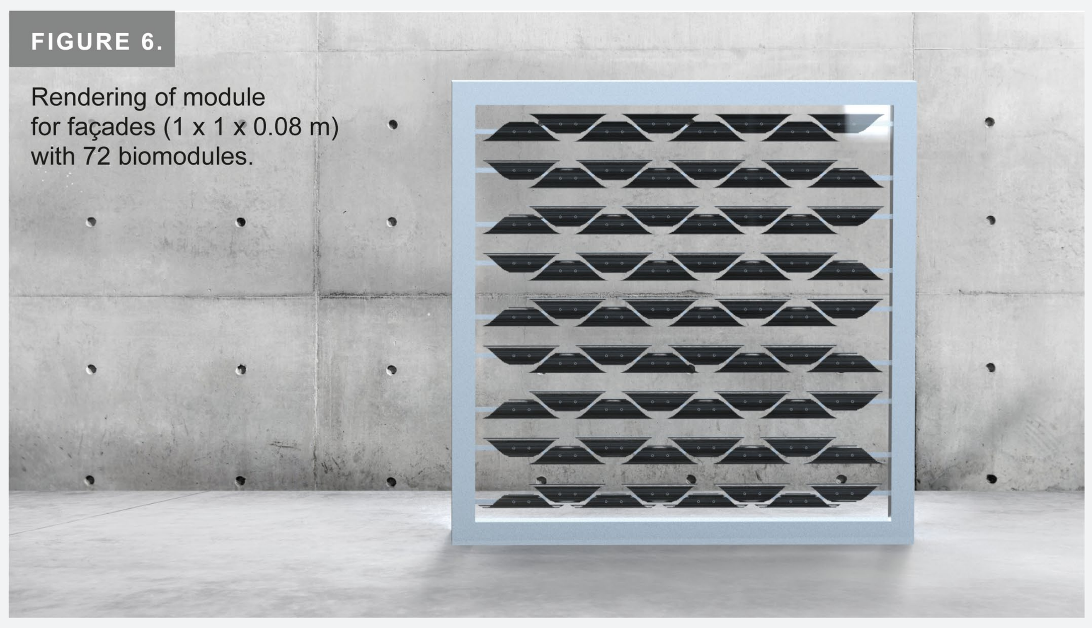

FIGURE 7. Schedule of activities in twelve ten-day cycles.

CODE	TASK	TEAM	1	2	3	4	5	6	7	8	9	10	11	12
1	**Project management**	JB, RM, NM, AA, TA	■	■	■	■	■	■	■	■	■	■	■	■
1.1	Coordinating team members		■	■	■	■	■	■	■	■	■	■	■	■
1.2	Evaluating project progress and risks		■	■	■	■	■	■	■	■	■	■	■	■
1.3	Supervising project dissemination								■	■	■	■	■	■
1.4	Submiting a final report													■
2	**Technical detail**	JB, NM, TA, SF, NV, MC, CP, CE	■	■	■	■	■	■	■	■	■			
2.1	Prospect suppliers		■	■	■									
2.2	Technical details of the solution			■	■	■								
2.3	Acquire material				■	■	■	■	■	■	■			
3	**Prototype development**	JB, RM, TA, NV, MC, SF, CE				■	■	■	■	■	■	■		
3.1	Develop prototype					■	■	■	■	■	■			
3.2	Evaluate prototype									■	■	■		
4	**Future developments and disseminations**	JB, RM, NM, AA, TA									■	■	■	■
4.1	Disseminate in indexed publications										■	■	■	■
4.2	Define future research											■	■	■
4.3	Develop final report											■	■	■

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Biomodule Bimetal Façade

SCIENTIFIC RELEVANCE FOR THE DISCIPLINE

The United Nations report warns that rapid and unprecedented changes are needed to limit global warming to 1.5°C instead of 2°C. Studies on Lisbon claim that there will be sixty days a year of heat waves by the end of the 21st century increasing by 6 weeks the present number. The EU member states must increase the number of zero-energy buildings (nZEB) to improve their energy performance. Adaptive façade solutions have the potential to reduce energy consumption when compared to static systems [2].

The proposal relates to two United Nations goals for Sustainable Development; 'SDG 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation' and 'SDG 13: Take urgent action to combat climate change and its impacts'. By developing a solution for zero-energy self-actuated façades, we seek to contribute to the thermal control of the built environment and the future design of nZEB buildings. The current development is relevant for safeguarding intellectual property by a patent and a future research project about ventilated façades controlled by smart materials.

EXPECTED ECONOMIC AND SOCIAL IMPACT

Recent studies have shown that adaptive façades can reduce a building's energy consumption by up to 29.0% in summer and up to 22.7% in winter, compared to a static façade system [2]. We estimate that the modular solution 'Biomodule Bimetal façade' will contribute to the thermal control of the façade and reduce the building's energy consumption, given the self-management of the biomodules without using an electromechanical device and energy power.

Through the prototyped façade element, we hope to validate the solution and contribute to the field of knowledge that aims to develop non-static façades that respond to environmental constraints as a living organism that constantly exchanges information with its surroundings. We also hope to provide a viable solution to safeguard intellectual property by patent registration and that it can be made commercially available in the future.

The biomodule will be both applicable on newly designed façades as on façade refurbishments. By the end of the project we expect to be at a TRL6, hence in position of starting industrial product development and respective business models.

RESEARCH PLAN AND TASKS

We propose three interrelated stages for the research a) technical detailing, b) physical prototype development, and c) future developments and dissemination. We have structured the four-month work plan into four main tasks, detailed below (Figure 7). The tasks overlap and complement each other during the development of the project.

Task 1: Project management

Objectives: to ensure that we achieve all the goals as planned from a scientific, technical, and financial point of view. It will occur throughout the project by 1.1) Team coordination. To ensure the workflow, we will hold weekly follow-up meetings; 1.2) Project progress evaluation and proposition of a contingency plan to mitigate development risks; 1.3) Supervision of project dissemination activities and expected indicators; 1.4) Final report submission.

Expected results:

a) Managing project performance within predefined deadlines;

b) Good communication between team members;

c) Connecting and relating results between tasks;

d) Dissemination of project results.

Connection with other tasks: Task 1 contemplates all other tasks since it will track and manage the other project activities.

Resources: No costs are associated with this task. We expect all team members to provide information about their activities, share decision-making, and contribute to the project's overall progress.

Members: JB; RM; NM; AA; TA.

Task 2: Technical detailing for the façade solution

Objectives: to develop a 1.00x1.00x0.08m façade solution with seventy-two biomodules fixed on aluminium rods between two layers of translucent glass. The way of fixing the biomodules on the rods can be reevaluated, considering the process of making the rods and using the material.

It is suggested to evaluate a fixing system that does not require rivets and screws, using only cuts and bends in the aluminium rod. To do so, we need to perform the following activities: 2.1) Solve and develop the technical details of the solution; 2.2) Prospect suppliers; 2.3) Acquire inputs.

Expected results:

a) Contact with suppliers;

b) Acquisition of inputs;

c) Solution definition;

d) Technical drawings.

Connection with other tasks: Task 2 provides input for Tasks 3 and 4.

Members: JB; NM; TA; SF; NV; MC; CP; CE

Task 3: Prototype development

Objectives: Development of a 1:1 physical prototype of window frames with materials that match the final specifications for façades through the following activities: 3.1) Development of a physical prototype. 3.2) Evaluation of the prototype in the climatic context of Lisbon. Most instruments required for the evaluation procedures already exist as they were used in the mentioned previous research. The façade solution should face the South façade of building 5 of the Faculty of Architecture of the University of Lisbon. It contemplates the first three objectives.

Expected results:

a) 1:1 prototype;

b) Evaluate prototype's self-shading given the influence of the properties of the two glass layers;

c) Critically evaluate the requirements and constraints of the development.

Connection with other tasks: Task 3 provides data for Task 4.

Members: JB; RM; TA; NV; MC; SF; CE.

Task 4: Future developments and dissemination

Objectives: To define future developments and disseminate what we achieve through the following activities: 4.1) Dissemination of results in an internationally indexed publication; 4.2) Definition of a research project on ventilated and self-actuated by smart material façade; 4.3) Develop a final report to consolidate the scientific contribution. For the future research project, we plan to test ventilation within the cavity between the glass layers to study eventual improvements of the façade module as a self-actuated element capable of both reducing and increasing temperature within the closed space environment. When high temperatures occur, the solar gain can be conducted outside the building by a system with shutters made of an smart material, which will also function regardless of electrical energy. In winter an inverse mechanism may also be studied.

In a nutshell, it will be possible to mitigate thermal gains by irradiation and contribute to the cooling of the space. In turn, at low temperatures, ventilation should occur between the glass cavity and the built environment. The solar gain inside the cavity should be directed towards the interior of the building to contribute to space heating. It should also be investigated the thermal and lighting performance in the tested environment; and the fatigue of the biomodules to assess how many cycles the kinetic elements can withstand environmental temperature changes.

Expected results:

a) an indexed publication;

b) a proposal for research on ventilated façade; c) a final report.

Connection with other tasks: It contemplates all the tasks of the project.

Members: JB; RM; NM; AA; TA.

EXPECTED SCIENTIFIC RESULTS

Expected results in four related domains: a) physical prototype development; b) indexed publication; c) final report, and d) research project to develop a ventilated façade system with airflow control, in the cavity between the two glass layers, by smart materials.

1. Set of approaches to implement 1:1 physical prototype development. Tasks 2 and 3 will define more specifically the research to be developed. The definition of relationships with suppliers and procurement of materials will be inherent to the development process.
2. Production of visual records and the systematized procedures as a result of the research and for indexed publication.
3. Registration of the technical detailing for prototyping and patenting processes. As part of the dissemination activities, we also expect the following results indicators: an article in an international journal; a finished prototype; a final report; and a research project.

BUDGET: € 7.427,400

This project requests funds to develop a 1:1 adaptable façade prototype, support the collaboration of a fellow for four months and help develop the application for (preferably) a European or national research project. The role of the fellow will be to plan research proposals for solid applications, as well as to increase indexed scientific production and to develop the façade prototype by searching for a supplier, acquiring raw materials, and developing the prototype.

To develop the 1.00x1.00x0.08m window frame prototype with aluminium profile frames and two layers of glass. Between the two layers of glass, seventy-two biomodules will be allocated fixed on aluminium rods. We present an estimated value, considering the need for developing the prototype, of 2000€.

The scholarship follows the values attributed by FCT (for a researcher with a master's degree), 1,199.64€, plus insurance, 142.21€ monthly, and accident insurance of 60.00€. The total amount is: (1,199.64+142.21) *4 + 60.00 = 5,427.40€.

Total budget: 5,427.40€ + 2,000.00€ = 7,427.40€.