AlgaeCobogó

Living multicoloured curtain walls towards new materiality in architecture

Professor Natasha Chayaamor-Heil (architect, researcher in biomimetic design)
Sahima Hamlaoui (algologist)
Alice Araujo Marques de Sá (designer, artist)

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Introduction

Designing with living organisms enables investigation and exploration into largely uncharted domains. At the intersection of biology and technology, design allows for bridging and reconnecting human-made objects with living matters. In Bioart, another creative area at this frontier, life processes are employed to represent science and to raise ecological awareness also pushing the barriers between the living realm and the technical context (Adenis, 2021; Giraud, 2012; 2024; Smith, 2024). Biodesign enables the use of living properties of organic matter for creating and improving functionality in objects while equally promoting new user interaction (Dongen, 2014; Klingler, no date).

Art, design, and architecture are interconnected disciplines, each characterized by specific yet overlapping approaches and focuses. While Art focuses on conceptual ideas, self-expression, emotion involving experimentation, abstract and technical skill, Design is a broad field with multiple sub-disciplines (e.g., fashion and industrial design) that encompasses several fundamental principles and resources for improving form, function, and user experience, also involving iterative processes, prototyping, and user-testing, including sustainable and social awareness (Bonsiepe, 2011; Cardoso, 2012; Papanek, 1985). Architecture is a multifaceted area, which includes additional layers of complexity, as it integrates creativity, project planning, construction, and other physical structures addressing the requirements of comfort, accessibility, and utility. Furthermore, it demands a deep understanding of materials, structural integrity, and environmental impact.

The notion of 'sustainability' as an opposite to the realm of 'aesthetics' is a common misconception. Natural matters have the potential to overcome and bridge the gap between these two supposedly opposite perceptions (Lee, 2011). There are several approaches within the nature-based design framework, such as bioinspiration, biomimicry, biophilic design, and living building materials (Chayaamor-Heil, Guéna and Hannachi-Belkadi, 2018; Sá and Viana, 2023). In fact, biodesign and biomimicry have been progressively used in architecture but there are still significant constraints on the transfer of biological knowledge and the integration of living organisms into design practices, which require specific models and methods, especially for creating analogies and adopting adequate abstraction processes, also including social and ethical acceptance (Chayaamor-Heil and Vitalis, 2020; Chayaamor-Heil et al., 2024).

The integration of living organisms in architecture and in construction industry remains largely limited to a biophilic design approach; where plants, green walls, and roofs or even tree structures (Baubotanik[1]) become part of architectural elements (Gong, Zoltán, and János, 2023; Ludwig, no date; Browning and Ryan, 2020). The use of microorganisms in architecture is indeed a relatively novel and emerging field, and has yet to achieve a widespread acceptance, due to multi-requirement and regulatory, safety, hygiene, functionality, and user-related constraints (Chayaamor-Heil et al., 2024). Nevertheless, several innovative concepts and experimental projects demonstrate the potential of integrating such living organisms into building design. Notable examples include self-healing concrete, biocement (using *Sporosarcina pasteurii*), bioluminescent passive lighting, and algae façades (Chayaamor-Heil et al., 2023). Among these, algae façade designs are considered the most advanced applicable

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[1] *Baubotanik* is a building approach in which architectural structures are created by the combination and interaction of technical joints with natural plant growth. The term entails the practice of designing and building structures using living plants (Ludwig, no date).

prototypes, due to the progress of photobioreactor technologies that enable survival and reproduction of microalgae within architectural context (Pruvost, 2014; Pruvost et al., 2016).

Moreover, algae biomass is one of the most efficient energy sources, which can be converted into bioenergy through the absorption of atmospheric CO_2 via photosynthesis. Buildings are significant energy consumers, therefore, there are many explorations and progress on designing building façade systems that aim to utilise the biochemical process of photosynthesis to enhance energy efficiency. But, the integration of algae into architectural materiality presents several challenges. While some proposals for algae façade systems exist, deeper investigation and experimentation of varied geometries and different typologies are essential to better adapt to specific architectural scales, functions, and social and cultural contexts (Kim, 2022; UOOU Studio, 2024; XTU, 2024). It is important to emphasize that algae colonies can limit visibility, due to their lack of full transparency. So, algae façade panel systems prevent natural light from effectively entering the building because of the density of the algae liquid mass. 'Natural light' is indeed an essential element in architectural design, enhancing both aesthetics and functionality while fostering a healthier indoor environment. Thus, including visually permeable elements in the façade, such as the Brazilian *cobogós*, could be a strategy to overcome the lack of transparency in algae panels. *Cobogós* are solar control architectural elements for building openings, that were broadly used in Brazilian modernist architecture. These breeze blocks are one of the passive building façade design strategies in vernacular architecture, allowing the entrance of sunlight into building interiors to enhance visual and thermal comfort (Rodrigues, 2013; Delaqua, 2017). In the contemporary context of climate change and other environmental challenges, the creation of active or hybrid façades co-designed with living organisms is increasingly being proposed to compensate and complement the passive ones. These new biologically-hybrid systems address multi-functional needs, interacting with outdoor environments, while simultaneously providing interior thermal and visual comfort. As Lee (2011) noted, the concept of 'sustainability' is often considered to be contrasting with that of 'aesthetics'. In this context, the present work also explored experimentation with chromatic perception, by utilising different algae species with varying spectra.

Through the interdisciplinary collaboration between an architect, a designer-artist, and an algologist, the authors blended art, design, science, and creativity within this framework to propose a new type of façade – a living multicolored wall *AlgaeCobogó*. This façade proposal was co-created with five different species of microalgae, each having distinct spectra, ranging from *chlorophylls* (green) to *carotenoids* (red, orange, yellow), to *phycobiliproteins* (blue, red). These species were combined with Brazilian traditional *cobogós*, which have aesthetically various geometrical patterns. The authors analysed microalgae strains, their descriptions, and specific growth conditions to better understand the required parameters, establishing and refining the selection of algae species for façade design. The microalgae strains and culture methods studied were sourced from the culture collection of the French National Museum of Natural History of Paris[2] (Hamlaoui et al., 2022). Finally, by mixing microalgae pigments with the traditional latticework of *cobogós* it is possible to achieve both aesthetic and functional excellence, advancing living-architecture materiality that promotes a unique colour perception and sensory experiences of 'vitalism'.

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[2] The National Museum of Natural History of Paris (MNHN), © Publications scientifiques du Muséum National d'Histoire Naturelle de Paris, Cryptogamie, Algologie, 2022

Cobogós: history and applications

Optimising sun protection and environmental comfort are essential aspects of architectural design that have developed over time. Reinterpreting and adapting elements of traditional and vernacular architecture can lead to the development of solutions that reduce and mitigate ecological impacts. From this perspective, it is worth highlighting an architectural element characteristic of Brazilian architecture, the *Cobogó* (Figure 1). The name of such an architectural element is an acronym composed of the first syllable of the last names of its three creators: Antônio de Góes, Amadeu Oliveira Coimbra, and Ernest August Boeckmann. *Cobogós* are a typical expression of Brazilian modernist architecture, commonly employed as a passive bioclimatic solution. They function as permeable walls that allow natural light and wind to pass through, acting as an element of thermal control, attenuating the incidence of direct solar radiation. Additionally, *cobogós* offer privacy to the inhabitants of a given space (Camacho et al., 2020; Santana et al., 2023).

Brazilian architecture exhibits a notable diversity, reflecting the country's varied climatic typologies and the countless influences of local and international cultures. However, one common denominator is the abundance of sunlight and high temperatures, thus requiring the appropriate design of windows and openings to provide thermal comfort, given the constant need for cooling and ventilation (Associação Brasileira de Normas Técnicas, 2005). These considerations were particularly embraced by architects of the modernist movement during a period characterised by the pursuit of national identity. This led to a high-quality architectural expression that was well adapted to the country's climatic conditions, often featuring *cobogós* as a façade element (Camacho et al., 2020; Silva and Góes, 2022). The historical origins of the *cobogó* are rooted in the influences of Arab architectural heritage, more specifically, in the *mashrabiyas* — wooden lattices that form complex geometric patterns used for solar control and that provide privacy to indoor spaces. Over time, Portuguese culture incorporated these elements and reinterpreted them in the form of *gelosias* and *rotulas*. Other references that possibly inspired *cobogós* include *claustras* of European churches. This set of elements and characteristics influenced the development of traditional Brazilian architecture. Later on, the modernists revived and redesigned this historical ensemble of elements, leading to the creation of the prefabricated hollow bricks now known as *cobogós*. They were patented prior to the widespread use of brise-soleils by Le Corbusier in 1933. Indeed, *cobogós* differ from brise-soleils as they are fixed modular features that not only provide thermal comfort and protection against rain and strong winds but also constitute the skin of the building (Andrade et al., 2021; Silva and Góes, 2022; Vettorazzi et al., 2024).

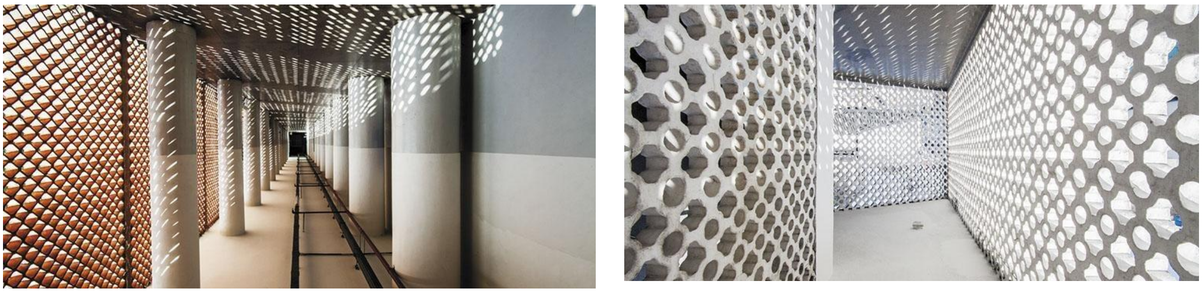

Fig 1. Rodrigues (2013) Interiors of buildings with cobogós. Natural light effects and shadow patterns create a visually engaging environment as sunlight passes through the breeze blocks during the day.

The diversified nature of projects with *cobogós* stems from its versatility, as it can be used both for façades and as partitions for internal environments, replacing conventional walls. Additional features include the low cost of *cobogós* (as they are prefabricated), their ease of application, and the environmental comfort they provide through thermal regulation, natural lighting, and ventilation, thereby reducing the need for costly artificial climate control systems. *Cobogós* are manufactured using many materials, including concrete, ceramic, glass, brick, natural fibres, plaster, and wood (A Bioclimática, 2024). A wide array of designs has emerged, providing aesthetically pleasing patterns that range from simple geometric shapes to complex, organic, and sculptural forms, often featuring variations in the openings. Thus, these distinctive characteristics make *cobogós* appealing to both specialists and the general public (Andrade et al., 2021; Piesco, 2020). Considering the aforementioned, *cobogós* can be classified based on the size of their openings (e.g., small, medium, large) and their geometry (e.g., simple extrusions with geometric motifs, simple extrusions with organic motifs, three-dimensional with simple projections, and three-dimensional with salient projections). The *cobogó* has a considerable aesthetic and ludic appeal since its intricate openings produce poetic shadow and light effects that create graphic compositions and patterns that are projected across indoor spaces over the day, changing according to the position of the incoming sun rays. As c*obogós* are objects closely associated with Brazilian cultural expressions, they have gone beyond architectural boundaries, giving rise to a variety of applications inspired by these elements in the design of furniture, decorative objects, and even a typographic dingbat-based style (Camacho, Sacht and Vettorazzi, 2017; Santana et al., 2023).

In summary, the *cobogó* is significant not only for its functionality, which is especially relevant in areas that require permanent ventilation, but also for its historical, cultural, and artistic relevance, as it is a symbol of Brazilian design and an interesting reference in contemporary architecture. However, this component has its limitations, since it is a fixed piece with a passive function in the building. Thus, rethinking this architectural component from the perspective of multifunctionality, increasing its responsiveness, and making it dynamic and or active are perspectives to be further investigated allowing for innovative uses of this traditional Brazilian element to be explored in new materiality contexts (Andrade; Beirão; Arruda and Cruz, 2021; Vettorazzi et al., 2024; Abdel, 2024).

Microalgae: properties and pigments

Microalgae are predominantly photosynthetic organisms that live in marine and freshwater environments, where they are the primary producers of oxygen and of valuable organic compounds (Franceschini et al., 2009, 2022). These microorganisms contain diverse pigments that play a crucial role in photosynthesis. Their coloration results from combinations pigments, which range from green to red, depending on the concentration of the dominant pigment of microalgae cells. Such pigments are classified according to their chemical composition and structure along with their spectral characteristics. Furthermore, microalgae produce a wide variety of natural pigments with diverse biological, chemical, and physical properties. Beyond their essential role in the life cycle and survival of these microorganisms, the pigments also represent significant potential for applications in biotechnology, medicine, cosmetics, food production, and the development of sustainable materials.

The main microalgae pigments and their properties are summarized below:

1. *Chlorophylls*: three types exist (Chlorophyll-a, Chlorophyll-b, and Chlorophyll-c). Presenting

the colour green, chlorophylls are the primary pigments in photosynthesis.

2. *Carotenoids*: there are five types (β-Carotene, Lutein, Astaxanthin, Fucoxanthin, and Zeaxanthin). Ranging from yellow to orange and red, they are strong antioxidants and UV-protective agents.

3. *Phycobiliproteins*: three types exist (Phycoerythrin, Phycocyanin, and Allophycocyanin). Are found in two opposite tones, red and blue. *Phycobiliproteins* are water-soluble and fluorescent and can be used as markers in scientific imaging.

4. *Xanthophylls*: there are three types (Zeaxanthin, Violaxanthin, and Canthaxanthin). All in different tonalities of yellow, they are antioxidants and UV-protective agents.

The coloration of microalgae is determined by environmental conditions and their adaptive abilities. Depending on the amount of light received and the conditions of its surroundings, microalgae develop pigments that are most appropriate to their situation. Under intense luminosity, chlorophyll production increases, resulting in a striking green colour. In other scenarios, where light is moderate, a combination of pigments produces a brown colour, while when there is low lighting, carotene pigments predominate causing microalgae to exhibit orange or red hues. The photosynthetic process in microalgae begins with the absorption of light energy by the chlorophyll pigments within the light-harvesting complexes (LHCs), which consist of proteins, chlorophyll, and carotenoid pigments.

The National Museum of Natural History of Paris (MNHN) is renowned for its extensive algae collection, which comprises about 80% of different freshwater species and 20% of marine species.[3] For the present study, the authors selected five different microalgae species from the MNHN collection displaying a diverse range of tones from green, brown, yellow, purple to red. This selection allowed for the study of microalgae pigments including their life conditions, functions, and properties and, also, their responses to external environmental stimuli. This context contributed to the development of conceptual propositions for a multicoloured algae façade, including the following species: 1) *Porphyridium purpureum*, 2) *Spirogyra varians*, 3) *Trentepohlia abietina*, 4) *Haematococcus pluvialis*, 5) *Centronella reicheltii* (Figure 2).

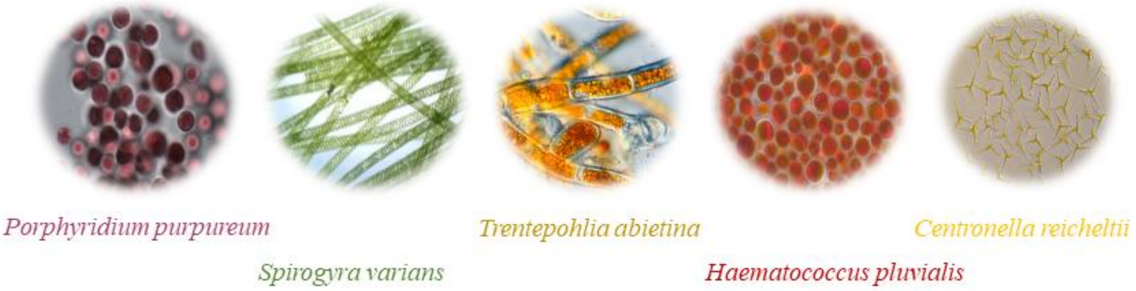

Fig 2. National Museum of Natural History of Paris (MNHN) (no date) The five species of microalgae were selected for their varied pigmentations.

Below, each species will be further detailed (Figure 2.1-2.5);

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[3] The biggest marine algae collection in France is the Roscoff Culture Collection in Bretagne (Roscoff Culture Collection, 2024).

Fig 2.1(a). Natasha Heil (2024) *Porphyridium* cells actively growing on a new culture medium.

Fig 2.1 (b). Sahima Hamlaoui (2024) *Porphyridium purpureum* is currently commercially cultivated on a larger scale and is known for its production of sulphated exopolysaccharides and the accumulation of the valuable red *phycobiliprotein* complex and *phycoerythrin*.

Fig 2.1. Old cultures of Porphyridium purpureum, a red marine microalga, from the MNHN collection maintained in a controlled culture.

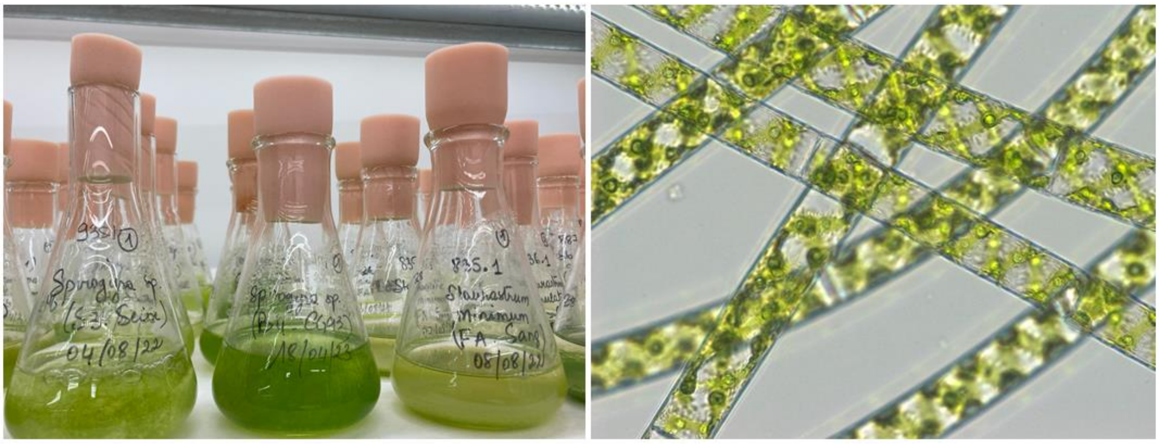

Fig. 2.2 (a). Natasha Heil (2024) Cultures of *Spirogyra varians* known as 'water-silk' and 'mermaid's tresses'. The pale green colour corresponds to old algal culture, the bright green was cultured in a recent and new medium, allowing for the algae cells to actively grow and thrive, resulting in a difference of coloration

Fig. 2.2 (b). Sahima Hamlaoui (2024) Cultures of *Spirogyra varians* known as 'water-silk' and 'mermaid's tresses' . A filamentous green alga, from the MNHN collection kept in a culture room under controlled light and temperature.

Fig 2.2. The pale green colour corresponds to old algal culture, the bright green was cultured in a recent and new medium, allowing for the algae cells to actively grow and thrive, resulting in a difference of coloration.

Fig 2.3 (a). Natasha Heil (2024) *Trentepohlia abietina*

Fig 2.3 (b). Sahima Hamlaoui (no date) *Trentepohlia abietina*

Fig 2.3 (c). Fraxinus excelsior - English Wood (no date) *Trentepohlia abietina* on Ash tree

Fig. 2.3. Cultures of *Trentepohlia abietina*, a filamentous green terrestrial alga whose yellow-orange colour is due to carotenoid pigments that mask the green chlorophyll colour (a, b). Although algae are usually mainly known in marine and freshwater habitats, they also occur in a wide variety of terrestrial environment, as *Trentepohlia abietina* on Ash tree (c).

Note that *Trentepohlia* species are more adapted to non-shaded habitats. Recent studies on *Trentepohlia* have demonstrated its potential as a natural source of antioxidants (Kharkongor and Ramanujam, 2017). These species are found on many different substrates (rocks, tree bark, leaves, twigs, fruit, soil, woodwork, carved stone, concrete walls and pillars, metals, and plastics), where they can form large orange, red or yellow patches in sites with high humidity. *Trentepohlia* is often lichenized.

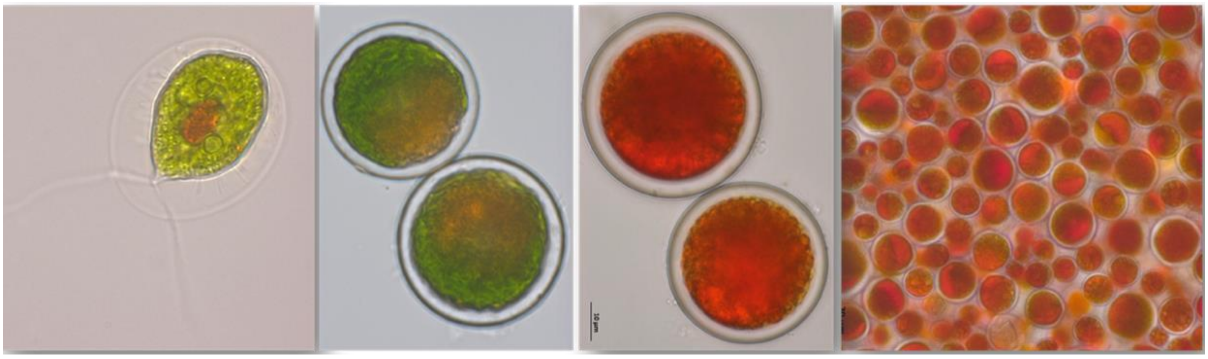

Fig. 2.4 (a). Sahima Hamlaoui (2024)

Fig. 2.4 (b). Sahima Hamlaoui (2024)

Fig. 2.4 (c). Sahima Hamlaoui (2024)

Fig. 2.4 (d). Sahima Hamlaoui (2024)

Fig. 2.4. The green freshwater alga *Haematococcus pluvialis* can exhibit different colorations. In favourable conditions, the cells are green and mobile with two flagella (a) during periods of stress (e.g., strong sunlight, drought, nitrogen or phosphorus deficiency); the cells start by losing their flagella and group together (b); then, the cell wall thickens and begins to accumulate a red pigment called *astaxanthin* around the nucleus (c, d); finally, encystment enables the microalgae to resist and survive until favourable conditions return. Algae Collections at The National Museum of Natural History of Paris (MNHN).

Haematococcus pluvialis is already commercially used for the production of *astaxanthin* as a source of antioxidants, for use as additives in human food and animal feed applications, in cosmetics, and as dietary supplements (Marino et al., 2020).

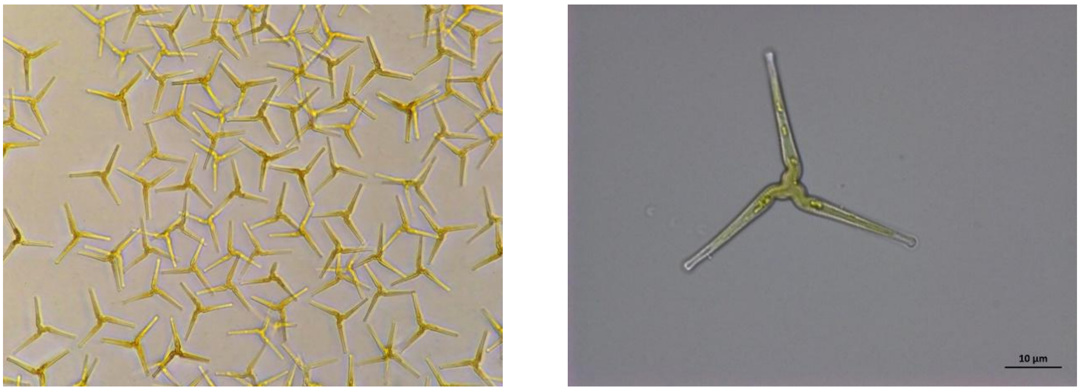

Fig 2.5. Sahima Hamlaoui (2024) The yellow, golden-brown freshwater algae Centronella reicheltii produces fucoxanthin and carotenoids that serve photoprotective and antioxidant functions. Algae Collections at The National Museum of Natural History of Paris (MNHN).

The role of colour perception, sensory experience, and psychology in architecture—particularly in façades, interiors, and exteriors—is profound. Colour influences human emotions, behaviour, and spatial perception, shaping how individuals experience built environments. It can create different moods and enhance architectural functionality, while also reflecting cultural associations and contextual sensitivity. Applying 'living colour' through the use of microalgae represents an innovative approach to developing natural, sustainable, and dynamic coloration in design and architecture. It is relevant to highlight that microalgae, as microscopic, photosynthetic organisms, are capable of producing vivid pigments. Thus, their integration into living systems offers a unique connection between science, art, and sustainability.

Methodology

Within the interdisciplinary art-design-science context, the authors developed a hybrid research framework bridging the disciplines of microbiology, art, design and architecture. This approach sought to generate new knowledge through scientific research, focusing on the possibilities to evoke emotion while mixing the domains of art and sciences, and using design and architecture techniques and processes as the main means for implementation. The adopted hybrid methodology incorporated microalgae as living elements within architectural façade systems, combining creative, functional, and scientific perspectives. The initial exploration was centred on the aesthetic potential of microalgae as a dynamic, living medium, focusing on its colour variations and the responsive designs that would interact with light, temperature, and other environmental aspects.

The authors used the Curiosity Microscope kit to observe and capture microscopic images of selected microalgae. The microscope is a tool developed by the Tara Ocean Foundation[4] (2024) in collaboration with the Plankton Planet[5] (2024) consortium. The strengths of the

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[4] The foundation is dedicated to scientific expeditions to study marine biodiversity and to anticipate and monitor the effects of climate change and pollution (Tara Ocean Foundation, 2024) For more information access: https://fondationtaraocean.org/

[5] The initiative aims to expand the horizons of researchers' curiosity and creativity co-developing new universal scientific instrumentation for monitoring marine microbiome diversity (Plankton Planet, 2024). For more information access: https://planktonplanet.org/

Curiosity microscope lie in its high definition, its capability to capture both photos and videos with a simple connection, and its user-friendly design (Figure 3a). The authors took sampling microalgae from *Lac de Créteil* as a site selection to observe their living conditions, functions, properties in relation to their different stages of vital pigments (Figure 3b).

Fig 3 (a). Sahima Hamlaoui (2024) Curiosity microscopic kit provided by Plankton Planet

Fig 3 (b). Natasha Heil (2024) Sampling different species of microalgae from *Lac de Créteil* for microscopic analysis

After observing and analysing the five selected microalgae, the authors gathered comprehensive data on the life conditions of each species, in relation to their environmental requirements. It is pertinent to remember that microalgae pigments are specialized molecules that absorb light for photosynthesis and provide coloration. The pigments present in microalgae influence their appearance, determining the wavelengths of light they can efficiently use. Different tones of such pigments are influenced by both biological and environmental aspects. In the design exploration phase, all factors related to the selected microalgae were considered, combining them with the modularity and the scalability of a *cobogó* functional system, to integrate microalgae into façades. During the transfer phase, biomimetics was adopted as a scientific approach to understand the biological and ecological properties of microalgae focusing on their potential for energy generation, air purification, and thermal regulation, with a particular focus on optimizing algae growth and advancing photobioreactor technologies. The authors used techniques of algae cultivation in laboratory experiments at the MNHN, also conducting an environmental performance analysis.

Photobioreactor systems were used for the digital prototype. Indeed, existing algae-based façades are only available through photobioreactors, mostly, in flat panel configurations (XTU, 2024). However, recent designs illustrate more advanced algae façades that can be configured in interlocking arrangements allowing natural light into spaces, but such examples remain at the initial prototyping and testing stages (Kim, 2022).

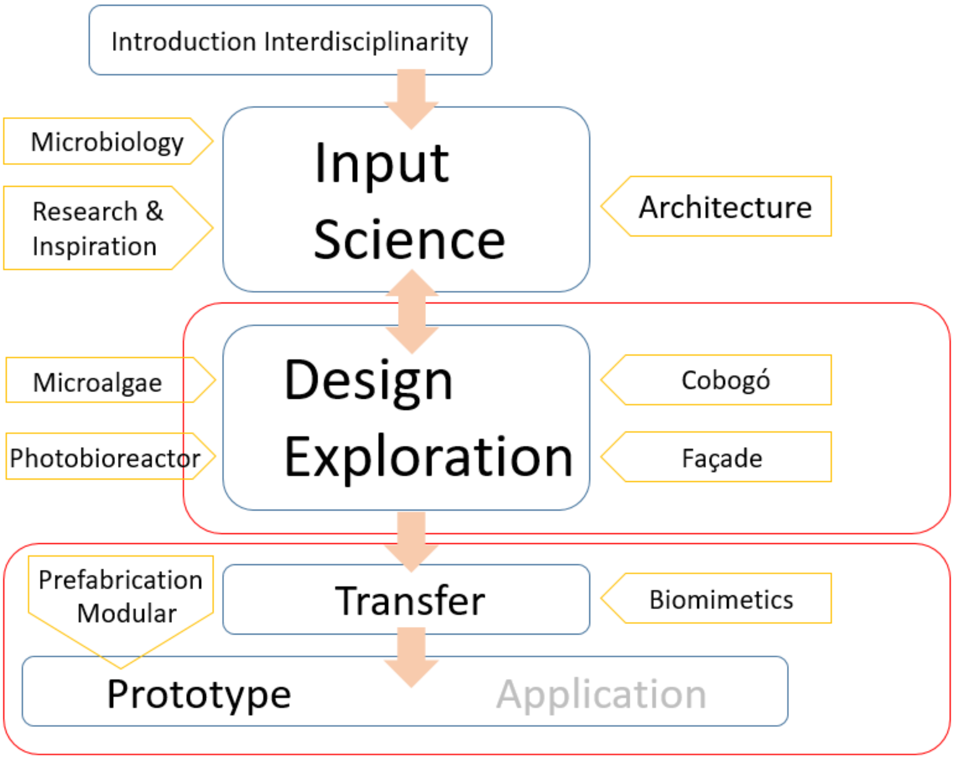

Fig 4. Natasha Heil (2024) Interdisciplinary design methodology implemented for creating the *AlgaeCobogó*.

Results

Upon completing the observation and analysis, design specifications were identified and summarized, integrating scientific, artistic, and design approaches for the development of a new concept of façade, the *AlgaeCobogó* (Figure 5).

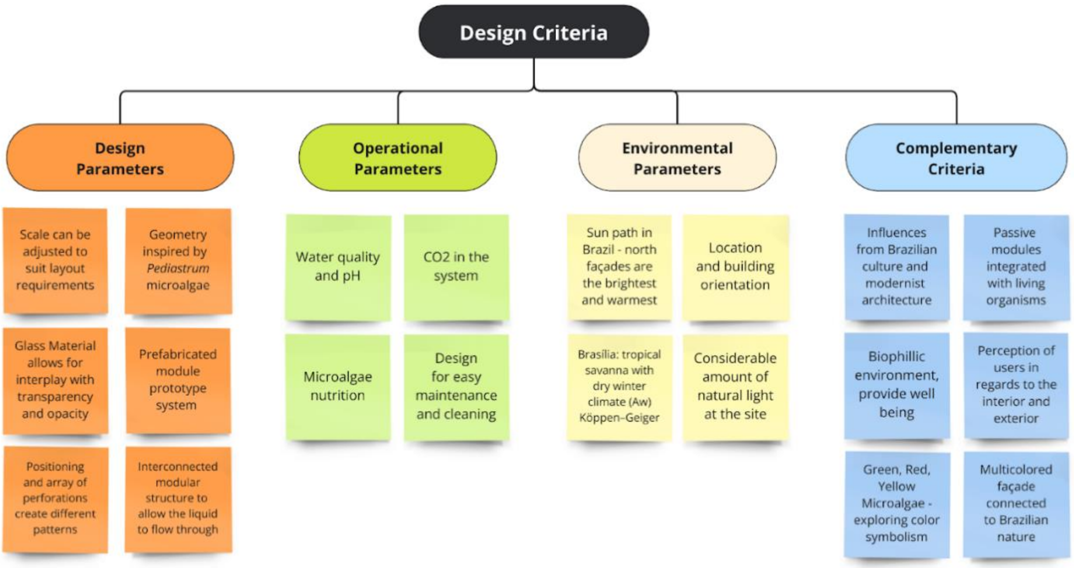

Fig 5. Alice Araujo Marques de Sá (2024) The adopted criteria included specifications of design, operational, environmental, and complementary parameters for the design and implementation of the *AlgaeCobogó*.

An example is provided in Figure 6, below, of a module composed of transparent or translucent materials (that are to be further specified) that would be used to culture microalgae inside. Different species with varied pigments and properties were chosen for each design, assessing which would be better suited to the application according to their functions, the sunlight exposure, and their required specific environmental conditions. This selection was also oriented by the indented architectural usage, and specific contexts and implementation sites (e.g., antioxidant, UV-protective, green energy).

The module features areas of varying opacity for containing and cultivating microalgae that would allow for collecting sunlight for photosynthesis and, also, for energy generation within the building. The perforated areas of the *cobogó* would promote natural light and ventilation. Each module was designed to be interconnected and disassembled, containing in its core the algae culture liquid. Thus, a system of connected modules with internal pipelines was created, allowing the microalgae liquid to circulate through the structure.

Fig 6 (a). Alice Araujo Marques de Sá (2024) Digital prototype of the *AlgaeCobogó*. Modules with different microalgae pigments

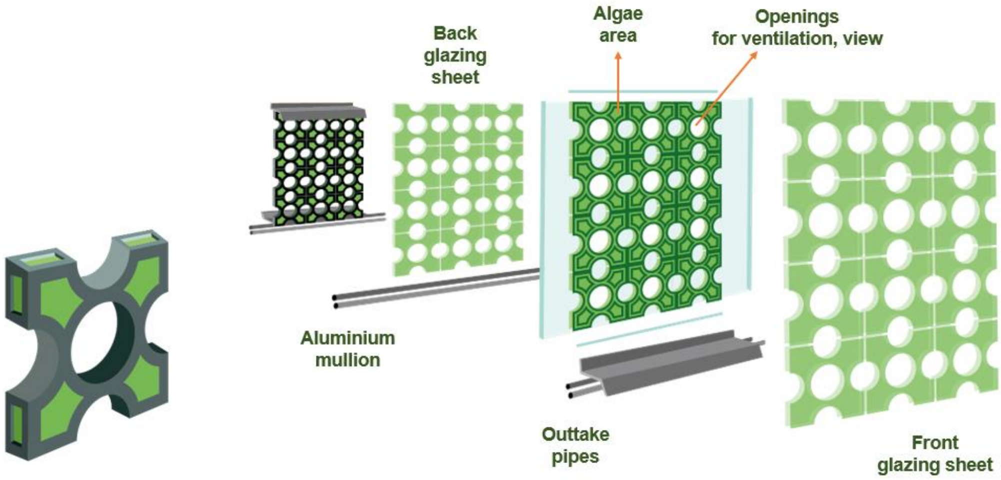

Fig 6 (b). Alice Araujo Marques de Sá (2024) Digital prototype of the *AlgaeCobogó*. A prototype at the façade scale for prefabrication that would be installed in a building located in Brasília, Brazil

The combination of an algae façade with a *cobogó* pattern demonstrates an original aesthetic composition, where new geometry and functionality meet, promoting performance excellence. The algae component of the façade absorbs natural light, converting it into energy used within the building. Some algae species can also effectively absorb CO_2 and other pollutants, while the opacity of the algae density protects from direct sunlight, mitigating extreme heat conditions. The small perforations with different geometrical patterns allow natural light to penetrate the building, also improving natural ventilation. The geometrical patterns further contribute to a new façade aesthetic, creating an original light-shadow pattern effects inside the space, that varies along the day, according to the sun's position.

Nevertheless, several challenges and paths for innovation require further investigation to implement a physical prototype of the present project:

1. Maintenance: microalgae systems require specific conditions such as adequate light, nutrients, and temperature control to thrive. Regular upkeep is essential to ensure consistent colour and performance for the system and the façade as a whole.

2. Durability: while living systems are visually striking, their longevity in architectural applications depends on robust containment and environmental compatibility.

3. Scaling Up: Transitioning from experimental to large-scale applications requires investment in technology and collaboration between scientists, designers, and architects.

Discussion

Although algae façade propositions exist, most are still at a speculative conceptual level (Hanafi, 2021). However, such concepts can expand the horizon of envisioned possibilities in the near future. The design concepts presented in this paper constitute significant contributions by demonstrating how to combine sustainability with aesthetics and how new forms and shapes can improve functionality and overall architectural considerations. The varied geometries and pigments available from different microalgae species provide opportunities to better integrate living matter into various architectural typologies and contexts. In the case of the present work, these biological elements were combined with the traditional *cobogó* pattern, reflecting the cultural context of Brasília, where the algae façade would be situated.

Designing with living organisms requires multiple paths of iterative experimentation and testing. Living organisms are inherently unpredictable and dynamic, thus, maintaining their viability demands specific and optimal conditions, much like the human necessity for comfort and for fulfilling basic needs. The integration of living elements in art and design has progressed further in the last few years comparatively to the architecture and construction fields. Indeed, to appropriately co-design with organisms within the architectural realm, it is important to fully embrace the vision of the "new ecological paradigm", and to address several crucial elements. These include developing advanced technologies, establishing innovative design processes, adopting digital and biofabrication techniques, creating new building and design standards specific to living matter, and working towards a shift in societal acceptance of such materials. Another key area for improvement is the development of a solid 'business model' to suit non-standard microalgae façades in the architecture and building industries. A supply chain must be established for the production and commercialisation of algae-based products. While cultivating algae is feasible, the business model success depends on the recovery and sale of microalgae. If more seaweed products are created, they can be more widely accepted in society, thus being less anecdotal or only 'novelty products'. Furthermore, educating the general public on the importance of co-living with other organisms, understanding their life conditions and ecosystems, and embracing the concept of buildings as vital components of the environment is essential.

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