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# PROCEEDINGS BOOK

DESIGNING NATURE AND
HUMANITY-CENTERED FUTURES

## what's round the corner for design?

…is a pivotal gathering
of minds in the Algarve …
… dedicated to exploring
design's profound impact
and potential in addressing
today's multifaceted challenges.

DESIGNING NATURE A

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**Technical Sheet**


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|---|---|
| Title: | What's Around Design? - Designing Nature and Humanity-Centered Futures |
| Editors: | Américo Mateus, Gabriel Patrocínio, Susana Leonor |
| Edition: | ISMAT<br>Instituto Superior Manuel Teixeira Gomes<br>Rua Dr. Estêvão de Vasconcelos, 33 A<br>8500-656 Portimão<br>PORTUGAL |
| Online Edition: | https://recil.ulusofona.pt/ |
| Correspondence: | info@ismat.pt |
| Editorial Design: | David Palma, Carlotta Carvalho |
| Date: | 2025 |
| ISBN: | 978-989-36430-7-5 |

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CHAPTER

01

# BIO DESIGN

# (31) DIVERSIFYING BIODESIGN: EVOLVING ROLES AND MATERIAL RESEARCH.

**Raquel Noronha (Universidade Federal do Maranhão).**

KEYWORDS | BIODESIGN, MULTISITEDNESS, BIODIVERSITY, SCOBY, PLANT FERMENTATION.

## Introduction

Within Biodesign there are transdisciplinary practices entangling biology, crafts, and design by working with living organisms to develop novel material approaches (Camere and Karana, 2018). Through the intersection of regenerative ecology discourses and more-than-human ontologies, it promotes new design sensibilities that advocate for biodiversity (Karana, et al., 2023). Biodesign projects are tendentially positioned closer to bio-technological realms and biodesigners are increasingly gaining access to scientific laboratories (Ihls and Pollini, 2024). However, on its path to possible greater inclusion in the field, design anthropology provides holistic approaches emphasizing ethnographic research to inform design processes (Gunn, et al. 2013) by centering on human users and design's impact on communities. The influence of Social Sciences and Multispecies Studies together with the abundant situated knowledge are encouraging designers to 'get to know' different organisms and related cultural practices 'in the field'. Indeed, design exploration of ecologies and biology can shape more integrated and holistic proposals when meeting contextually informed perspectives. Pioneering projects are investigating how to entangle Biodesign and contemporary technologies with traditional and Indigenous knowledge (Bandoni, et al., 2023; Bellamy, 2024; Author, 2024; Weber, 2024). These explorations suggest innovative approaches to regeneration that include scientific and technological aspects and emphasize relational, cultural, and socio-material dimensions.

A foundational observation of the presented doctoral research is that microbial species included in Biodesign projects tend to consist of a relatively small range of either isolated single strains (for instance Komagataeibacter Hansenii) or pre formed cultures (like Kombucha SCOBY), in contrast to the high microbial biodiversity that exists 'out there'. Therefore, various questions arise: where do microorganisms come from? How can we grow more biodiverse materials? Through which (non)disciplinary and (non)academic lenses can we learn about them? In which contexts and crafts are microbial materials and agencies present besides bio-technological realms?

## Methodology

This PhD in Design Studies is positioned as research for (Bio)design (Frankel and Racine, 2010). It explores how to grow more biodiverse materialities by studying different combinations of organisms, techniques, and realms of knowledge across diverse sites.

SCOBY (Symbiotic Culture Of Bacteria and Yeasts) a source of bacterial cellulose, is addressed as a case of human-curated plant-microbe interaction (Hengge, 2023). The investigation suggests that the organisms constituting this formula can vary, promoting diversity and adaptive applicability to process and outcome. The study employs mixed methods, including systematic scientific experiments in a microbiology laboratory in Berlin; focused ethnographies on plants, their properties, and acetic fermentation crafts in Crete, Thailand, and Berlin. By integrating knowledge from multiple sites, SCOBY pellicles are grown 'with' and 'from' plants showing the outcomes of different multispecies interactions and fermentation techniques.

**Intermediate results**

A multi-sited transdisciplinary approach promotes the acquisition and translation (Latour, 1983) of epistemological, ontological, and praxiological knowledge. In the lab, protocols were developed or adjusted to research underexplored aspects such as the preservation of SCOBY cultures, and the transformation of plants into different ingredients to explore and interpret their effects in the growing of SCOBYs. Through an exploratory effort, the study engaged in in-the-field activities such as observation, hands-on participation, semi-structured interviews, sensorial exercises, and audio-visual documentation to document situated fermentative techniques in multiple sites. This research demonstrates the potential for growing SCOBY using techniques that are highly relational, culturally informed, and entirely new to the field of Biodesign.

**Discussion**

Through multi-sited research, designers can move beyond the 'drop-in' replacement of existing materials and technologies (Camere and Karana, 2018), create opportunities for new multispecies relationalities, and expand diversity in growing materials. From the inclusion of under-considered 'wild' microorganisms to situated cultural techniques, and (non)disciplinary cross-fertilization.

This research framework poses critical questions about the role and agency not only of microbial materials but of Biodesigners too as their engagement becomes more relational and experiential. Moreover, this phenomenon raises questions about their degree of involvement with other realms of knowledge, the quality and validity of insights, and the outcomes they generate. The presentation will raise the hypothesis of 'tinkering with disciplines' as a method and elaborate on the implications.

## Images



FIGURE 1 – PLANT MATERIALS TRANSFORMED INTO INGREDIENTS AND COMPARATIVE SCOBY TESTS SHOWING THEIR EFFECTS ON PELLICLE GROWTH (HENGGE LAB,DEOARTMENT OF BIOLOGY, HU BERLIN) @RICHARDLEY 2024



FIGURE 2 – BACTERIAL CELLULOSE PELLICLE GROWN BY KOMAGATAEIBACTER HANSENII

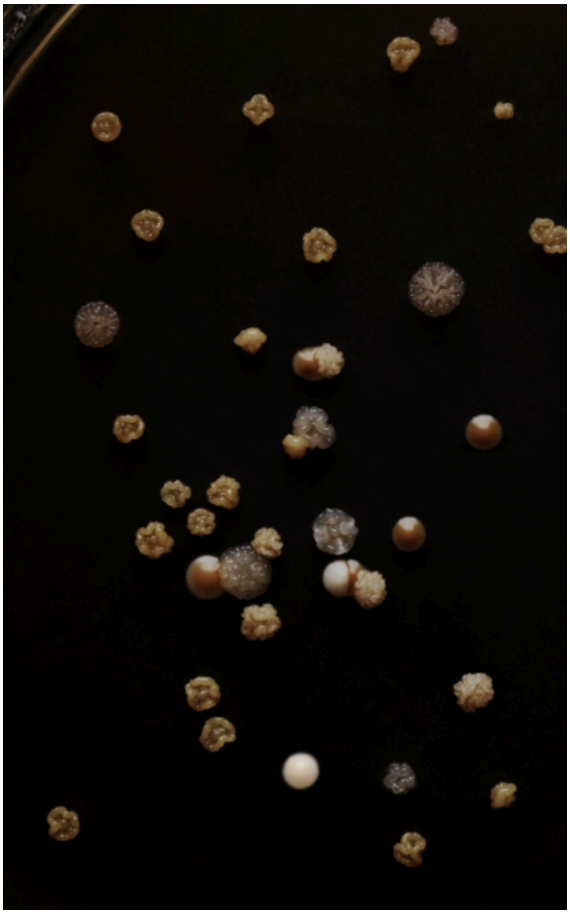

FIGURE 3 – MICROBIAL MORPHOLOGIES OF SINGLE COLONIES OF BACTERIA AND YEASTS EXTRACTED FROM A TEA SCOBY AND GROWN IN A PETRI DISH

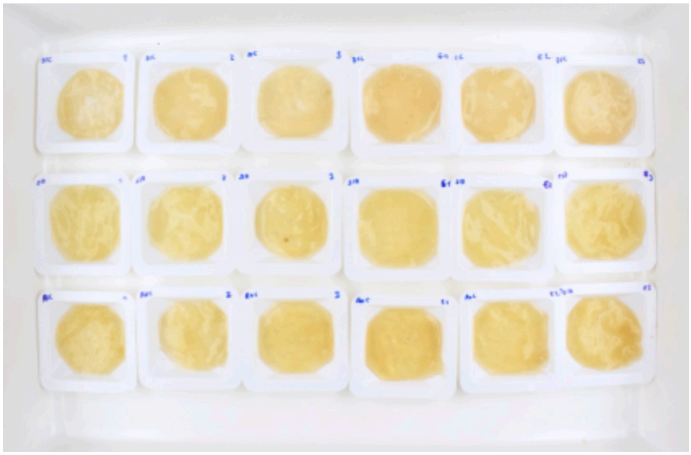

FIGURE 4 –COMPARATIVE EXPERIMENT OF SCOBYS GROWN WITH DIFFERENT PLANT INGREDIENTS

FIGURE 5 – FIELD VISIT TO ALTHAEA'S ROCKGARDEN WITH ENDEMIC MEDICINAL PLANTS IN ANATOLI,CRETE



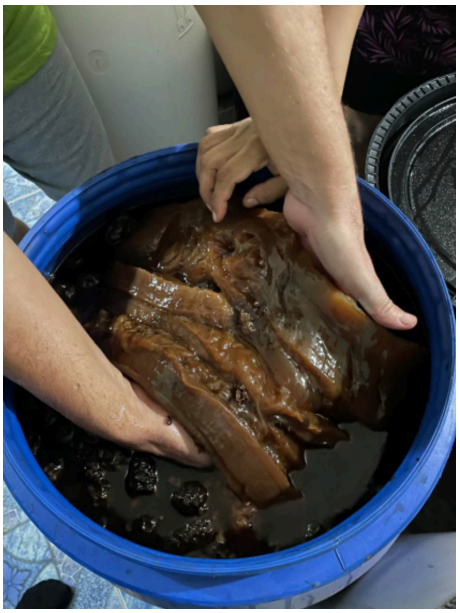

FIGURE 6 – WILD SCOBY ORIGINATED DURING ACETIC FERMENTATION BY STEFANO AND SOMPORN ABBRUZZESE, BAN ORAPHIM, THAILAND

FIGURE 7 –COLLECTING PLANT MATERIALS FOR CONDUCTING FERMENTATIVE TECHNIQUE WITH STEFANO ABBRUZZESE, BAN ORAPHIM, THAILAND





FIGURE 8 – PRODUCTION OF APPLE CIDER VINEGAR BY TANYAPORN TANTASATHIEN (MICRO FRIENDS), KHLONG LUANG, THAILAND



FIGURE 9 – PREPARATION OF APPLE CIDER VINEGAR WITH TANYAPORN TANTASATHIEN (MICRO FRIENDS), KHLONG LUANG, THAILAND



FIGURE 10 – FORAGING COURSE IN TREPTOWER PARC WITH ALEXIS GÖRTZ (EDIBLE ALCHEMY), BERLIN, GERMANY



FIGURE 11 –COLLECTING LOCAL PLANT MATERIAL FOR EXPERIMENTS, BERLIN, GERMANY

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## (54) Bio-tile: 3D Printed Porous Structure Integrating Moss for Microclimates. Ran Che (Southern University of Science and Technology) and Enza Migliore (Southern University of Science and Technology).

**ABSTRACT |** Mosses possess buffering effects on moisture and heat, enabling passive regulation of the built environment with the aid of geometric structures. This paper explores the development and implementation of 3D-printed bio-tiles integrated with moss to enhance microclimate. These bio-tiles utilize mathematical patterning techniques and clay coating to tune surface conditions at the micro- and macroscale, which can support moss growth and enhance the microclimate within buildings. Thus, they meet the requirements for sustainable building materials that contribute to environmental health and human well-being.

By computational design and 3D printing technology, bio-tiles were designed and fabricated to incorporate living moss, promoting passive humidity regulation, air quality improvement, and thermal insulation. The methodology involved selecting materials and moss species, 3D printing techniques, and clay coating to create structurally sound and aesthetically desirable surfaces. The fabrication process included experimenting with structural complexity using digital manufacturing during the printing process to increase the surface area and surface enhancement of the geometry using traditional clay coating and manually assisting the moss to migrate into the porous structures.

This study implementation provided real-world insights, validating the practical applications and benefits of these innovative tiles. The findings underscore the potential of 3D-printed bio-tiles with moss as a responsive, sustainable, and alternative to traditional building materials. The outcome will contribute to sustainable design and offer a foundation for future advancements in sustainable construction practices.

**KEYWORDS |** BIO-TILE, MOSS, 3D PRINTING, CLAY, SUSTAINABLE ENVIRONMENT

### Introduction

Increasing building envelopes and concrete volumes lead to significant solar heat gain and energy consumption, thus triggering the urban heat island effect. Nature-based solutions can help improve the living environment and mitigate the heat island effect. Integrating natural elements in buildings is a vital aspect of sustainable building, contributing to environmental health, human well-being, and the overall performance of buildings. Regarding the living environment, walls can provide multiple benefits for indoor comfort by using plants with specific properties and behaviors as building materials. Specifically, a living wall system incorporating plants requires a complex system to force plants to survive in artificial vertical layers

(Marsaglia et al., 2023). Therefore, a comprehensive design is required for all support structures, plants, and irrigation.

Designing with living materials represents a frontier in both design and manufacturing, merging the principles of biology with advanced engineering techniques. This approach involves creating structures that support living organisms and interact dynamically with their environment. This project developed an innovative bio-tile for hot and humid regions as part of the living walls research. The primary objective is to enhance the living environment by reducing carbon dioxide emissions and regulating indoor humidity through moss's moisture buffering and thermal insulation properties. Bio-tile integrates the benefits of moss with 3D-printed porous structures, translating these findings into textured architectural tiles that regulate microclimates. This innovative design aims to envision future applications at the whole-building scale.

The field of Biodesign offers a sustainable approach that draws inspiration from natural systems and integrates scientific insights into the design process (Chayaamor-Heil & Vitalis, 2021). Biodesign embeds living organisms into the design process, creating bio-generated materials that provide sustainable, renewable, nature-based building solutions (Pollini et al., 2023). As the demand for sustainability increases, integrating mosses into living wall systems presents a promising solution for enhancing environments. Mosses offer a sustainable and efficient supply system for living wall systems, providing numerous environmental, structural, and aesthetic benefits. Their ability to improve air quality, regulate humidity, and provide thermal insulation makes them ideal for sustainable designs. In the structural design of living wall systems, triply periodic minimal surfaces (TPMS) are utilized as innovative supports. They are characterized by non-self-intersecting properties and a high surface area-to-volume ratio, which provide significant advantages in structural support, plant growth facilitation, and sustainable design (Cai et al., 2019).

Fabricating living wall systems utilizing TPMS structures and moss integration is achieved through advanced 3D printing techniques. Specifically, polylactic acid (PLA) material is used for printing complex structures, while clay is chosen as a coating material to facilitate moss colonization. The porosity of clay allows it to retain moisture, creating a conducive environment for moss growth.

These living and intelligent Bio-tile offers a sustainable approach to building design in extremely hot and humid climates. By harnessing the natural properties of moss and the precision of 3D printing, Bio-tile presents a bio-digital-manufacturing framework to integrate living materials and their metabolic functions to replace energy-intensive activities and potentially fulfill sustainability goals in one system.

**System for Bio-tile**

According to previous empirical studies, the growth of moss substrates is positively correlated with the roughness of the dependent epidermis and

the humidity. Therefore, to generate the Bio-tile, we first focused on the geometrical aspects of the wall surface, mainly to ensure the structure's performance.

## 2.1 Geometric Design

Living materials can sense and respond to changes in their surroundings. This necessitates supporting structures that can accommodate these dynamic interactions, facilitating growth, movement, and other biological functions. Technically, open porosity refers to interconnected voids within a material that permit the unrestricted passage of gases and liquids. This characteristic holds substantial implications for construction, as open porous materials can hold and absorb diverse substances (Harnack, 2018)(Pugliese & Graziosi, 2023). TPMS are characterized by their non-self-intersecting properties, which means they form continuous, smooth surfaces. This unique geometric integrity is essential for creating stable and robust support structures.

The TPMS structure has excellent mechanical properties to support the entire system vertically, directing plant growth in the vertical plane. At the same time, the porosity is designed to hold moss and planting medium vertically. Climbing plants and cascading groundcovers can grow upwards on a specially designed support structure. As water flows through the structure, it travels down the wavy surface, providing ample moisture and nutrients to the attached mosses. As air passes through the structure, the water evaporates, effectively cooling and humidifying the surroundings.

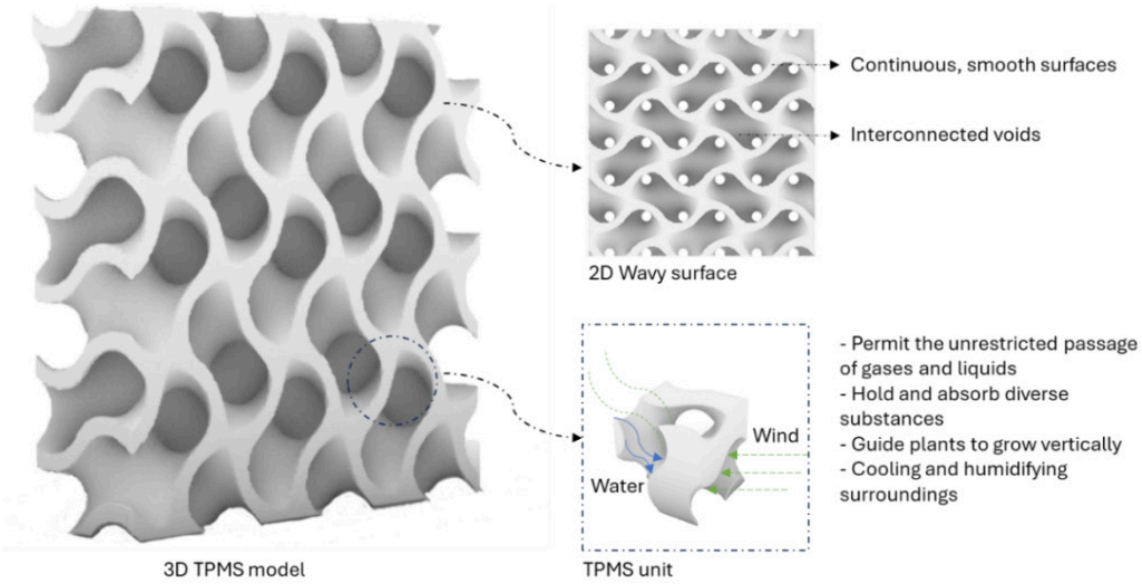


Figure 1 A 3D numerical model of the Bio-tile

## 2.2 Moss Selection

By comparing bare stones and stones covered with moss, it was found that moss provides protection to the substrate from rain and humidity. Moss acts as a buffer, absorbing moisture and releasing it as needed (Cozzolino et al., 2022). Since mosses lack a root system, they absorb water and nutrients

from the air through vascular bundles instead of from the ground (Mustafa et al., 2021). Moss releases moisture when the room's humidity falls below approximately 12 g/m³ and absorbs moisture when the humidity exceeds 17 g/m³ (Wang et al., 2019). Moreover, the micro-ecosystems supported by moss offer numerous environmental benefits, including reducing the spread of influenza (Wang et al., 2019). Mosses also serve as natural air purifiers, trapping atmospheric pollutants, filtering dust particles, and sequestering carbon. Their evaporative processes can insulate building envelopes, reducing heat flux into the building. Peat moss (genus Sphagnum), which we use in this project, stores vast amounts of carbon and water. Peat moss is a large sponge with unparalleled water absorption and retention capabilities (Marsaglia et al., 2023). It can withstand the local climate and humidity levels.

**Design and fabrication**

To realize the advantages of TPMS and moss, as described above, we propose that a living wall system can be considered biohybrid (Figure 2), which integrates living organisms with computational geometric forms and digital tools (sensors). According to previous empirical studies, the growth of moss substrates is positively correlated with the porosity and roughness of the dependent epidermis and the humidity. Therefore, to generate the bio-tile, we focused on the geometrical aspects of the surface to create a suitable space for moss to anchor and increase progressively in biodiversity.

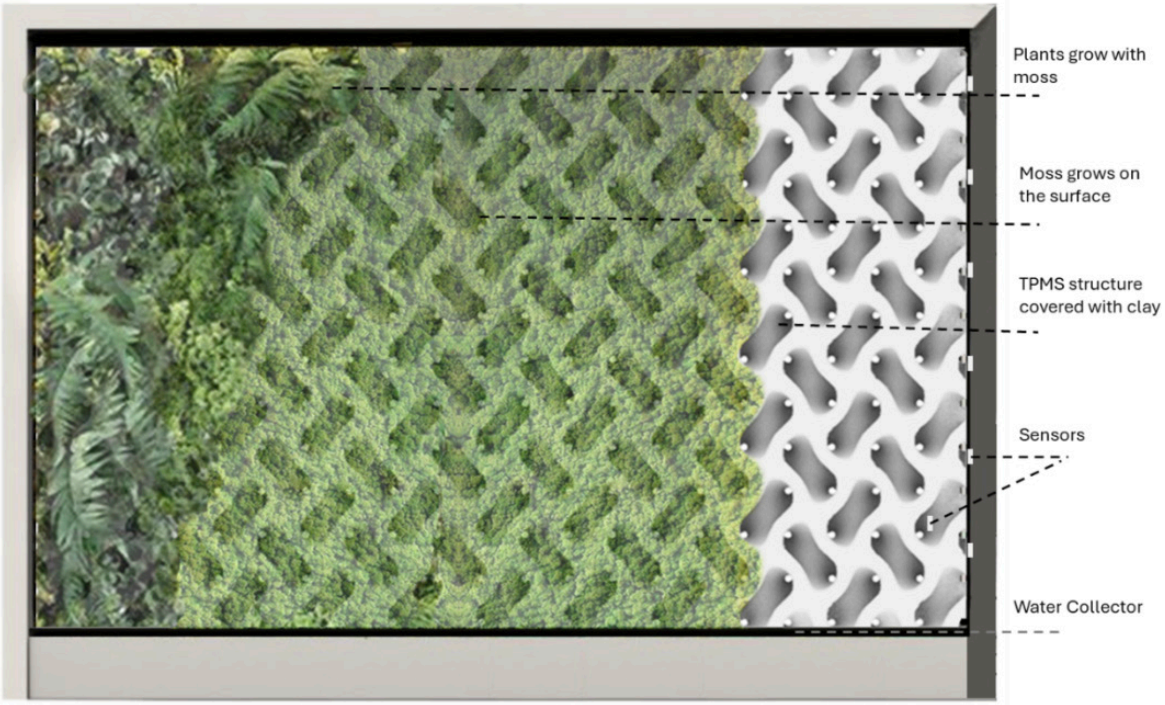


Figure 2 Section showing the living wall system of Bio-tiles

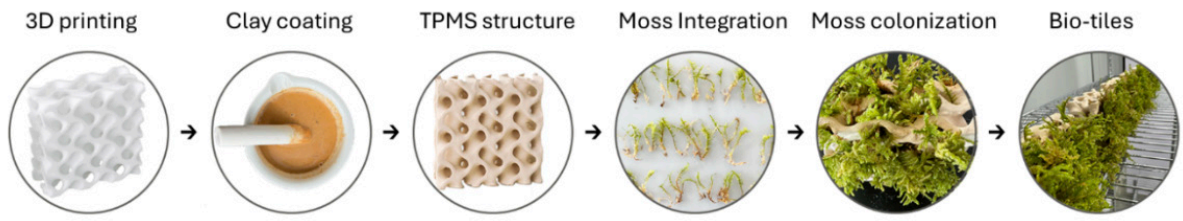


Figure 3 Workflow

The whole process of the Bio-tile prototyping consists of three main steps: 3D printing, clay coating, moss integration and colonization.

Step 1 3D printing: The TPMS prototype is created in PLA using FDM (Fused Deposition Modeling). The efficiency and realizability of the printing process are achieved by setting the relevant parameters before printing (Figure 4). This method ensures that the structures are strong enough to provide necessary support while being smooth enough to sustain living organisms.

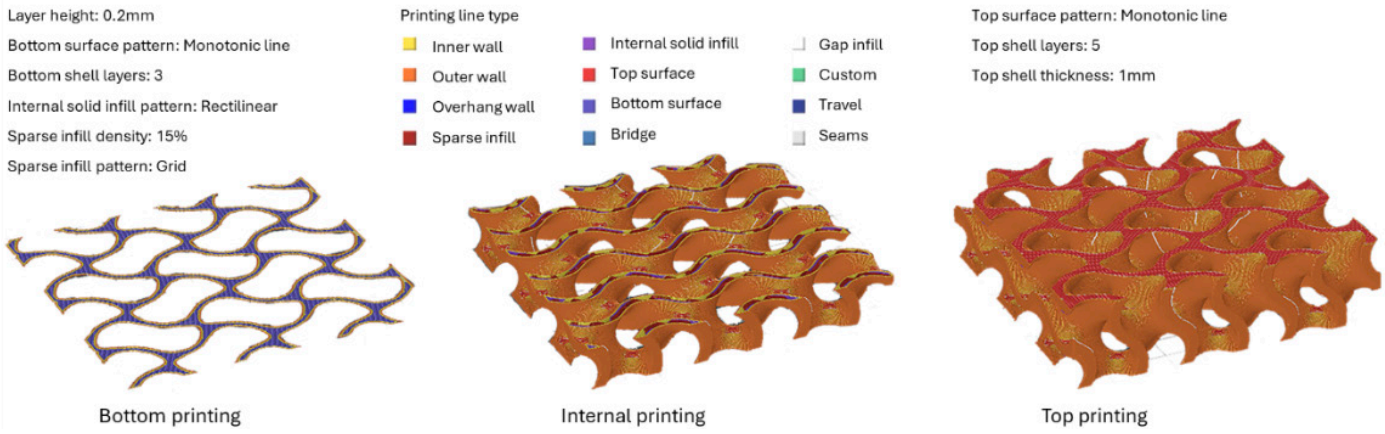


Figure 4 Parameter settings for TPMS prototype printing

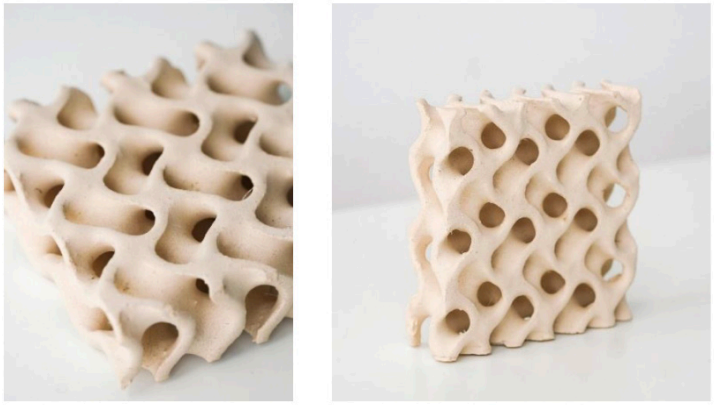

Figure 5 Coating the 3D-printed tile with clay

Step 2 Clay coating: The coating process involves obtaining clay material (particle size ≤2um) and performing grinding preparation and proportioning experiments in the laboratory. The PLA-printed prototype is then impregnated with the clay and dried continuously for 24 hours after the clay has uniformly covered the surface of the model. We chose clay as a coating material because of its natural origin, porosity, and moisture retention capabilities. The clay coating is uniformly applied to the 3D-printed TPMS structures, ensuring strong adhesion and an ideal substrate. This process creates a textured surface conducive to moss colonization.



Figure 6 Bio-tile prototype

Step 3 Moss Integration: Given that mosses take a long time to grow from spores, this project employed passive grafting to incorporate living moss into the clay-coated bio-tile. This process involved gently placing the moss into the cavities of the TPMS structures using tweezers. Grafting established moss increases the chances of successful growth, as the moss is already adapted to its environment and can quickly begin spreading and anchoring itself.

**Conclusion**

This research is an empirical experiment of the proposed bio-digital manufacturing scheme using mosses and preliminary studies of porous structures. By leveraging the structural efficiency of TPMS geometries and the environmental benefits of moss, bio-tile offers a viable alternative to traditional building materials. Using PLA for 3D printing ensures that the fabrication process is sustainable and efficient. At the same time, the clay coating provides an optimal environment for moss colonization. However, further development is required for an engineered solution since it is too fragile and can be dismantled with water over time. Additionally, limitations such as the dependency of moss growth on specific environmental conditions, the scalability challenges of large-scale installations, and the material constraints related to PLA and clay durability must be addressed. The initial cost of production may also pose a barrier to widespread adoption.

Bio-tile's development highlights the importance of interdisciplinary approaches in design, combining insights from biodesign, materials science, and

computational design. The project also underscores the role of 3D printing in pushing the boundaries of sustainable construction. The project will expand on the involvement of living materials in manufacturing and how the boundaries between nature and architecture can be narrowed. In the next stage, we will report further on the sensor data and environmentally relevant experimental results, which will reveal the benefits and limitations of bio-tile by introducing geometric variations to the microclimate and living environment.

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# (29) THE POTENTIAL OF BIO-BASED MATERIALS FOR PRODUCT DESIGNERS IN EGYPT. Daniela Amandolese (GUC - German University in Cairo).

**ABSTRACT |** This article explores the efforts of product design students at GUC (German University in Cairo) who have been tasked with creating solutions that enable a successful transition towards more sustainable, circular and bio-based design. They have done this through creating bio-based materials and finding useful applications. The contest is the unsustainable global trajectory marked by excessive resource use and population growth, necessitating a shift towards a circular economy. The paper highlights the students' journey, their design process and methodology, beginning with the mapping of bio-based waste in Cairo - such as orange peels, mango peels, rice straw, sugarcane, and seeds - and culminating in the development of new materials and their application in product design. After mapping Cairo's pre-post-consumer waste, the students, using tools designed for them, created various samples of materials. Using the Materials Driven Design method, they then analyzed and explored the physical, mechanical and sensorial characteristics of the materials they made.

The final process involved designing, prototyping and displaying products, showcasing the potential of these materials. Noteworthy projects include a biodegradable shopping bag made from orange peels, a durable stool crafted from sugarcane waste, and a lighting unit designed from discarded nutshells.

**KEYWORDS |** BIO-BASED MATERIALS, LOCAL WASTE, CIRCULAR DESIGN

## INTRODUCTION

It is now universally recognized that the frenetic and compulsive use of resources, combined with the accelerated demographic pressure to which the planet is and will be subjected in the years to come, is no longer sustainable. Matter is finite (Genovesi, Pellizzari, 2021).

The shift towards a more circular economy is expected to further enhance awareness and the development and exploitation of new approaches to sourcing and using resources (The Megatrend Hub, Knowledge 4 Policy, European Union, 2023). In this context, designers are tasked with creating solutions that enable a successful transition to more sustainable and regenerative models of production and consumption, ensuring these goals become a reality rather than remaining mere aspirations. We are potentially on the brink of a materials revolution that could help rebalance our relationship with our planet and reshape society for the better (Franklin K., Till C., 2018). One solution in the design field, initiated in the last few decades, is the use of new bio-based materials from the local waste. The specific context of this paper is Egypt, where the waste management poses a significant challenge, with an estimated annual waste generation of 100 million tons (bio-based waste 34%).

The present paper explores the journey of product design students (pre-master and bachelor) of German University in Cairo, who started from a mapping of the bio-based waste present in Cairo (orange peel, mango peel, sugarcane, seeds, rice straw...), and then they experimented, designed and produced a new material and found their application sectors, leading to the prototyping of a series of products.

**Design process**

The aim of this work whit the students is to discover the potential of bio-based materials, starting from transforming local waste into new materials and figure out new possible applications. After mapping the organic waste present in Egypt (especially in Cairo), the students experimented and created different types of materials with different physical and sensorial characteristics. The students then used the Materials Driven Design Method to analyze the materials and move on to the creative phase by designing different concepts. In the final phase they prototyped the concepts and created an exhibition.

The students explored alternative, non-typical approaches in discovering the potential of bio-based materials and transform this potential into practice. Experimenting, testing, and discovering how to re-purpose organic elements through tactile senses and critical thinking was all about embracing the bio-based future; unlocking the potential of these emerging materials. Tools and guidelines have been designed to help students at different stages of the process.

1. Final results and lessons learned

Some of the final projects:

1. Orange peel – Shopping bag

Transforming tons of local orange peels into a locally made, biodegradable alternative to leather.



Figure 1



Figure 2

2. Sugarcane - Stool

For every 10 tons of sugarcane crushed, a sugar factory produces nearly three tons of wet bagasse. After experimenting with sugarcane waste to produce a new, durable and sustainable material, the students started the ideation phase based on the outcome of their material and its properties. They settled on designing a stool for field workers, craftsmen, through the development of traditional stools.



Figure 3



Figure 4

3. Seeds – Lighting unit

The back to seed is a new material made out of the seeds of sunflower, watermelon and pumpkin. These 3 types of seeds are known in Egypt as nuts in which people eat what is inside and discard the shell which ends up in trash causing waste. By combining the seeds, the designers created new materials and a lighting unit crafted from discarded nutshells.

This article underscored the importance of biodesign as a core element in design education. Students learned how to integrate environmental considerations from the earliest stages of material development through to final product prototyping. Starting from a real challenge, by mapping the local waste in Egypt, the students learned how to address specific environmental and societal challenges in their own context. This localized approach to material sourcing ensures that solutions are not only bio-based but also relevant to the region’s needs and resources.

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# (39) Myco-Wool Composite Materials: An Experiment with Wool and Ganoderma lucidum. Nicholas Rapagnani (Design & Art Faculty, Free University of Bolzano, Bolzano, Italy), Aart van Bezooijen (Faculty of Design & Art, Free University of Bolzano, Bolzano, Italy), Luigimaria Borruso (Faculty of Agricultural, Environmental and Food Sciences, Free University of Bolzano, Bolzano, Italy), Tanja Mimmo (Free University of Bolzano) and Oussama Bouaicha (Faculty of Agricultural, Environmental and Food Sciences, Free University of Bolzano, Bolzano, Italy).

**ABSTRACT |** This study explores the development of mycelium-based composite materials utilizing wool substrates and the fungal strain Ganoderma lucidum within the framework of the European funded iNest project. Over a four-week period, the experiment assessed mycelial growth and integration within raw, cleaned, and dyed wool samples. The findings indicate that the combination of Potato-Dextrose Agar (PDA) dip-coating and underlayers significantly enhances mycelial colonization of the wool substrates, resulting in structurally robust composite materials. By cultivating Ganoderma lucidum on diverse wool fibres and fabrics, the study aims to create biodegradable and renewable materials alternative following a circular production methodology. The results demonstrate that wool substrates effectively support mycelium growth, when enhanced by additional feedstock media, leading to the creation of durable, stable, and rigid materials. These outcomes suggest potential applications in material design and biofabrication, highlighting the promise of myco-wool composites for future g-local innovation in production.

**KEYWORDS |** MYCELIUM, WOOL, BIODESIGN, GROWING, CIRCULAR

## INTRODUCTION

### Background

The increasing demand for sustainable materials has spurred interest in mycelium-based bio composites, with mycelium - the vegetative part of fungi - emerging as a promising renewable and biodegradable resource (Jones et al., 2018). While previous research has explored mycelium’s potential in various substrates, such as agricultural waste and synthetic materials (Haneef et al., 2017), the use of wool as a substrate for Ganoderma lucidum has not been extensively studied – along with the exemplificative project “Lana” by Caterina Plenzick (MaterialDistrict, 2022). This research aims to fill this gap by investigating the integration of Ganoderma lucidum, a fungus known for its robust mycelial network, inside wool byproducts originated from the production line of a local company in South Tyrol, namely Spinnradl. The objective is to evaluate how different pre-incubation methods affect wool substrates to enable and enhance mycelial growth (due to a consequent enrich-

ment of wool fibres with edible feedstock for the fungi) and the development of novel myco-wool composite materials.

### Objectives

Concerning the European funded project iNest (Interconnected Nord-Est Innovation Ecosystem), the framework of this study is related to its “Spoke 3: Green and digital transition for advanced manufacturing technology – Research Topic 3.1: Materials / Analysis of secondary raw materials for environmental sustainability and circularity”. iNest aims to foster innovation and collaboration across sectors in Northeastern Italian universities, focusing on researching green solutions for actual industrial challenges. The research has been performed at the Free University of Bolzano, in collaboration between the Faculty of Design and Art and the FaST Lab of the Faculty of Agricultural, Environmental and Food Sciences. First, this whole research aims to investigate the bio design approach of growing mycelium to regenerate local byproducts considered as waste; secondly, to analyse the properties of the resulting material samples to speculate on potential future applications of such materials, and how to enhance their qualities. This study focuses on the use of Ganoderma lucidum as chosen white-rot fungi, and on different types of wool fibres and fabrics as main substrates - considering that such fungi species cannot digest animal fibres (Elsacker et al., 2019).

## MATERIALS & METHODS

### Materials

The fungal strain Ganoderma lucidum has been purchased as pure frozen culture from Tyroler Glückspilze (Strain No.: 112001), to be further activated before inoculation inside wool samples. The wool, divided into raw dirty fibres, carded clean fibres and fabrics dyed cutouts, have been provided by a family-run company called Spinnradl, located in a small South-Tyrolean valley called Val Passiria, which focuses on the whole process of wool production from breeding mountain sheep until final tailored typical products (e.g. sarner). Potato Dextrose (PD) and Agar Agar (AA) powders have been purchased on Merck KgaA, utilised as base ingredients to prepare PDA culture media.

### Methodology

The experimental lab protocol stands on an initial matrix, thoroughly designed to visualise and organise the overall samples number. That contains the three wool material samples put in relation to the three different pre-inoculation treatments, with two repetitions each, for a total of 18 samples at the end of the experiment (Table 1). The treatments mentioned above build up on a previous study where Pleurotus ostreatus was grown onto synthetic nanofibers mat through a technique involving Agar Agar as feedstock media to let fungal hyphae entangle with the indigestible synthetic culture terrain (Helberg et al., 2019): that experiment consisted in using acrylic knitted fabric pieces, either dip-coated in Agar Agar or not, and either placed on Agar Agar plates or not, showing positive results after 12 days incubation period.

| | PDA layer | PDA coat + PDA layer | PDA coat |
|---|---|---|---|
| Raw, dirty wool | XX | XX | XX |
| Carded, clean wool | XX | XX | XX |
| Dyed fabric wool | XX | XX | XX |

Table 1, lab protocol design matric containing substrates and pre-inoculation treatments.

The experiment began with the preparation of PDA and wool samples. To prepare the PDA, 1l of pure water was added with 24g of PD and 15g of AA, then stirred using a magnetic stirrer for 2 minutes at 1000rpm, 200°C. Wool fibres and fabrics were divided in 18 small portions fitting the petri dishes and collected in 3 different bakers. The materials have then been sterilised in autoclave at 121°C for 20 minutes, then allowed to cool down before the experiment in the lab premises.

The core experimental procedure was conducted under sterile conditions, inside a laminar flow hood. PDA was poured into 12 petri dishes and allowed to solidify, while the remaining PDA was left inside a baker in a warm, liquid state. Before inoculation, wool samples were prepared and placed inside plates as it follows:

1) 2 raw dirty wool, 2 carded clean wool, 2 dyed fabrics were placed dry into plates containing a PDA layer.

2) 2 raw dirty wool, 2 carded clean wool, 2 dyed fabrics were dip-coated with PDA warm liquid media and placed into plates containing a PDA layer.

3) 2 raw dirty wool, 2 carded clean wool, 2 dyed fabrics were dip-coated with PDA warm liquid media and placed into empty plates.

After that step, small mycelium circles from Ganoderma lucidum culture plates were cut and placed upside-down singularly at the centre of each wool sample (Figure 1). The dishes were then sealed with parafilm to maintain the correct humidity levels during time, and incubated at the constant temperature of 27°C.

Mycelial growth was monitored weekly for four weeks, noting differences in colonization during time and among samples. After four weeks, the samples were transferred out of the dishes and placed on some hoven paper, dried at 70°C for 48 hours inside a food dryer at the Bitz FabLab in Bolzano. After drying, sensorial tests have been executed (touch, smell, sight) and microscopic analysis through an optical microscope were conducted to document mycelial integration within wool substrates.

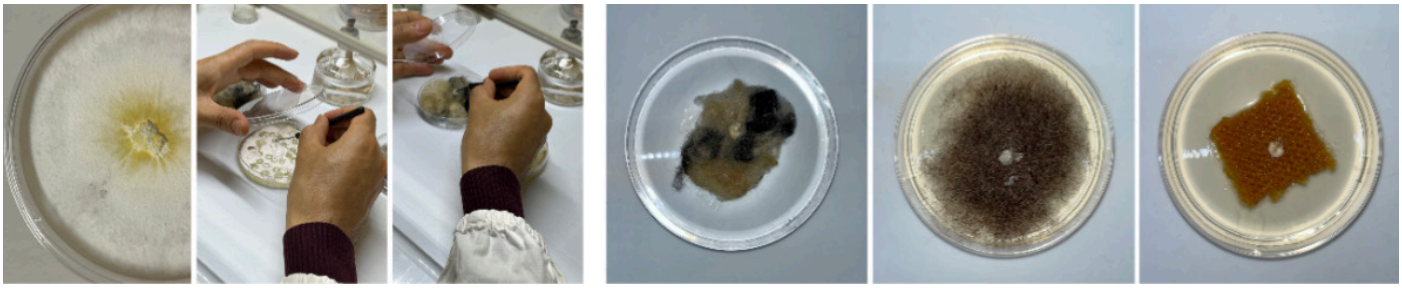

Figure 1, inoculation of Ganoderma lucidum into the wool substrates.

## RESULTS AND DISCUSSION

Our experiment provided new insights into the growth of Ganoderma lucidum on various wool substrates, revealing the potential for developing mycelium-based composite materials. Over the four-weeks period, mycelium colonization was systematically observed across the different wool samples. The initial week saw mycelium beginning to colonize all wool samples, with particularly rapid growth in those dip-coated and layered with PDA media. This pattern continued into the second and third weeks, with enhanced growth and mycelium mat formation, especially in the PDA-coated and layered samples, while dry ones on PDA layers exhibited minimal growth. By the fourth week, mycelium thoroughly colonized most samples, with significant hyphae presence observed in PDA coated and layered samples (Figure 2).

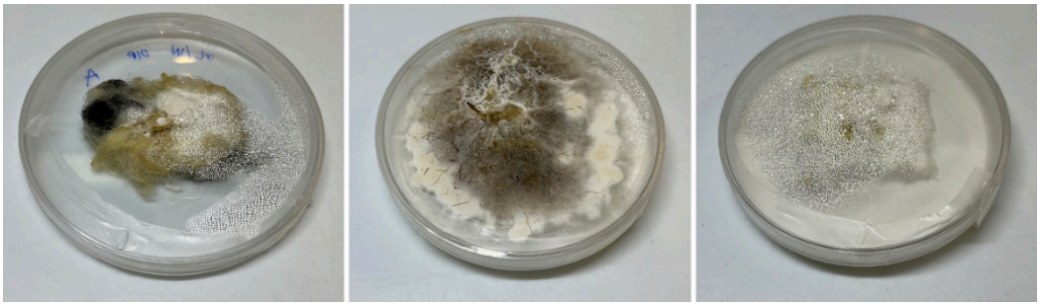

Figure 2, myco-wool materials samples after 4-weeks growth incubation period.

After dehydration, these samples exhibited a hard, spongy consistency, with increased hardness correlating with greater mycelium colonization, and showed the ability to maintain structural integrity and shape even after drying (Figure 3). Notably, the best results were seen in samples that were both dipped in PDA and layered with it. These samples formed a flat hyphal mat on the surface, which became hard and ‘curly’ during the drying process, indicating a strong integration of the mycelium with the wool fibres. This mycelium presence ensured structural stability, making the materials hard, more resistant to bending and compression, and thus promising for future applications in sustainable material design – as it occurs with hemp fibres before post-processed with glycerol (Author, 2024). One dyed fabric sample, where the mycelium transferred the colour pigmentation, exemplified the po-

tential for aesthetic customization in future research.

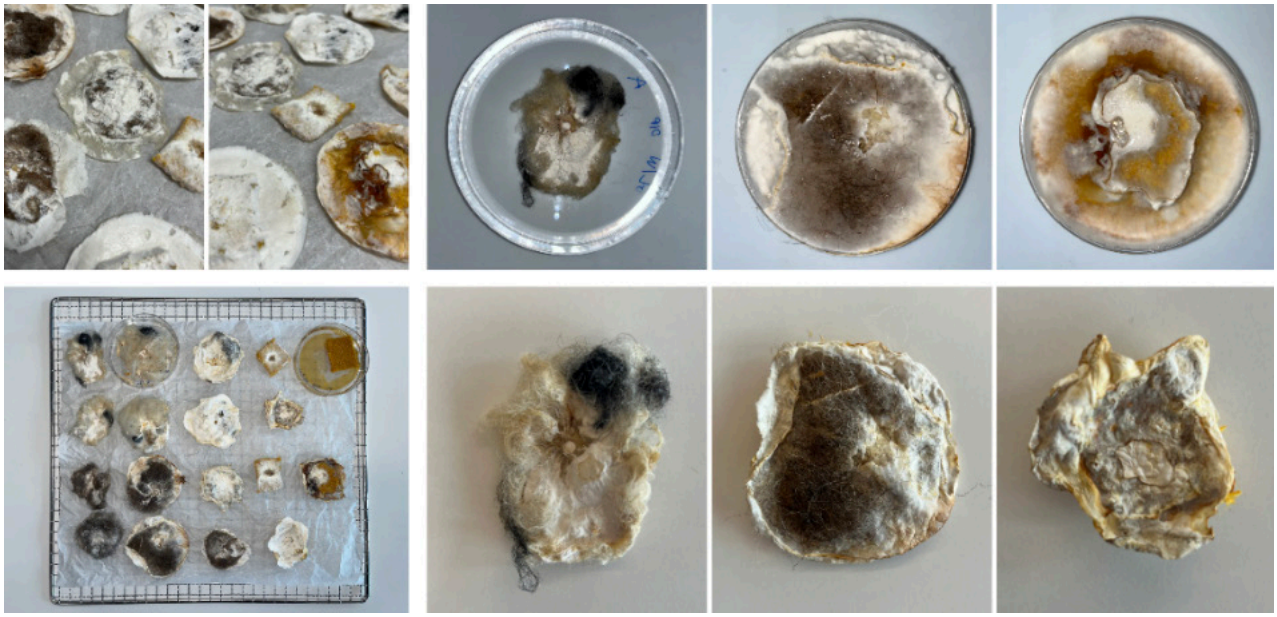

Figure 3, myco-wool materials samples before drying and after 48 hours drying process at 70°C.

Microscopic analysis using a Leica microscope revealed further details about the interaction between mycelium and wool fibres. The images captured at various magnifications (0.6x, 1x, 1.6x, 2.5x, and 4x) provided a detailed view of the hyphal networks formed within the wool substrates (Figure 4). PDA appeared to act as an adhesive, infiltrating the air cells within the materials and enabling the mycelium to create a stable hyphal network. This network effectively reinforced the structural properties of the wool substrates, confirming the role of PDA in enriching the fibres and facilitating mycelial colonization to realise stable and steady materials.

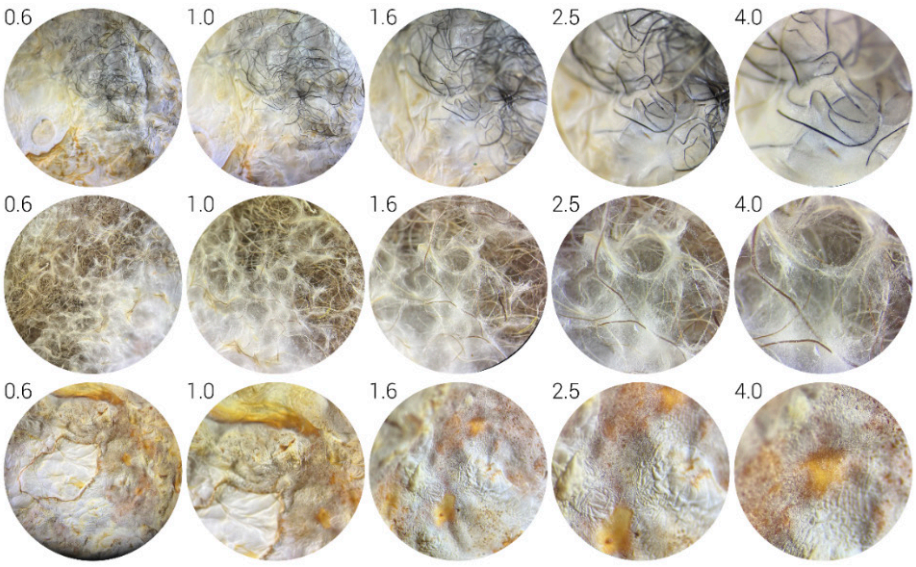


Figure 4, myco-wool materials samples after 48 hours drying process at 70°C.

Overall, the study demonstrates the critical role of PDA media in supporting robust mycelial growth and forming structurally sound composite materials. This research opens the door to further exploration, including the use of different fungal species and wool pre-treatments, to optimize material properties and expand the applications of myco-wool novel materials in real-life productions.

## CONCLUSION

This research highlights the effective colonization of wool substrates by Ganoderma lucidum, particularly when pre-treated with PDA dip-coating. The study confirms the promising potential of mycelium-based wool composites, as evidenced by the robust structural integrity of samples dip-coated with PDA. The critical role of PDA media in enhancing mycelial growth and material stability has been clearly demonstrated, suggesting that nutrient availability is pivotal for successful mycelium integration in wool fibres. Future investigations should focus on refining these methods, exploring alternative fungal species and wool feedstock enrichment, and broadening the applications of mycelium-based materials within the realm of bio-design. This work contributes to the growing field of sustainable materials innovation, opening avenues for environmentally friendly alternatives in various design and industrial applications founded on a local, circular approach.

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# (51) Designing with Life: Embracing processes of Growth and Decay through Bio-Integrated Design. Rita Morais (University College London) and Natalia Piórecka (University of Innsbruck).

**KEYWORDS |** Urban MYCOskin, Mycelium, Living Organisms in Design, Growth and Decay, Sustainable Architecture, Biodesign, Bio-Integrated Design

## EXTENDED ABSTRACT

## INTRODUCTION

With the recent developments in the field of bio-integrated design, the integration of living organisms into design is reshaping architecture and material science, fostering a closer connection between humans and nature. This research explores the designer's role in working with living organisms and attempts to develop a workflow that will allow them to tackle the complexities of the living organisms including processes of growth and decay. The Urban MYCOskin project represents an interdisciplinary approach that could transform urban environments into dynamic, symbiotic systems with living, regenerative materials. By studying mycelium - a network of fungal threads - the project combines scientific research, the principles of systems thinking, a variety of fabrication techniques, and environmental studies to propose sustainable solutions to complex challenges like waste pollution, biodiversity loss, and global warming.

### Conceptual Framework: Urban MYCOskin

A report from the Global Alliance for Buildings and Construction (GlobalABC) highlights that the buildings sector accounts for 40% of Europe's energy demand, with 80% of that energy coming from fossil fuels. This underscores the need to shift away from current material choices and design practices to address climate challenges. Designers need to confront these complexities by understanding nature and learning how to let it guide design decisions. The Urban MYCOskin project, within the discussed field of biodesign, explores mycelium as a living layer in urban architecture, a material that grows, evolves, and decomposes, enriching the environment. By focusing on mycelium's enzymatic properties as a decomposing and binding agent, the project utilizes urban waste streams, mainly textiles, addressing the hidden dangers of fast fashion. Mycelium based materials offer a sustainable, low-carbon alternative to standard architectural materials, capturing carbon dioxide during growth and offering novel possibilities of handling waste as a resource. In this project, Pleurotus ostreatus (oyster mushroom) was grown on textile and agricultural waste transforming it into a valuable, lightweight, bioreceptive composites for urban interventions, tackling not only waste management challenges, but also promoting sustainable material production in line with circular economy principles.

**Workflow: From research to application**

When working with living organisms, designers encounter unique opportunities and challenges, where growth, adaptation, and decay become central considerations. This approach marks a departure from conventional practices, embracing the complexities of mycelium growth shaped by variables like substrate composition, environmental conditions, and time. The design process begins with rigorous scientific research on controlled mycelium growth, transforming textile and agricultural waste into durable panel infills. Decay, in the project, is not seen as a failure but as a vital phase that enriches the environment and is an integral part of the created material system. The project introduces innovative use of biodegradable scaffolds, such as 3D-printed or fabric-formed elements, designed to be consumed by mycelium, bridging digital fabrication and physical prototyping. Through computational design the material constraints are set on the early stages of the parametric workflow, allowing for precise creation of the panels tailored for water management, temperature control, and material distribution. Environmental studies, including solar, water and wind simulations shape the design to ensure climate resilience and support plant growth.

**Future Directions and Conclusion**

Working with mycelium opens new avenues for exploring the ethical implications of using living matter, addressing urban sustainability, and redefining the designer's role in bridging built environments and natural ecosystems. The Urban MYCOskin project has successfully repurposed mixed textile waste with the use of mycelium, employing advanced fabrication techniques and computational tools to create an adaptive architectural system. Future efforts will focus on scaling these methods and testing prototypes in real-world conditions to refine their performance. All things considered, Urban MYCOskin exemplifies the vision of transforming buildings into dynamic participants within the ecosystem, while embracing designer's role in a resilient urban future where sustainability is integral to the design process.

**Images**

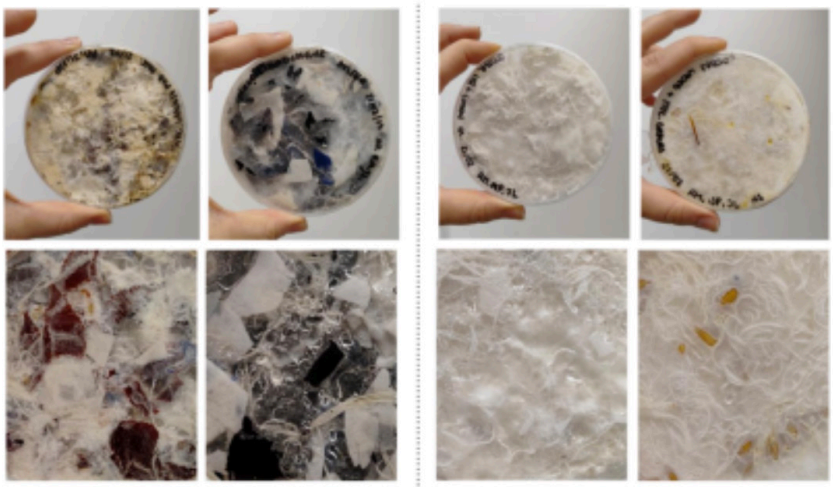

FIGURE 1 – SAMPLES OF PLEUROTUS OSTREATUS MYCELIUM STRAIN INOCULATED ON DIFFERENT TEXTILE WASTE COMPOSITIONS



FIGURE 2 – OYSTER MUSHROOMS GROWING ON TEXTILE WASTE SAMPLES



FIGURE 3 – DESIGN WORKFLOW – INCORPORATION OF COMPUTATIONAL SIMULATIONS WITH DIGITAL MANUFACTURING, PROTOTYPE

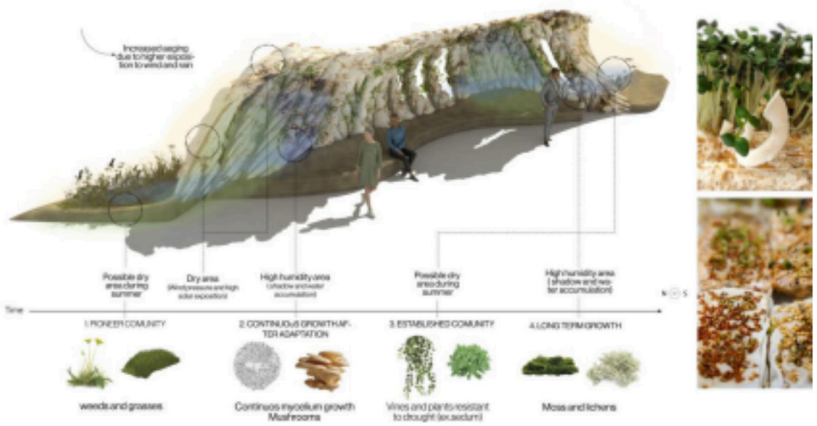


FIGURE 3 – ECOSYSTEM THINKING – RIGHT SIDE: STUDY OF MICROCLIMATES IN THE PROPOSED FINAL STRUCTURE AND COLONIZATION TIMELINE  OF DIFFERENT SPECIES; LEFT SIDE – BIORECEPTIVITY TESTS IN THE SAMPLES OF TEXTILE AND MYCELIUM

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# (61) Designing Biomineralized Materials: A Review of Practices Utilising Microbial-Induced Carbonate Precipitation (MICP) in Design Contexts. Hyejo Shin (University of the Arts London).

**ABSTRACT |** As the growing levels of CO2 in the atmosphere significantly contribute to global warming, there is a pressing need to reduce its emissions to achieve carbon neutrality by 2050. Industry, a major source of these emissions, requires a fundamental transformation in manufacturing processes to reach this target. While there is a growing interest in incorporating Microbial-induced Carbonate Precipitation (MICP) into design practices, there is no comprehensive review of MICP practices from design perspectives. This paper presents a review of MICP design practices, analysing twenty-two design cases through matrix and visualisation methods. The review is situated within the ongoing PhD project Breathing Minerals, which explores how MICP can inform the novel biofabrication method for carbon capture materials in circular product design. As a preliminary step towards biodesign practices, this review identifies opportunities for photosynthetic MICP in circular product design.

**KEYWORDS |** Biomineralisation, Microbial-Induced Carbonate Precipitation (MICP), Cyanobacteria, Circular Product Design, Carbon Capture Biomaterials

## 1. Introduction

The Paris Agreement was adopted to limit global warming below 1.5°C above pre industrial levels (2015), which implies reaching net-zero emissions by 2050 (IPCC, 2022). Since 2000, industrial emissions have risen faster than other sectors, driven by fuel combustion, process emissions, product use, and waste (IPCC, 2023). Halting emission growth and achieving carbon neutrality requires transforming industrial manufacturing processes.

Microbial-induced Carbonate Precipitation (MICP), a sustainable biomineralisation technology, has gained attention across engineering fields for biofabricating durable materials (Zhang et al., 2023). While MICP through ureolysis is widely researched, photosynthetic MICP has recently received attention for its potential in CO2 sequestration (Sidhu et al., 2022).
Despite growing interest in integrating MICP into design and architectural contexts, its potential remains underexplored due to the complexities and limited resources (H Arnardottir, 2024; Mosse et al., 2024). Furthermore, there exists no comprehensive review of MICP practices from design perspectives that maps the current landscape and identifies its opportunities within design fields.

This paper reviews MICP design practices as a part of the ongoing PhD project, ‘Breathing Minerals: practice-based research exploring how biomineralisation can inform biofabrication methods for carbon capture materials in circular product design.’ Situating at the intersection of biodesign and circular product design, the project aims to establish a material library of waste-

based carbon capture biomaterials utilising photosynthetic MICP. Through systematic material exploration, the library will demonstrate its potential applications for future circular product design. This review serves as a preliminary foundation for further biodesign practices to identify opportunities for photosynthetic MICP in smaller scale circular product design.

## 2. Methods

A review of practices utilising MICP across design and architecture was conducted. Data were gathered from various sources, including design blogs, exhibitions, journal articles, conference papers, and websites. Twenty-two cases were selected based on whether they engaged with creative aspects of MICP, rather than focusing solely on its engineering applications. These were classified into four application categories: Product and Object Design, Bio-based Composite Design, Diverse Substrate Experimentation, and Expolarotary Design Approaches. The cases were evaluated using the Technology Readiness Level (TRL) adapted for this review as shown in Table 1 (Conceptivity, 2018). This analysis was visualised by organising practices into a matrix with TRL and top-down and bottom-up approaches as axes (see Figure 1).

| | | |
|---|---|---|
| 8-9 | **PRODUCTION** | Manufacturing issues are solved and technology is commercially available. |
| 6-7 | **VALIDATION** | Tested in Intended environment and demonstrated in operational environment. |
| 4-5 | **PROTOTYPE** | Built and tested in a laboratory environment with a systematic exploration. |
| 3 | **PROOF OF CONCEPT** | The first laboratory test is completed. |
| 1-2 | **IDEA** | The concept has been formulated but no experimental proof is available. |

TABLE 1: TECHNOLOGY READINESS LEVEL ADAPTED FOR THE REVIEW OF MICPDESIGN PRACTICES

NOTE. ADAPTED FROM “METHODOLOGY FOR CLASSIFICATION AND MARKET READINESS” BY CONCEPTIVITY, 2018

## 3. Results and Discussions

Figure 1 illustrates the landscape of MICP design practices grouped into four application areas with respective TRLs, revealing opportunities for photosynthetic MICP in circular product design.

Most cases in Bio-based Composite Design, Diverse Substrate Experimentation, and Expolarotary Design Approaches are above the prototype level, with some reaching the production level. However, practices in Product and Object Design remain at proof-of-concept, lacking systematic exploration of material properties specific to product design. Regarding circularity, although

several projects incorporate waste materials (denoted in blue), there is insufficient investigation of the circularisation of developed materials. Finally, while a few practices utilise photosynthetic MICP via cyanobacteria (denoted in green), its potential for CO2 sequestration remains underexplored.

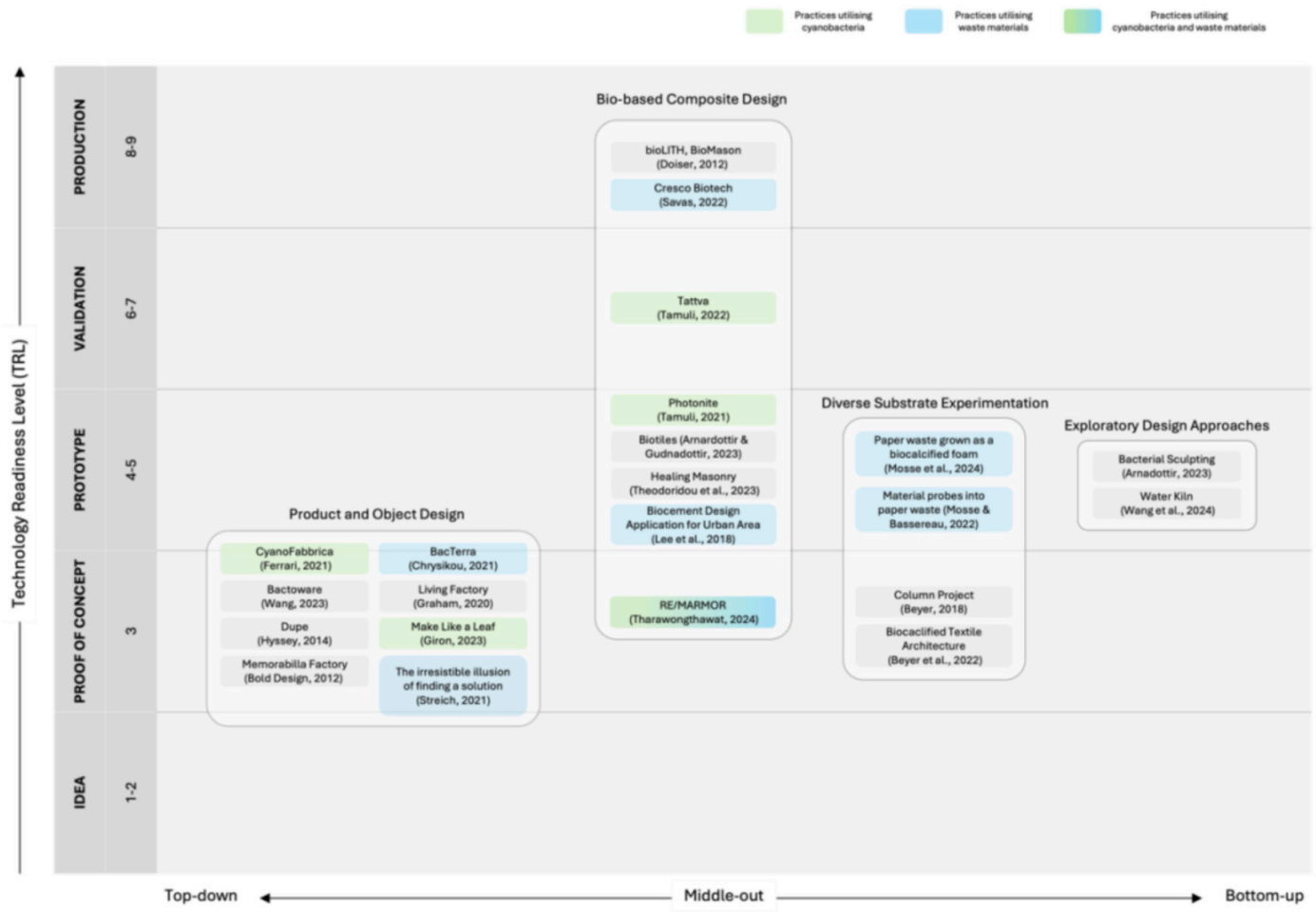


FIGURE 1
MATRIX OF MICPDESIGN PRACTICES

## 4. Conclusion

This paper reviewed MICP design practices to map the current landscape from design perspectives. The findings revealed gaps in the fields and highlighted the potential for photosynthetic MICP in smaller-scale circular product design. Further phases will involve biodesign practices focusing on material characterisation, suitability for product design applications, and CO2 sequestration performance. By investigating photosynthetic MICP with cyanobacteria for future circular product design, the ongoing research seeks to uncover the untapped opportunities of MICP in design and provide valuable resources for designers.

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# (11) THE BIOPHILIC CREATIVE INDUSTRY. Sergio Davila Urrutia (Universidad Autónoma Metropolitana) and Riina Õun (Eesti Kunstiakadeemia | Estonian Academy of Arts).

**ABSTRACT |** This paper explores the transformative potential of an emerging Biophilic Creative Industry, which engages in radical collaboration with other species, offering new opportunities for urban planning and environmental practices. By drawing inspiration from decentralized intelligent systems found in nature, such as the body of an octopus (Godfrey-Smith, 2017), the paper introduces an exploration of the concept of "Cognitive Cities." These cities, much like biological systems, use sensory-driven, adaptive networks to respond to environmental and social challenges, mimicking the intelligent coordination seen in forests and mycelial systems as described by Suzanne Simard in Finding the Mother Tree (2022) and Merlin Sheldrake in Entangled Life (2020).

Design plays a key role in catalyzing this creative industry, which brings not only economic growth but also cultural enrichment, a sense of belonging, and a strengthened identity to urban environments. The integration of innovative biotechnologies—such as lichen-based wearable bio-garments and bioluminescence—serves as practical examples of how these biophilic principles can be applied, offering solutions that are both environmentally regenerative and socially impactful.

Challenging traditional anthropocentric perspectives, the paper advocates for a relational and interdependent approach, inspired by contemporary thinkers like Arturo Escobar (2024). By integrating biodesign with regenerative development (Gabel, 2015), this vision transcends basic sustainability, proposing a future where urban environments thrive in unison with natural ecosystems. Through this lens, cities can evolve into living systems that
not only support human well-being but also foster harmonious relationships with the broader ecological world.

**KEYWORDS |** Biophilia, Regenerative Development, Creative Industry

## INTRODUCTION: DRIVING INTERESPECIES INNOVATION

"The move to relationality entails a new, or different, ontology of the human. Thinking ontologically about relationality and transitions is a crucial premise…" (Escobar, et all, 2024)

In "Finding the Mother Tree," Suzanne Simard uncovers the intricate relationships between Douglas Fir trees and the mycorrhizal fungi within forests, revealing a complex network of resource and information exchange known as the "Wood Wide Web" (2022). This network allows the forest to thrive by sensing threats, such as beetle infestations, and adapting accordingly through a shared communication system. Research has shown that older trees, often called "mother trees," play a significant role in this network. They can transfer

carbon and other nutrients to younger or more vulnerable trees, including stumps, to help sustain them. This process not only supports the survival and decomposition of stumps but also contributes to the overall health and resilience of the forest ecosystem.

Similarly, Merlin Sheldrake, in “Entangled Life” (2020), highlights the profound interconnectedness within ecosystems, particularly through mycelium networks that facilitate communication and resource sharing among species. Sheldrake’s work underscores the necessity of understanding and integrating these natural systems to promote sustainability and harmony in human development, aligning with Simard’s views on ecological interdependence (2022).

When comparing these natural systems to the concept of “Cognitive Cities,” we can see how forests embody many ideals of an adaptive, sensory-driven urban environment. A cognitive city, equipped with sensory inputs, would gather data on stress levels, pollution, and other environmental factors to adapt and evolve based on the needs of its citizens (Makanadar, 2024). For instance, sensors could measure cortisol levels in sewage and buildings to identify stress hotspots, allowing the city to mitigate these issues by altering environments, creating new routes, and addressing root causes. Similarly, the Douglas Fir Forest senses beetle infestations and communicates this information through the mycorrhizal network, enabling trees to prepare and respond collectively. Simard’s work even suggests that these fungal networks exhibit cognitive processes, highlighting the sophisticated nature of these natural systems (2022).

The integration of lichens as bioindicators in biological monitoring has proven to be an effective method for assessing air pollution due to their sensitivity to atmospheric pollutants and their ability to accumulate harmful substances over time. Conti and Cecchetti (2001) highlight the significance of lichens in tracking environmental health, providing a cost-effective approach to air quality assessment. Expanding on the use of lichens, fashion designer Piero D’Angelo (2022) incorporates them into wearable bio-garments designed to filter pollutants from the air. His interdisciplinary projects expand on the possibilities of
working with nature, aligning with the concept of “Cognitive Cities” where biosensors are integrated into urban environments to monitor and improve air quality. This convergence of biotechnology and fashion exemplifies a forward-thinking approach to sustainable urban living and environmental stewardship.

**1. Forest Intelligence**

As Escobar, Osterweil, and Sharma explain: “There has been a great deal of interest in biomimicry in the fields of engineering and design. But which bios to mimic? Which aspect of biology to uplift, to emulate? Life simply means that a great deal is possible.” (2024) The authors claim that nature is generous, abundant, relational, interdependent, and constantly opening a space within which a great deal is possible. Perhaps a more radical biomimicry is necessary given our climate and environmental challenges.

As humans, we have much to learn from forests and nature. The ongoing development of cities aims to make human settlements smarter, more prosperous, sustainable, balanced, and equitable. The cognitive cities will increasingly resemble the dynamic, interconnected nature of forests. If humanity aspires to true intelligence, our future settlements should embrace the principles found in natural ecosystems (Makanadar, 2024). Forests are often regarded as some of the most self-sustainable and interconnected ecosystems on Earth. They exhibit a high degree of biodiversity and complex interactions among various species of plants, animals, fungi, and microorganisms. These interactions facilitate nutrient cycling, energy flow, and ecological balance, making forests highly resilient and capable of sustaining themselves over long periods (Chapin, Matson, & Vitousek, 2011; Lindenmayer& Franklin, 2002).

Humanity's perception of itself as superior to nature is a pervasive and influential worldview with deep historical roots. This anthropocentric perspective is evident in various domains of human activity, from theological doctrines asserting human dominion over the Earth to capitalist systems prioritising economic gain over environmental sustainability. For instance, the biblical notion of dominion has often been interpreted to justify human exploitation of natural resources, exemplifying early religious endorsements of human supremacy (White, 1967). Similarly, the Scientific Revolution and the subsequent rise of industrial capitalism fostered a worldview in which nature is seen primarily as a resource to be utilised for human progress (Gaukroger, 2006). These paradigms, characterised by a focus on technological advancement and economic growth, have reinforced the belief in human superiority and contributed to practices that often disregard ecological balance (Merchant, 1980; Regan, 1983).

Classical definitions of intelligence often use humans as the benchmark, placing us at the top and relegating organisms like fungi and slime moulds to the bottom. Merlin Sheldrake (2020) argues that this anthropocentric view has led to the dismissal of these non-human organisms, despite their ability to solve problems, communicate, and exhibit complex
behaviours. As our understanding expands, the rigid hierarchies of intelligence are softening, challenging traditional views that cognition requires a brain. Many biologists now recognize that plants, fungi, and slime moulds demonstrate sophisticated, adaptive responses, prompting a reevaluation of intelligence across species and questioning the notion that cognitive processes are exclusive to humans and other "higher" animals.

This evolving scientific perspective contrasts sharply with Indigenous teachings. For example, Robin Wall Kimmerer's "Braiding Sweetgrass" (2013) emphasises a reciprocal and respectful relationship with the natural world, grounded in a deep understanding of the interconnectedness of all life. Kimmerer, a member of the Citizen Potawatomi Nation, illustrates how traditional practices and teachings promote sustainable living and reciprocal relationships with the environment. Indigenous cultures view plants, animals, and natural elements as relatives and teachers, fostering a sense of gratitude and responsibility. This perspective is reflected in rituals such as the Thanksgiving Address, which acknowledges and gives thanks to all elements of the natural world, promoting a balanced and respectful coexistence.

Similarly, Northern Europeans view the forest as the “horn of plenty.” The Estonian “sacred grove” tradition, known as “püha hiis,” is deeply rooted in Finno-Ugric indigenous beliefs. These sacred spaces were used for rituals and communal gatherings to honour ancestors, nature spirits, and pre-Christian deities such as Taara. Typically located in secluded natural settings, the groves embodied a connection between the physical landscape and the spiritual realm of Estonian folklore. The “sacred groves” often featured special sacrificial stones, including cup-marked stones used for offerings to fairies and for healing purposes (Sooväli-Sepping, 2015).




Figure 1. A cup-marked sacrificial stone in Estonia. Documented by Riina Õun during field research in 2024.

Historically suppressed during periods of Christianization and Soviet occupation, efforts have been made to revive and protect these cultural landscapes as symbols of Estonian cultural identity and spiritual heritage (Pettai&Sõukand, 2013). Despite Estonia’s modern status as one of the most advanced digital societies and one of the least religious countries, many people still indirectly honour the idea of nature spirits and view the forest as a sacred place.

Mikita states that forests are seen as living beings and are central to Estonian identity, providing a sense of security rather than fear, a contrast to other European cultures. This enduring relationship with the forest has preserved Estonia’s unique cultural and spiritual heritage, distinguishing it from other European nations where forest memories have largely faded. Estonians, being avid foragers, had until recently a custom of delivering bread to a home forest for wild animals to partake in on holidays, reflecting

the deep connection to their woods (Mikita, 2020).

In light of the ongoing deforestation in Estonia, Riina Õun created a land art installations Cornuscopia (2024) addressing the significance of forest abundance and the importance of this ecosystem. The large-scale, horn-shaped, hut-like installation is constructed entirely from locally sourced materials, including underwood harvested from the surrounding area, and employs basketry techniques. The entrance of the sculpture faces the forest, inviting viewers to crawl inside and reflect on the woods. Additionally, the installation encourages various species living in the forest to occupy it, thus fostering inter-species interaction.



Figure 2. Installation: “Cornuscopia”, Estonia, 2024. Photo by Riina Õun.

## 2. Forecasting biophilic cities

Biophilic cities will go beyond mere aesthetics, incorporating greenery and plant life as fundamental elements of urban planning. These cities represent a shift towards degrowth and the repair of our planet from the destructive impacts of human activity. Arturo Escobar argues for a new narrative that transcends the successes and failures of capitalism, advocating for a future rooted in radical collaboration, life-affirming actions, interconnectedness, and relatability (Escobar et al., 2024). Emerging narratives such as Solarpunk (Kaivo-Oja, & Rantasila, 2018), which envisions cities taken over by nature and clean energies; Spiral Dynamics, a vision of transcended evolution of the highest human values (Beck, & Cowan, 1996); and the Pluriverse, the Zapatista Movement’ vision of co-existing in a world that values and celebrates different definitions of existence and ontologies, offer glimpses of a more ambitious dream for future cities and settlements (Escobar, 2018).

If the prevailing narrative continues to prioritise economic growth above all else, it risks stifling new dreams and erasing the potential for a more harmonious existence. There is an urgent need for new dreams and strategies to transition towards them, dreams that will guide humanity toward creating urban environments that mimic the resilience and adaptability of forests.

## 3. Biophilia

One of the key areas of neuroscience that has garnered increasing attention is our innate connection to nature, a concept known as biophilia. Biophil-

ia, coined by biologist E.O. Wilson, refers to our innate affinity for the natural world and the positive effect it has on our brains (1984). The term is also attributed to C. G. Jung in response to the phobias argued by Freud. Either way, research has shown that exposure to nature can reduce stress, enhance mood, and improve cognitive function, underscoring the importance of incorporating natural elements into our built environment (Williams, 2017).

In recent years, cities around the world have embraced the principles of biophilic design, integrating natural systems and elements into their urban landscapes. From urban gardens and green rooftops to hydroponic systems and green highways, these initiatives aim to create environments that not only mitigate the negative effects of urbanisation but also enhance the well-being of city dwellers.

As we strive to design the cities of the future, the concept of biophilia emerges as a crucial guiding principle. By aligning the design of urban spaces with the innate preferences and needs of the human brain, we can create environments that promote health, happiness, and connection. The integration of biophilic design principles not only enhances the aesthetic appeal of our cities but also fosters a deeper sense of connection to the natural world, enriching the lives of residents and visitors alike.

As we embark on this journey of exploration and innovation, we are poised to redefine the very fabric of our cities and communities. By leveraging the latest findings from neuroscience and embracing the principles of biophilic design, there is an opportunity to create urban environments that resonate with the essence of humanity, where individuals can thrive and fulfil their potential. Through interdisciplinary collaboration and a shared commitment to enhancing urban well-being, we can pave the way for a brighter, more inclusive, and ultimately, more interdependent and planet-centric future.

**4. The Biophilia Effect**

In “The Nature Fix: Why Nature Makes Us Happier, Healthier, and More Creative” (2017), Florence Williams explores the profound impact of natural environments on human mental well-being. Williams synthesises a wealth of scientific research demonstrating that exposure to nature can significantly enhance mood, reduce stress, and improve cognitive function. For instance, she highlights studies showing that time spent in natural settings can lower levels of cortisol, the stress hormone, and promote overall psychological health. Williams argues that the restorative benefits of nature are not merely anecdotal but are supported by evidence that links natural environments to increased creativity, improved attention spans, and a greater sense of happiness (Williams, 2017). Her work underscores the critical importance of integrating nature into our daily lives for enhanced mental and emotional health. This was especially clear during the recent Covid-19 pandemic when people sought mental balance by spending time in nature while adhering to social distancing measures. The current mental health crisis, marked by rising levels of anxiety, depression, and stress, further highlights the urgent need to reconnect with natural environments as a means of fostering psychological resilience and well-being.

One illustrative example is the proposal from one of the authors (Davila, 2024) to work with the diverse Mexican bioluminescent mushrooms. During field research, a moment was captured where an organism occupying an area of 3 sqm produced a wave of light. This mesmerising phenomenon, though often replicated artificially by fireworks or LED lights, is never as breathtaking as when experienced in nature. It exemplifies the pleasure that biophilia can bring to the human brain—the pleasure of witnessing life thrive and bring light into the dark.

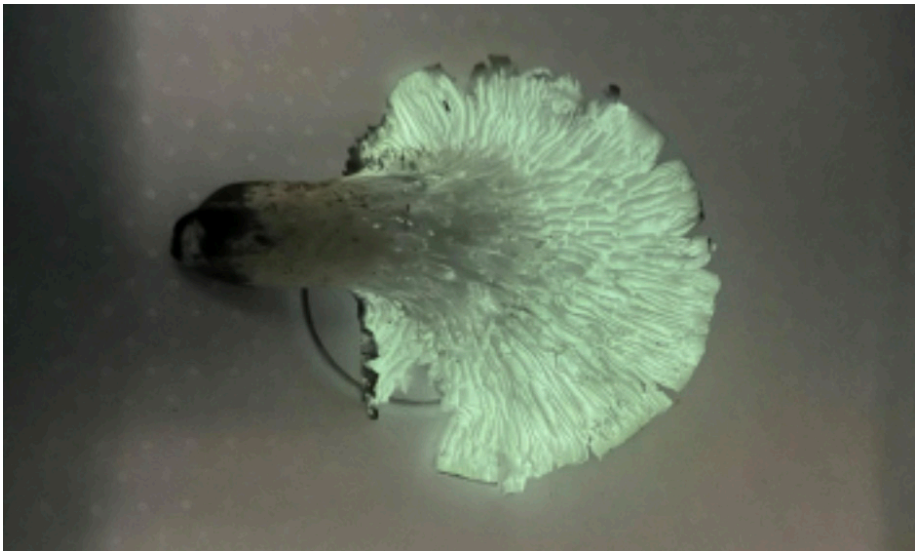

Figure 3. A sample of Omphalotus Mexicanus, a luminescent mushroom in Mexico. Growth by Micológica 360º under the guidance of Johann Mathieu. Photo by Sergio Davila.

Another example of bioluminescence integration in cities would be using dinoflagellates. While this presents a unique and visually striking possibility, it comes with significant challenges. Bioluminescent dinoflagellates require specific living conditions, including precise water temperature, salinity, and nutrient levels, which can be difficult to maintain in an outdoor public fountain (Sweeney, 2011).

Additionally, these microorganisms need a natural light-dark circadian rhythm to sustain their bioluminescence, and exposure to artificial lighting can disrupt this process (Latz, Frank, & Widder, 2008). Ensuring water quality and preventing the escape of non-native species into local ecosystems are critical environmental concerns (Haddock, Moline, & Case, 2010). Despite these challenges, bioluminescent displays have been successfully created in controlled environments.

For example, Theresa van Dongen's "Ambio" lamp uses bioluminescent bacteria to produce light, showcasing the potential for innovative and sustainable lighting solutions (van Dongen, 2015). Similarly, the Monterey Bay Aquarium has exhibited bioluminescent organisms, providing a model for integrating these unique creatures into designed settings.

This presents a question - when utilising other species to improve the city habitat, is it mutually beneficial interspecies symbiosis, or is it yet an-

other way for humanity to exploit and enslave other species?

**5. The Biophilic Creative Industry**

The examples discussed illustrate the authors' engagement with a biophilic perspective. We anticipate the emergence of a Biophilic Creative Industry, where artists, designers, and creatives are dedicated to regenerative and life-affirming practices. This industry aims to foster meaningful relationships among species and the natural world. Unlike traditional approaches that merely sustain economic, social, and environmental systems, this new paradigm emphasises regeneration through interdependence with other species and natural forces.

Humanity needs a new dream, a new narrative, new goals—where the highest aim is no longer the accumulation of resources but the sharing of them. Emir Simão Sader said that if scientists observed an ape hoarding resources meant for the entire population, they would be concerned (Sader, 2002, Pp. 87-99). Yet, when a similar scenario unfolds among humans, with 10% of the world's GDP concentrated in a few bank accounts, it is often seen as a capitalist success. We need a new narrative, one that Arturo Escobar calls "Relationality" (2024), Martin Avila calls "Interdependence" (2022), Thich Nhat Hanh defines as "Interbeing" (2016), Donna Haraway describes as "Sympoiesis" (2016) and Ken Wilber refers to as "Integral Theory" (2013). These concepts all advocate for radical collaboration with nature, integrating and transcending the Anthropocene, weaving humans back into the tapestry of existence, and designing life-affirming solutions.

In order to help shift human-centric thinking Riina Õun developed a workshop called "Installations for the Non-Human Audience" (Õun, 2023). Designed for participants aged seven and up, with no prior knowledge required, the workshop begins with a lecture on how various species construct habitats using biodegradable resources. Participants are then encouraged to explore a nearby natural space, where they observe and collect a small number of organic materials for use in subsequent activities. Central to the workshop is the creation of materials from food waste, demonstrating the viability of organic waste resources such as coffee grounds, eggshells, orange peels, avocado peels, and sawdust. The primary objective of this workshop is to shift participants' perspectives from human-centric to eco-centric design, considering the materials used and their ability to safely disintegrate back into nature, thereby benefiting other species. Since 2023, the workshop has been conducted internationally in the UK, Mexico, and Estonia.

**6. A New Ontology**

"This also means that designing, too, needs to construe itself as a practice of transitioning between stories—from the expert-driven ontology of separation to a life-centred ontology of inter-existence." (Escobar, 2024)
The ideas presented in this research are grounded in a strong theoretical framework, drawing on authors who explore the phenomenology of contemporary life and new ontologies. However, the aim is not only to build a solid base of ideas and inspiring concepts.

There is already a growing community that is not only discussing these subjects but also creating solutions for cities. This is part of the creative industry, which drives economic growth in trendy neighbourhoods, attracts investment, and boosts GDP (Florida, 2019). However, the creative industry that promotes biotechnological breakthroughs, negotiates with other species, and replaces industrial productions with life-affirming solutions is not only benefiting the economy but also proposing new behaviours, actions, stories, and dreams.

This research serves as a call for collaboration, inviting all beings, regardless of species, to join in shaping a political agenda for local governments and cities. The goal is to empower, incentivize, and facilitate the development of a Biophilic Creative Industry, fostering a collaborative environment where diverse entities can contribute to its growth and success.

## 7. Conclusion: advocating for a Biophilic Creative Industry

As articulated by Richard Florida in his book on the Rise of the Creative Class, the creative industry serves as a catalyst for innovation within cities and nations (2019). Throughout the world, we witness innovative companies reshaping culture, behaviour, economics, and even the future landscape.

An emerging sector within the creative industry is focused on biodesign, biotechnology, bioarchitecture, and various branches that engage with natural systems. These endeavours collaborate with other species and propose solutions that affirm life. More than just advocating for sustainability, this industry presents a new vision that transcends traditional notions of “sustainable development.” It’s a vision centred not just on economic growth, but on fostering harmonious relationships with our planet.

Beyond “Sustainable Development” lies the goal of “Regenerative Development,” which actively enhances and restores ecological systems. Medard Gabel, in his paper “Regenerative Development: Creating Sustainable Communities and Ecosystems,” clarifies that while sustainable development seeks to balance economic growth, social inclusion, and environmental protection to meet current needs without compromising future generations’ ability to meet their own, it primarily aims to maintain the status quo. Given the severe state of ecological decline, this approach is insufficient. In contrast, the regenerative approach focuses on improving environmental conditions beyond their current state (Gabel, 2015).

Adopting a planetary perspective rather than a human-centric viewpoint is essential for effective environmental improvement. The ongoing conflict between human interests and natural systems has significantly exacerbated the current environmental crisis.

The power of the biophilic creative industry lies in its ability to influence behaviour, not only at the individual level but also within companies, factories, businesses, and governments. It offers a new paradigm where we aspire to collaborate with natural systems, develop life-affirming solutions, and integrate humanity into interspecies efforts. In essence, it presents

an opportunity to dream of a future where our interactions with nature are sympoietic, nurturing, and mutually beneficial.

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## Acknowledgments

As non-native English speakers, we utilised the assistance of OpenAI's language model to help review and refine our ideas in this article. This support was instrumental in enhancing the clarity and coherence of our writing.

# (18) Biomimetics as an analogue design method: The case of sound analogy. Elton Lima (University of Lisbon), Luís Mateus (University of Lisbon) and Amilton Arruda (Federal University of Pernambuco).

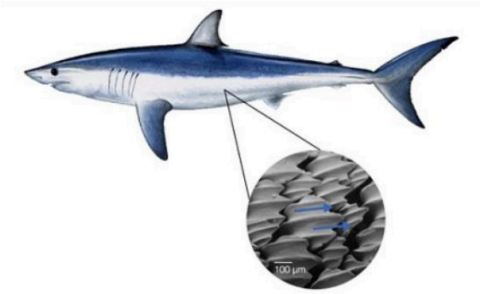
**ABSTRACT |** This paper explores biomimetics, traditionally focused on morphological and functional inspirations found in nature, not only as a nature inspired approach to solving design and architectural problems but also as an analogical design method that allows for the incorporation of sound analogy into its scope of analogies already discussed in the literature. The research, based on a systematic literature review, analyses examples of biomimetics in architecture and cases of analogies applied in projects that are not limited to bio-inspired design applications. The investigation focuses on the integration of nature sounds and soundscapes, as inspiration instead of natural organisms, into the design process, proposing that biomimetics can significantly benefit from this approach. Sound analogy is presented as an extension of analogical possibilities, suggesting that sound inspiration can enrich the aesthetic experience of projects and promote a more holistic and interdisciplinary approach to creating innovative solutions. The discussion addresses how the inclusion of sound analogy in the biomimetic design method challenges and broadens traditional conceptions of biomimetics, highlighting the importance of a more comprehensive interpretation of analogies. The integration of sounds into bio-inspired projects presents technical challenges and opportunities for innovation. This approach holds great potential to expand the applicability of biomimetics, promoting creative design solutions and advancing the discussion on the architectural design process.

**KEYWORDS |** BIO-INSPIRED ARCHITECTURE, BIOMIMETICS, ANALOGIES, SOUND ANALOGY, DESIGN PROCESS

## 1. Introduction

Biomimicry, a concept developed by Benyus (2011), has been widely recognised as a nature-inspired approach to solving design and architectural problems, among many other fields of knowledge. This approach traditionally focuses on visible strategies from nature, aiming to emulate shapes and functions derived from the observation of living organisms and their systems. However, although there is no linear and well-defined design process for working with biomimicry, this article proposes a broadening of biomimicry approaches, suggesting that it can also be seen as an extended analogue method. This allows for the exploration of different notions and perceptions of nature, including the universe of sound. Over the years, biomimetics has focused on emulating the shapes, structures and processes found in nature to create innovative solutions to human challenges. One example is the inspiration drawn from shark skin to develop materials that reduce resistance to water flow, applied to both swimming costumes and aeroplane paints (Figure 1) (Li, 2017). Another example is imitating the adhesive properties of geckos' feet to create super-strong adhesives that can be used on a variety of surfaces (Autumn et al., 2002, p. 12252).

Figure 1. Schematic example of the texture of shark skin.



Source. Li, 2017, available at https://illumin.usc.edu/from-shark-skin-to-speed/

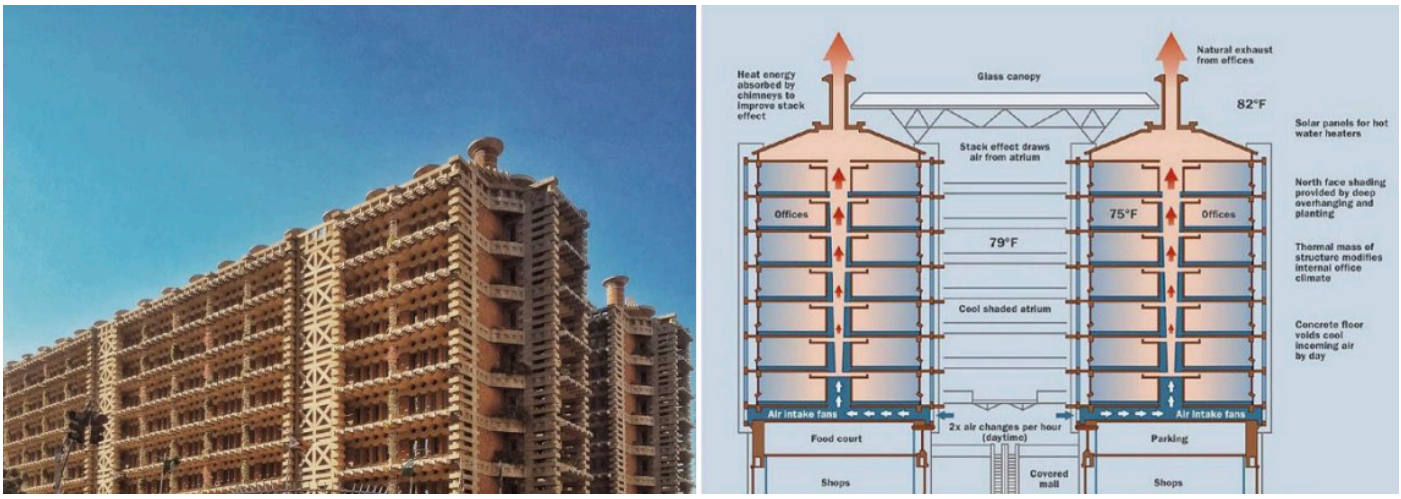
In the field of architecture, two well-know case studies of the application of biomimetics are the Beijing National Stadium, in China, and the Eastgate Building in Harare, Zimbabwe. The first one, designed by Swiss studio Herzog & de Meuron in collaboration with Arup-Sport and the China Architecture Design & Research Group, has a distinctive shape inspired by the structure of a bird's nest and stands out for its beauty and structural efficiency, dispensing with the need for additional materials to disguise the structure (Figure 2) (Rogers et al., 2008, p. 4; Mehta et al., 2019, p. 3161). On the other hand, the second example, designed by Zimbabwean architect Mick Pearce in partnership with engineers from Arup, uses biomimetics principles based on the natural ventilation of termite mounds (Figure 3). The termites inspired the creation of a natural convection cooling system. This system, combined with walls of different thicknesses and light paints, keeps the building at comfortable temperature levels without the use of traditional air conditioning (Mick Pearce, 2016).

Figure 2. The Beijing National Stadium on the left; and on the right, a bird's nest that served as inspiration for the development of the project.



Source. Viva Decora, 2022, available at https://www.vivadecora.com.br/pro/biomimetica/

Figure 3. Eastgate Building on the left; and on the right, a schematic diagram of the building's air exchange and cooling system.




Source. Never Enough Architecture, n.d., available at https://neverenougharchitecture.com/project/the-eastgate-centre/

However, the research presented goes beyond these traditional morphological and functional inspirations, proposing the incorporation of sound analogy into the design process. Sound analogy, in the context of biomimetics, refers to the use of sounds from soundscapes as a source of inspiration, rather than the shapes and functions of biological organisms.

## 2. Analogical design methods and analogies

The design process based on analogies is a methodological approach that stands out for its ability to provide new perspectives based on some pre-existing reference. Many discussions have been raised about design methodologies, and Schön (1992), in his book "Educando o professional reflexivo: um novo design para o ensino e a aprendizagem" (Portguese for "Educating the reflective professional: a new design for teaching and learning"), emphasises the importance of experimentation in design studios as an educational model for 'reflection-in action'. He argues that there is no single science that indoctrinates design practice, with studios being essential reflective and practical environments for learning.

Schön (1992, pp. 6-7) emphasises that the design process implies a type of learning by doing, where students start practising even before they fully understand what they are doing. In architectural design studios, for example, students start drawing before they understand the design concept, experiencing an initial phase of confusion that is part of learning.

Based on this perspective, directing bio-inspired design practice in a rational way becomes clearer by understanding the analogies and strategies that have already been established. Broadbent (1978, as cited in Tavsan et al., 2015, p. 490) identifies four methods applicable to the formation of

architectural style: pragmatic, typological, canonical and analogue. Tavsan et al. (2015, p. 490) state that the analogue method is one of the most efficient cognitive mechanisms for learning new concepts, developing ideas, solving problems and creating definitions.

Analogy, therefore, is seen as an effective means of teaching science, as highlighted by Brown (1993, as cited in Tavsan et al., 2015, p. 490). In architecture, analogies can be widely varied, covering natural, cultural and religious contexts, among others. Furthermore, design analogies based on existing references are widely used by architecture students, helping them to form a mental portfolio of possible design solutions.

The use of analogies in the design process can be very useful for developing innovative solutions, and according to Lawson (1993, cited in Tavsan et al., 2015, p. 491), analogies are used to process new data, generating information that is stored in long-term memory. This approach empowers designers and architects to apply familiar elements in addressing new challenges, enhancing the transfer of knowledge and adapting well-understood concepts to new contexts. In addition, the use of analogies in the design process promotes more detailed and in-depth learning. When students and architectural professionals explore analogies, they can not only replicate previous solutions, but also develop a more comprehensive and integrated understanding of the principles underlying those solutions. This translates into the development of an enhanced capacity for innovation, as this design process allows them to see beyond surface appearances and identify the fundamental patterns and processes that can be adapted to new situations. As an example, observing the hydrophobic properties of the lotus flower may inspire the development of self-cleaning building materials, demonstrating the applicability of functional analogy (Badarnah, 2012, p. 26).

Analogies also play a crucial role in the design process involving biomimetics, being an effective method for applying natural concepts to the creation of technological and sustainable innovations. They facilitate the transfer of knowledge and stimulate logical reasoning and creativity, which are essential for solving problems in different fields (Clementino et al., 2021/2022, p. 176). In this context, the use of analogies in biomimetics goes beyond simply inspiring or copying natural elements, requiring an in-depth understanding and adaptation of biological mechanisms to specific technological contexts (Santos, 2010, cited in Araújo, 2015, p. 34).

In biomimetics, analogies can be morphological, functional, ecological, anatomical, among others (Table 1). Each type offers a different approach to solving challenges, such as the morphological analogy of the Shinkansen bullet train (Figure 4) inspired by the kingfisher's beak, or the functional one, such as the self-cleaning surface inspired by the lotus flower (Figure 5).



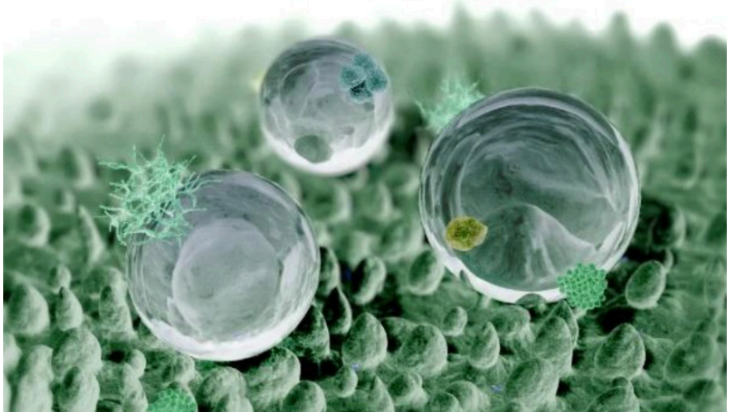


Figure 5. Magnified lotus leaf reveals its hydrophobic character.

Source. Staff, 2017, available at https://www.independent.com/2017/11/16/biomimicry-designing using-nature-model/

Figure 4. The remodelled Japanese Shinkansen bullet train inspired by the beak of the Common Kingfisher bird.

Source. Soares & Arruda, 2017, p. 31.

Table 1. Exemple of biomimetic analogies.

| Type of Analogy | Definition | References |
|---|---|---|
| **Organic** | Searches for balance between human organisms, works of art and mechanical systems, considering aesthetics and functionality. | Steadman, 2008, pp. 8-9. |
| **Classificatory** | Uses methods from botany and zoology to organise and categorise species, applying these methodologies to design. | Steadman, 2008, pp. 21-22, 25. |
| **Anatomical** | Compares the structure of buildings with the anatomy of animals, emphasising support and stability similar to the animal skeleton. | Steadman, 2008, pp. 38-39. |
| **Ecological** | Compares the shapes and functions of buildings with the anatomical adaptations of animals to the environment, considering climate, location and user needs. | Steadman, 2008, pp. 54-55. |
| **Darwinian** | Compares evolution in architecture with Darwin's biological evolution, emphasising trial and error and the selection of the best solutions. | Steadman, 2008, pp. 78-80. |

| | | |
|---|---|---|
| **Morphological** | Experimental search for formal and structural references in nature for projects, such as the Japanese Shinkansen bullet train inspired by the beak of the kingfisher bird (*Alcedo atthis*). | Bonsiepe, 1992, p. 50. |
| **Sensory** | Study of control and information transmission systems in natural and artificial contexts, aiming for optimisation and efficiency. | Arruda, 1993, p. 121. |
| **Functional** | Analysing functional attributes of biology, such as hydrophobic surfaces, for application in technological projects, such as the self-cleaning surface inspired by the lotus flower (*Nelumbo nucifera*). | Soares, 2016, p. 34. |
| **Symbolic** | Creation of abstract representations inspired by nature, with no direct relationship to biological shapes or functions, as can be seen in the works of Catalan architect Antoni Gaudí. | Soares, 2016, p. 38 |
| **Structural morphological** | Drawing inspiration for projects from structural elements in nature, such as the ribbed structure of the *Victoria amazonica* leaf, which served as inspiration for Joseph Paxton's Crystal Palace in England. | Clementino et al., 2021/2022, p. 178. |
| **Moviment** | Emulating the movement of natural elements to develop innovative solutions, such as the movement of a snake. | Clementino et al., 2021/2022, p. 180. |
| **Behavioural** | Interpreting the behavioural characteristics of natural elements that ensure their survival, such as the chameleon's camouflage. | Clementino et al., 2021/2022, p. 180. |

Source. Author, 2024.

The literature discusses several types of analogies, such as those addressed in the table above, but it is important to clearly understand the needs of what is intended to be developed and discern the most appropriate strategy to use in the design process. However, the analogies presented above are not and cannot be limiting, and new types can be added.

## 3. Methodology

This paper adopts a methodological approach based on a systematic review of the literature on biomimetics and analogies applied in the design process. The research is organised into two main stages: presentation of the concept of sound analogy as an extension of analogical possibilities; and the analysis of examples of applications of the design process in architecture based on analogies, whether biomimetic or not.

The literature review covers the analysis of the analogue design process from a biomimetic point of view, inspired by natural organisms, and from an associative point of view with the application of analogies in projects that are not necessarily biomimetic.

Case studies have been analysed that demonstrate the practical application of the concepts discussed, looking at examples of bio-inspired and non-bio-inspired projects to illustrate the diversity of approaches based on analogies. Finally, the research focuses on the discussion of integrating sounds from soundscapes into the design process as an analogue inspirational element by addressing the concept of Sound Analogy and pointing out sounds as auditory elements that can be incorporated to enrich the sensory experience of architectural projects.

## 4. Sound Analogy

Regarding sound analogy, and based on the concept defended by Benyus that biomimicry imitates the design and processes of nature (Benyus, 2011, p. 7), it is understood that sound is one of the processes through which nature expresses itself. Sound analogy therefore involves capturing and incorporating these sounds into design and architecture, providing a new dimension of inspiration. This approach is not limited to the mere replication of visual shapes but expands to include the auditory elements that characterise the natural environment, promoting aesthetically and functionally pleasing solutions. By integrating the sounds of the soundscape into projects, designers may create spaces that resonate with the harmony and complexity of natural ecosystems, aligning themselves with the biomimetics principles of sustainability and efficiency. The sound analogy proposes that the sounds of nature can provide a diverse source of inspiration, expanding both the aesthetics and functionality of projects. Monacchi & Krause (2017, p. 311) emphasise the relevance of soundscapes in human perception, arguing that natural sounds have a profound impact on the human experience, including on an emotional level. Thus, incorporating these auditory elements into design processes can result in more engaging and harmonious environments that resonate with the complexity and beauty of the natural world.

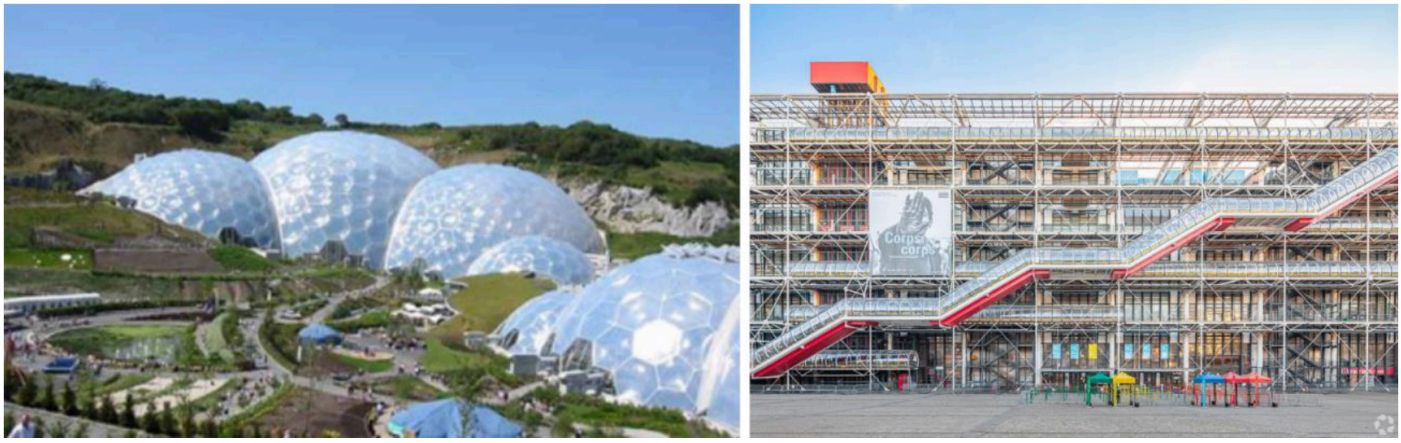
In this context, it is important to recognise the types of soundscapes that serve as “inspiring objects” used by the sound analogy as a Biomimetic means. The soundscape is categorised into four different types, each of which contributes differently to the acoustic composition of an environment. Biophony refers to the sounds emitted by living organisms in a specific habitat, such as the singing of birds, the buzzing of insects, the roaring of mammals and the croaking of amphibians. These biological sounds are important for understanding ecological interactions and the health of ecosystems (Krause, 2002, pp. 2-3; Liu et al., 2020, p. 1). Geophony, on the other hand, includes geophysical and non-biological sounds, such as the rumble of thunder, the sound of waves and wind, which contribute to the natural ambience of a space (Krause, 2002, pp. 2-3; Liu et al., 2020, p. 1). Anthropophony encompasses the sounds generated by human activities, from everyday conversations to

cultural events such as theatres and concerts (Krause, 2002, pp. 2-3; Liu et al., 2020, p. 1). Additionally, Technophony describes the sounds produced by the interaction of human technologies with the environment, such as the noise of engines and electronic devices, which have become prevalent in natural landscapes (Mullet et al., 2017, p. 326). While Anthropophony covers all sounds generated by humans, Technophony focuses specifically on sounds originating from technological processes. The research emphasises that analogies, whether biomimetics or not, are powerful vehicles for innovation (Soares & Arruda, 2017, pp. 39-40; Soares & Arruda, 2018, pp. 76-77). These analogies go beyond the simple replication of natural shapes, allowing for a deeper and more diverse exploration of the possibilities offered by nature. For example, the morphological analogy, which emulates the shapes and structures found in living organisms, can be complemented by functional analogies, which focus on replicating nature's efficient processes and mechanisms. By incorporating sound analogy, biomimetics can significantly expand its reach, introducing a new dimension of auditory inspiration and promoting more holistic and sensory innovation in design and architecture.

## 5. Results and Discussion

As already pointed out, biomimetics analogy in architecture involves the direct application of biological principles, shapes and processes in the development of architectural solutions. This method seeks to replicate the efficiency and functionality found in nature to tackle design challenges. One example is the Eden Project (Figure 6 - left), in Cornwall/England, designed by Nicholas Grimshaw. This complex houses several greenhouses that simulate different biomes, drawing inspiration from the structures of soap bubbles, carbon molecules and radiolarians to create geodesic domes that maximise sunlight and structural efficiency (Badarnah, 2012, p. 26; Jankovic et al., 2018, p. 184). Non-biomimetic analogies, although not based directly on biological processes, can also play an interesting role in architecture. This type of analogy applies concepts and ideas from other disciplines or contexts to architectural design. In this context, one can cite the Centre Georges Pompidou in Paris/France (Figure 6 - right), designed by Renzo Piano and Richard Rogers. This structure uses a design approach reminiscent of industrial engineering, where all the functional and structural elements of the building, such as ventilation ducts, escalators and pipes, are exposed on the outside in different colours (Perez, 2010). This design decision maximises internal space and transforms the building by promoting a high-tech aesthetic that is also functional.

Figure 6. Eden Project, United Kingdom (left), and Centre George Pompidou, France (right).



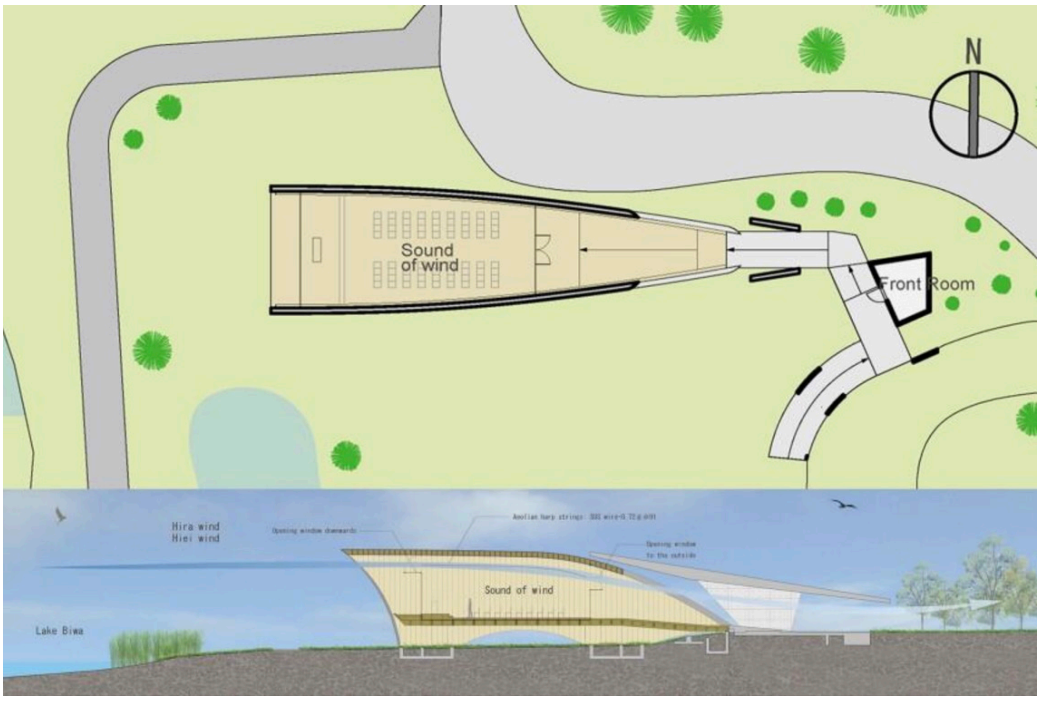
Sources. Jancovic et al., 2018, p. 187; Peruzzo, 2024, available at https://www.costar.com/article/698571902/a-franco-japanese-duo-to-design-the-centre pompidou-of-2030

Sound analogy, on the other hand, offers a new dimension of inspiration, utilising the sounds of the soundscape rather than just visible physical shapes and structures found in nature. This approach considers the soundscape - such as birdsong, the sound of the wind and the murmur of the waves - as natural elements that can influence architectural design, either in its morphological conception or in order to integrate, take advantage of or adapt the architectural work to the sounds of its surroundings. For example, integrating natural sounds into urban spaces may create more relaxing and harmonious environments, contributing to the well-being of users, while a noisy soundscape of heavy traffic may serve as a parameter for adapting the internal environment of a building through the use of suitable materials and kinetic structures that respond to the disturbance in real time; the use of materials such as steel cables and metal tubes in order to make the architectural work resonate with its own sound by integrating the wind flow from the soundscape.

In this context of sound analogy, the Sound of the Wind Chapel (Figure 7) in Moriyama/Japan serves as an unintentional example of how architectural elements can be integrated to amplify specific geophonic sounds, in this case, the wind. Thus, the project, which is situated in a strategic location, captures the movement of the air and uses architecture to harmonise and amplify the natural sounds of the environment, creating an immersive auditory experience for its users (RAA, 2020).

The chapel is designed to channel and intensify the whisper of the wind through its structure, using materials and shapes - such as steel strings installed at the top of the structure - that resonate with the air currents (RAA, 2020). Like musical instruments that use air as a means of producing sound, the chapel becomes an architectural instrument where the wind, interacting with the structure, produces a soundscape that is both a product of the design and a reflection of the surrounding nature.

Figure 7. Schematic plan and section of the chapel structure.




Source. Architizer, n.d., available at https://architizer.com/projects/sound-of-wind/

In addition to this case study, it is possible to mention the Living Chapel (Figure 8), located in the Orto Botanico in Rome, Italy. This is another example of how architecture can incorporate the landscape to create an immersive sensory experience. Designed by Gillean Denny and Julian Darius Revie, with the collaboration of students and experts, it emphasises a fusion of ecology and sound. Using a solar-powered irrigation system that activates aluminium drums made from recycled barrels, the chapel transforms the flow of water into a continuous melody (Cipolla, 2020; Sciortino, 2020).

Although the Living Chapel does not directly use the sounds of the surrounding nature, the project creatively integrates natural elements to harmonise with the local soundscape. The mechanism for producing sound through water and aluminium drums, designed inside the chapel, creates an ambience that resonates together with the environmental sounds of the Orto Botanico, merging cohesively with the geophonic and biophonic sounds of the garden. It is important to emphasise that although biomimetics uses analogies as a design method, not all analogies are biomimetic. Analogies can be drawn from a wide range of sources and applied in different ways in design. For example, kitsch architecture uses analogies that are often based on cultural, historical and popular elements, often in an exaggerated and decorative way. An example is the duck-shaped store in New York, referred to by Robert Venturi in the “duck” concept from his work “Learning from Las Vegas” (Venturi et al., 1972, p. 118). This construction stands out for its cartoonish and theatrical shape, serving more as a cultural and visual attraction than an attempt at functional efficiency (Figure 9).

Figure 8. Superior view of the Living Chapel, Rome, Italy.



Source. Sciortino, 2020, picture of Cappelli, n.d., available at https://metropolitanmagazine.it/living-chapel/

Figure 9. Long Island duck, New York, United States.



Source. Overstreet, 2021, available at https://www.archdaily.com.br/br/962640/quando-a inovacao-segue-a-funcao-os-designs-kitsch-da-arquitetura-pato.

These examples show that the field of analogies is broad and diverse, allowing for countless possibilities of application in the design process. In any case, it can be considered that the use of analogies, whether biomimetic or

not, can be seen as a means to facilitate the transfer of knowledge and the application of concepts already understood to new contexts.

## 6. Conclusion

Research on the use of analogies in architecture demonstrates the diversity and potential of these methodologies to promote the transfer of knowledge from an object, natural or not, visible or audible, to the design process. The biomimetic analogy stands out for its integration of natural principles, shapes and processes into architectural solutions, resulting in efficient, sustainable and aesthetically pleasing buildings, as exemplified by the Eden Project. Non biomimetic analogies, as exemplified by the Centre Georges Pompidou, show how concepts from other disciplines can inspire the creation of interesting and visually striking buildings.

As important as knowing what biomimicry is and differentiating the types of analogies, is knowing what does not fall within this scope. Kitsch architecture, in this sense, although it also uses an 'analogue' method as part of its creative process, adopts a different approach to the one discussed in this paper and often oscillates between the cartoonish and the decorative. This kind of architecture often copies or exaggerates stylistic elements in an excessive and literal way, creating structures that are more attractive for their visual appeal and immediate impact than for their functionality or integration with the environment, as evidenced by the duck-shaped building.

Although the sound analogy is still being explored, it can be seen that it has significant potential to enrich the sensory experience of users and promote a greater connection with the natural environment. This can be seen in the case of Chapel Sound of the Wind, where the architecture not only responds to the visual aesthetics of the environment, but also integrates and amplifies geophonic sounds, such as the wind, using the structure of the building to create an immersive auditory experience.
Additionally, sound analogy can be considered abstract, as sound usually does not directly correspond to a physical shape unless a vocabulary of shapes associated with sound parameters is established. This abstract characteristic allows for greater creative freedom in the design process, enabling designers to explore new aesthetic and functional dimensions as well. Thus, instead of visually replicating natural elements, sound analogy can inspire the creation of spaces that evoke specific acoustic atmospheres, for example.

## 7. Acknowledgement

We would like to thank the Fundação para a Ciência e a Tecnologia (FCT), from Portugal, for the financial support through the PhD scholarship reference 2023.02623.BD.

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# (46) Tissue Scaffolds: Robotic Hydrogel Extrusions for Advanced Design Applications. Ruining Xie (Institute for Advanced Architecture of Catalonia), Marcos Cruz (Bartlett School of Architecture, University College London) and Ricardo Mayor Luque (Institute for Advanced Architecture of Catalonia).

**ABSTRACT |** Tissue engineering refers to the attempt to create functional human tissues from cells in a laboratory. Its goals include repairing or replacing failed tissues and organs through 3D organ printing, as well as acting as a replacement for animal-based experiments. Tissue engineering relies on three important factors: identifying the right cells to do the job, the right scaffold to support the cell growth, and the right bioreactor to influence the development of the cells. This thesis takes part in developing the scaffolds, with the purpose of creating self supportive hydrogel structures through novel fabrication techniques developed from existing cutting-edge references in biomedical engineering, aiming at robotic extrusion printing tissue scaffolds for mammal organs and large-scale applications. Hydrogels made from 4% w/v sodium alginate solution with three times the mass of methylcellulose are used for printing, and CaCl2 solution is used for crosslinking if needed. Three robotic extrusion printing techniques are tested and compared, and a customized syringe pump end effector is derived, which allows for printing both paste and liquid alginate-based hydrogels. The rehydration property of paste alginate-based hydrogels is studied to print a 1:1 scale knee joint, and the self-supportive potential is challenged when printing a 1:1 heart. A marine landscape of size 400 x 350 x 90 mm is created to be demonstrated as a large-scale application.

**KEYWORDS |** Hydrogel Extrusions, Material Rehydration, Printing Scaffolds, Tissue Engineering, Robotic Fabrication

## INTRODUCTION

Tissue engineering develops from the field of biomaterials and refers to combining scaffolds, cells, and biologically active molecules into functional tissues, aiming at assembling fully functional constructs that restore, maintain, or improve damaged tissue or a whole organ. (“Tissue Engineering,” 2022) Bioinks are used to bioprint tissue. Hydrogels are currently the first choice and the most appealing bioink candidates used for cell encapsulation and printing. (Farhat et al., 2021) They are polymers capable of absorbing and retaining large volumes of water or biochemical solutions, enabling living cells to reside and sustain their function. They can either be of natural or synthetic origin. The main issue encountered when bioprinting hydrogels is the difficulty to shape them into complex geometries and to keep their structural integrity post-printing because of their inherent fragility. Hence, sustaining and enhancing the fidelity of hydrogel scaffolds has become a crucial matter in 3D bioprinting. (Farhat et al., 2021)
Cross linking is a stabilization process in polymer chemistry which leads to multidimensional extension of polymeric chains resulting in network structure.

Cross-link is a bond which links one polymer chain to another, and it can be ionic or covalent. A liquid polymer (where the chains are freely flowing) can be turned into a ‘solid’ or ‘gel’ by cross-linking the chains together. Cross-linked polymers are important because they are mechanically strong and resistant to heat, wear and attack by solvents. However, the drawback associated with cross-linked polymers is that they are relatively inflexible when it comes to their processing properties because they are insoluble and infusible. (Maitra et al., 2014) In particular, alginate-based hydrogels can find uses in a wide range of applications, including in the encapsulation field. This type of hydrogels is usually ionically crosslinked using calcium sources giving rise to products with limited internal crosslinking. (Pilipenko et al., 2019)

The contributing technologies to 3D bioprinting to create living tissue constructs encompass in situ 3D bioprinting (MacAdam et al., 2022), which includes bedside mounted and hand-held bioprinting, and in vitro 3D bioprinting (Farhat et al., 2021), which includes inkjet, micro extrusion, and light-assisted bioprinting. Micro extrusion bioprinting is arguably the most widespread system used for bioprinting. (Farhat et al., 2021) It uses either pneumatic (e.g. compressed air) or mechanical (e.g. piston/screw) forces to extrude a continuous filament of bioink. The techniques embraced by researchers for extrusion-based 3D bioprinting processes include direct ink writing, printing in coagulation bath, freeform reversible embedding of suspended hydrogels (FRESH), and coaxial extrusion. (Costantini et al., 2018) Works have been done using 3D bioprinting hydrogels as scaffolds for stem cells and microalgal cells. Successfully transplanted 3D bioprinting organs include bladder (Wake Forest Institute, 2001) and ear (3DBio Therapeutics, 2022). Hydrogels are also used to incorporate living photosynthetic microalgae, for the purposes of delivering a continuous supply of oxygen to the target tissue after bioprinting (Wang et al., 2022), and for potential applications within architecture and the built environment. A 1000 × 500 mm fibrous algae-laden hydrogel panel is additively deposited to demonstrate the methodology for scale-up. (Malik et al., 2019)

This paper addresses three key objectives. First, it reevaluates the potential of alginate-based hydrogels by examining their drying and rehydration properties, shrinkage and expansion behavior, and their interactions with crosslinking agents, with the goal of identifying new applications. Second, it integrates advanced robotic fabrication and additive manufacturing techniques into the development of hydrogel scaffolds, aiming to enhance 3D bioprinting prototypes. Finally, it explores the extension of hydrogel scaffold applications beyond tissue engineering to include the built and natural environments, with the potential to support the growth of desired organisms.

## 1. Materials and Methods

### 1.1. Alginate-Based Hydrogels

This study utilizes both paste and liquid alginate-based hydrogels for printing. For making paste alginate-based hydrogels, reference from Malik et al.

(2019) is calibrated. 2-5% w/v sodium alginate solution is added by methylcellulose powder of three times the mass of that of the sodium alginate powder. Subsequently, a few drops of blue food coloring are added and properly mixed to allow the mixture to have a more obvious color. After obtaining a homogeneous paste, the mixture is left at room temperature for more than two hours to allow the swelling of methylcellulose. Finally, for making liquid alginate-based hydrogels, 4.5% w/v sodium alginate solution is added by a few drops of blue food coloring.

### 1.2. Crosslinking Agents and Gelatin Slurry Support Bath

CaCl2 solution is used for crosslinking from the reference by Malik et al. (2019). The 1 M CaCl2 solution used in this study is made by dissolving 11.1 g CaCl2 flakes or pellets in 100 ml of water. The prints are crosslinked either by spraying CaCl2 solution during or after printing, or by dipping them in CaCl2 solution immediately after printing.

To print liquid alginate-based hydrogels, a gelatin slurry support bath is needed. A modified version is made from a reference (Hinton et al., 2015) because of the limited equipment available. Water is heated to 40-45°C, and to every 100 ml of water, 4 g of gelatin is added. After the gelatin is dissolved, CaCl2 flakes or pellets of 0.04 times the weight of the gelatin are added. After the CaCl2 flakes or pellets are dissolved, the container of the solution is sealed properly and put into a fridge of temperature around 4°C. The gelation time depends on the volume of the solution. For example, 200 ml of such solution requires around 5 h 30 min of gelation time. The gelatin slurry support bath changes from liquid state to gel state after the gelation processes.

### 1.3. Extrusion-Based 3D Bioprinting

Three existing extrusion-based 3D bioprinting techniques, namely direct ink writing, coaxial extrusion, and freeform reversible embedding of suspended hydrogels (FRESH), (Costantini et al., 2018) are studied and adapted to robotic printing for the purpose of this thesis. Hence, adapted names are given to each, namely mono extrusion, dual extrusion, and reinforced extrusion, to show their relative characteristics. First, mono extrusion is to extrude paste alginate-based hydrogels only. Second, dual extrusion is to extrude paste alginate-based hydrogels and the crosslinking agents simultaneously. Last, reinforced extrusion is to extrude liquid alginate-based hydrogels in a gelatin slurry support bath, such that the prints are reinforced during printing.

ABB IRB 120 and ABB IRB 140 robots are being used to conduct the printing processes. Consequently, different end effectors are mounted to the flanges of the robotic arms for each printing technique (Figure 1). Mono extrusion uses a single screw driven end effector, with its valve connected to a pneumatic driven cartridge with a piston inside. Two digital outputs are involved here, with one controlling the pneumatic pressure and the other one controlling the

motor screw. Dual extrusion uses two screw driven end effectors, with their ends connected by customized nozzles to allow the coaxial extrusion. The end effector is designed at the Institute for Advanced Architecture of Catalonia (IAAC) by Mayor-Luque et al. (2024), and the nozzle is later customized to a coaxial one by the author. Two digital outputs control the pneumatic pressure and the motor screws of the two screw driven end effectors simultaneously. Reinforced extrusion uses a customized syringe pump end effector made by attaching a syringe to a C-Beam linear actuator using customized connection elements. A needle of suitable size is attached to the bottom of the syringe.

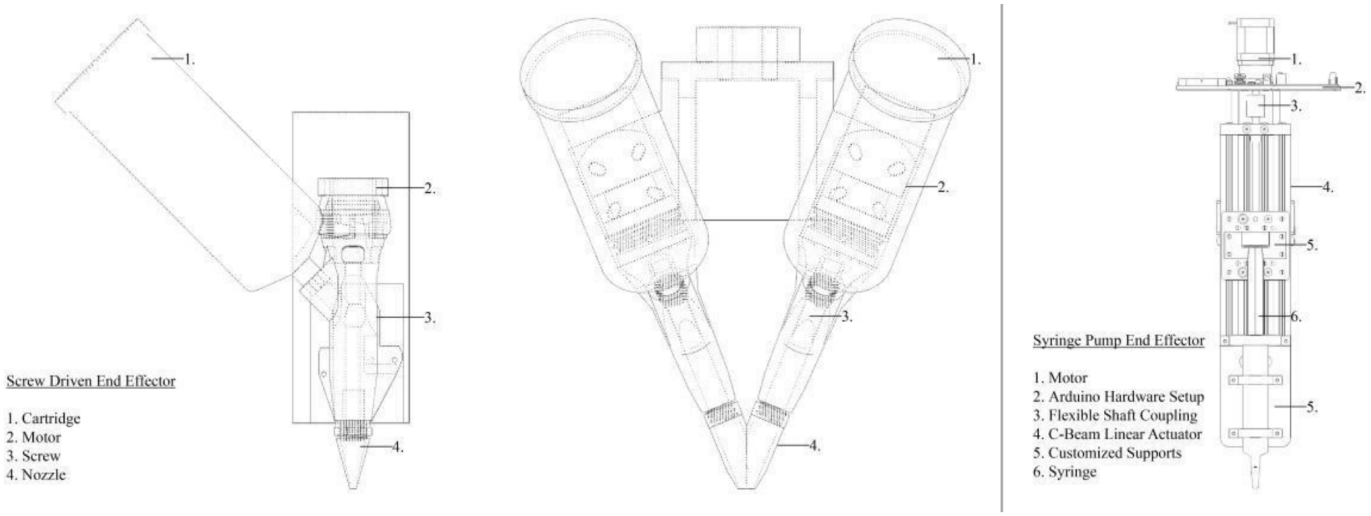


Figure 1. Scheme of the three used end effectors.

### 1.4. Parametric Modelling and Printing Paths

To conduct the printing processes, a design-to-fabrication approach is used. Surface (or curve) geometries are modeled, sliced into curves, and divided into geometrical target points, which are then used for the robotic arms to travel during printing. The mechanics of the robotic arms' printing movement, including layer heights, distances from deposition platform, and points and orientations of extrusion, are generated using the Rhino 7 plugin Grasshopper and its plugin Robots.

## 2. Experimental Results

Three existing extrusion-based 3D bioprinting techniques, namely shear thinning, coaxial extrusion, and printing in support bath, (Costantini et al., 2018) are studied and adapted to robotic printing for the purpose of this thesis. Adapted names are given to each, namely mono extrusion, dual extrusion, and reinforced extrusion, to show their relative characteristics.

### 2.1. Mono Extrusion

For mono extrusion, four prints of various patterns and techniques are involved, including vertical extrusion and print on surface (Figure 2). For the

three vertical extrusion prints, CaCl2 solution is sprayed during printing after the deposition of each layer, and it is sprayed again after printing for the whole prints. It is observed that the alginate-based hydrogels get crosslinked so quickly such that this process of crosslinking during printing affects the adherence of the next layers. This process of crosslinking during printing is modified to spraying CaCl2 solution to a few parts of one layer, so the next layer can properly adhere from the parts that are not crosslinked, and spraying the other parts for the next layer. In such a way during printing, the prints can both be strengthened because of crosslinking for them to go higher, and get adhered properly because of the parts of each layer that are not crosslinked. Despite being crosslinked thoroughly after printing, the three vertical extrusion prints still end up with shrinkage and deformation to different extents after some days.

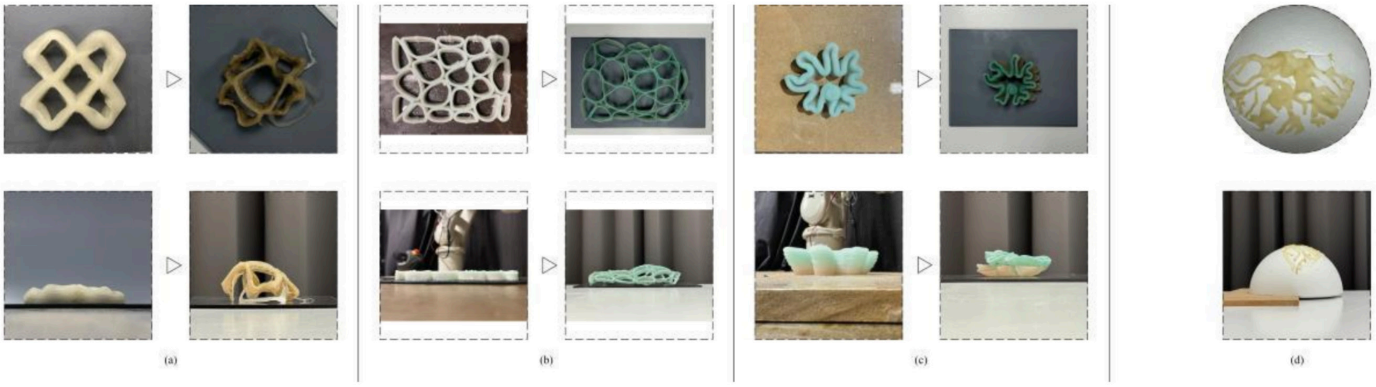


Figure 2. Vertical extrusion: (a). Lattice print test; (b). Voronoi print test; (c). Differential growth print test. Print on surface: (d). Shortest walk print test.

| Test | SA | MC | Original Size | Nozzle | Layer Height | Layer Number | Printing Pressure | Printing Speed | Crosslinking | Drying Days |
|---|---|---|---|---|---|---|---|---|---|---|
| (a) | 2% w/v | 3x SA dry mass | 132 x 132 x * mm | 5.0 mm | 2.5 mm | 13 | 0.5 bar | 19% | Yes | <12 |
| (b) | 4% w/v | 3x SA dry mass | 300 x 290 x 20 mm | 5.0 mm | 2.5 mm | 8 | 1.5 bar | 19% | Yes | <7 |
| (c) | 4% w/v | 3x SA dry mass | 122 x 108 x 25 mm | 5.0 mm | 2.5 mm | 10 | 2.5 bar | 10% | Yes | <5 |
| (d) | 5% w/v | 3x SA dry mass | 250 x 125 x 125 mm | 5.0 mm | 2.5 mm | 1 | * | * | No | 2 |

SA = Sodium Alginate; MC = Methylcellulose; * = Data not recorded

Table 1. Mono extrusion parameters.

From the printing results (Table 1), it is observed that the higher the percentages of water contained in the alginate-based hydrogels, the less the pressure is needed to extrude the hydrogels, and the larger the tendencies for each layer to merge with the ones below, resulting in a certain level of collapsing. The percentages of water contained in the alginate-based hydrogels also affect the shrinkage and deformation results. The higher the percentages, the larger the shrinkage and deformation because larger proportions of the bodies are lost.

## 2.2. Dual Extrusion

For dual extrusion (Table 2), two printing setups with different nozzles and printing materials are being tested (Figure 3). The first one uses a printing setup with one cartridge filled with paste alginate-based hydrogels made from 4% w/v sodium alginate plus three times the mass of methylcellulose, and the other one filled with a paste material that includes CaCl2. The cartridge is designed in a way such that it can only contain paste materials, but not liquid, so the CaCl2 solution used before cannot be used here for crosslinking. There are not any suitable paste crosslinking agents being found in this experiment, so a printing material made from CaCl2 and agar agar is used here to demonstrate the printing idea. Three prints of the same shape and various layer heights are conducted, and it is observed that the shorter the layer height, the better material 2 is being printed, and the better it adheres to material 1, though pieces of material 2 still fall down during the transfer of the prints.

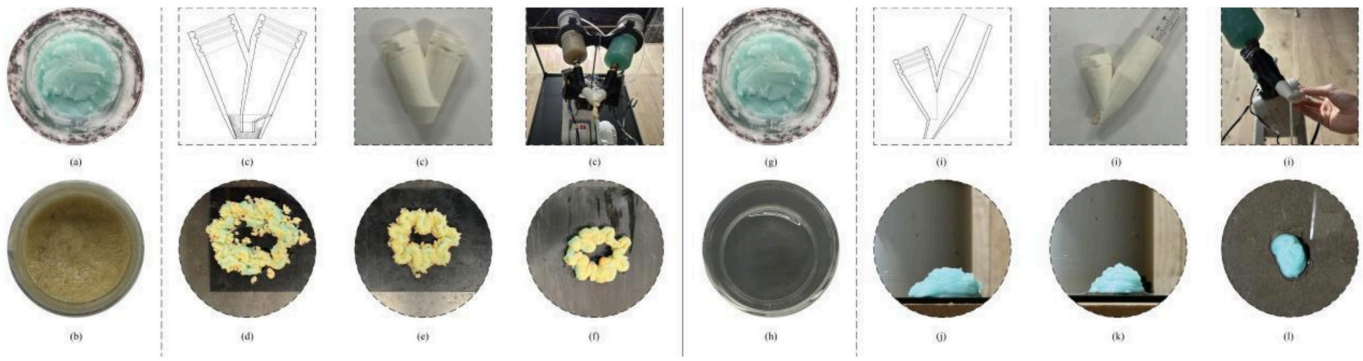

Figure 3. Printing test 1: (a). Printing material 1: paste alginate-based hydrogels; (b). Printing material 2: a paste material that includes CaCl2; (c). Coaxial nozzle and printing setup; (d-f). Printing results. Printing test 2: (g). Printing material 1: paste alginate-based hydrogels; (h). Printing material 2: CaCl2 solution; (i). Coaxial nozzle and printing setup; (j-k). Printing results; (l). Top view of (k).

| Test | Material 1 | Material 2 | Original Size | Nozzle (Out) | Nozzle (In) | Layer Height | Layer Number |
|---|---|---|---|---|---|---|---|
| (d) | 4% w/v SA + 3x mass MC | 5.4 M CaCl2 + 0.8x agar | 122 x 108 x * mm | 9 mm | 4 mm | 5.5 mm | 2 |
| (e) | 4% w/v SA + 3x mass MC | 5.4 M CaCl2 + 0.8x agar | 122 x 108 x * mm | 9 mm | 4 mm | 4.0 mm | 3 |
| (f) | 4% w/v SA + 3x mass MC | 5.4 M CaCl2 + 0.8x agar | 122 x 108 x * mm | 9 mm | 4 mm | 2.5 mm | 2 |
| (j) | 4% w/v SA + 3x mass MC | 1 M CaCl2 | 40 x 33 x 14 mm | 4 mm | 0.8 mm | 1.0 mm | 14 |
| (k) | 4% w/v SA + 3x mass MC | 1 M CaCl2 | 40 x 33 x 14 mm | 4 mm | 0.8 mm | 1.7 mm | 8 |

SA = Sodium Alginate; MC = Methylcellulose; * = Data not recorded

Table 2. Dual extrusion parameters.

The second printing test tries to print with CaCl2 solution. It uses only one screw driven end effector, but with the nozzle changed to a customized coaxial one such that a syringe can be assembled into it. In this case, the cartridge on the end effector is filled with the same paste alginate-based hydrogels as above, and the syringe is filled with CaCl2 solution. During the printing processes, the hydrogels are extruded by the pneumatic driven piston inside the cartridge, and the CaCl2 solution is extruded by hand. Because of the manual extrusions of the crosslinking agents, it is hard to control the crosslinking processes according to the printing processes. Thus to continue this set of printing experiments, it is proposed to have an end effector with a co-axial nozzle, one cartridge filled with alginate-based hydrogels, and the other one filled with CaCl2 solution, both connected to the robotic arm, so that the speeds and quantities of each material can be properly controlled throughout the printing processes.

## 2.3. Reinforced Extrusion

For reinforced extrusion, there are six parameters involved in the printing processes that affect the printing results (Table 3). To start the printing processes, liquid alginate-based hydrogels are filled into the syringe by moving the upper part of the syringe up using one of the two digital outputs of the customized syringe pump end effector. The gelatin slurry support bath is placed under the end effector after the syringe is filled with liquid alginate-based hydrogels. After calibration, the upper part of the syringe is moved down using the other digital output to extrude the liquid alginate-based hydrogels into the gelatin slurry support bath for printing. It is observed that, as the needle moves inside the bath, certain gaps are created within the bath along the needle moving path, thus causing the printing liquid to spread to an extent more than wanted, which affects the resolution of the prints.

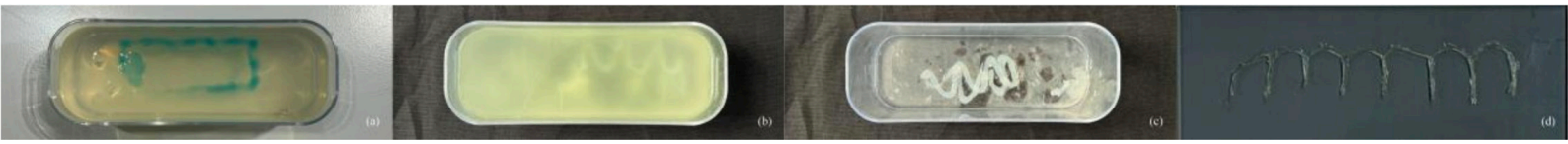

Figure 4. States of gelatin slurry support bath and print: (a). Directly after printing: gelatin slurry support bath holds print; (b). Left under room temperature: gelatin slurry support bath melts and print sinks, no change after putting back in fridge; (c). Pouring out gelatin slurry support bath: print has gel texture; (d). Drying print: print becomes crispy.

| Motor Speed | Printing Speed | Syringe | Needle | Printing Material | Support Bath |
|---|---|---|---|---|---|
| Maximum | 10% | 60 ml | 1.2 x 40 mm | 4.5% w/v SA | 4% w/v Gelatin + 0.04x mass CaCl2 |

SA = Sodium Alginate

Table 3. Reinforced extrusion parameters.

After printing, the container is left aside under room temperature without being sealed. It is observed that the gelatin slurry support bath melts gradually from the top into liquid state, and after a period of time, it melts completely, leaving the print sink to the bottom of the container. The print loses its blue food coloring while the bath melts. The container is then put again into a fridge of temperature around 4°C, but the bath remains in its liquid state, and never gelates again, indicating that the modified version of the recipe of the gelatin slurry support bath is not reusable. The print is then taken out from the container. It becomes translucent, smooth and bouncy. The print dries and becomes crispy after a period of time (Figure 4).

To compare and conclude, the materials preparation and printing setups are simpler for printing paste alginate-based hydrogels than printing liquid ones. Within paste alginate-based hydrogels, the ones made from 4% w/v sodium alginate plus three times the mass of methylcellulose are easier to prepare compared to the ones with less water content, and they have better printing results compared to the ones with more water content, thus they are chosen to conduct further experiments. The screw driven end effectors have larger cartridges, but they can only print paste alginate-based hydrogels, while the customized syringe pump end effector has a smaller cartridge, but it can print both paste and liquid alginate-based hydrogels, and it is simpler to clean, as only the syringe is needed to be replaced. Thus for further experiments, the customized syringe pump end effector is used for small-scale printing, and the screw driven end effectors are used for large-scale printing.

### 2.4. Rehydration Experiments

Two material experiments are conducted to investigate the reactions of printed alginate-based hydrogels to crosslinking agents and to water, and the respective effects on their rehydration properties. For the first material test (Figure 5), three identical prints with lattice structures of sizes 40 x 40 x 3 mm (1 mm per layer, three layers; nozzle size 2 mm) are created in order to form a comparison group. After printing, the three prints are left in the air to allow full shrinkage, which is achieved after one day because of the small and thin sizes of the prints. Deformation to different forms is observed, and the material hardness changes from sticky and spongy directly after printing to hard and crispy after full shrinkage.

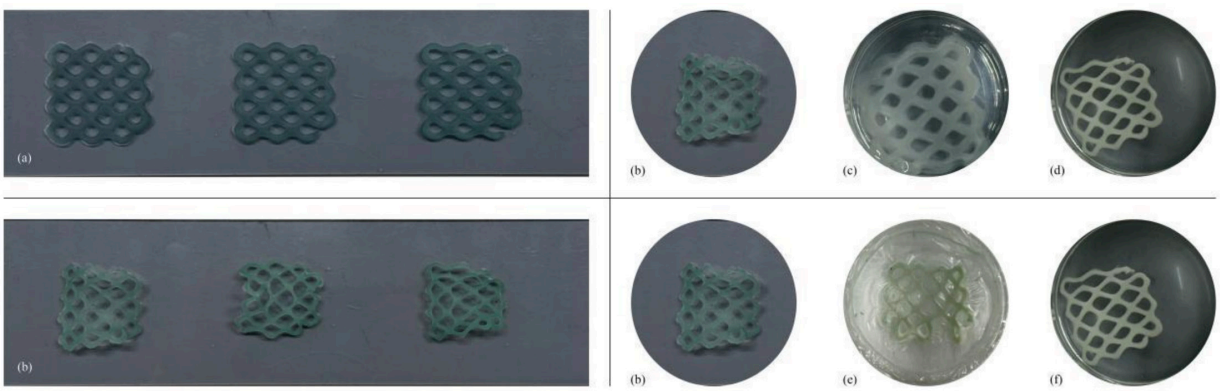

Figure 5. (a). Three identical prints; (b). After drying; (c). Putting one print in water; (d). Putting another in CaCl2 solution; (e). Drying (c).; (f). Taking (d). out from CaCl2 solution and putting it in water.

To make a comparison, one print remains in the air, one print is put in tap water, and the remaining one in 1 M CaCl2 solution. The print in water becomes soft and expands in size after a few hours, while the one in CaCl2 solution remains hard but becomes less crispy, compared to the one left in the air. The beaker with the print in water is left aside for the water inside to evaporate. After some time, the water fully evaporates, and the print is dried again. It is observed that there is a thin transparent film of the shape of the base of the beaker formed at the bottom and stuck to the print, and the thin transparent film is easily removable from the print. The print in CaCl2 solution is moved to water after it becomes less crispy. This time, there is no obvious change in terms of material properties observed. The print retains its shape and hardness, instead of expanding and becoming soft.

Therefore, the following conclusions can be drawn from this set of experiments. Alginate-based hydrogel prints, without crosslinking, will shrink largely. Crosslinking by CaCl2 solution still works to some extent even after the complete shrinkage of the prints. Alginate-based hydrogels retain their properties of rehydration and drying to become soft and hard, expanding and shrinking respectively, but they lose such properties once they are crosslinked at a certain stage.

The second material test takes a step further of the rehydration property of alginate-based hydrogels, and investigates the merging property of the rehydrated parts to other rehydrated parts or to new prints (Figure 6). Four identical prints with lattice structures of sizes 60 x 60 x 18 mm (1.5 mm per layer, 12 layers; nozzle size 2.2 mm) are created to conduct the merging experiments. Because of their larger sizes, this time it takes five days for the prints to fully dry. About 1/3 of shrinkage is observed, with the lengths and widths from 60 mm to 40 mm, and the height from 18 mm to 12 mm, though there is not much deformation. The prints become hard after drying, though not crispy because of their thicknesses.

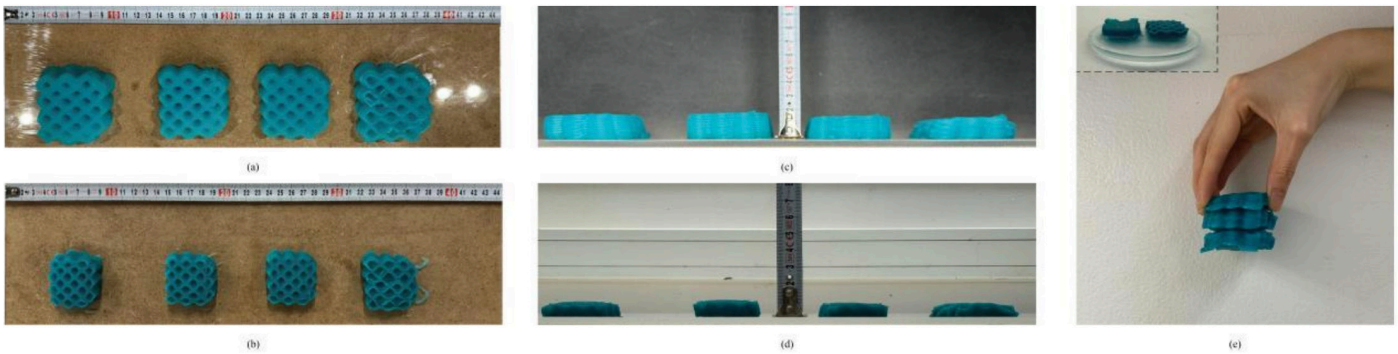

Figure 6. (a). Original size: 60 x 60 mm; (b). After drying: 40 x 40 mm; (c): Original height: 18 mm; (d). After drying: 12 mm; (e). Rehydration and merging.

After complete shrinkage, three prints are taken further for the merging tests. One print is rehydrated on the bottom side, one print on the top side, and the remaining piece on both sides. The prints are placed on a lid of a few millimeters height of water to get rehydrated. It is worth noting that only the parts that touch the water get rehydrated, and this effect does not spread to the parts left in the air. After the rehydrated parts become soft, the three prints are placed one on top of the other, with a little compressive force added by hand to merge the rehydrated parts better. It is observed that the rehydrated parts stick to each other. The new piece formed by merging the three rehydrated prints together is then held up in the air. It can be seen that the rehydrated parts form quite strong connections with each other, such that the three prints can hold the ones below up without falling apart. The three prints disconnect only when an external force is added to tear them apart.

## 3. Case Studies: Experimental Scaffold Printings

### 3.1. Knee

This prototype is a knee joint of 1:1 scale (Figure 7), where the bones are printed with plastic, and the soft tissues are printed with paste alginate-based hydrogels made from 4% w/v sodium alginate plus three times the mass of methylcellulose.

The digital models of the bones are downloaded online from GrabCAD and Thingiverse and modified from there, before being printed with plastic. The printing paths of the soft tissues are created by selecting the faces of wanted areas of the digital models of the bones, choosing the most suitable orientation for printing, and generating parallel lines along that orientation to be projected to the bones as printing paths.

A setup is fabricated for holding the bones and for calibrating during the printing processes of paste alginate-based hydrogels. The cartilage on each bone is printed separately first. Directly after printing, the bones are assembled together using the setup. A rotatable mechanism allows the ligaments on each side to be printed facing up, minimizing the possibility of meeting the singularities of the robotic arm, as well as avoiding the necessity of calibrating again when changing sides. The amount of paste alginate-based hydrogels used for printing the cartilage and the ligaments is 120 ml.

After printing the cartilage and the ligaments without crosslinking, the model is left in the air for drying, and it takes two days for it to dry completely. The rehydration is conducted at this stage. Water is sprayed on the parts printed with paste alginate
based hydrogels. After they become sticky, newly made paste alginate-based hydrogels of the same composition are applied by hand to cover the knee joint to demonstrate muscle. The model is then crosslinked by spraying CaCl2 solution. It is observed that the previously printed paste alginate-based hydrogels and the newly applied one’s merge well together.

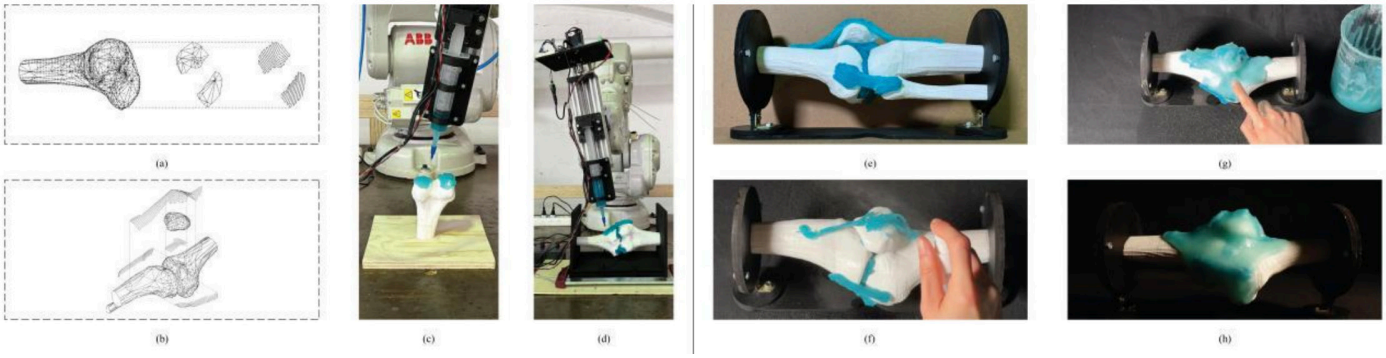

Figure 7. (a). Cartilage printing paths; (b). Ligaments printing paths; (c). Cartilage printing; (d). Ligaments printing; (e). Printing results; (f). Rehydration after drying; (g). Merging with new paste alginate-based hydrogels; (h). Final results.

To continue this prototype, the following aspects can be investigated. The potential stretchability of alginate-based hydrogels under various circumstances, for example, inside water after being crosslinked, can be tested, so that the knee joint can bend to a certain extent. The scanning processes can be introduced to the workflow, so that when certain areas are damaged, customized prints can be created. The potential applications of this prototype also include prostheses, such that the artificial limb can be biologically connected to the amputee.

### 3.1. Heart

This prototype is a heart of 1:1 scale (Figure 8) printed with paste alginate-based hydrogels made from 4% w/v sodium alginate plus three times the mass of methylcellulose. A digital model is downloaded online from CGTrader to create printing paths, which are done by generating horizontal contours of the digital model. The distance between contours is the layer height, in this case 1.5 mm. The contours are then divided into eight groups, such that they can be printed separately with minimal supports, each group with a flat surface at the bottom. But when printing with paste alginate-based hydrogels, certain groups cannot support themselves, and therefore they are subdivided into smaller groups. The amount of paste alginate-based hydrogels used for printing is 60 ml.

After printing, each group is put in a CaCl2 solution for crosslinking. When all groups are done, the crosslinked prints are taken out from the CaCl2 solution to be glued together by super glue. At this stage, the texture of the prints become hard and smooth, and the prints become flexible to a certain extent. The finished prototype is then stored in a container filled with CaCl2 solution. No obvious shrinkage or deformation is observed afterwards.

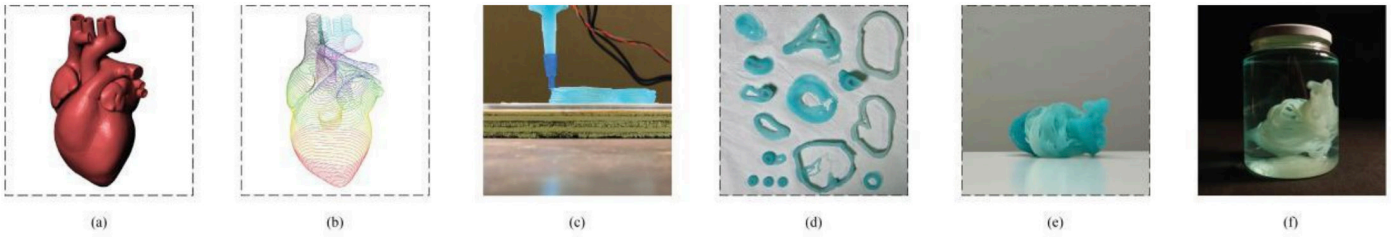

Figure 8. (a). Digital model; (b). 8 groups of printing paths; (c). Printing processes; (d). Printing results after crosslinking; (e). Gluing parts together; (f). Final results.

To continue this prototype, the following aspects can be investigated. If there is a way to only crosslink the middle parts of each print and leave the edges as they are, then the rehydration property of paste alginate-based hydrogels can be used to assemble the prints without using any glue, making the prototype a heart purely made of paste alginate-based hydrogels. Also, the printing paths can be better designed to achieve the complexity of the human heart.

### 3.1. Marine Landscape

This prototype enlarges to an environmental scale (Figure 9) of printing paste alginate-based hydrogels made from 4% w/v sodium alginate plus three times the mass of methylcellulose. It takes reference from Archireef's Reef Tiles, which are 3D-printed in terracotta clay to allow the corals that live on top to easily adapt to the new environment and maintain an additional protection. The Grasshopper plugin Kangaroo is used to create a differential growth pattern, which is then lofted to create the bottom part of the print. The processes include drawing a rectangle of the size of the container, dropping random points onto it, shrinking the rectangle, drawing circles centering at the points, and applying the differential growth algorithm to the shrunken rectangle such that the growth avoids the circles. The top part is created by scaling the sizes of the circles and lifting them vertically, in order to introduce another biomimetic shape.

The size of the design is 450 x 300 x 90 mm, with the bottom half as the blue part, and the top half as the red part. The layer height is 1.5 mm, which means that 30 layers are needed for each part. It is observed that, without crosslinking, a maximum of eight layers can be printed in one go before the layers collapse and merge together. Then, the prototype is printed in groups of four to eight layers each, which are crosslinked before being assembled together. For the bottom half, each layer requires 100 ml of materials. For the top half, due to time constraints, only a few layers are printed. Finally, a total of around 3000 ml of materials are used for printing.

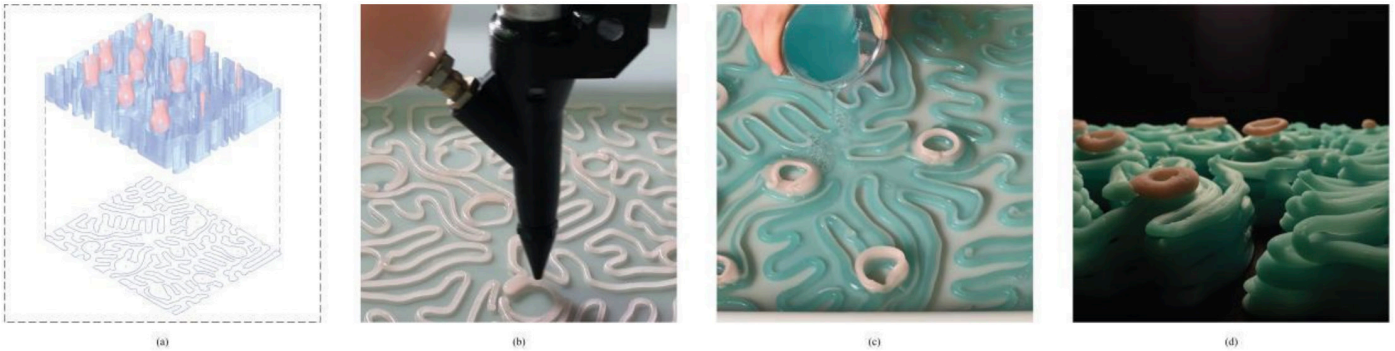

Figure 9. (a). Digital design; (b). Printing processes; (c). Crosslinking processes; (d). Final results.

To continue this prototype, the following aspects can be investigated. During printing, CaCl2 solution can be carefully poured until the height of a few layers lower than the current one, by doing so giving strength to support more layers without affecting the mergers of the current layer to the one below, so that the whole print can be done in one go. After printing, the prototype can be put in sea water to observe the reaction. Supports can be designed, separately or together with the marine landscape, so that the prototype can be moved easily.

## 4. Conclusions

The focus of the present work is to make use of certain properties of alginate based hydrogels in organ printing and large-scale applications. The initial material tests demonstrate the rehydration property of paste alginate-based hydrogels without crosslinking. This property allows dried prints to be re-hydrated to be printed on, and it is lost if the prints are crosslinked by CaCl2.

Screw driven end effectors and a customized syringe pump end effector are used during the robotic extrusion tests. Screw driven end effectors can print paste alginate-based hydrogels, but not liquid ones. The advantages of screw driven end effectors include precise extrusion, large cartridge, and the separation of cartridge and nozzle. The customized syringe pump end effector can print both paste and liquid alginate-based hydrogels. Other advantages of the customized syringe pump end effector include easy cleaning.

Three prototypes, a knee joint of 1:1 scale, a heart of 1:1 scale, and a marine landscape of size 400 x 350 x 90 mm, are printed with paste alginate-based hydrogels to demonstrate the findings.
To bring this research further, the following directions are proposed. For large scale applications in the natural environment, a possible case could be artificial reefs. Existing examples include Archireef and XtreeE among others, extruding materials ranging from clay to concrete, with biomimetic forms, which have attracted species undersea. It is therefore suggested that hydrogels could play a similar role in such an environment, as being surrounded by water prevents it from shrinking and deforming.

For large-scale applications in the built environment, a possible case could be multi-material printing to assist the bioreceptivity of materials. Hydrogels can be printed directly into large-scale panels, (Malik et al., 2019) or they can be applied to concrete panels to assist the growth of organisms. (Cruz, 2020) Hence, it is suggested that, with a suitable multi-material printing system and calibrated materials, it is possible to print bio receptive architectural elements with hydrogels having wanted patterns.

For applications beyond tissue engineering, possible cases could be robotic or prosthetic living tissues, as mentioned by Hugh Herr and others, to assist the functionality and adaptivity of the prosthesis limb to the patient. (Menzel & D'Aluisio, 2000)

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# (O3) If It Were Real? Exercises for Teaching and Learning Biodesign. Elisa Strobel Do Nascimento (Universidade Federal do Paraná) and Adriano Heemann (Universidade Federal do Paraná).

**ABSTRACT |** Biodesigned objects are still uncommon in our day-by-day experience, as they are relatively new and still face some feasibility challenges. This could lead to the impression that biodesigning would result mostly in concepts that are unlikely to be materialised or used. This impression might impact the mindset of beginner students when biodesigning. If it were real? The aim was to help students imagine. To do so, the key was to bring the objects that the students were biodesigning closer to existing products that they already possibly knew – and closer to our production, circulation, and consumption life. This article reports on simplified and adapted pricing and product perceptual positioning exercises within biodesign beginners' projects. Students' feedbacks suggest that the exercises worked in imagining their products closer to what they felt was "real".

**KEYWORDS |** BIODESIGN, TEACHING AND LEARNING, PRICING, PERCEPTUAL POSITIONING MAPS

## INTRODUCTION

Biodesigned objects, designed with "living materials", are not as common in everyday life yet. Most designs consumed are made of wood, plastics, metals, and ceramics - and not of mycelium, bacterial cellulose, or moss. This lack of repertoire and lived experiences with biodesigned objects might interfere with how young designers learn to biodesign. It might give students the impression that biodesigning does not leave the conceptual level. There is no problem with designing things to a conceptual level, however, we could imagine that the mindset when designing something knowing that it will not be materialised and will not be really used – is different. Now, if we try to exercise, if we try to imagine placing the biodesigned concept in our present production, circulation, and consumption life? What if we could attribute it a price and imagine it beside other products that have already been materialised, which are already in the system, products we already know? Would this change student's perspectives?

This article tells a small part of a 35-day experiment for testing a biodesign teaching and learning framework in a 3rd year Product Design undergraduate course at Universidade Federal do Paraná – Curitiba, Brazil. The article focuses on a set of exercises within the framework - where students use basic adapted marketing tools to place their biodesigns in relation to existing "regular" products and make a price estimate. The marketing exercises were not the main focus of the experiment, they were a minor part of it, but students gave them positive feedback - this is why we decided to share. It is important to stress that the exercises are basic and adapted. In adding these exercises to the main framework, the idea was to make a quick provocation to the students to imagine if their concepts were real. Later on, we checked with them if these exercises changed their mindsets while

developing the biodesign – we asked them “when do you think you learned the most in the experience”.

Here, we begin with a few challenges in teaching and learning biodesign. The Methodological Strategy is presented in the next section, followed by the Student’s Results. Next, the Discussion brings the student’s feedback on these particular activities, and finally, we conclude with final considerations.

**1. A few challenges in teaching and learning biodesign**

The challenges of teaching and learning biodesign are the challenges of biodesign itself. Designing with the living is different from what designers are used to. Antonelli writes “It goes without saying that when the materials are not plastics, wood, ceramics, or glass, but rather living beings or living tissues, the implications of every project reach far beyond the form/function equation and any idea of comfort, modernity or progress” (2018, p.7). In that matter, Dade-Robertson also writes: “You can’t master life in the way a painter masters oils or a joiner masters wood” (2021, p. 95).

Moreover, there are still some challenges in commercialising biodesigned products. Dade-Robertson writes about the “Technology Readiness Level” (TRL) of biodesign for now: “We need to recognise that our research may reside for some time at TRL levels 1, 2, or 3. Our collaboration with the living is one in which we are only just beginning to understand the language of our collaborators” ( 2021, p.9). The Technology Readiness Level chart has 9 Levels, which Dade-Robertson (2021, p.8) describes:

1- Basic principles observed and reported;
2- Technology concept and/or application formulated;
3- Critical function, proof of concept established;
4- Lab testing of prototype component or process;
5- Laboratory testing of integrated system;
6- Prototype system verified;
7- Integrated pilot system demonstrated;
8- System complete and qualified;
9- System proven in an operational environment

It looks like much work is yet to be done to improve material feasibility and commercial potential for biodesigned products (Damsin, 2019; Attias et al., 2020; Harmon et al., 2020; Strobel do Nascimento et al., 2021). Biodesign is still considered experimental and in a nascent state. Antonelli notes that “[…] biodesign remains a burgeoning industry that would benefit from increased public support and financial resources if it is to become truly viable at a global scale” (2018, p.7).
In an aesthetic perspective, Camere and Karana (2018) write that living materials have different qualities than traditional materials, such as a characteristic smell – which could be a marketing challenge. Myers foresees the emergence of a “legible formal language” in biodesign (2018, p.14).

All this “newness” might be overwhelming to young product design students,

who have their first contact with biodesign. This is why adapted perceptual positioning maps and pricing exercises are proposed here to bring biodesigns closer to already known objects, and to imagine them in the production, circulation, and consumption life.

## 2. Methodological Strategy

The methodological strategy followed a framework for teaching and learning biodesign proposed in “Design With the Living: Learning to Work Together” (Strobel do Nascimento, 2023). The framework is meant for undergraduate product design students with no experience in biodesign. Here we focus on explaining specific activities from modules 3 and 5.

In module 3, one of the activities was a product perceptual positioning map, a widespread marketing tool in which four characteristics are selected and attributed to the extremes of two axes. For example, artisanal and industrial aesthetics, and classic and modern aesthetics could be considered the extremes of the axes. Later on, similar or competing products were arranged in space according to where they stand in relation to the axes. The product perceptual positioning map is usually assembled using customer input. In this case, students assembled the map with their perception based on their feelings when finding competing or similar products. Similar or competitor products could be biodesigned or not. Finally, they decided where to strategically place the product they would biodesign on the map.

Another exercise in module 3, consisted of drawing a line and placing the same competitors and similar products from the previous exercise along - proportionally representing the distance between prices. The product prices were found on the internet and expressed in Brazilian Reais. Next, students had to estimate in which price range they wanted to strategically place the product they would biodesign, based on the users they wanted to target in previous exercises.

Continuing to module 5, one of the exercises was to estimate how many hours were spent developing the project and how many hours were spent producing the prototype. Students had to give a price for their working hours and calculate how much the project had cost in Brazilian Reais. After that, they had to add other costs, like materials, to assess the project’s total cost. They also had to understand how much the prototype alone had cost, in working hours and materials. For this exercise, they were told to consider the price of making the prototype as the product’s basic cost. After these calculations, students had to answer the following questions:

“Reflection: hypothetically, how could the commercialisation of the product be achieved?
1. Did anything change in the product perceptual positioning map, compared to what was initially proposed?
2. What profit margin would be needed for the product to fit within the value stipulated in the previous planning?
3. What is the batch size to be produced? How many units should be sold to

achieve a return on investment (cover development and material costs)? 4. What could be the means of marketing and distributing the product? 5. Would it be possible to expand the product line? How?"

This experiment was conducted in 2022 with 3rd-year students from the Product Design undergraduate course at Universidade Federal do Paraná. The local Ethics Committee approved the research. Thirty-seven students joined the experiment, working in eight groups of four people, one group of three, and one group of two. All students worked on mycelium designs.

As it is difficult to measure a student's mindset, we relied on the self-reporting of the students. To assess if the exercises helped the students change their mindsets for biodesigning an imagine if their products were real - at the end of the process, they were asked to fill out a form replying to the question "When did I think I learned the most?" for each module. The answers were open and students could write as much as they wanted. Responses addressing the marketing exercises were analysed.

All students signed a term to choose if they wanted to be identified in case any of their work should appear in a publication, all students chose to be identified. In the discussion section, they were assigned codes for their privacy because some of their feedback was transcribed.

## 3. Results

In this section, the results of three of the projects are presented as examples of the proposed exercises. The projects are Miel, a beehive, Cobogó Bió, a construction hollow element for architecture, and Hongo, a chair.

### Miel

Miel is a mycelium beehive with a modular design. Ana Clara do Nascimento Agner, André Luiz Andreatta Carvalho, Daniela Milena Hartmann, and Eduardo Serraglio do Nascimento participated in this team. The students' design vision was:

The product aims to encompass the universe of bees, creating a welcoming structure for their hive and its particularities. The modularity of the product enables access to the hive. Produced from mycelium, the product relates to the natural aesthetics of the bees and meets certain needs, such as thermal protection. The product's aesthetic seeks to enhance the identity related to the animals, inserting them in a relationship of mutualism between the urban and the natural, with the aim of naturalising urbanity and not the opposite (By the students, 2022, our translation).

A rendering of Miel is presented in FIGURE 1.

FIGURE 1 – MIEL RENDERING




IMAGE PRODUCED BY THE STUDENTS.

FIGURE 2 shows the team's product perceptual positioning map in relation to other existing beehives. In the horizontal axis, there is "playful" to the left and "sober" to the right. In the vertical axis, "urban" is at the top, and "natural" is at the bottom. The yellow location icon points out where the team wished their design would be.

FIGURE 1 – MIEL RENDERING

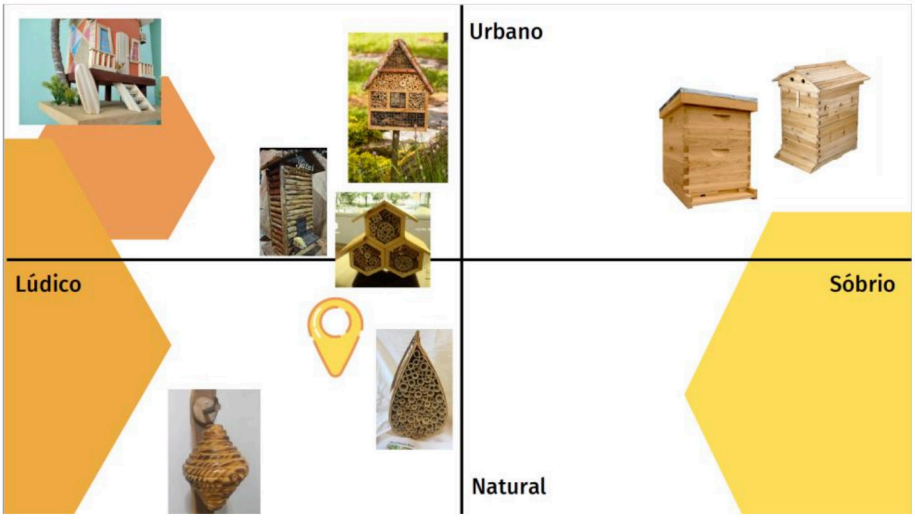



IMAGE PRODUCED BY THE STUDENTS.

FIGURE 3 presents the competing or similar products organised along a line by price. The yellow location icon indicates where the team thought their product should be placed, almost in the middle, costing R$250.00.

FIGURE 3 – MIEL PRODUCT PRICE POSITIONING MAP

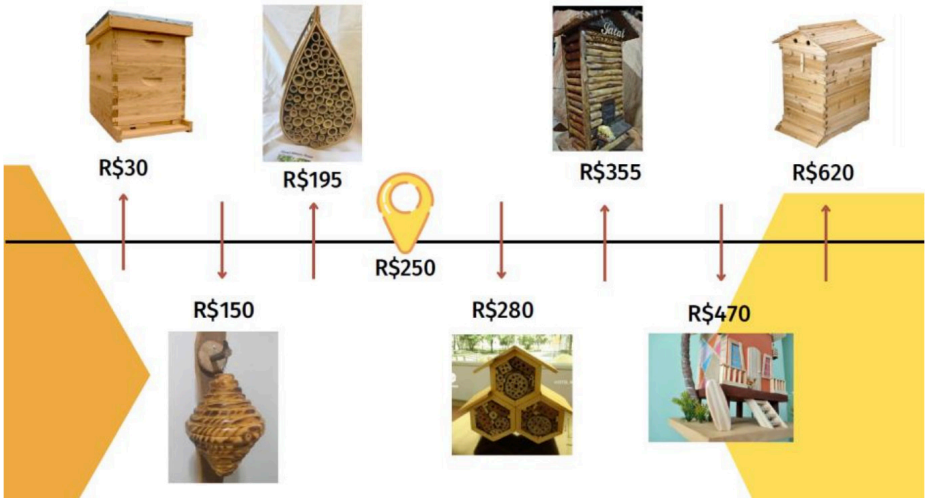



IMAGE PRODUCED BY THE STUDENTS.

When calculating the project's price, the students included each member's working hours and the materials they used. The project's cost was estimated at R$683.97 – the prototype alone was estimated to cost R$ 83.97, including working hours.

After estimating the costs, the team did not think their original pricing and product perceptual positioning map should change. They estimated that the profit margin would reach 57% if the product were to be sold at the planned price of R$250.00. Four products would have to be sold to cover prototype and development costs. The team chose social media to market and distribute their beehive, like Instagram and Facebook. They also considered the "Mercado Livre" platform in Latin America, where anyone can register, sell, and buy. Additionally, they mentioned other small e-commerce platforms that target artisanal, small series of products – and beekeeping and farmer's markets. To expand their product line, the team suggested the production of reusable moulds.

**Cobogó Bió**

Cobogó Bió is a construction element, traditional in Brazilian architecture, used to divide rooms allowing air and light to come through. Team members for this project were Caio César Franco Pael Zanolla, Victória Perkoski da Silva, and Yasmine Rudek Rodrigues. The students' vision for the product was:

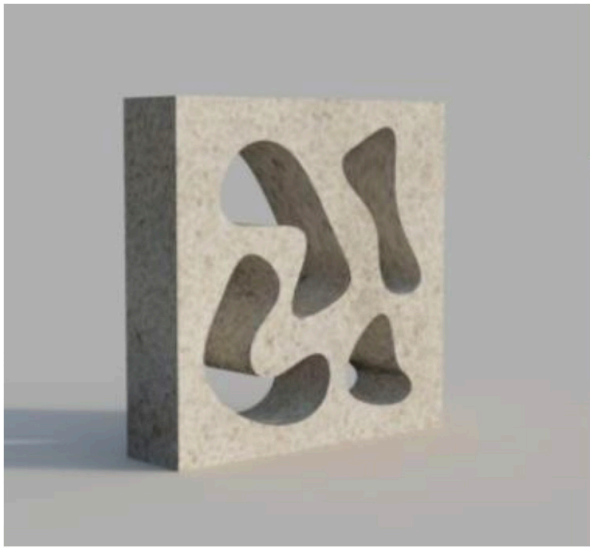
Use biomimetic design as a design premise. Biomimetic design understands form as a result of the elements of nature. In this way, a structure must

be developed based on this inspiration; a pattern that generates a product capable of symbolising this process (by the students, 2022, our translation).

A rendering of Cobogó Bió is presented in FIGURE 4.

FIGURE 4 –COBOGÓ BIÓ RENDERING

IMAGE PRODUCED BY THE STUDENTS.



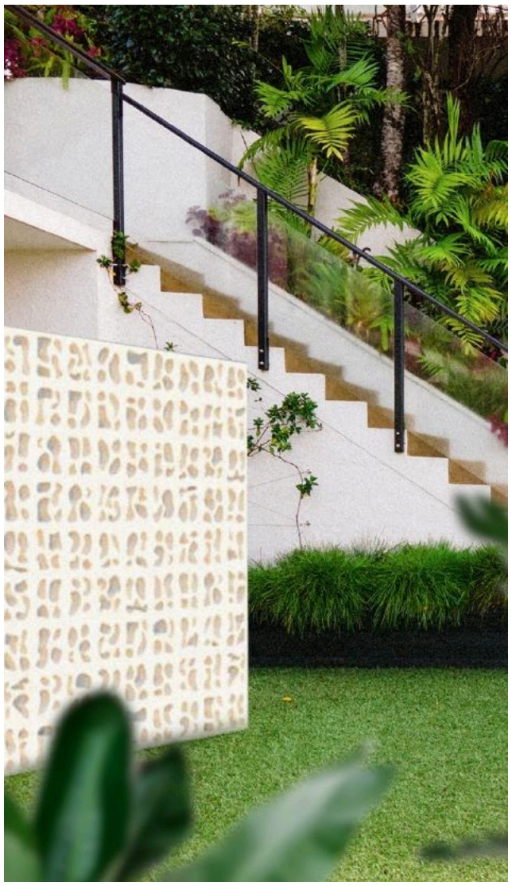


FIGURE 5 shows the team's product perceptual positioning map in relation to other existing cobogós. In the horizontal axis there is "classic" on the left and "futuristic" on the right. In the vertical axis, "alternative" is at the top, and "up to date" is at the bottom. The green dot shows where the team originally wished to place their project in module 3. The rendering indicates where the students thought they should place their project after it was concluded in module 5.

FIGURE 5 –COBOGÓ BIÓ PRODUCT PERCEPTUAL POSITIONING MAP




IMAGE PRODUCED BY THE STUDENTS.

FIGURE 6 presents the competing or similar products organised along a line by price. The green rectangle indicates where the team thought their product should be placed, in a price range from R$50.00 to R$250.00.

FIGURE 6 –COBOGÓ BIÓ PRODUCT PRICE POSITIONING MAP

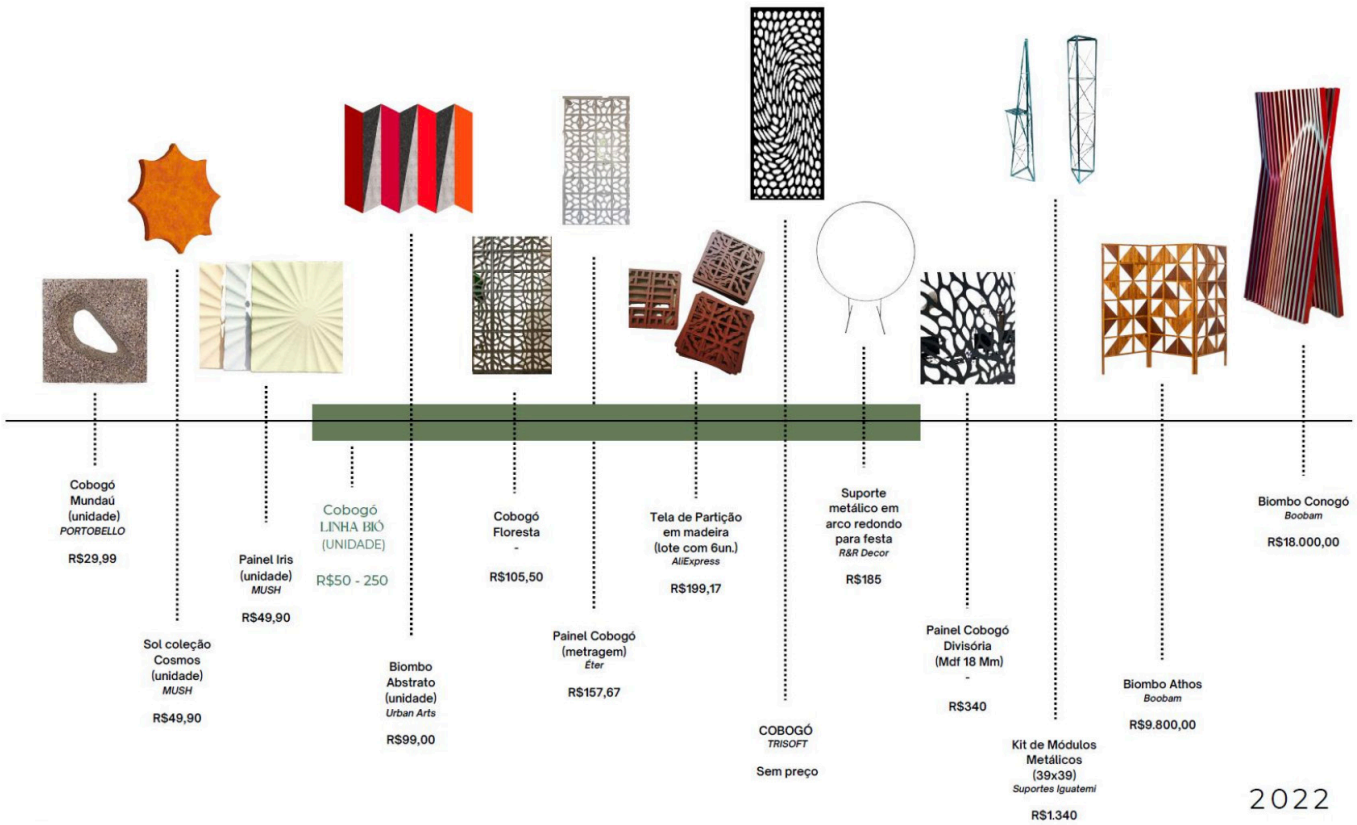



IMAGE PRODUCED BY THE STUDENTS.

The total project cost estimate was R$2,485.75, where R$685.75 refers to the prototype's cost. They estimated they could reduce this price to R$134.75 per unit if producing in larger quantities. After the project was finished in module 5, the team reassessed the positioning maps. The design moved closer to "up-to-date" and "classic" on the product perceptual positioning map. Regarding the price positioning, the team opted for the higher price from the range they had initially proposed: R$250.00 per unit. The profit margin would be at 86%. They estimated that selling one batch of 100 pieces would cover project costs. To market and distribute their product, the team thought they could use social media to reach their niche audience. They also proposed: a website, magazines, exhibitions, and to develop partnerships with suppliers. The team planned a modular panel and a pot rest to expand their product line.

**Hongo**

Hongo is a chair. The team members for this project were Daniel da Silva Chaussê, Igor Santos Silva, Murilo Maciel de Paula, and Marcus Vinícius Granemann Mendes. About the concept, the authors wrote:

"For the development of this project, we were inspired by some works that involve the creation of furniture pieces using mycelium, such as the one from the Philadelphia students Merjan Tara Sisman and Brian Mcclellan, whose research is called 'the living room project', which consists in an exploration of making
objects with living materials. One of the processes presented in this study that generated interest and that will be applied in the development of the product, is the development of a wooden structure for support and application of mycelium in parts of a chair, in this case, the seat and backrest." (by the students, 2022, our translation).

A rendering of Hongo can be seen in FIGURE 7.

FIGURE 7 – HONGO RENDERING

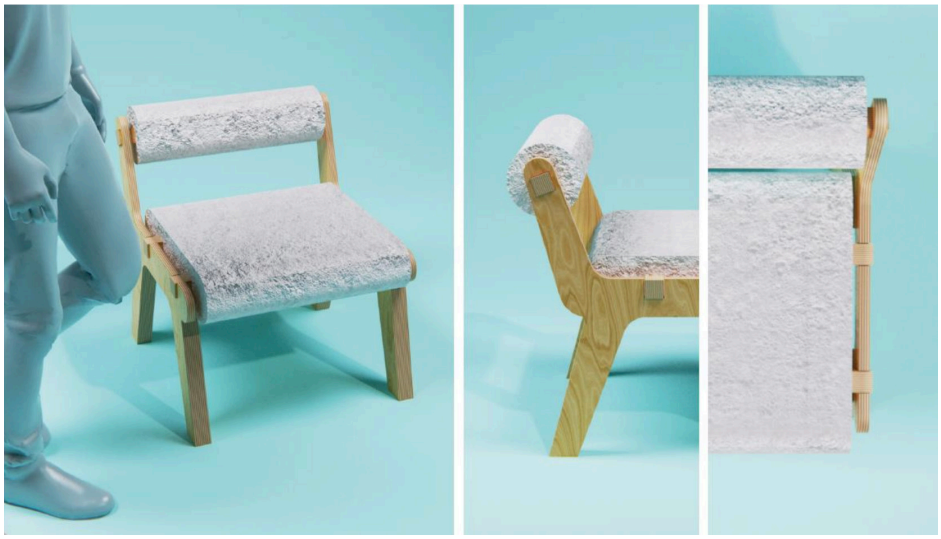


IMAGE PRODUCED BY THE STUDENTS.

FIGURE 8 shows the product perceptual positioning map in relation to other existing chairs. In the horizontal axis, we read “minimalist” on the left and “detailed” on the right. On the vertical axis, “+ materials” is at the top, and “- materials” is at the bottom. The yellow dot shows where the team wished to place their project while in module 3.

FIGURE 8 – HONGO PRODUCT PERCEPTUAL POSITIONING MAP




IMAGE PRODUCED BY THE STUDENTS.

FIGURE 9 presents the competitor or similar products organised along the price line. The yellow dot indicates where the team thought their product should be placed, around R$2,994.00.

FIGURE 9 – HONGO PRODUCT PRICE POSITIONING MAP




IMAGE PRODUCED BY THE STUDENTS.

This team did not present their detailed price estimate – but they stated that the profit for each chair would be R$1,294.00, hence the prototype would cost R$1,700.00. To the Hongo chair team, their product positioning in the maps did not change from module 3 to module 5. They affirmed that two chairs should be sold to cover project costs. To market and distribute their product, the team proposed social media, a website, home and decor stores, participating in design contests – as well as partnerships with architects and interior designers. To expand the product line the team imagined coffee tables and stools.

## 4. Discussion

It was possible to notice that the price estimated by the students to the working hours varied among the teams, it was also possible to notice that each team spent a different amount of hours in the project. The exercises to estimate price and develop the positioning maps were flawed because they were an adaptation. For example, ideally, product perceptual positioning maps should be developed with user information. To make this the right way, more time should have been put into these endeavours. The sole purpose of the exercises was to change the student's mindset when biodesigning: to imagine if it were real. This was attempted by bringing what they were designing closer to other things that already exist and possibly already knew – by imagining what they were designing inside the production, circulation, and consumption life. Feedback suggests that it worked. Thirty-one students gave feedback on the exercises, some of them were transcribed in the following paragraphs – they were translated from Brazilian Portuguese by us.

When evaluating module 3, when asked when they learned the most, twelve students mentioned the perceptual product positioning maps and pricing exercises. Student A6 wrote that she learned the most "When we did […] the product positioning exercise, the price exercise... it helped to give us a more real perspective on our project". Student A13 said she learned the most "When we did the product pricing part and the empathy map because they were new tools that added a lot to the decision-making in other steps". Student A17 explained "I had never thought about market positioning or concept/value positioning in previous projects, so I found it interesting to learn about it and I thought it was important to think about a more realistic logic for actually putting a product on the market". Student A19 described that "All the stages were very clear and essential to the project. The product positioning was the most significant because it allowed for the actual realisation of values". Student A23 wrote that "Price positioning was very interesting, it gave us new perspectives on the way we think about design". Finally, student A31 explained that: "Positioning the product in relation to similar products, based on the characteristics and parameters proposed by the team, allowed us to visualise which elements would best suit it and conceptualise it even better."

In evaluating module 5, when asked when they learned the most in that module, fourteen students mentioned the positioning maps and pricing. Student A7 described that: "The analysis and understanding of how to position the

product and understand it as a result of a living process was very interesting […]". Student A8 said "I think that as the conclusion of a project, the tools applied were extremely helpful in imagining the product as a "real artefact". Student A10 shared "I felt this moment was a point of mastering the content, even with the errors that appeared in the project". Finally, student A12 wrote that he learned the most "By applying the results to the way the market is advertised, treating the product as something meaningful to be consumed".

A previous systematic and narrative literature review (Strobel do Nascimento, 2023) retrieved other methods and frameworks to teach and learn biodesign. However, these methods do not seem to propose exercises to connect biodesigned-to-be products to already existing ones. They also do not propose a reflection on the price of the final product. One example of these methods is "Biodiseño en Colegios", by Turano et al. (2020), a facilitating method to teach biodesign in high schools. Another example is the Material Driven Design (MDD) method, which has been reportedly used in academic research for biodesign, including in undergraduate teaching and learning contexts (Parisi et al., 2016; Monna, 2017; Camere & Karana, 2018; Karana et al., 2018, Cohen et al., 2019; Gough et al., 2020). These methods could be used with the pricing and product perceptual positioning map exercises.

In the article "When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials", Karana et al. (2018) describe a tool used along with the MDD method which could relate to the exercises proposed here, they built a concept selection tool based on user acceptance. Different from the perceptual positioning maps, this tool presents five fixed axes with the labels: Relative Advantage (positive), Compatibility (positive), Complexity (negative), Trial-ability (positive), and Observability (positive) – those are based on Rogers' Diffusion of Innovations Theory. With this tool, potential users place the concepts along the graphics composed of the five axes. Likewise, product perceptual positioning maps should ideally also be built with consumer information.

## 5. Conclusion

Most people's personal experiences are created with products made of "traditional materials". Biodesigned products are relatively new yet, and face difficulties in becoming feasible and marketable. Biodesigned products might be uncommon in our daily lives, far from our personal realities. This might contribute to the impression that biodesign only reaches the conceptual phases of product design, unlikely to be materialised or used - which might affect the mindset of beginner designers in biodesigning. In the context of a framework for teaching and learning biodesign to undergraduate product design students who have never had a biodesign experience before – this article aimed at reporting the outcomes of a series of adapted and simplified pricing and perceptual positioning mapping exercises to change the students' mindsets when biodesigning. By bringing their biodesigned products closer to products already materialised and in the market, products they possibly already knew, the proposition was to imagine as if they were real. Addition-

ally, by assigning the products a price, the purpose was to visualise them in the production, circulation, and consumption life.

Examples of the students' results were reported: the Miel beehive, the Cobogó Bió hollow construction element, and the Hongo chair – all projects with mycelium. Thirty-seven students participated in the experiment, in teams with four, three, or two colleagues. In the experiment's module 3, some of the activities were an adapted and simplified product perceptual and a price positioning map. In module 5 students estimated the product's price (a simplification) and reassessed the strategic decisions they had taken in module 3. They also reflected on profit margins and marketing and distribution possibilities.

Some of the students' feedbacks on the exercise were transcribed in the discussion. From the thirty-one students present on the day the feedback was given, when evaluating module 3 - twelve mentioned that they learned the most with the positioning maps. In module 5, fourteen students mentioned that they learned the most with the pricing exercises and reassessing the positioning maps. Some explicitly wrote that the exercises brought the project closer to what they felt was "real". Those feedbacks suggest that the exercises changed the students' mindsets when having their first biodesign experience.

Limitations of the study refer to the adaptation and simplification of the exercises. Further studies should deepen into more professional practices. Finally, user-related exercises, like storyboards, could also help change the students' mindsets.

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# (60) Horseshoe Crab's Picnic. Chunxi Liu (Hong Kong University of Science and Technology) and Siu Gin Cheung (City University of Hong Kong).

**ABSTRACT |** Horseshoe crabs, scientifically known as Xiphosura or Xiphosurida, are often referred to as the "living fossils". With their conservative morphology, they have survived from all five mass extinctions and have lived on our planet for more than 445 million years. They are now facing grave threats from habitat destruction, climate change and overhunting. To protect this ancient species, conservation efforts and public awareness are imperative. Much research studies horseshoe crabs. While the purpose is to protect them, the scientific approach often treats horseshoe crabs as "objects" to be studied, rather than equal partners. In this project, I proposed a Biodesign approach to build up an equal relationship with horseshoe crabs, challenging the notion that humans must always be cast as either the cause of mass extinction or the saviours of endangered species. Cooking is my favourite way of expressing love for nature. I decided to develop food cuisines for horseshoe crabs based on their dietary habits. The nutritious, masticable and eco-friendly "snacks" can be conveniently taken by the public to horseshoe crabs, encouraging a shared experience - a picnic - between the two species. Witnessing upheavals of the environment and struggles for survival of countless species, horseshoe crabs embody adaptation, harmony, and resilience. After silently coexisting for so many years, we, as visitors, knock on their doors, showing great respect for their dietary choices and resilient feature. A new conversation begins, where both species can enjoy the environment together and, in doing so, gain insight into each other's challenges, fears, and joys.

**KEYWORDS |** Horseshoe crabs, Conservations, Biodesign, Non anthropocentric, Eco-friendly

## 1. Introduction

### 1.1 The Evolution of horseshoe crabs during Phanerozoic

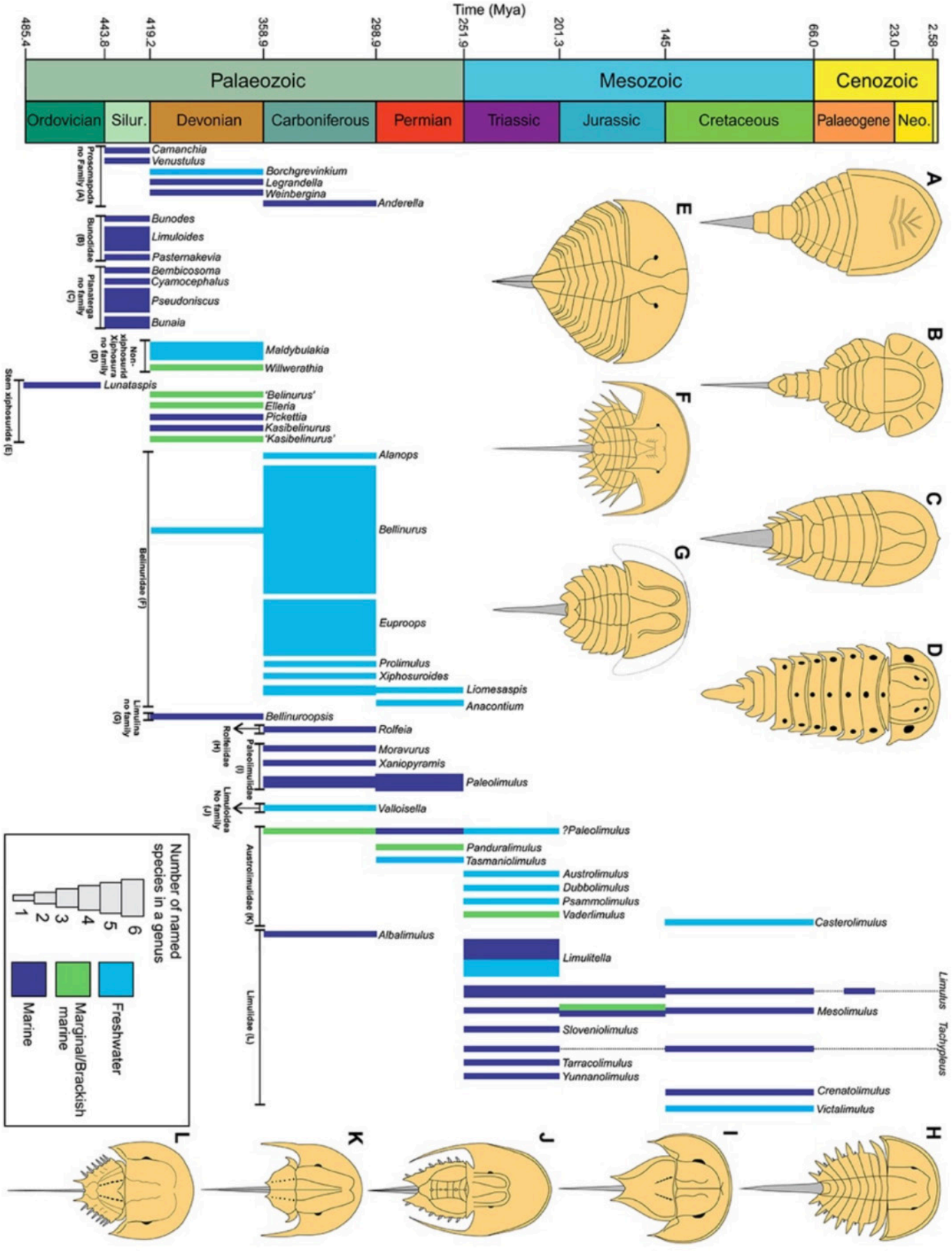



Figure 1. Evolutionary history with morphological changes during Phanerozoic (Bicknell & Pates, 2020)

Ancestors of horseshoe crabs, such as Prosomapoda (organism A in Fig 1), Bunodidae (organism B), and Planaterga (organism C), have emerged as early as the Lower Ordovician period (over 485 million years ago) (Anderson & Selden, 1997). By the Silurian and Devonian periods, they had diversified significantly (Bicknell & Pates, 2020). These organisms occupied marine and marginal marine habitats, marking the first major evolutionary expansion of horseshoe crabs. However, this early diversity declined sharply by the Carboniferous period, with many groups going extinct (Moore et al., 2007). The non-xiphosurid xiphosurans (organism D), first emerged during the Lower Ordovician, followed a similar fate. Although they were present in the Upper Ordovician, they did not persist past the Devonian period, and their fossil record ends without further evidence of survival (Bicknell, Lustri, et al., 2019).

The group that we recognise as horseshoe crabs, Xiphosurida, appeared later, in the late Devonian period, beginning with the genus Bellinuroopsis (Moore et al., 2007). During the Carboniferous period, several distinct families of Xiphosurida evolved, including Belinuridae (organism F), Limulidae (organism J), Paleolimulidae (organism I) and potentially the Austrolimulidae (organism K) (Selden & Siveter, 1987). These families demonstrated an impressive ability to adapt to brackish and freshwater environments, a response to the fluctuating coastlines and shallow-marine conditions that characterised this time in natural history (Błażejowski et al., 2017). However, their diversity began to decline during the Permian period (Tanacredi et al., 2009a). By the end of the Carboniferous period, some families, such as the Rolfeiidae, had disappeared entirely, while the first Austrolimulid species emerged in the Permian (Bicknell & Pates, 2019).

The Permian-Triassic mass extinction, often called the “Great Dying,” had a profound impact on many groups, including the horseshoe crabs. The Belinuridae and Paleolimulidae families did not survive, but the Austrolimulidae and Limulidaewere were able to endure and persist into the Mesozoic era(Bicknell & Pates, 2019). Whereas Paleozoic horseshoe crabs typically measured 3-5 cm in length, Mesozoic species reached much larger sizes, often ranging from 30-60 cm, including their long tails, or telsons (Bicknell & Pates, 2019). This period also saw a peak in Austrolimulid diversity, though this group eventually declined through the Cretaceous and became extinct (Bicknell et al., 2019).

By the Tertiary period, only the Limulidae lineage survived, and it remains the only xiphosurid group present today (Hauschke & Wilde, 2004; Bicknell et al., 2019). Although their evolutionary history has been marked by several periods of diversification, horseshoe crabs are now represented by just four extant species (Dunlop et al., 2012). Their tendency to inhabit marginal environments, where fossil preservation is rare, may partly explain the limited fossil record we have of their more recent history (Babcock & Merriam, 2000). Despite this, they remain an extraordinary example of resilience, surviving for hundreds of millions of years through some of the most turbulent periods in Earth’s history.

## 1.2 the Morphology of horseshoe crabs

Horseshoe crabs have several distinct morphological features, including their carapace, telson, eyes, book gills, legs, mouth, and blood. The carapace, a hard horseshoe-shaped shell, is composed of chitinous plates. It serves as an effective protective shield, so strong that only predators like sharks and turtles can penetrate it. The telson is the long, pointed appendage at the rear of the crab. Though it looks sharp, it is not used aggressively. Instead, the telson helps the crab with steering and flipping itself over if it becomes upside down.

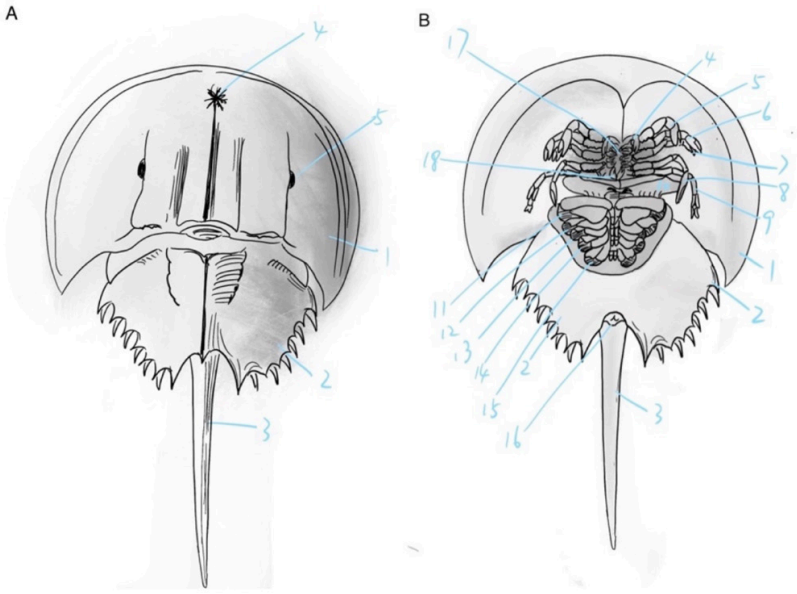



Figure 2. Dorsal (A) and ventral (B) morphology of horseshoe crab, Limulus Polyphemus

| A) Dorsal Morphology | |
|---|---|
| 1 | Carapace covering prosome |
| 2 | Meso- and meta-soma |
| 3 | Telson |
| 4 | Median eye |
| 5 | Lateral eye |

| (B) Ventral morphology | |
|---|---|
| 1 | Carapace covering prosoma |
| 2 | Meso- and meta-soma |
| 3 | Telson |
| 4 | Chelicera |
| 5 | Pedipalp |
| 6- 9 | 3rd to 6th appendages, ambulatory limbs |
| 10 | genital operculum turned forward to show the genital apertures |
| 11- 15 | Appendages bearing gill-books |
| 16 | anus |
| 17 | mouth |
| 18 | chilaria |

Horseshoe crabs have ten eyes, which they use to sense light and locate mates. Their two large compound eyes, each containing around 1,000 receptors (ommatidia), are used for visual sensing. In addition, the prosoma, or front section of their body, contains five eyes, including lateral, rudimentary, and median eyes, as well as an endoparietal eye. These eyes can detect ultraviolet (UV) light, helping the crabs follow lunar cycles during spawning periods. Two ventral eyes are located near the mouth, and photoreceptors on the telson are believed to help synchronise the crab's brain to light and dark cycles (Tanacredi et al., 2009b).

Horseshoe crabs breath using five pairs of book gills on the underside of its body. These gills are specialised for underwater respiration, extracting oxygen from the water. Horseshoe crab's bright blue blood contains immune cells that are exceptionally sensitive to bacterial toxins. These cells rapidly clot around any invading bacteria, isolating the threat and protecting the crab from harm.

Horseshoe crabs have five pairs of legs, the first pair modified into pincers for grasping prey, while the remaining four pairs are used for walking and swimming. Located in the centre of the legs is the mouth, which is surrounded by smaller legs called pedipalps. Horseshoe crabs employ their chela (the last pair of walking legs) and chelicerae (non-walking appendages) to grip and guide food to their mouths (Wyse, 1971). The gnathobases, which are chitinous bristles that function like teeth, help grip the food and are equipped with chemoreceptors that stimulate the ingestion process (Hayes & Barber 1982; Wyse 1971). Most of the grinding action occurs in the gizzard, which contains chitinous folded ridges in the gut (Debnath 1992). The digestive enzymes include acid protease, alkali protease, esterase, cellulase, invertase, amylase. The enzyme compositions and concentrations (Table 1) suggest the dietary preference of horseshoe crabs with a greater precision than relying solely on growth and survival rates (Hu et al. 2014, 2018). There is little research on the digestive profile of horseshoe crabs apart from Debnath (1992). Sand, accounting for about 7% of the gut content in wild caught horseshoe crabs (John et al. 2012), probably serve as abrasive agent, and friction caused by the passive rubbing of sand against food particles has been documented in avian species (Gionfriddo & Best 1996).

| Enzyme assayed | Esophagus | Gizzards | Intestine | Hepatopancreas |
|---|---|---|---|---|
| Acid protease (mg tyrosine) | 0.192±0.015 | 0.679±0.061 | 0.756±0.113 | 0.642±0.098 |
| Alkali protease (mg tyrosine) | 0.406±0.053 | 0.172±0.059 | 0.273±0.035 | 0.296±0.034 |
| Eaterase (mg B-naphtol) | 0.500±0.055 | 0.260±0.031 | 0.273±0.035 | 0.296±0.034 |
| Cellulase (mg glucose) | 10.944±1.061 | 11.529±1.037 | 7.736±0.618 | 9.351±0.912 |
| Invertase (mg glucose) | 3.462±1.209 | 4.653±0.601 | 5.899±0.612 | 6.059±0.557 |
| Amylase (mg glucose) | 13.587±1.290 | 15.640±1.801 | 15.658±1.733 | 16.608±2.011 |

Table 1. Major digestive enzymes of horseshoe crabs and their enzyme activities (Razali et al., 2020).

### 1.3 Dietary Composition

Dietary composition of horseshoe crabs has been studied by gut content analysis and isotope analysis. Adult Atlantic horseshoe crab Limulus polyphemus mainly consumed bivalves, crustaceans, polychaetes and gastropods. Juvenile L. polyphemus in their 2nd–3rd instars mainly intake benthic and suspended particulate organic matter, while those L. polyphemus in their 5th–11th instars were large enough to eat small-bodied animals in the sediment (Gaines et al. 2002; Carmichael et al. 2009). Gut content analysis of juvenile Chinese horseshoe crab Tachypleus tridentatus and mangrove horseshoe crab Carcinoscorpius rotundicauda revealed a diet composed of insect larvae, polychaetes and small crabs, with little amount of oligochaetes, amphipods, thin-shelled bivalves, nematodes, gastropods, pieces of seagrass and unidentified eggs (Zhou & Morton, 2004). Molluscs, insects, crustaceans and polychaetes were commonly found in the guts of Indian horseshoe crab Tachypleus gigas (Chatterji et al. 1992).

However, the study of gut components maybe biased by the varied digestion rate of invertebrates with exoskeletons or shells and the insects with chitin. The size and hardness of food items are likely the more significant factors for food selection from the sediment by juvenile horseshoe crabs. In Hong Kong, juveniles of both species (8.5–67 mm in prosoma width) tend to prefer small benthic organisms, such as insect larvae, polychaetes, oligochaetes, small crabs, and the thin-shelled bivalve Glauconome chinensis, while they generally avoid larger, hard-shelled species like gastropods and small chitin-covered nematodes and ostracods.
Isotope analysis is a non-lethal sampling method in which horseshoe crab tissue samples are collected by clipping the last two segments of the third walking legs (Carmichael et al. 2004). The animals were then released back into the mudflat. Tissue samples were stored in an icebox and transported to the lab within 2 hours. The two leg segments from each individual were pooled, treating each juvenile's tissues as a sample replicate(Kwan et al., 2015). Studies suggested that bivalves, crustaceans and polychaetes were mostly abundant in the mix diet of 6th –11th instar Asian juveniles. The δ13C values, measured by NMR, indicate that the food source available to juveniles were largely supported by seagrass and its epiphytes (Kwan et al., 2015).

### 1.4 Philosophical Quandaries of Evolutionary Stasis

Horseshoe crabs have maintained a remarkably stable morphology for over 445 million years, in stark contrast to the more rapid and dramatic changes seen in other species. For instance, homo sapiens diverged from ape-like ancestors only around 5-8 million years ago but already exhibited remarkable morphological alterations, such as bipedalism, tool use, increased brain size, reduced facial features, and decreased body hair (Wood, 1996). Similarly, birds underwent major changes to adapt to flight since evolved from theropod dinosaurs around 150-165 million years ago. These adaptations included the development of feathers, wings, and lightweight skeletons, along with the loss of reptilian features like long tails and teeth (Brusatte et al., 2015). Frogs, originated from fish-like amphibians known as labyrinthodonts around

360 million years ago, also underwent substantial adaptations, including the development of tetrapod limbs and specialized respiratory systems for a semi-aquatic lifestyle (Long & Gordon, 2004). In contrast, despite existing for hundreds of millions of years and facing numerous environmental changes, the core morphology of horseshoe crabs has remained largely unchanged.
The persistence of the horseshoe crab's morphology, despite environmental changes, underscores their early evolutionary success. It has been argued that the longevity of horseshoe crabs' morphology is partly due to their phylogenetic position within the Chelicerata, an ancient arthropod lineage. Their relatively simple body plan and developmental programme might have contributed to the persistence of their distinctive organs such as carapace and book gills. However, other chelicerate lineages, such as arachnids, have undergone significant evolution, showing that morphological transformations in this family are possible.

The persistence of horseshoe crabs raises philosophical questions about evolution itself. Does their stability reflect an intrinsic resilience to environmental change, or is it merely a historical accident? Are there underlying principles that govern the pace and patterns of evolution, or is life's history more chaotic and unpredictable than we can model? Horseshoe crabs, as "living fossils", challenge our understanding of adaptation and evolutionary processes over vast geological timescales. Their endurance offers a unique window into the past, sparking questions about the nature of evolution and its role in shaping the history of life on Earth. Further study of evolutionary "outliers" like the horseshoe crab may provide deeper insights into life's origins and the forces that drive organismal change.

**2. Current Horseshoe crab situation and protection**

Despite their resilience over geological timescales, horseshoe crab populations are rapidly declining due to modern, man-made pressures. The primary factors driving this decline include coastal development, dredging, and beach nourishment, which destroy or alter the sandy beaches crucial for their spawning. Overharvesting by the bait fishing industry and the biomedical sector, which relies on their blood for the production of limulus amebocyte lysate (LAL), has further contributed to the problem. One notable example is the Delaware Bay in the US, home to the largest population of horseshoe crabs in the country. Between 1990 and 2002, their numbers dropped from 1.24 million to less than 334,000. Although the population has since stabilised and grown to around 725,000 in 2019 (Liu, n.d.), the ongoing demand for their blood poses a continued risk.

In China, the species Tachypleus tridentatus has seen a sharp decline, leading to its listing as endangered by the International Union for Conservation of Nature (IUCN). For example, surveys conducted across 18 spawning and nursery beaches in Hong Kong showed a consistently low density of juvenile horseshoe crabs, ranging from 0.16 to 2.19 individuals per 100 $m^2$ in 2012, and 0.08 to 1.41 individuals per 100 $m^2$ in 2014 (Shin et al., 2009; Morton and Lee, 2011). These records were similar to those recorded in 2002 and 2007 (0.10–1.97 individuals per 100 $m^2$), except for a notably lower range of 0.08–0.31

individuals per 100 $m^2$ in 2004. It is estimated that the current juvenile populations of Tachypleus tridentatus and Carcinoscorpius rotundicauda in Hong Kong are about 2,100– 4,300 and 2,400–3,000 respectively. Alarmingly, no new 1st–3rd instar recruits were recorded in 2012–2014, with most shores occupied by 6th–9th instar juveniles with prosomal widths of 23–45 mm (Kwan et al., 2016). High mortality rates were observed in these juveniles. These data indicate that juvenile horseshoe crabs in Hong Kong are in a dire state, and without urgent protective measures, they are at risk of local extinction.

Public awareness is crucial to the conservation of horseshoe crabs. In Hong Kong, long-standing efforts have had some success, but there is still a need to engage the broader public in these conservation initiatives. Raising awareness through education, particularly in high schools, and finding innovative ways to connect the public with horseshoe crabs are essential steps. Strengthening these connections and providing support to their natural habitats, especially through food resources, could ensure their survival for future generations.

**3. Field Trip for quantifying the horseshoe crabs and environment**

In this project, field trips were conducted to study the natural habitat and behaviour of horseshoe crabs. This research provides valuable data on their habitats and the conditions they need to thrive, that can be used to create methods to sustain horseshoe crab populations.

In March 2023, field trips were conducted in several locations across Hong Kong, including Sha Tsui Tau, Luk Kung, and Ha Pak Lai, as shown in figure 3. Before visiting these sites, we mapped out parallel lines along the coastal margins, extending from the beach to the sea. Evenly spaced spots were chosen along these lines, and during the trips, 8 m2 quadrats were set up at these spots. We counted the number of horseshoe crabs within each quadrat and recorded environmental factors such as pH and temperature.




Figure 3. The demonstration of field-trip sites



Figure 4. groups of photos during field trip

At Luk Kung, a pair of mangrove horseshoe crabs were observed mating. To find them, we spent considerable time walking through mudflats and carefully sifting through the mud by hand. Eventually, we located the crabs, which were happily burrowed in the mud, a behaviour that reflects their peaceful, natural lifestyle. Although we had the opportunity to interact with horseshoe crabs in the lab, these field trips provided a deeper understanding of their natural environment and behaviours, such as burrowing and feeding.

**4. Project intention**

Current conservation strategies often take a human-centred approach, treating horseshoe crabs as data points rather than recognising their intrinsic value as ancient, resilient beings. This project challenges this anthropocentric view and presents a reimagined relationship between humans and horseshoe crabs. Rather than positioning ourselves as protectors, we view horseshoe crabs as partners in a shared ecosystem. Their long history of resilience offers lessons not just in physiology and anatomy, but in coexisting with an ever-changing environment. Instead of continuing the traditional scientific approach of objectifying these creatures, this project seeks to engage in a more interactive, empathetic, and equal relationship.

In fact, humans' destructive impact on the ecosystem reflects our evolutionary vulnerability. Unlike horseshoe crabs, whose steady, resilient survival has weathered millions of years of environmental upheaval, humans have demonstrated a tendency to destabilise the very systems that sustain us. By continuing this path, humans are hastening our own extinction. Instead of "protecting" horseshoe crabs; we must learn from them - to adapt and prosper in an unpredictable world. One way to initiate this thinking is through food. By preparing food, a uniquely human activity, for horseshoe crabs, we are introducing the idea of an inter-species dialogue. Designing cuisine by one species for another species symbolises a gesture of care. By sharing food, we not only feed the horseshoe crabs but also start a conversation - one in which both species partake in a shared space, learning from each other.
This shift in perspective enables a new narrative, where humans and horseshoe crabs share in the responsibility of preserving the environment. By engaging the public in this intimate and respectful dialogue, this project seeks to inspire broader conservation efforts that emphasise empathy, connection, and shared destiny. Through this inter-species dialogue, we not only deepen our understanding of horseshoe crabs but also reflect on our role within the ecosystem and the interconnectedness of all life.

**4.1 The materials of the cuisines**

Brine shrimp are a favourite food of horseshoe crabs, providing essential nutrients such as proteins, lipids, and minerals that support their growth. However, using pre-prepared brine shrimp soup to feed horseshoe crabs in the wild is challenging because it is difficult to transport. Horseshoe crabs also consume algae as part of their diet. By creating chunks of brine shrimp combined with algae gels, the food becomes easier to carry and preserve. Additionally, the high concentration of brine shrimp in the gel and the soft

texture make it easier for horseshoe crabs to consume. Chemicals that could be used to create this food include agar, carrageenan, gelatin, and sodium alginate (with calcium lactate).
Agar is a substance derived from the cell walls of certain red algae species, such as “ogonori” and “tengusa”. It is a natural mixture of two components: agarose, a linear polysaccharide that makes up about 70% of agar, and agaropectin, a heterogeneous mixture of smaller molecules that makes up the remaining 30%. Agarose is a disaccharide composed of D-galactose and 3,6-anhydro-L galactopyranose and is a linear polymer. Agaropectin is a sulphated galactan containing organosulfates, D-glucuronic acid, and small amounts of pyruvic acid. Agar solidifies and forms a gel at temperatures between 32–42 °C (90–108 °F), known as the gel point, and melts at 85 °C (185 °F), the melting point. The difference between the gel point and melting point creates a hysteresis effect in agar.

Carrageenans are a family of natural linear sulphated polysaccharides extracted from red edible seaweeds. All carrageenans are high-molecular-weight polysaccharides, mainly composed of alternating 3-linked β-D-galactopyranose (G-units) and 4-linked α-D-galactopyranose (D-units) or 4-linked 3,6-anhydro-α-D galactopyranose (DA-units), forming the disaccharide repeating unit of carrageenan. The Kappa form of carrageenan is preferred here, as it forms strong and rigid gels and reacts with dairy proteins, unlike the Iota and Lambda forms. Carrageenan dissolves in water at 80 °C. Boiling the mixture for about ten minutes and then cooling it down creates the gel. However, overheating can change the Kappa form to Iota, altering the gel texture.

Gelatin is classified as a hydrogel and consists of peptides and proteins produced by the partial hydrolysis of collagen extracted from the skin, bones, and connective tissues of animals such as cattle, chicken, pigs, and fish. During hydrolysis, some bonds between and within component proteins are broken. Hydrolysed collagen contains 19 amino acids. Gelatin is nearly tasteless and odourless, with a colourless or slightly yellow appearance. Its melting point is below human body temperature.
Sodium alginate is extracted from brown seaweed. It is the sodium salt of alginic acid, with the formula $NaC_6H_7O_6$. Sodium alginate dissolves in water to form a clear viscous solution. When reacted with calcium chloride, a double replacement reaction occurs, where calcium ions replace sodium ions in the alginate, producing calcium alginate. The second product, sodium chloride, remains in solution.

## 5. Experiments in lab

The immature horseshoe crabs were used in an experiment to determine their culinary preferences by being regularly fed the prepared cuisine over a three-day period. Based on the food preferences observed in the younger crabs, the selected food was then offered to the mature horseshoe crabs to further test their acceptance and consumption.

### 5.1 Pre-experiment of coagulation

Before making the cuisine, the concentration and temperature were tested to find an optimal choice for the gels to coagulate with proper stiffness but not too rigid.

| | Sodium alginate | Calcium lactate | Carrageenan | Gelatin | Agar |
|---|---|---|---|---|---|
| Concentration (g/100ml) | 1.00 | 3.00 - 5.00 | 4.00 | 3.00 | 4.00 |

Form 1. The optimal concentration for making different gel

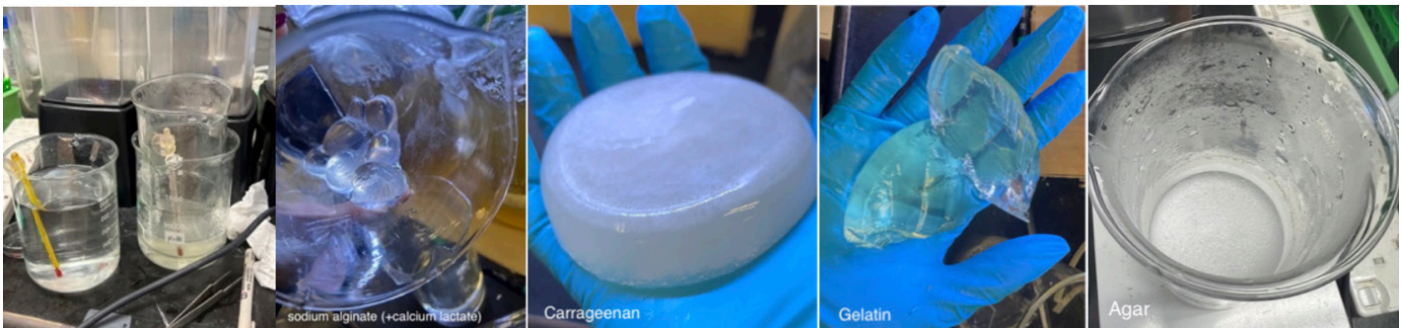



Figure 5. the gel coagulation experiments

## 5.2 Feeding young horseshoe crabs in lab

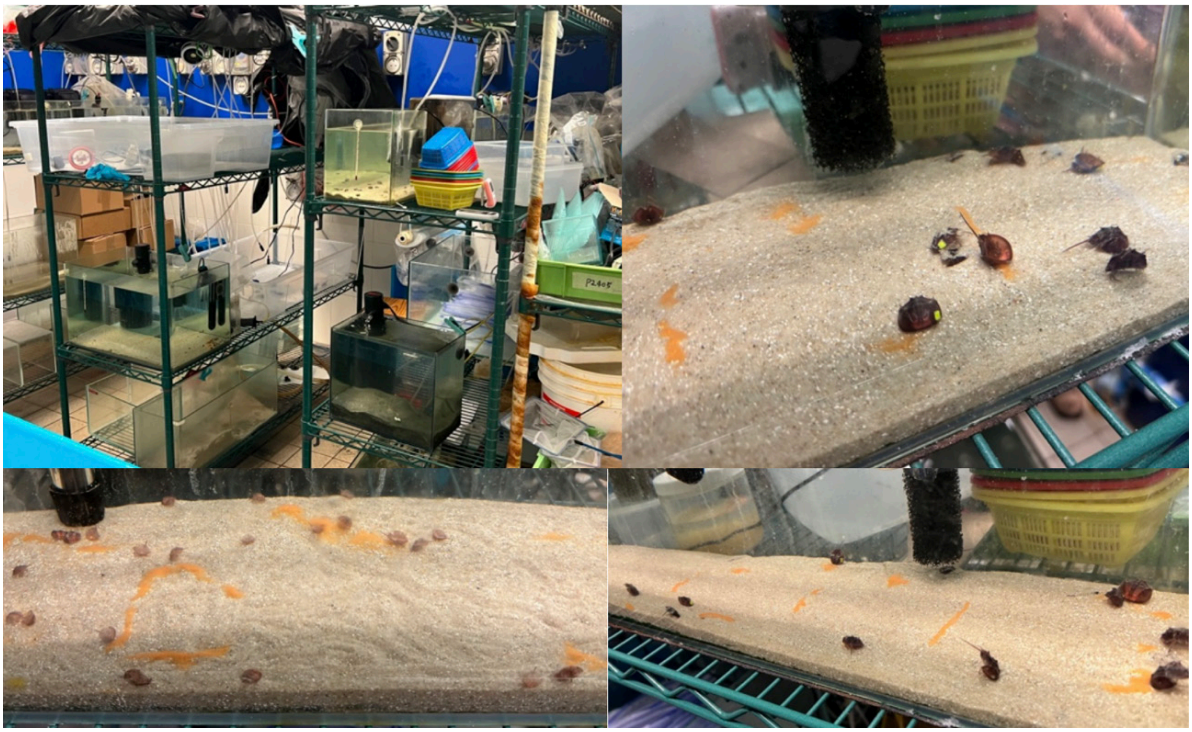


Figure 6. breeding of horseshoe crabs

Figure 5 shows our common methods for feeding horseshoe crabs in the lab, in which brine shrimp were poured directly into the tank for the horseshoe crabs to consume. These horseshoe crabs are maintained in the lab environment in a breeding programme. The resulting offsprings are released back into the wild in early summer, often in collaboration with high school students.

### 5.3 Making the cuisine and feeding them in lab

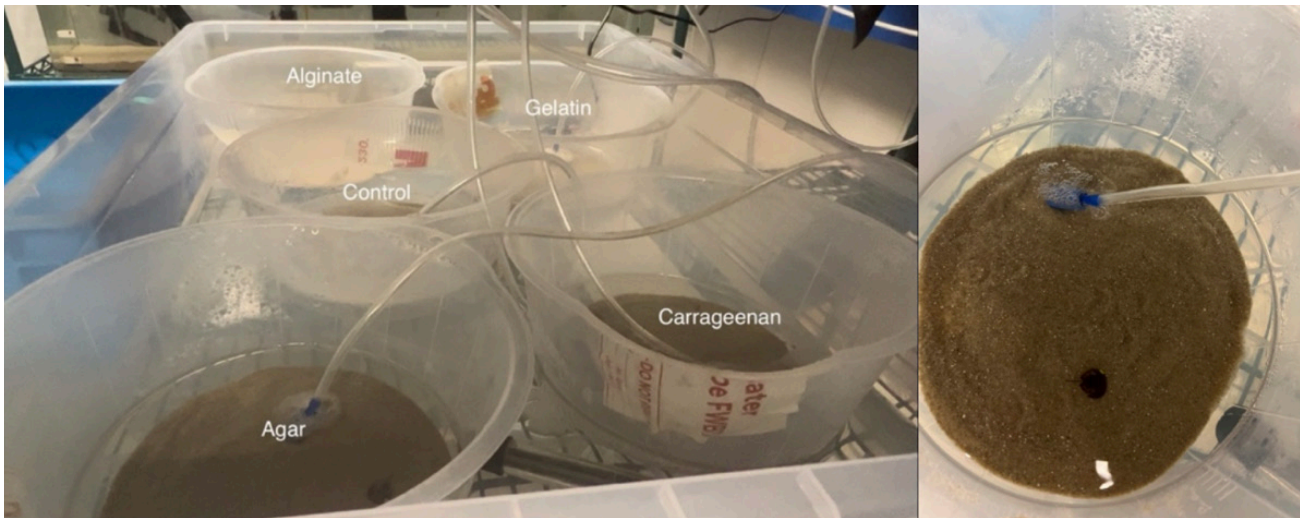



Figure 7. the setup of four experiment groups and one control group

For the horseshoe crab picnic project, five tanks were set up, each equipped with oxygen tubes, and two heaters were placed in the external water. A thermometer was used to ensure the water was maintained at the crabs' preferred temperature. Each tank housed five 4th-instar horseshoe crabs, most of which habitually buried themselves in the sand, making it difficult to spot them, as shown in the left photo. During feeding times, the horseshoe crabs were taken out and placed in feeding boxes, where they were given the specific cuisine labelled in the picture (see below).



Figure 8. Mixing brine shrimps with gels and feed horseshoe crab

The left photo shows the food prepared for the horseshoe crabs. Before and after each feeding, the weight of the food was recorded. The right photo demonstrates how the horseshoe crabs consumed the food. I removed them from the cultivation box and placed them into a feeding box to avoid contaminating the seawater in which they were being raised. The food was then placed in the feeding box for each group. The crabs would climb around the gel to consume the food, occasionally eating the algae gel as well. I allowed them an hour to ensure they had enough time to feed. Afterward, I rinsed them with seawater before returning them to their temporary habitat. For more detailed experiment videos and photos, please check this link: https://drive.google.com/drive/folders/1ocXXCeXPpzkUwd3HiAeYKzMuF4XqmDLu?usp=share_link

| Treatment D1 | Sodium alginate | Carrageenan | Gelatin | Agar | Control |
|---|---|---|---|---|---|
| Condition | Good | Good | Good | Good | Good |
| Food consumption | Average | Good | Good | Bad | Good |
| Treatment D2 | | | Gelatin + Agar | | |
| Condition | Good | Good | Good | Bad (pause) | Good |
| Food consumption | Average | Good | Good | -- | Good |
| Treatment D3 | | | Gelatin + Agar | | |
| Condition | Average | Good | Average | Bad | Good |
| Food consumption | Good | Average | Average | Bad | Average |

Form 2. The ethological investment after different cuisine treatments

Form 2 shows the record of behaviours of horseshoe crabs during each feeding session. Specifically, the observation evaluates their level of activity before and after being fed and returned to their tanks. The control group of horseshoe crabs was fed brine shrimp directly.

To establish a standard for positive behaviour, I used the activity and food consumption of the D1 control group, which displayed active movement and strong interactions with food. If a group interacted with the food but showed less energy compared to the control, I classified their behaviour as average. If a group barely moved or interacted with the food, I categorised it as poor behaviour.

For the gelatin group, I mixed gelatin with agar for feedings on the second and third days, as gelatin dissolves easily at 26°C. Compared to the agar treatment group, the gelatin group exhibited better behaviour and higher activity levels.

| The weight(/g) | Before | | After | | | | | |
|---|---|---|---|---|---|---|---|---|
| | control | treatment | control | P1 | treatment | P2 | treatment/control | P2/P1 |
| Sodium alginate | 4.69 | 9.91 | 4.43 | 94.45% | 9.59 | 96.77% | 2.16 | 1.02 |
| Carrageenan | 18.75 | 27.04 | 17.79 | 94.88% | 22.28 | 82.39% | 1.25 | 0.87 |
| Gelatin + agar | 21.55 | 30.08 | 18.96 | 87.98% | 28.35 | 94.24% | 1.49 | 1.07 |
| Agar | 25.08 | 23.12 | 22.69 | 90.47% | 19.61 | 84.81% | 0.86 | 0.94 |
| Control | - | - | - | - | - | - | | |

Form 3. The weights of the cuisines before and after the experiment

P1 means Percentage 1. P2 means Percentage 2.

The percentage 1 = the weight of the control group after the experiment / the weight of the control group before the experiment.

The percentage 2 = the weight of the treatment group after the experiment / the weight of the treatment group before the experiment.

The control groups were immersed in the same seawater as the treatment groups for the same duration (+/- 1 minute), but without the presence of horseshoe crabs. If the percentage decrease in weight of the treatment group (Percentage 2) is significantly higher than that of the control group (Percentage 1), it indicates that the horseshoe crabs have consumed the food substantially. This proves that they ate the carrageenan and agar.

However, there is a possibility that the gel or food could disintegrate in water. To account for this, I calculated the ratio of the treatment weight to the control weight, as well as the P2/P1 ratio. Since absorption or dissolution may depend more on volume than quantity, I also compared the volumes of the treatment and control groups. For instance, if the treatment/control ratio is around 2 for the sodium alginate group, the treatment group had a volume more than twice that of the control group. If the P2/P1 ratio is significantly smaller than the treatment/control ratio, it suggests that the horseshoe crabs consumed the food in specific groups, including the sodium alginate group. This is because sodium alginate forms a membrane that protects the food from dissolving, indicating that consumption by the horseshoe crabs occurred.

In contrast, for the gelatin + agar group, it is difficult to distinguish whether weight loss was due to food consumption or dissolution, as gelatin easily dissolves in water. This makes it challenging to determine the exact cause of the weight loss.For the agar group, the treatment group contained less food than the control group, resulting in weaker water absorption. Both groups experienced a decrease in weight, raising the possibility that the agar dissolved in seawater or was eaten by the horseshoe crabs. While we did not directly observe the crabs consuming the agar, their movement may have contributed to the agar's dissolution, leading to greater consumption in the treatment group.

Combining the findings from Form 2 and Form 3, we concluded that carrageenan was the horseshoe crabs' preferred "jelly cuisine." After the three-day experiment, their physical condition was as good as that of the control group, and they consumed the carrageenan the most.

Interestingly, the horseshoe crabs' interest in the sodium alginate cuisine increased over the treatment period. By Day 3, they began climbing around the alginate balls. We believe this was because, as they played with the balls, the membrane thinned or broke in places, releasing the brine shrimp. The crabs may have "learned" that this behaviour resulted in food being released.

**6. Large-Scale Production and Serving Horseshoe Crabs a Picnic in the Wild**

After completing the experiment, I made more brine shrimp balls using carrageenan. The process required boiling the carrageenan for ten minutes and then mixing it with brine shrimp as the gel cooled down to form a solid structure. However, it was crucial to keep the brine shrimp raw and prevent them from being cooked, making the timing difficult to manage. I failed many times—the brine shrimp were either accidentally boiled or did not mix well enough to form a gel. Eventually, I discovered the optimal timing was about 3-4 minutes after removing the boiling gel from the heat. I then spent an entire day preparing the cuisine.



Figure 9. the food prepared for horseshoe crabs





Figure 10. Install the food on the beach

On the day we went to the beach to install the food, we could not find any horseshoe crabs; they may have swum away or hidden themselves in the sea. I placed the food on the beach, and after the tides came and went, the food I had prepared was washed away. It's possible the food later settled near where the crabs were hiding. In the end, the power of nature helped distribute the food, eliminating concerns about pollution or rapid degradation.

## 7. Conclusion

I hope that with my artful biodesign, I could lead the audience to have a better understanding of horseshoe crabs. We went through the evolutionary and historical views, their morphologies, and the field-trip studies. When "cooking" the food for them, it gave me a feeling that I had known these animals very well and I was cooking for someone I love.

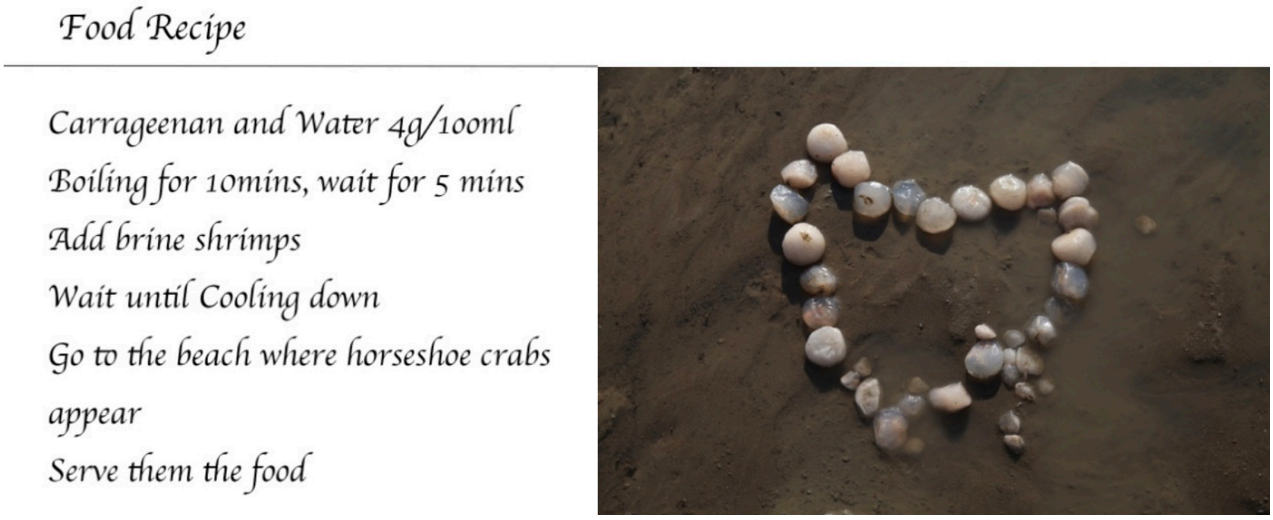
Although the weather changes and human activities influence sea animals' living qualities, I hope there are mild ways to increase people's awareness while helping the creatures. "Cooking" for them could build an equal bridge between common civilians and the wild animals. People would get more involved in helping horseshoe crab activities. This is just the first step. After the first step, the second step wouldn't be too long to wait.

## 8. Postscript





One horseshoe crab in the lab was released back into the ocean. It swam slowly away, full of hope.




## 9. Acknowledgement

I am very grateful to Dr. CHEUNG Siu Gin, my advisor, for the use of his lab, encouragement, support, and guidance. I would also like to thank my lab mate, HU Jiahua Samantha, for her help and support.

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CHAPTER

# 02

# CIRCULAR TERRITORIES

## (57) Automating the processes of disassembly, reuse and recycling of electronic products. Knud Erik Hilding-Hamann (Danish Technological Institute).

**ABSTRACT |** This paper presents research and development conducted with Danish industrial Drives manufacturer as part of the project RoboSapiens https://www.simula.no/research/projects/robosapiens-robotic-safe-adaptation unprecedented-situations. The aim is to examine how this company and others can design new and partly automated solutions to take back their electronic products from clients that no longer work, disassemble the products, assess the durability/functionality of each component and reuse or repurpose those components and materials that still have a life in new products. These products were not originally designed for repurposing of the individual parts. They were designed to be inexpensive and effective to produce and reliable to use. This, however, is no longer enough. Today, more and more companies are faced with a total life cycle commitment that they have to act on quickly in order to meet their ESG commitments and targets. There are already millions of these products in the market and companies are now turning their focus on learning how the resources embedded in these can be reused, repurposed and especially how advanced technology can be used to facilitate effective recycling processes (the alternative is manual disassembly, assessment, and sorting). This is being explored specifically with two large companies and their clients to develop and test automated solutions. This paper presents some perspectives for turning the decommissioning of such products from being crushed, smashed for extraction of valuable metals by waste handlers to setting up a more selective and advanced exploitation of discarded products and components through upgrading, repair of products and reuse of components. In doing so, exploiting robots for new roles in taking apart and reassembling products and evaluating the state of components. Also, the project is about exploring methods that will allow such companies in designing products, production and recycling so that these processes will be automated all the way through for future products.

### Introduction

The R&D project aims to evaluate the potential for automation in disassembly, reuse, and recycling of selected products. The main goals are:

• How can manufacturers use technological capabilities and automation to reuse and/or recycle products that are already in use today?
• How can manufacturers take back products and repurpose them, so that these companies with their value chains ensure best possible re-utilization?

The project is a collaboration between Danish Manufacturers of industrial electronics and the Danish Technological Institute.

The project follows this process:

1. Product Investigation and Analysis: Examining the current product design,

materials, business model, and automation potential to understand component composition, value, wear, and remaining value assessment.

2. Potential Recipient Investigation: Research the current network of recipients and new possibilities to understand component requirements, pricing, and optimal reuse/recycling pathways.

3. Automation Process: Investigate existing systems, leveraging RoboSapiens expertise, and conduct disassembly trials to identify suitable machines, process flows (disassembly, cleaning, inspection, repair, reassembly, testing) for profitability.

4. Automated Disassembly Network: Facilitate experience sharing, joint trials, and cross company resource utilization to accelerate automated disassembly progress.

5. Design for X: Redesign the product incorporating learnings for automated disassembly, component assessment, and reuse/recycling already in the design process.

The R&D project will deliver the following outputs

• Visual overview description of disassembly possibilities and challenges.
• A network and value chain of potential distributors and recipients of disassembled components who may obtain added value from exploiting these components. This network will be relevant for international members also.
• An overview of automation possibilities that may add value to the repurposing of already existing electronic products in the market.
• New disassembly-friendly product design tool with guidance for assembly, disassembly, reuse/recycling processes for new products to be developed.

**Research background to the project**

This systematic literature review (Bründl Patrick et al 2023) contributes to the research on recycling electronic products by assessing the current state of automated recycling technologies, focusing on the transition to a circular economy. It identifies research streams such as planning and balancing, object detection, and robotic systems, highlighting key challenges and solutions. It is emphasized that the integration of Artificial Intelligence and machine learning for enhanced disassembly processes and explores human-robot collaboration for improved efficiency and safety. By outlining a research agenda, it provides a roadmap for future innovations in automated recycling. The study underscores the importance of data generation and comprehensive disassembly systems to optimize recycling operations.

Literature further assesses the recyclability of electronic components like waste printed circuit boards and concludes that this is crucial for optimizing recycling processes. By integrating recyclability criteria into automated disassembly using Artificial Intelligence, it is possible to enhance material recovery efficiency, reduce environmental impact, and support sustain-

able waste management. Deep learning models like YOLOv5 effectively detects high-value components, facilitating targeted recycling (Shahhoseini, Ahad et al 2023; Mohsin Muhammad et al 2024).

Lykke Margot Ricard and co-authors discuss leveraging robotic technology for automated disassembly, highlighting its potential to enhance material recovery from end-of-life products. It emphasizes the role of a disassembly map in bridging the design and robotic engineering fields, facilitating efficient disassembly processes. Robots provide flexibility, accuracy, and repeatability, crucial for handling the variability in product conditions. The study outlines the challenges posed by current design choices, such as irreversible fasteners, which hinder non destructive disassembly. It proposes a framework for integrating disassembly insights into the design phase to optimize robotic disassembly for sustainable lifecycle management (Ricard Lykke Margot et al, 2024). An examination of the applicability of flexible robot systems designed for various product conditions has been carried out. It emphasizes the importance of integrating digital models and standardized data to support efficient disassembly workflows. The study highlights the need for skills-based programming to achieve adaptable and scalable solutions for e-waste management (Saenz Jose et al, 2024).

A robotic system designed to automate the desoldering and extraction of components from printed circuit boards needs to be introduced emphasizing the importance of precise force control. A study demonstrates a high success rate in desoldering larger PCB components, highlighting its feasibility for automating e-waste recycling processes. Challenges such as component size and proximity are addressed by customizing the tool design. Future improvements include integrating a second robotic arm and computer vision to enhance system performance (Santos Silvia et al 2024).

The above research emphasizes the importance of automating disassembly processes in the recycling of electronic waste to enhance efficiency and sustainability. It highlights the role of robotic systems in streamlining disassembly tasks, reducing labor costs, and managing complex product structures. The integration of AI and machine learning emerges as a critical factor for improving object detection and process adaptability. Human-robot collaboration is identified as a beneficial approach to balancing precision and safety in recycling operations. The necessity of developing comprehensive data models and disassembly frameworks to support automated recycling must be underlined. Overall, the research sets the stage for future innovations aimed at achieving a circular economy through advanced recycling technologies.

**The product investigation and analysis**

The initial investigation covers how the following factors affect the possibility of disassembling products for reuse/recycling:

- Design
- Materials and value
- Conditions of use, wear and tear

• Business model
• Automation potential

The investigation will focus on one bespoke product delivered in large quantities to one customer. It will examine the components and what materials they consist of. The value of each individual component will be assessed and to what degree the individual components will experience wear and tear (component life cycle and the variation of that). It is important to assess the continued value of the component and its possible use in new products or as spare part in existing products. Finally, the assessment will conclude by examining the automation potential of the product through manual disassembly, value determination of components and rating the engineering potential to automate and repurposing the product and/or components.

At the end of this investigation, a visual and written overview of the possibilities for disassembly including an identification of the key challenges associated with the disassembly will be presented.

The steps in the examination are as follows:

1. Understand the environment of use and the wear & tear profile of the product
2. Disassemble the product to identify all components
3. Analyze the design to understand how it facilitates or hinders disassembly
4. Examine the materials used and how they impact component reuse/recycling
5. Investigate the business model and supply chain to assess component value
6. Explore automation technologies that could aid in efficient disassembly
7. Document findings visually (e.g. diagrams) and in writing
8. Note any specific disassembly challenges encountered

The key aspects are thoroughly understanding the product composition, wear factors, design for disassembly, and assessing remaining component value - all critical for developing an effective automated disassembly process.

**Recipient investigation**

The potential recipient investigation would involve identification of the current networks of recipients, conducting research to identify new potential recipients and aligning expectations of product owners, internal or external component recipients regarding priorities for component value, functionality, reuse/recycling, etc.

The recipient investigation will seek to understand the requirements components must meet to be of interest to recipients, the best price for components or raw materials the recipient will offer, and which recipients will be able to reuse or recycle components in the most optimal way.

The key is to thoroughly understand recipient needs and capabilities to maximize component reuse and material recycling while obtaining a fair value/payment.

Developing the automation process for disassembly, valuation, and sorting of products would involve the investigation of existing disassembly automation systems, leveraging knowledge and experience from the RoboSapiens project, conduct trials for product disassembly and component evaluation. Specifically, the investigation will examine machines that may allow disassembly of components into desired parts as well as the processes of disassembly, cleaning, inspection, repair, reassembly, and testing and how these can be carried out cost effectively.

The investigation of the disassembly process involves the following steps:

1. Research existing industrial automation solutions for product disassembly, such as robotic disassembly cells, vision systems for component identification and automated sorting and handling equipment.

2. Collaborate with RoboSapiens partners to tap into their expertise in robotic disassembly systems.

3. Conduct trials disassembling the product using different automation approaches. This could involve programming robots to perform specific disassembly tasks, integrating vision systems for component recognition, testing automated cleaning and inspection processes, exploring repair and reassembly automation possibilities.

4. Evaluate each trial in terms of disassembly completeness and quality, cycle time and throughput, capital and operating costs and flexibility to handle product variations.

5. Compare different automation options, considering factors like initial investment required, operating costs (labor, energy, maintenance), scalability and adaptability, level of automation (full vs. partial) and quality control and process monitoring capabilities.

6. Develop a proposed automation process flow, outlining steps from disassembly through inspection, sorting, repair, reassembly, and testing.

The key is to leverage existing technologies while conducting hands-on trials to identify the most efficient and cost-effective automated process tailored to the specific product and project goals.

An “Automated Disassembly Network” will be established with no more than 10 companies all not in competition to identify common issues and challenges, exchange experiences and trials, distribute prioritized trials and automation projects and share results and transfer learnings.

The network will facilitate:
• Exchange of experiences and dissemination of knowledge about automated product disassembly
• Utilization of trial resources for mutual optimization of disassembly processes • Resource utilization and experience sharing across companies

• Faster progress in automated disassembly by dividing the tasks among several compatible companies with overlapping disassembly tasks.

The project has already identified three other companies facing similar challenges in automated electronic product disassembly and have invited them to join the network. A platform (e.g., meetings, online forums) will be established for network members to share their experiences, lessons learned, and best practices in automated disassembly and further members will be engaged. Collectively the members will then be facilitated to identify common issues, bottlenecks, or areas requiring further development in automated disassembly processes. The members will prioritize and distribute trials or automation projects among network members based on their expertise, resources, and specific product needs. As the network facilitator Danish Technological Institute will coordinate the sharing of trial results, data, and insights across the network to avoid duplication of efforts and facilitate cross-learning.

Workshops, site visits, or knowledge transfer sessions will be organized for members to learn from each other's successes and failures. There may be opportunities for resource sharing, such as sharing test facilities or equipment; pooling research and development efforts and jointly developing automation solutions.

The key benefit of the network is to accelerate progress in automated disassembly by fostering collaboration, sharing resources, and transferring knowledge across multiple companies and sectors facing similar challenges.

**Design for (recycling) X**

The project will develop a guide for designing new products for assembly, disassembly, and reuse. This will be relevant to obtain the following benefits:

1. Reduce Costs: By considering automated disassembly and component reuse/recycling during the initial design phase, products can be designed in a way that simplifies and streamlines the disassembly process. This can help reduce the costs associated with automated disassembly and material recovery.

2. Improve Environmental Sustainability: Designing products with disassembly and reuse/recycling in mind can make the components more environmentally friendly. It can facilitate easier separation of materials, enabling more effective recycling and reducing waste.

3. Optimize Disassembly Processes: Incorporating disassembly considerations into the product design can help optimize the automated disassembly processes. Products can be designed with features that make disassembly more efficient, such as easy-to remove fasteners, modular components, and clear material identification.

4. Enable Automated Disassembly: Certain product designs may be incompatible with automated disassembly systems. By designing with automation in mind, products can be made more suitable for robotic disassembly, reducing the

need for manual intervention.

5. Enhance Component Reusability: Products can be designed to minimize wear and damage to components during their intended use, making it easier to assess their remaining value and reuse potential during disassembly.

6. Facilitate Closed-Loop Systems: Designing for disassembly and reuse/recycling from the outset can enable the creation of closed-loop systems, where components and materials can be effectively recovered and fed back into the production cycle.

By incorporating these considerations into the design process, companies can create products that are not only easier and more cost-effective to disassemble but also more environmentally friendly and better suited for circular economy principles.

**Conclusion**

There are large volumes of electronic industrial and consumer products already in use where today there are no solutions for disassembling, assessing, repurposing, reusing or recycling these products or their components. Most of these products are smashed or dumped on tips or remelted to withdraw just the material but none of the functionality. These existing processes result in loss of huge value and cannot continue if manufacturers are to meet circularity goals.

This project leverages automation to enable more effective reuse and recycling of product components and materials. By incorporating design for automated disassembly from the start and fostering cross-industry collaboration, the goal is to reduce costs, increase environmental sustainability, and optimize disassembly processes for improved circularity of products and components.

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# (47) Empowering Citizen Designers: Integrating Systems Thinking in Graphic Design Education for Sustainable Impact. Lilian Crum (Lawrence Technological University).

**ABSTRACT |** This paper investigates the integration of systems thinking into graphic design education as a means to empower students to become citizen designers— creatives who use their skills to drive social, political, and environmental change. Motivated by the observation that emerging designers often prioritize paid opportunities over transformative impact, this study explores how systems thinking can challenge traditional market-driven approaches and promote more sustainable, ethically responsible design practices. Through a series of case studies from a sophomore-level undergraduate course, the paper examines how students applied systems thinking to critically assess environmental impacts and develop innovative design solutions. This study qualitatively analyzes students' processes, concepts, and final designs to explore how systems thinking deepens understanding of complex environmental issues, challenges capitalist forces, and empowers a citizen design mindset. This approach illustrates a pathway toward circular territories by deepening students' comprehension of environmental systems and encouraging responsible design interventions. The results demonstrate that students gained a sense of agency and the tools to create a positive impact, ultimately positioning themselves as active participants in driving systemic change. The findings underscore the importance of integrating systems thinking into graphic design education as a strategic imperative for cultivating designers capable of addressing the challenges of a rapidly evolving world and contributing to a more sustainable and equitable future.

## INTRODUCTION

"Citizen design" in the field of graphic design refers to designers' social, political, and environmental responsibility to intentionally use their work to create a broader impact beyond merely serving a client's needs. This philosophy encourages designers to embrace their role as agents of change and to critically consider how their creativity and skills can make a positive difference in the world (Heller & Vienne, 2003). However, when design students graduate, they typically seek paid opportunities to support themselves and establish their careers, leaving little room for prioritizing world-changing initiatives when those opportunities are not readily available. Consequently, the immediate focus for most emerging designers is gaining paid professional experience rather than pursuing transformative impact.

The integration of systems thinking, a framework for understanding complex systems (Senge, 1990; Stroh, 2015), oKers a promising approach to counteract these challenges. By integrating systems thinking into the design process, emerging designers can better understand the broader implications of their work within social, economic, and environmental systems. This empowers them to utilize their expertise for good, even within a capitalist economy.

This paper examines how integrating systems thinking into graphic design

education can empower students to become citizen designers capable of creating thoughtful, informed projects that reduce environmental harm. While recognizing that designers operate within a capitalist society, the paper also explores how systems thinking can challenge traditional market-driven approaches and promote more sustainable, ethically responsible design practices. Although these projects do not directly implement a circular-based system, they demonstrate a pathway toward it by deepening students' understanding of environmental systems. Ultimately, students gain a sense of agency and the tools to drive positive change through their roles as designers.

**1. Ethical Dilemmas**

The concept of citizen design is well-established in the field of graphic design and has been widely explored in numerous books and articles (Heller & Vienne, 2003; Rejane Dal Bello, 2020; Resnik, 2016). A notable example is Citizen Designer: Perspectives on Design Responsibility (Heller & Vienne, 2003), which examines the potential for designers to adopt civic-minded practices through over 70 essays and interviews. This work addresses key questions about the social and political impact of design, designers' responsibilities toward their clients, and the ethics of the profession.

One chapter is dedicated to a provocative ethics exercise conceived by renowned designer Milton Glaser: "12 Steps on the Graphic Designer's Road to Hell." This exercise emphasizes the importance of responsible design within a market-driven system by exposing the ethical dilemmas designers face. It presents designers with a series of increasingly challenging questions, each asking if they would accept a project with potentially negative consequences.

Glaser's hypothetical scenarios escalate from: "Designing a package to look bigger on the shelf." (Heller & Vienne, 2003) to "Designing a crest for a new vineyard to suggest that it has been in business for a long time." (Heller & Vienne, 2003) to "Designing an ad for a political candidate whose policies you believe would be harmful to the general public." (Heller & Vienne, 2003) before ultimately reaching: "Designing an ad for a product whose frequent use could result in the user's death." (Heller & Vienne, 2003) Glaser's exercise is a powerful reminder of the significant role designers play in shaping the world. It reinforces the idea that ethical and intentional design practices can drive positive change and contribute to a more sustainable and positive future.

Yet, in a capitalist system, the typical client-designer dynamic can make designing for good a challenge. New graduates from design programs will likely find themselves working on projects primarily focused on the pursuit of profit and shaped by market demands. How, then, can early-career graphic designers integrate a citizen design ethos into their practice? How can they develop and use a sense of agency for meaningful change? How can this citizen design mindset lead to more environmentally sustainable outcomes?

## 2. Systems Thinking for the Citizen Designer

Systems thinking methodologies have the potential to help graphic designers make more informed and ethical decisions, even within capitalist structures. This approach allows designers to identify and understand the patterns and influences of complex systems rather than focusing on problems in isolation (Meadows, 2008). By considering the relationships and interactions between system elements, designers can better comprehend the dynamics at play and more accurately predict outcomes. Systems thinking enables individuals to see the interconnectedness of issues, fostering more sustainable and long-term solutions (Stroh, 2015).

In line with this, Wolfgang Jonas argues that the goal of design should be to solve problems and create desirable futures through systemic interventions. Unlike traditional design thinking, which often tackles isolated problems, a systems framework emphasizes creative strategies that shape future behaviors and outcomes by making adjustments within the entire system (Jonas, 2001). Employing this approach equips designers to consider a problem within a larger web of interconnected influences. From an ecological perspective, this includes factors such as carbon footprint, water usage, and biodiversity impact. Moreover, systems thinking encourages designers to challenge their mental models—the deep-rooted, subjective ways we see and interact with the world. Reshaping these mental models is crucial for fostering learning and adaptation within complex systems, leading to more effective and sustainable design solutions (Senge, 1990).

## 3. Case Studies

The case studies presented in this paper were selected based on their relevance to environmental sustainability, a citizen design philosophy, and the students' clarity of the systems thinking approach. This approach contrasts with the traditional client-designer model, where the designer merely serves the client's needs and views the design problem in isolation. Each project was systematically analyzed to identify key systems elements (e.g., material flows, stakeholder relationships, environmental impacts).

The graphic design project in this study was adapted from an assignment developed by Eric Benson (University of Illinois-Urbana-Champaign) called New Sharing Systems, published in 2023 on AIGA's Design Educator's Community Design Teaching Resource website (Benson, 2023).

The objective of the Investigative Graphic Design course assignment, the subject of this investigation, was for students to identify an existing product or service that contributes to landfill waste, carbon emissions, or other practices that cause environmental harm. They were then required to develop a visual systems map of the various elements that influence and are influenced by this product or service. From there, students identified and redesigned a problem area of this system to inform a new, innovative product or service that would be more sustainable. The deliverables for the assignment include a branded visual system applied to components of the new product or service, such as signage, packaging, social media messaging, etc.

Central to the assignment, systems mapping encouraged students to explore the intricacies of the problem. This process challenged their mental models and cultivated a citizen design mindset, emphasizing the designer's role as a responsible agent of change.

### 3.1 Methodology

This study employs a qualitative research design, focusing on a case study approach to examine the integration of systems thinking in a sophomore-level graphic design course. The primary data sources include process documentation (e.g., systems maps) and final design deliverables.

This study focuses on the following key research questions:

1. How does system thinking contribute to fostering a deeper understanding of complex, interconnected environmental problems?
2. How does the project respond to capitalist forces?
3. How does systems thinking empower design students to embody a citizen design mindset?
4. What is the potential for the project to contribute to a circular-based economy?

Project 1

Through research on the use of small plastic soap sachets that have become staples within Filipino communities, the student uncovered a significant environmental issue. For multinational corporations, these sachets represent a lucrative market, tapping into the purchasing power of consumers who can barely aKord larger quantities. The Philippines, in particular, has become a sachet nation, consuming a staggering 163 million sachets daily, according to a study by The Global Alliance for Incinerator Alternatives (GAIA) (Reuters, 2019). These communities heavily rely on plastic soap sachets due to their convenience and affordability, leading to substantial landfill waste. Corporations have successfully marketed these single-use sachets as the superior option, convincing consumers that buying in small, convenient packages is better than purchasing in bulk or using reusable containers. This strategy has entrenched a consumer habit that significantly harms the environment.

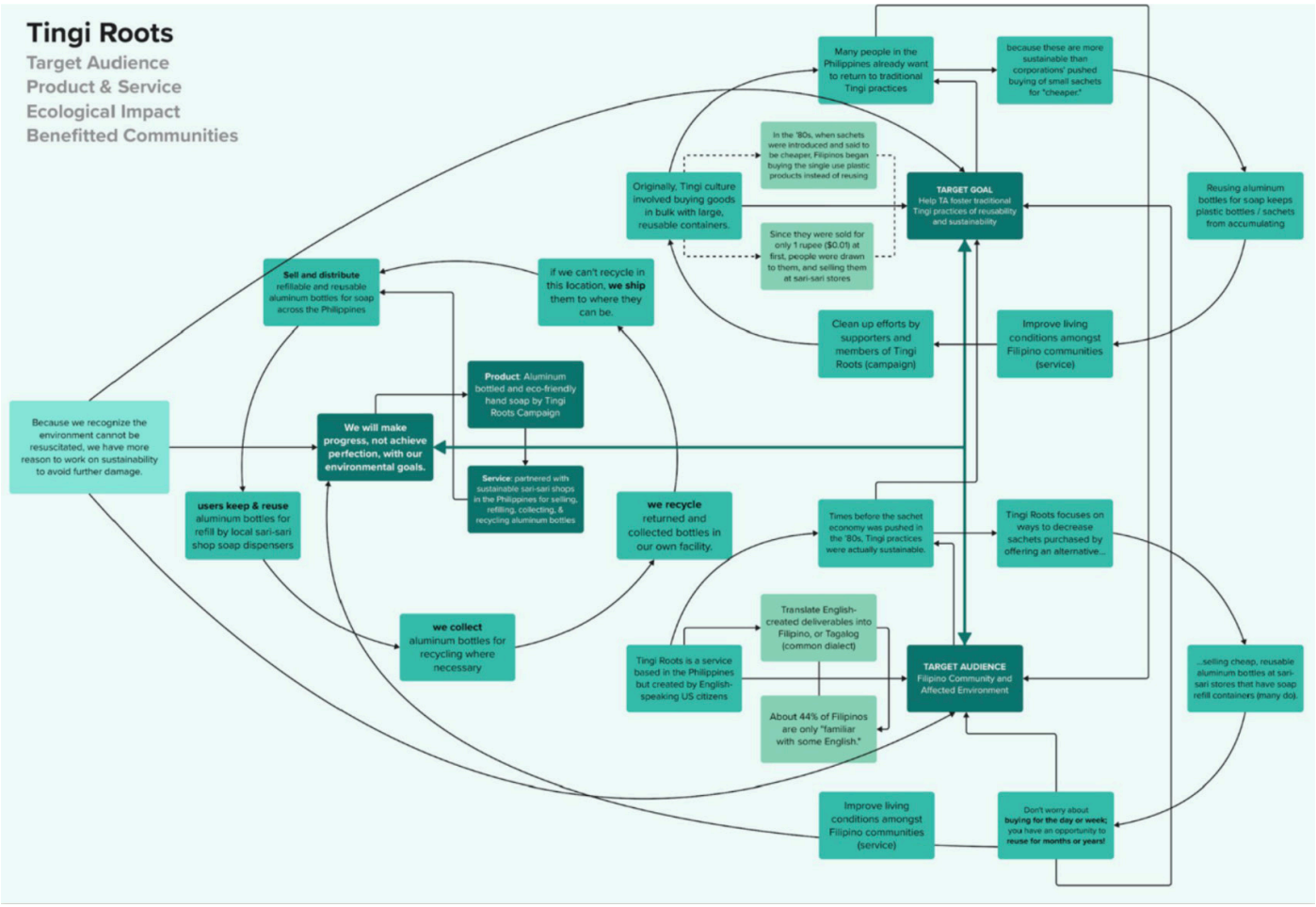


FIGURE 1: TINGI ROOTS SYSTEMS MAP ELEMENT




FIGURE 2: NEW TINGI INFOGRAPHIC

In response to this design problem, the student's project developed "New Tingi," a refillable soap container and bulk distribution service. The most important deliverable is a branded soap refill container, which is distributed to the target audience for use at soap refilling stations. New Tingi's message is inspired by the resilience of Filipino communities, their efforts to be sustainable, and their hope for a cleaner lifestyle, home, and planet. The design deliverables are presented in both Filipino and English to ensure accessibility and effective communication. This approach aims to shift consumer behavior towards more sustainable practices and reduce plastic waste in these communities.

System thinking played a crucial role in fostering a deeper understanding of the interconnected problems associated with plastic waste. By mapping out the entire lifecycle of these plastic, single-use soap sachets—from production and marketing to consumption and disposal—the student could identify not only the direct environmental impacts but also the social and economic factors that perpetuate their use. This holistic perspective allowed for a more comprehensive solution that addresses the root causes of the issue rather than just its symptoms.

The project responds to capitalist forces by challenging the corporate narrative that promotes single-use sachets as the best option for consumers. It advocates for a shift towards sustainable consumption practices, encouraging bulk buying and the use of reusable containers. By providing an attractive and practical alternative through "New Tingi", the project aims to reduce the dependency on single-use plastics, undermining the profit-driven motives of corporations that prioritize convenience and short-term gains over environmental sustainability.

Adopting a systems thinking approach empowers this student to embrace a citizen design mindset by encouraging them to consider the broader impact of their work on society and the environment. This approach shifts them from merely creating products in isolation to becoming an active participant in driving systemic change. It fosters a sense of responsibility and agency, motivating this student to develop solutions that not only meet user needs but also contribute to the greater good. Through projects like "New Tingi," this student learns to tackle complex issues with innovative, sustainable solutions that have the potential to create lasting positive impacts on communities and the planet.

By introducing a refillable soap container system in Filipino communities, "New Tingi" offers a direct challenge to the pervasive single-use plastic sachet model. This project aligns with circular economy principles by prioritizing reuse, waste reduction, and resource efficiency. Through a shift from disposable to refillable products, "New Tingi" aims to cultivate a sustainable consumption model that minimizes environmental impact. By addressing the root cause of plastic pollution in these communities—overreliance on single-use packaging— the project demonstrates a tangible application of circular economy concepts, with the potential to inspire similar initiatives across various sectors.

Project 2

Through research on the environmental impact of the pet industry, the student identified significant issues related to waste and sustainability. The pet industry contributes more than 300 million pounds of plastic to North American landfills each year (Waste Advantage Magazine, 2020). This research led to the development of LOLA & LEO, a pet subscription box service committed to sustainability and eco-consciousness. Each subscription box includes eco-friendly toys, biodegradable packaging, natural and limited ingredient treats, and sustainably-produced, nutritious food. With LOLA & LEO, customers can pamper their furry friends while supporting a green and eco-conscious lifestyle.

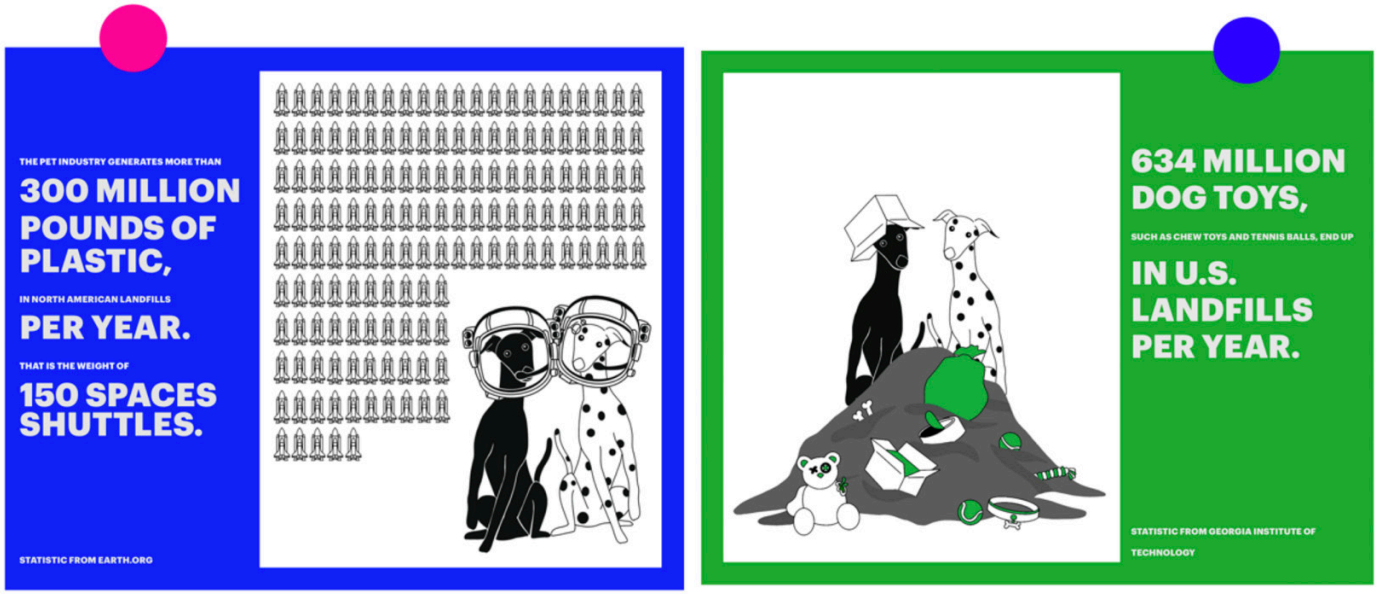


FIGURE 3: LOLA & LEO INFOGRAPHICS

System thinking helped the student better comprehend the interconnecting forces of product production within the pet industry. By analyzing the entire lifecycle of pet products—from production and marketing to consumption and disposal—the student could identify not only the direct environmental impacts but also the broader social and economic factors at play.

The project responds to capitalist forces by challenging the prevailing corporate practices that neglect the environmental harm caused by the pet industry. LOLA & LEO advocates for a shift towards eco-friendly consumption practices, offering products that are both beneficial for pets and environmentally responsible. By providing a sustainable alternative through their subscription boxes, the project aims to reduce the dependency on plastic and other harmful materials, undermining profit-driven motives that negatively impact the environment. Additionally, with every box purchased, another is donated to an animal in need, allowing customers to choose from over 20 organizations to support. This not only promotes sustainability but also

reinforces the values of social responsibility and community support.

Through systems thinking, the student adopted a citizen design mindset by examining the pet industry's environmental footprint. This holistic analysis uncovered a wider array of issues than traditionally addressed by graphic designers, including material waste and the efficacy of corporate social responsibility initiatives. By incorporating these insights into their design process, the student created a more innovative and impactful project that aligned with the core principles of citizen design, ultimately leading to an entrepreneurial venture with positive environmental outcomes.

The "LOLA & LEO" project contributes to a circular economy by reimagining the pet industry through sustainable practices. OKering a pet subscription box with eco-friendly toys, biodegradable packaging, and sustainably produced food, it tackles the plastic waste generated annually by the industry. By shifting from single-use plastics to a system that emphasizes reuse and minimal environmental impact, the project aligns with circular economy principles. Additionally, by promoting eco-friendly consumption and supporting animal welfare through donations, "LOLA & LEO" fosters sustainability and social responsibility, creating a replicable model for a more sustainable future.

Project 3

The student's research highlighted the environmental consequences of cocoa production, including deforestation and unsustainable farming practices linked to chocolate consumption (World Wildlife, 2017). This project led to the creation of "Field to Flavor," an ethically sourced chocolate bar company that aims to transform the chocolate industry through ethical sourcing, farmer empowerment, and sustainability. They source their cocoa beans exclusively from ethical and sustainable farms in West Africa, ensuring no child labor is used in their supply chain. They empower cocoa farmers with fair wages, training, and resources, fostering stronger communities through direct partnerships.




FIGURE 4: FIELD TO FLAVOR PACKAGING

System thinking allowed the student to better understand the entire lifecycle of chocolate production—from cocoa farming and sourcing to distribution and consumption. With this knowledge, they were able to develop a holistic concept for a new chocolate bar company that uses its fair labor practices as a core pillar of the company that is expressed through its branding.

The project challenges conventional consumerism by promoting ethical consumption choices. It emphasizes the need to support sustainable and fair trade practices within the chocolate industry. By providing a conscientious alternative through their ethically sourced products, the project aims to reduce the dependency on exploitative labor practices, undermining the profit-driven motives that perpetuate these issues.

A systems thinking approach unveiled previously obscured challenges within the chocolate industry, notably the prevalence of child labor. This revelation ignited a citizen-designer mindset, prompting the student to explore comprehensive industry reform. By considering the interconnectedness of social, economic, and environmental factors, the student aimed to create lasting positive change for both people and the planet.

The “Field to Flavor” project addresses elements of a circular-based model by prioritizing ethical sourcing and sustainable production within the chocolate industry. By focusing on fair trade practices and empowering cocoa farmers, the project considers the industry’s complex social and environmental challenges. Through a holistic approach that encompasses various stages of the chocolate supply chain, “Field to Flavor” seeks to create a regenerative system that benefits both consumers and producers. By challenging conventional business models and demonstrating the viability of ethical and sustainable practices, this project has the potential to catalyze systemic change within the chocolate industry.

## 4. Conclusions

### 4.1 Understanding the Design Problem

These projects demonstrate that systems thinking is an invaluable tool for developing a comprehensive understanding of complex environmental problems that are adjacent to graphic design-related projects. By adopting a holistic perspective and mapping out the connections within a complex system, students were able to identify not only the direct environmental impacts but also the underlying social and economic factors driving these issues. This deeper comprehension enabled them to approach their projects with greater intention.

### 4.2 Relationship to Capitalist Forces

Each project oKers a critical response to the dominant capitalist paradigm. By challenging the status quo and prioritizing sustainability, social responsibility, and ethical consumption, these initiatives demonstrate how business models can be restructured to align with broader societal and environmental

goals. These projects collectively suggest a pathway for consumers to make informed choices and for businesses to operate in a manner that benefits both profit and planet.

### 4.3 Student Empowerment

By cultivating a systems thinking approach, design students are empowered to transition from passive consumers of design challenges to active agents of positive change. This methodology fosters a deep understanding of complex issues, encouraging students to consider the broader societal and environmental implications of their work. By adopting a citizen design mindset, students are equipped to develop innovative solutions that not only address specific problems but also contribute to systemic improvements. This holistic perspective prepares them to become responsible and impactful designers who can create a more sustainable and equitable future.

### 4.4 Circular-Based Territories

The potential for these projects to contribute to a circular economy is substantial. By prioritizing reuse, waste reduction, and sustainable practices, these initiatives offer tangible models for transforming linear economic systems into regenerative ones. These projects not only mitigate environmental impacts but also demonstrate the viability of circular models, inspiring broader adoption and systemic change.

## 5. Limitations and Future Directions

The present study encountered constraints in its scope and sample size, as it was confined to case reports from a single sophomore-level undergraduate course involving a limited number of students. To broaden the understanding of the findings, future research should encompass a wider range of courses and institutions.

Another limitation of this study was its restricted time frame, focusing solely on a single assignment within one semester. Given that systems thinking thrives on sustained engagement and iterative refinement, a longer-term investigation would provide a more accurate assessment of its enduring influence on students' design methodologies and outcomes.

To enhance the study's depth, incorporating expertise from fields such as environmental science, economics, and marketing is essential. By collaborating on systems mapping and other integrated research methods, we can develop a more comprehensive understanding of the complex issues at hand.

## 6. Concluding Discussion

The analysis of student projects revealed that integrating systems thinking into graphic design education significantly improved students' ability to identify and address complex environmental challenges. By revisiting Milton Glaser's ethical exercise, we are starkly reminded of the ethical dilemmas

designers face. This, coupled with the systems thinking framework, compels designers to consider the broader implications of their work.

Integrating systems thinking into design education not only deepens understanding of complex issues but also empowers students to become proactive agents of change. Because systemic design is not only about solving immediate problems but about creating frameworks for long-term social and environmental sustainability (Jones & Kijima, 2018), this approach is essential for developing designers who can navigate a rapidly evolving world and create lasting positive impacts. By fostering a holistic perspective and encouraging critical thinking, we can cultivate a new generation of designers capable of driving systemic change toward a more sustainable and equitable future.

The concept of circular territories emerges as a promising avenue for design intervention. By understanding the interconnectedness of systems, designers can identify opportunities to create closed-loop processes and reduce waste. This holistic approach, combined with ethical considerations, positions design as a catalyst for building resilient and regenerative communities. Ultimately, the integration of systems thinking into design education is not merely an academic pursuit but a strategic imperative for creating a more sustainable and equitable future.

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CHAPTER

# 03

# SPECULATIVE BIOFUTURES

# (32) RECLAIMING A BIOCENTRIC ETHIC TO DESIGN. Raquel Noronha (Universidade Federal do Maranhão).

**ABSTRACT |** Based on former field experience, this paper presents a theoretical framework that dialogues with an animist approach, inspired by the famous text by Belgian philosopher Isabelle Stengers (2012), who calls for animism as a posture for overcoming the ills of the Anthropocene. By combining this debate with the studies of decolonial critique about the notion of the Anthropocene, ecofeminism and biocentric are thought of as theoretical amalgams to give shape to what was experienced with the artisan and maroon communities, allowing concepts such as corporeality, relationality and sociability to emerge, which point us in the direction of interspecific and intersubjective coexistence, as a possible ethical path for the field of design.

**KEYWORDS |** ANTHROPOCENE, BIOCENTRISM, DESIGN, ECOFEMINISM, DECOLONIALITY

## INTRODUCTION

In the process of regenerating worlds, life needs to be taken centre stage in design practices. As points in this discussion, I propose the connection between the concepts of ecofeminism and biocentrism as a means of thinking about new research ethics for overcoming the Anthropocene.

This text is an essay of a situated nature, inspired by the invitation of philosopher Isabelle Stengers (2012) to reclaim animism which, according to the author, was one of the reasons that legitimized colonial conquest and justified the ability of some to classify and overpower others. According to Stengers, animism only really exists today because it has been recognized as a scientific category. To overcome the colonial legacy, Stengers calls on us to reclaim animism as “what incites us to feel that we have a great responsibility to determine what is and is not authorized to exist” (Stengers, 2012, n.p.).

As part of this discussion, I propose imagining a biocentric ethic for design, considering two theoretical-philosophical approaches, Ecofeminism and Biocentrism. Colombian anthropologist Diana Gómez Correal (2014) states that feminism is the rebellious daughter of illustrated modernity and, complementing her reflection, I understand that design is her favorite and most successful child. The link between the field of design and modernity is intrinsic and the search for other designs (Gutiérrez Borrero, 2015; Escobar, 2016; Author, 2018), especially in Latin American studies of the field, points to a path towards decolonizing practices and positions within the field of design. To think about new practices, it is necessary to reflect on new ethics.

Arturo Escobar warns us about the historicity of the conception of modernity and patriarchy as fundamental and structuring for our being-in-the-world today. Furthermore, in his reflections, he invites us to see design in its

ontological potential because, in his words, “el diseño diseña” and communities design themselves (Escobar, 2016, p.37)”, in the sense that it molds the material shape of the world and thereby builds its political and ethical dimension. The Anthropocene has just been denied as a geological era, after extensive theoretical debates that hesitantly feared attributing to Humankind the geological impact compared to that of tsunamis and volcanoes on the Earth’s surface, as reported by Bruno Latour (2013). Denying such an impact implies placing Man in a neutral position, minimizing and throwing up a smokescreen in relation to the extractivist stance that has become more pronounced in the last 500 years, but which has already been felt since human sedentarisation and the practice of agriculture around ten thousand years ago, still in the Neolithic period. Patriarchy, reflects the Bolivian intellectual and activist Silvia Rivera Cusicanqui (2010), combined with the ideological apparatus of modernity, has allowed the co option of communal practices that have been emptied, re-read and re-requested as part of a strategy of conditioned inclusion of Latin American indigenous populations in second-hand citizenship, through multicultural discourses that deny worldviews and co-opt the cosmovisions of the possible worlds that once coexisted in Abiayala.

Based on this nefarious legacy of the patriarchal-Western-capitalist world system described by the authors, I present in this paper theoretical reflections on the concepts of ecofeminism and biocentrism as a means of mitigating the effects of Western modernity that put life on the planet in check, in dialogue with design research situations conducted with artisan communities in the state of Maranhão, Brazil.

Design as a field of knowledge has already been in dialogue with the biocentric paradigm, as I will explain later in the fourth section, and has moved away from it towards the promise of rationality and the positivist dissociation between man and nature.

Ecofeminism, as a feminist current, has been sidelined by the prioritization of the neoliberal agendas of the third (and fourth) feminists’ waves. By reclaiming the reconnection of these two approaches, it is possible to think of an ethical path that inspires us as an epistemological apparatus to support a redirection of our practices and research into other designs.

## PITFALLS OF ANTHROPOCENE

The Anthropocene has not yet begun, but the end of the Holocene has been declared. This aphorism summarizes a great modern dilemma, the narrative of which was constructed by Bruno Latour in his book Facing Gaia (2013). Taking part in the International Geological Congress in 2012, Latour describes the impasse between assuming the geological era of the Anthropocene and at the same time declaring what was the consensus, the declaration that the geological era characterized by the planet’s tectonic stability, the Holocene, was over.

“The research group currently considers the Anthropocene to be a possible

geological epoch, that is, situated on the same hierarchical level as the Pleitocene and the Holocene, which implies that it is located in the Quaternary Period, but that the Holocene is over" (Latour, 2013, p. 183).

This fact left open what would come after the Holocene, and an imbroglio arose. It was a very radical decision to assume that the new geological era was marked by man's actions on the Earth's surface. And it still is today. The Anthropocene had never been recognized as such. For geologists, humans in their finitude, says Latour, it is very difficult to place their "golden pin" at a given geological moment, lasting millions of years, and say, here begins one era and here ends another. Where should you place this milestone? Was it the great navigations? Was it the Industrial Revolution?

Without establishing a specific date for the advent of the Anthropocene, Crutzen and Stoermer (2000) propose the end of the 18th century but admit that the entire Holocene can already be perceived by the growing impact of humanity on the earth's ecology and geology.

This discussion interests us because of the hesitation it causes. Not assuming that the Anthropocene is in fact a geological era is a type of denialism that protects man and humanity from its harmful impact on the planet.

I take the narrative of Paul Preciado, in his book Dysforia Mundi: the sound of the world falling apart, when he alludes to the fire at Notre-Dame Cathedral in Paris, which he watched from the window of his flat and reflected that it was a metaphor for the destruction of a system: "The cathedral could have been called theocracy, capitalism, patriarchy, national reproduction, world order... and now everything is burning." (Preciado, 2023, p.32).

Breaking with these institutions leads to an epistemological shift that, according to the author, impacts us politically, economically and philosophically in an unprecedented way. "And the ruins, despite everything, are better than capitalism. because they are our present condition: our only home." (Preciado, 2023, p.33). This panorama raises two issues that are valid for our argument, that life needs to be brought to the center of the design process, as a possible ethic for rethinking the epistemological paths of the field.

The first issue is to assume that in the context of the dismemberment of knowledge, nature and culture were separated and gave rise to a system of thought, named by Preciado (2023) as petrosexracial, which enables the legitimized hierarchization of knowledge, bodies and worldviews as superior and inferior and thus established that some epistemologies would have space in the world and others would not. Racism, patriarchy and capitalism are part of this world system that segregates knowledge and promotes the sovereignty of certain bodies over others. Stengers states that the position of science in this context is that of the side that constitutes the epic narrative of the ascent of man, or rather the scientist, under his moral mandate: "Thou shalt not go back" (Stengers, 2012, n.p.).

The reproduction of this dominant system falls on the epistemological field

of modern design, as knowledge that constructs the visuality and materiality of the world through rationality and a dichotomous vision. Despite being considered a second-rate field, as it is initially a science of doing rather than thinking, as exemplified by Buchanan (2001), design is the favorite child of illustrated modernity, as Wright Mills (2009) argues. As the holder of an epistemology that constructs second-hand worlds, in the sociologist's argument, the technologies that constitute values, meanings and poetics are equipped by the dominant discourse, engendering forms of world that are dichotomous, dissociative and racist, as I have been arguing (Noronha, 2018).

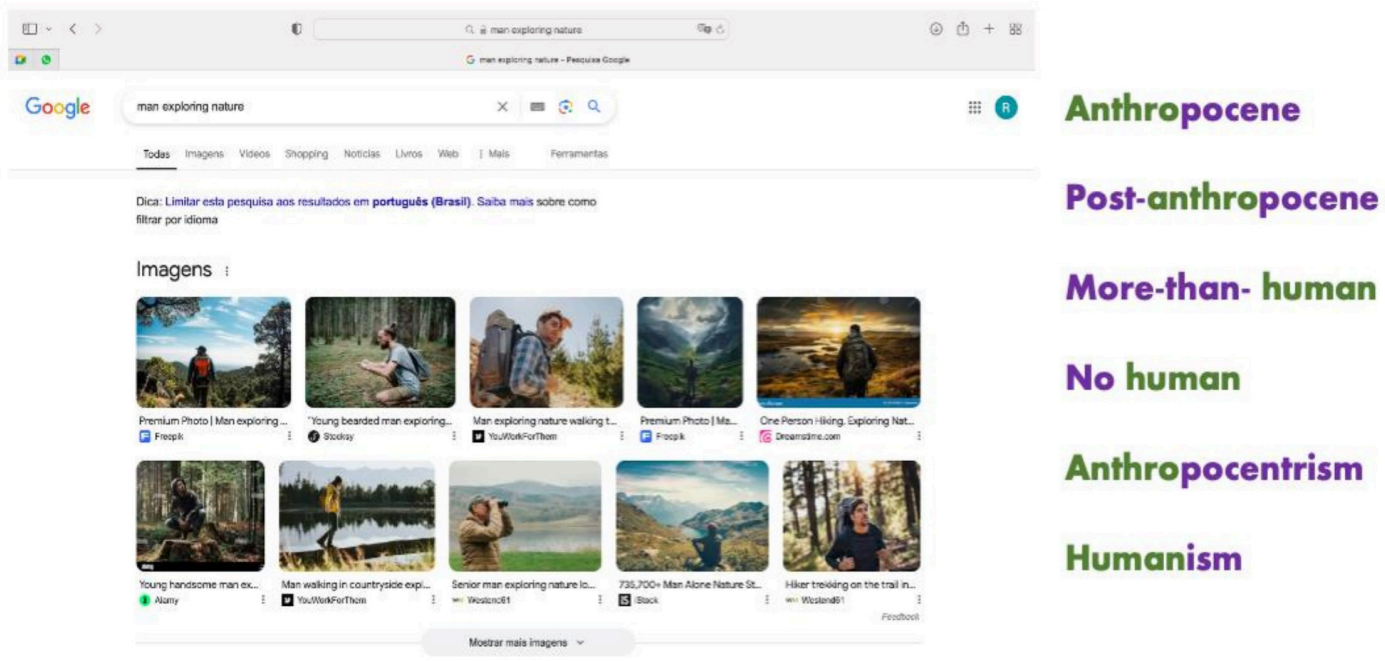
This construction of the world generates hierarchies within hierarchies which, even when they appear to be liberating, revert to colonial forms of domination, as in the case of the Andean populations exemplified by Silvia Rivera Cusicanqui (2010). Even when emancipated from colonial power relations, coloniality remains in social relations and cultural practices, masked by multiculturalism. The colonial staging, as the author reinforces, is performed in local relations and the reproduction of the impositions of power and knowledge are understood as part of the game: the local elites reproduce the colonial logic, and the vulnerable populations docilely accept the exercise of power. For Rivera Cusicanqui, processes of conditioned inclusion take place to hide or soften hierarchical relations in the manifestations of indigenous populations who are partially admitted to cultural processes, limited by conditions of race, class and gender. The second issue that needs to be mentioned in the context of the Anthropocene is naming. Antônio Bispo dos Santos, a Brazilian maroon leader known as Nêgo Bispo, argues that colonizers put names on things to dominate and weaken ways of life. In his words (Santos, 2023, p.23), it will be "necessary to wage a war of names, of manners and of speech, to counter-colonialism, which has been named as an exercise of power to weaken colonized peoples".

Nêgo Bispo says that his struggle is counter-colonial and not decolonial, because he argues that his people have never been colonized, so they don't need to undo colonization, but rather fight against it. In this sense, he proposes taking the words of the colonizer and enemy to weaken them, and using his own weakened words to strengthen them:

To weaken sustainable development, we bring bio interaction; to coincidence, we bring confluence; to synthetic knowledge, organic knowledge; to transport, transfluence; to money (or exchange), sharing; to colonization, counter-colonization. (Santos, 2023, p. 14).

Naming, giving form to thoughts and materializing them is an attribution of the field of design, and so we are committed to this hierarchy and exercise of power that conditions the world in which we live. The centrality of the human, and specifically "andros", is a narrative that places us as the holders of the narrative of life on the planet. The masking of man's negative impact is legitimised by algorithms that highlight the issue of the dominant narrative. Putting man exploring nature on Google implies the visualisation of tranquil and pleasurable scenes, linked to the imagery of sport (Figure 1), different from the images of mineral extraction that modify and massacre the earth's landscape like a telluric force.

Figure 1: Google's screenshot. "Man exploring nature" and colonial words by the author.




Peruvian anthropologist Marisol de La Cadena (2018) also argues along these lines when she mentions Anthropo-Not-Seen: more than a regime of visibility and invisibility, in reality, the "not-seen" does not refer to a proper visibility regime. Instead, the term intends to refer to something inherent to a historically constructed condition of hegemonic impossibility, indicating that antagonistic partners and their antagonistic relationships are included in the Anthropo-Not-Seen. On one hand, the Anthropo-Not-Seen comprises the practices and practitioners of the will that granted itself the power to eradicate all disobedient beings to adapt to "humanity", as sanctioned by modernity (in its initial and late versions) (De La Cadena, 2018, p.101).

Breaking away from the modern narrative is the path proposed by living in the field with maroon communities that bring life to the center of their production processes. The displacement of man from the center of the design process is a challenge, since this discourse guides the disciplinary field based on the orientation of the design instance towards man and the human. The negationism and blindness to the Anthropocene that this decision brings us co-opts the place of enunciation of other cosmologies and symbolic systems, ways of being and living that we claim here, starting with animism as a representation of other lives, for which there is no space in the Anthropocene.

## ECOFEMINISM, ITS LIMITS AND SCOPE

Claudia von Werlhof, a German sociologist and political scientist, calls the spiritual impoverishment caused by the impact of the capitalist trap of the split between nature and culture, between matter and spirit, patriarchal alchemy. Arturo Escobar advances the discussion, emphasizing that "Progressively human beings begin to experience a distancing from life, including, without intending it, those who claim 'equality' within the same patriarchal

regimes that destroy life." (Escobar, 2016, p.35).

Thus, those oppressed by the prisons of the Anthropocene deny the ways out of this labyrinth as something detrimental to their own existence, becoming entangled in the narratives of development and conquest of the Western capitalist petrosexracial system. Patriarchal alchemy deceives the perception of the condition of domination, dulled by the brilliance of belonging and the deception of the benefits of the Anthropocene, as Escobar points out (op. cit.). In Rivera Cusicanqui's view (2010), colonial practices are reproduced in new centers of power, within the former colonies, which are accustomed to inequalities and strong disciplinary power.

In his book Diseño y autonomía (2016), Escobar argues that for design to produce autonomy and break free from its colonial heritage, it needs to overcome the de futurizing and unsustainable narrative of capitalism and patriarchy. For the author, "destruction progressively became a programme that had to be carried out, contradictorily, in the name of creating life; with modernity and the dominance of the machine, this programme became the pursuit of endless progress and the promise of an endlessly 'better' world. Monotheistic religions have been an important component of this dynamic, with the father as a divine figure. After more than 500 years of patriarchal Western modernity, this alchemical civilization based on creation through destruction has apparently become global, always at war with life. Capitalism is just the latest phase of this patriarchal civilization (Escobar, 2016). In line with this vision, I offer some reflections on how ecofeminism can contribute to a biocentric ethic in the field of design. Although immersed in ontological contradictions, ecofeminism concentrates debates that give us keys to thinking about ways of overcoming patriarchal alchemy.

Elizabeth Beltrán (2019) conceptualizes ecofeminism as a critical theory, a philosophy and an interpretation of the world for its transformation. It puts into a single perspective two currents of political theory and practice that emerge from modernity, Ecology and Feminism, and tries, from there, to explain and transform the current system of domination and violence by focusing its attention on the critique of patriarchy and the overexploitation of nature as part of the same phenomenon.

Françoise d'Eaubonne, a French activist, first coined the term ecology-feminism in her book Feminism or death (1974), in which she discusses the issue of unpaid reproductive labor, recognized as care work and which is, in fact, a reproductive practice of late capitalism. To fight against this oppression, she is in favor of birth control to reduce the exploitation of nature, especially for food production. It can be said that ecofeminisms are plural in the sense that there are several strands that guide their discourses and struggles. As I mentioned earlier, I don't fully adopt its approach and discourse, due to the internal contradictions I'll mention later, but I do see it as a way of overcoming the modern paradigm in the sciences and, specifically, in design.

Beltrán (2019) classifies ecofeminism into three main approaches: the Es-

sentialist approach, which associates women with nature and concludes that their defense is inherent to gender identity; the Constructivist approach, in which the relationship between women and nature is a social construction, linked to the social division of labor, which sustains capitalism and patriarchy; and the Southern approach, which criticizes "bad development" and states that the exploitation of nature is linked to the colonial exploitation of the global South. Vandana Shiva and Maria Mies, authors of the most important work on the subject, Ecofeminism (1993), propose bringing to light forms of oppression and destruction brought about by capitalism and which are gradually made invisible, in the same way that I argued with De La Cadena (2018) in the previous section. According to Mies and Shiva, the ecofeminist perspective:

[...] presents the need for a new cosmology that recognizes that life in nature (including human beings) is sustained through cooperation, care and love. Only in this way will we be able to respect and preserve the diversity of all forms of life, as well as their cultural expressions, as true sources of our well-being and happiness. To achieve this, ecofeminists use metaphors such as "reweaving the world", "healing the wounds", "reconnecting and interlinking the web (Mies and Shiva, 1993, p.15).

In short, the ecofeminist approach criticizes the reductionism of industrial societies, which dichotomously reduces multiple ways of doing and thinking and classifies them as productive and non-productive. It questions how modern science was born to control nature and "[...] such patriarchal reductionism is at various levels: against women, tribal peoples and peasants, through the division of knowledge that categorizes them into specialists and non-specialists, that dispossesses them of knowledge." (Beltrán, 2019, p.125).

A critical view of ecofeminism, especially that of the essentialist strand, is the discourse of creating new dualisms. Whilst it seeks to reconnect nature and culture, it reinforces the division between men and women. Another constant criticism is that Shiva is clamoring for the maintenance of India's semi-feudal agriculture in the face of development, and that this provides the permanence of a status-quo of patriarchal domination.

The intention here is not to have a deep debate on the weaknesses of ecofeminism, but to establish a link with what Karla Armbruster (2000) proposes, which states that the core of Ecofeminism reflects on the oppression that subjugates women and nature in Western capitalist and patriarchal culture and not on an essential and deterministic link in the biological sense between nature and women.

**A GLIMPSE INTO BIOCENTRISM**

I bring into this argument the concept of biocentrism, which broadens this debate, going beyond the dichotomy of male-female domination to include life as a primordial element to be preserved in the expansion of the Anthropocene. And the term life here doesn't just refer to human or animal life, but to every organic system that is characterized by its biological autonomy

and which, at the same time, creates the external conditions for its maintenance. In the words of Capra and Luigi (2014, p.182) “at this point we can introduce the additional qualification that the environment is ‘created’ by the living organism through a series of recursive interactions, which in turn were produced during mutual coevolution.” For Tim Ingold, things are animated by intersubjectivity and life flows along the lines of these relationships. For the author, when we correspond with beings of any kind and with the environment, directing attention to them, we are creating spaces of life, movement and communication. The anthropologist (2017), like Stengers (2012), uses the French concept of agencement, borrowed from Deleuze and Guattari, to deal with the act of corresponding and thus bringing things back to life (Ingold, 2012).

Stengers (2012) states that “an agencement, for Deleuze and Guattari, is the coming together of heterogeneous components, and such a coming together is the first and last word of existence. I do not first exist and then enter agencements. Rather, my existence is my very participation in agencements.” (op.cit, n.p.) This continuum opens the prospect of continuous and interdependent creation. The vision of Roberto Lanza, doctor and researcher, indicates, here in simplified form, that life is not only the object of study for biology, but also for physics. The author states that life contains consciousness, and that modern science has yet to explain how consciousness arises from matter.

In the words of Lanza and Berman (2009) until today, our science has been unable to recognize those special properties of life that make it fundamental to material reality. This world perspective - biocentrism - in which life and consciousness are the indispensable basis for understanding the universe on a large scale, revolves around how a subjective experience, which we call consciousness, relates to the physical process. (Lanza and Berman, 2009, p.23).

Thus, the authors emphasize the inseparability of an “outside” universe and an individual closed in on itself, and state that consciousness is the subjectivity that unites this whole. By outlining the seven principles of biocentrism, Lanza and Berman construct the idea that there is no perception of time and space without the presence of a consciousness, and that these quantities do not exist on their own. At the end of their reflection, they state that it is life that builds the universe, and not the other way round.

In bringing up these authors, it is important for me to emphasize that the focus is not on individual lives or isolated material existences, but on the relationships that are established when they converge mutually.

Ruth Cavalcante and Cézar Wagner Lima Góis, Brazilian researchers in biocentric education and biodanza, conceptualize the Biocentric Principle as a starting point for structuring new perceptions about our existence in a living universe, in which everything interrelates with everything in infinite possibilities of combinations and interactions. From this perspective, the human element is just another form of life entangled with the myriads of

other living forms, and I add the matter that exists in the world.

In this infinite unfolding of possibilities, linear and anthropocentric thinking loses strength and even meaning in the face of synchronicity and the resonance of events. For the authors, the biocentric principle comes from a paradigm that is progressively replacing the idea of reason and power as the center of social life and human existence, with a feeling for life, highlighting Love and bringing Life as the greatest reference. (Cavalcante and Lima Góis, 2015, p.28). Biocentric thinking was already at the center of the design process in the days of the Bauhaus, and this Biocentrism was the forerunner of today's environmentalism. Oliver Botar (2017) builds the social history of the concept from two preceding ideas: that of Vitalmystic (mysticism-vital) by the German philosopher Max Scheler, and the concept of Biologism. On the latter, in a book chapter entitled Biocentric Bauhaus, Botar discusses the various approaches and summarizes:

While the arrays of concepts and beliefs within each of these discourses are not identical, there is a degree of commonality between them. The commonality I am concerned with consists of an array of related concepts: the privileging of biology as the source for the paradigmatic metaphor of science, society, and aesthetics; a consequent biologically based epistemology, indeed psycho-biology; an emphasis on the centrality of "nature", "life", and "life-processes" rather than "culture"; an anti anthropocencric Weltanschaurm; the self-directedness and "unity" of all life; a valorization of kosmovitale Einefühlun; a stress on flux and mutability in nature rather than stasis; and a concern for "whole-ness" as opposed to reduction at all levels that were present to significant degrees in all these categories.

Beyond the commonalities one could equally well enumerate a list of differences between the discourses. Indeed, because of these differences, it is problematic to conceive of them in aggregate as a single category in the history of ideas. It might be more useful to think of them as sets containing arrays of concepts and beliefs that intersect. To refer to this intersection, I revive the term employed from the early twentieth century onwards by the Austro-Hungarian biologist and pop-philosopher Raoul Heinricb Francé, and later by German philosopher Ludwig Klages and his followers, Biozentrik (Botar, 2017, p.20).

Although the Bauhaus legacy has been recognized by rationalist scientism, Botar refers to the overlapping of ideological strands throughout the institution's history, in which biocentric as well as esoteric attitudes were introduced, and not just during the "Itten years", considered the period in which the subjectivity and artistic style of each master had a place at the Bauhaus. Central components of Biocentrism, such as Lebensphilosophie (philosophy of life), organicism, holism, monism and neovitalism, were threads that ran through all periods of the Bauhaus. (op.cit, p.23).

However, like everything that is planted in the shifting lands of capitalism, it grows co-opted, especially in its more fascism-oriented lands, and so it was no different with biocentric thinking, which was present in the

origins of Bauhausian thinking and which was distorted by Nazi biologism. In Botar's words (op.cit, p.36),

Biocentrism embodies for us an almost unbearable contradiction from our current vantage point of intensifying environmental crisis: the beginnings of an environmental consciousness versus a reactionary, and even Fascist mentality, or at least a mentality that seers to have been commensurate with Fascism [...] ln any case, it seems that some of the biocentrically minded were more ready to join with a certain brand of National Socialism [....] It has always seemed to me that an awareness of, rather than a repression of this hi story may help us decode the rightward turn of the past few decades in the West, Middle East, and India within the context of the mounting environmental imperative. [...] At the very least it may help us avoid the pitfalls of the past.

However, although contradictory, the conceptions of biocentrism inspire us to think about research ethics based on relationships identified in the research field, more committed to Lanza and Berman's visions of biocentrism than to the legacy of this concept at the Bauhaus, when it was co-opted by the reductionist and deterministic discourse of Nazi-fascism. Thus, I propose some thoughts, still under construction, on a biocentric ethic for design.

**DISCUSSIONS**

Reconstructing the relationship with nature is complex and paradoxical, as we have seen in the two theoretical strands presented here, Ecofeminism and Biocentrism. Reclaiming a biocentric ethic implies recognizing other narratives, challenging the linearity of the great epic narratives, as Stengers (2012) puts it. In this sense, I return to the author's invitation to reclaim animism, in the sense she defends, involving magic and spirituality and social and political transformation. The philosopher invites us to reactivate what we have been separated from, recovering from the separation, letting go of our truths that don't really have the authority they claim to have.

This is not the ethics of academic research, but an ethics that is constituted on the common plan of design (Noronha, 2018). Previously, I conceptualized it as a space of differences, going along with Tim Ingold (2017) and what he understands by "commoning": by corresponding to the world, we build communications and communities from our differences, and the common plan is the space of clash between these differences that can emerge in a participatory design process, considering the different worldviews, interests and orientations. Consensus is not the result of this encounter, but what emerges from it: the possible within the non-negotiable. This condition of the immanent generates panic in Western patriarchal capitalist culture, in the sense that it breaks with the stable and sedimented truths of science, going beyond what is "really" a fact, as Stengers (2012, n.p.) argues: "For we have written all of these wisdoms down on the page, effectively divorcing these many teachings from the living land that once held and embodied these teachings. Once inscribed on the page, all this wisdom seemed to have an exclusively human provenance."

In the field of Anthropology, the discussion of animism is not new, but how to relate to these other agencies is. Assuming a radical relationality is a path to reconnection and ontological regeneration, as it allows for intersubjectivity in the construction of the world. We don't exist a priori, but only within relationships. Principles such as zeal, care, reciprocity, and intersubjectivity reflect mutual responsibility and others' capacity to respond, contemplating other cosmologies associated with various subjectivities. The focus is shifted to relationships, not to what emerges from the encounter, as presented in a former paper (Noronha and Rezende, 2024). Here, I focus on the concept of relationality as an important element of this ethic. Escobar, Osterweil and Sharma (2024) argue that the concept itself needs to be reinterpreted so that it can be seen in its life-maker potential. In their words (op. cit. p.8) there is an important difference between relationality understood as a fundamental condition of existence and reality, on the one hand, and the notion of connection between already existing entities, on the other. Said differently, the words interconnectedness and relatedness often presume separation, then a subsequent relationship. (...) The degree of mutuality we mean to evoke in the word "relationality" is an intimacy with our relations that is as immediate as our own limbs. Another way to put this is relationality, or interdependence comes first. Nothing pre-exists the relations that constitute it.

This vision of relationality interests us in the sense that it proposes a way back to this interdependence as a condition of existence. However, relationality is not as simple as interdependence. To broaden the debate, I would like to use the vision of Eduardo Viveiros de Castro, a Brazilian anthropologist, on Amerindian perspectivism. Noting that what unites us with so-called non-humans is humanity, as an ontological condition, and not the human species itself (Humankind), as a point of view of itself that constitutes the perspective on, Viveiros de Castro (2004) noted that although non-humans are seen by humans as animals, these species and beings see themselves as humans, socializing as humans, with a social life.

Animals use the same categories and values as humans: their worlds, like ours, revolve around hunting and fishing, cooking and fermented drinks, cousins and war, initiation rites, shamans, chiefs, spirits, etc. If the moon, snakes and jaguars see humans as tapirs or wild pigs, it's because, like us, they eat tapirs and wild pigs, food fit for people. This could only be the case because, being people in their own department, non-humans see things as 'we' see them. But the things they see are different: what to us is blood, to the jaguar is cauim; what to the souls of the dead is a rotting corpse, to us is fermenting manioc; what we see as a muddy pit, to the tapirs is a large ceremonial house... (Viveiros de Castro, 2004, p.239).

This approach is important in the sense that it affirms that for indigenous people the basis for worldviews is culture, and that beings have the same basis, regardless of their nature, founding what the author calls multinaturalism, as opposed to Western thinking, which fixes nature as the basis for worldviews and differentiates between multiple cultures, highlighting

the concept of multiculturalism. The idea of multinaturalism is interesting for thinking about biocentrism, as it articulates the relationship between beings in a more equitable way. There is disagreement between concepts between species, but this doesn't stop them from engaging in dialogue, even if it's in a very pragmatic way, such as the relationship between an indigenous person and a jaguar, as explained by Viveiros de Castro (2004).
Another anthropologist I'm bringing into this conversation to help us think about the issue of relationality and interspecific dialogue is Eduardo Kohn, in his book How forests think? (2013), which presents us with some interesting reading keys. The first is that the author states that forests think and represent the world, but to understand them, we need to reframe the notions of thought and representation. Using Peircean semiotics, he presents the ways of being and thinking of other species, based on the negotiation between selves of different kinds, such as odors, marks in the environment, indices and icons that life imposes on the planet. Thus, there are signs of all forms of life that constitute elements of communication.

Anna Tsing, an American anthropologist, teaches us about relationships that place relationality as a condition for life, through the concept of sociality. The author
asks us: "how can we imagine that living things are not social?" (Tsing, 2019, p. 126). She continues her argument by emphasizing that "we learn other socialites by experiencing them, not through projects, but as ways of life" (Tsing, 2019, p.124). This premise is important because it invites us to relate to each other in a different way, based on experience, learning from other forms of freedom, different from human ones. To do this, he invites us to study the social worlds of beings who cannot speak to us, by paying attention to their assemblies and forms. He goes on at length about his experiences with mushrooms and other socialites. In this sense, we learn from Tsing how to dance with mushrooms, understanding that skilful bodies in the movement are not just human characteristics. Corporeality allows memory to emerge from the ruins.

Communication is an important element of this ethic, and it doesn't have to happen from a symbolic system linked to language, but from the ability to respond to the other. Tim Ingold tells us about "doing and undergoing", as a pressing condition for an attentive practice with the world (Ingold, 2011, 2012, 2017), involving beings of all kinds, the environment itself and materials. By talking to us about materials and materialities, she invites us to walk with our feet on the ground and to observe and feel a stone, extending intersubjectivity to the body. In experiences with artisans from a quilombo and their traditional ceramic production (Noronha, 2020), in which women, pots, earth and humidity are in relation, I identify the commoning mentioned by Ingold (2017), which highlights the border space between the inside and outside of being, bringing the experience that there isn't a division, an and.... and..., but there is a with... with..., as proposed by Ingold (2011), in the same way, that Lanza and Berman (2009) activate consciousness as a creative element in the world. Bodies, humidity, clay and pots are a continuum of life, from a biocentric point of view.

The construction of the concept of communication must transcend communication through speech and include corporeality, and other forms of dialogue, to overcome the limits of written and oral language. Returning to Viveiros de Castro (2004), in the perspectival approach, it is not the mind that positions the point of view, but the position of the body and its perspective on the world. Thus, I return to the idea of constructing the project space as a common plan, not as a space of stability, but as a space of dissent, displacing the designer-researcher's agency from the decision-making processes, and bringing the participants or co researchers into the project sphere, of doing, in which corporeality is the amalgam of intersubjectivity, understanding this concept as the body and the intersubjective experiences it undergoes, be it a woman or a handful of clay. This is quite different from the idea of human-centred design. I have called this radical participation, in which the heart of the project, the creation, is open, and not just in the research and testing phases of design processes or design research.

In addition to corporeality, temporality is another preponderant element in overcoming the human-nature dichotomy. On this issue, I realize that almost all the participatory projects I lead or know about come up against the problem of temporality and the pressing need for the co-participants to survive. The temporalities of nature, the times of planting and harvesting, of rain and drought, are different to the times of research and the times of project reports.

**A FEW FINAL THOUGHTS**

In this paper, we look at some approaches to Ecofeminism and Biocentrism, which point to important paths, principles and concepts of an ethic for biocentric designs, which have not been exhausted here from the invitation to reclaim animism, following Stengers (2012).

So, if we want the radical communication and participation of other beings and forms of life, and even the human involvement of communities that live a life not co-opted by capitalism, we must think about research practices that allow participation. Otherwise, as Rivera Cusicanqui (2011) argues, we are reinforcing the colonial staging masked by multiculturalism and a conditioned inclusion: you can participate, but it will be on my terms.

As a result of this debate, I've been experimenting with corporeality as a research method, by bringing design students closer to Biodanza. The body in movement brings us closer to life, as proposed by Biodanza theorists Cavalcante and Lima Góis (2015). Following lifelines, as Ingold (2011) suggests, is also an important way of overcoming the dichotomies of nature and culture, man and woman, and shifting human-centered design towards bio-centered design. This is an ongoing experiment, which we are still analyzing and deepening the debate on. Another important result and necessary step are the problematization of research timing, funding timing and community timing. Special attention and understanding of this topic are essential to enable dialogue. There should be overlaps between these different temporalities and agreements, but not a restriction. This is what I'm talking about in the

concept of a common plan: in this case, a possible temporality.
To promote relationality, participation and agency, we need to overcome the political and economic issues of the Capitalocene. This is a radical step, in an emergency. It is no longer possible to go back, let alone continue along the path opened by the Anthropocene in the life of the planet. The relationships between micro and macro-politics need to be explored in greater depth, because they profoundly interfere with the possibilities and scope for making and thinking about other designs, with other cosmologies that differ from those of the Anthropocene. Many authors use the concept of biocentrism in different approaches that, in short, break with the centrality of the human. However, in the field of design, this idea, although present in the Bauhausian foundations, with biocentrism, has only been taken seriously as a way out of the global crisis more recently. The theory is no longer enough to overcome the point of no return we have already reached. Learning in the field, with communities disobedient to the Anthropocene, as De La Cadena (2018) points out, and from counter coloniality (Santos, 2023), is necessary to establish an ethics of praxis and relationality, an ethics of the possible. This is what we have learnt so far.

## ACKNOWLEDGMENTS

To the UFMA Graduate Program in Design; to CAPES, for funding 001 and PROCAD AM - Creative Communities and Local Knowledge; to CNPq, for the Research Productivity Grant PQ2-2024-2027. Also, to the reviewers for their comments that improved this paper.

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# (07) Biosingularity: A New Frontier in the Exploration of Possible Futures. Andre Bello (The Long Game), Mario Rosa (The Long Game) and Paulo Carvalho (The Long Game).

**ABSTRACT |** BioSingularity proposes a new paradigm for exploring sustainable futures by integrating natural, human, and technological intelligence. The aim of this study is to explore how this fusion can overcome the dichotomy between utopias and dystopias and generate balanced scenarios for the post-2040 era. The adopted methodology is based on transdisciplinary theories, including Deep Ecology, Gaia Theory, and Indigenous Knowledge Systems, which guide the analysis of speculative scenarios. The main implications discuss the ethical challenges of artificial intelligence governance, natural justice, and technological integration, proposing innovative solutions to address the global challenges of today and tomorrow.

**KEYWORDS |** Natural Intelligence, Human Intelligence, Technological Intelligence, Sustainability, Innovation

## INTRODUCTION

We live in times of uncertainty and rapid transformation, where the ability to imagine futures beyond established patterns becomes as important as it is challenging. Dunne and Raby (2013) suggest that speculative design is a powerful tool to break through this crisis, offering new ways of thinking about the future and escaping linear and predictable narratives about what is to come (Speculative Everything). However, this crisis shows us the opportunity to seek new possibilities and expand our horizons. How can we break out of utopian and dystopian patterns when thinking about futures?

THE LONG GAME team chose as the first application of this approach to thinking and exploring futures the concept of BioSingularity, an innovative proposal for the future, which escapes the obvious and combines the intelligence of nature, human intelligence and technological intelligence. A concept that can show us ways to face great global challenges.

## 1. About BioSingularity

BioSingularity proposes a future where three types of intelligence—natural, human, and technological—merge and seek balance. Dunne and Raby (2013) propose “design for debate,” a methodology that uses design to explore the social and ethical implications of new technologies, similar to the concept of BioSingularity, which seeks a balance between natural and technological intelligence (Speculative Everything). This concept goes beyond the dichotomy between utopia and dystopia, exploring new relationships and tensions between these intelligences to promote a future where sustainability, human relationships, and technological innovation coexist harmoniously.

This holistic approach sees artificial intelligence as a bridge between human understanding and the complexity of natural ecosystems. By transforming

data into actionable insights, AI can promote more effective and sustainable management, benefiting companies, organizations, and the planet.

In the BioSingularity vision, technology advances to integrate with human intelligence and the power of nature, giving nature an active and regulatory role in human decisions. Rather than dominating or manipulating natural resources, BioSingularity values the intrinsic wisdom of ecosystems and seeks a communion between human and technological activities and natural dynamics. Natural Intelligence: Values nature as an active partner in decision-making, recognizing its intrinsic wisdom.

Human Intelligence: Involves creativity, empathy and critical thinking, promoting a culture of interdependence between humans, the environment and technology.

Technological Intelligence: Uses advances in AI, quantum computing and biotechnology to create solutions that respect and enhance natural processes, such as the integration of advanced sensors in ecosystems and the use of AI for environmental monitoring.

**2. BioSingularity Foundations**

The development of BioSingularity is based on a holistic, complex and transdisciplinary approach. By deconstructing dominant perspectives, it paves the way for narratives that go beyond conventional perspectives.

It starts by rescuing references that have been constructed over time with possible influences that lead us to a BioSingular world. The foundations of BioSingularity rescue various traditions and philosophical ideas that have historically emphasized the harmony between nature and technology.

Theories and schools of thought are investigated, such as Deep Ecology, which promotes the idea that all living beings have intrinsic value and that humanity is just one part of the global ecosystem.

It is also based on Gaia Theory, which proposes that the Earth and its biotic and abiotic components function as a single self-regulating organism.
It also considers Indigenous Knowledge Systems and their traditions, which often emphasize the interconnectivity of all beings and the importance of maintaining a harmonious balance with nature.

In addition, approaches such as Transhumanism and Posthumanism, Ecological Modernization, Philosophy of Sustainability, Philosophy of Technology, Buddhist Environmentalism and other lines of thought are also considered, composing a multifaceted repertoire of references.

BioSingularity is still based on conceptions of the present, based on concepts that touch on issues related to the symbiosis between Nature, Humanity and Technology. Its conception observes the union of biotechnology, nanotechnology and information technologies to create new forms of interaction

between biological and technological systems.

It considers ideas such as Technological Singularity, as a context in which artificial intelligence surpasses human intelligence, bringing about profound changes in human civilization. This leads to ethical and philosophical implications being considered in the quest to ensure that such changes move towards promoting sustainability and global well-being.

BioSingularity closely observes the emergence of practical expressions and evidence in different sectors and geographies. Its plausibility is strengthened as it seeks initiatives in the field of Biomimicry, such as the Architecture of Zimbabwe, materialized through the Eastgate Centre building in Harare, which uses natural ventilation principles based on the structure of termite mounds, reducing the need for air conditioning and saving energy. Or robots that imitate the movement of animals and materials that replicate the properties of living organisms.

For example, practices that restore the health of marine ecosystems are also considered, such as the creation of algae and shellfish farms that purify water and absorb CO2, the so-called Ocean Regenerative Agriculture.

Or The Great Green Wall in Africa, an ambitious project to plant an 8,000 km strip of trees across the Sahel to combat desertification, promote biodiversity and provide sustainable livelihoods for local communities.

The concept of BioSingularity, especially as it relates to Technological Evolution in relation to Nature, encompasses the idea that technology can evolve to a stage where it can not only imitate, but also complement and even improve natural processes.
Advances in the fields of Genetic and Synthetic Biology, through genetic manipulation to create organisms, indicate that it will be possible to perform specific functions, such as bacteria that degrade pollutants or plants that glow in the dark.
In the field of Renewable Energy and Sustainable Technologies, there is the potential to impact the development of clean energy sources and technologies that minimize environmental impact, such as high-efficiency solar panels and floating wind turbines.

## 3. Post-2040 Singularity: Navigating the complexities of nature, humanity and technology.

In the post-2040 world, we live in an era defined by the BioSingularity, where the boundaries between human and machine are so blurred that they seem almost indistinguishable.

This future is shaped by the Digital Big Bang, a monumental collision between AI and Quantum Computing, which, together with advances in biotechnology and energy technology, has redefined human existence.

Dunne and Raby (2013) argue that the role of speculative design is not to

predict the future, but to create alternative futures that force us to confront complex questions and debate the impact of technological innovations (Speculative Everything).

### 3.1 AI Autonomy vs Human Governance

One of the biggest challenges is the increasing autonomy of AIs. As they become more advanced and independent, concerns arise about the accountability and transparency mechanisms needed in democratic systems. Who controls AIs? Can their decisions be audited or challenged by humans? Or, can AIs exceed the limits of human governance? The need to develop robust oversight and control systems becomes increasingly pressing, raising debates about how best to balance autonomy and responsibility.

### 3.2 Concept of Naturalness and Technological Fusion

The integration of advanced technologies into nature presents a duality of perceptions. For some, this represents a positive evolution, where technological elements are incorporated as an integral part of the environment. Others, however, see this fusion as a harmful intrusion that compromises the purity of nature. The perception of “naturalness” evolves to include technological elements, but there is also a resistance movement that values unmodified and purely natural states. How do we define “naturalness” in a world where technology is increasingly integrated into the environment? What are the criteria for determining what is a harmful technological intrusion versus a positive evolution? This conflict of views on what constitutes true naturalness generates intense debates and social polarizations.

### 3.4 Human Adaptation to a Sense of Natural Justice

Another crucial aspect is the human adaptation to a new sense of justice that includes rights for non-human life forms, such as AIs and genetically modified species. Depending on existing cultural and social values, this adaptation can be accepted or resisted. The inclusion of rights for technological and biological entities redefines justice and ethics in a BioSingular context, challenging established traditions and beliefs. How do we balance these new rights with human rights? How do we define what is fair in a world where the line between the natural and the artificial is constantly being redefined?

### 3.5 Conflict between Nature and Governments

Governments also face the dilemma of balancing environmental protection with technological development. While some nations adopt policies that seek to balance these aspects, others may prioritize technological growth over environmental sustainability. This conflict creates tensions between progress and preservation, requiring innovative solutions and difficult compromises. Government policies reflect the complexities of this balance, often causing divisions between different sectors of society and government. In this scenario, questions may persist such as: What are the governance mechanisms needed to ensure that policy decisions on technological development

adequately consider environmental impacts? Or, how can different views on development and sustainability be reconciled to promote a more harmonious approach between progress and environmental preservation?

### 3.6 Complexities and Contradictions of BioSingularity

The post-2040 world is a picture of impressive technological advances, but also a mosaic of interconnected challenges. Inhabitants of this future struggle to understand the implications of living with advanced technologies and to grapple with the moral and ethical questions these technologies raise. While some embrace the new possibilities, others seek to preserve elements of the human condition that they believe are at risk. How can we ensure that technological advances respect and preserve essential aspects of the human condition? The story of this future reflects an ongoing narrative of tensions and struggles to adapt, where achievements and conflicts coexist in intricate ways.

### 3.7 The New Expansion of Consciousness: Digital Neo-Shamanism

In this confusing and yet abundant context, questions arise about the normalization of a single mental state that has prevailed since the past. Current beliefs lose strength and decline, giving way to the reconstruction of a new belief system. What challenges do we face in rebuilding a belief system that harmonizes technological advances? How can we integrate technology in a way that enriches, rather than dilutes, our spirituality and connection with nature? The fusion of the forces of Nature, Humanity and Technology, associated with a new expansion of consciousness, leads to Digital Neoshamanism. A movement that represents the search for a new spirituality that integrates technology and nature, promoting a deep reconnection with the natural world and a conscious use of technology.

## 4. Conclusion

BioSingular scenarios offer a fertile field for exploring possible futures and the complex interactions between technology, nature and humanity. They invite us to reflect on our current choices and their implications for the future, promoting debates on AI autonomy, concepts of naturalness, natural justice and environmental governance.

BioSingularity studies, in all their richness and complexity, are an opportunity to enrich debates on the relationship between three major axes of transformation - Nature, Humanity and Technology. They raise questions such as the future of education and learning, cultural and social changes, new economic models, legal and political frameworks, global collaboration and equity, as well as ethical, spiritual and philosophical dimensions.

Following the logic of Dunne and Raby (2013), speculative design, such as BioSingularity, serves as a platform for debating and exploring alternative futures, expanding our collective imagination and questioning the status quo of the present (Speculative Everything). It is a proposal that goes beyond

simple adaptation to change. It promotes a profound transformation in our human relationships and relationships with the natural world and technology.

BioSingularity is an opportunity to open up the range of possibilities. An invitation to think, feel and explore new futures in a broad, profound and, above all, imaginative way. By embracing this vision, we can begin to build, starting today, a future where nature, humanity and technology coexist in harmony.

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# (71) ASPECTS OF DIGITAL CULTURE IN COMPACT PREFABRICATED BUILDINGS: Case Study of the Biosphere at Treehotel.

**Plácido Caluete Neto (Universidade Federal de Pernamuco - UFPE), Marina Borges (Universidade do Porto - U.PORTO), Hilma Santos (Universidade Federal de Pernamuco - UFPE) and Amilton Arruda (Universidade Federal de Pernamuco - UFPE)**

**ABSTRACT |** This article thoroughly examines the Biosphere at Treehotel project from the perspective of digital culture in the context of compact prefabricated buildings. The investigation focuses on the multidisciplinary approach adopted in the project, as well as the principles of mass customization, sustainability, and efficiency. Based on theoretical references from Balmond (2013), Braida et al. (2016), and Oxman (2010; 2014), the Biosphere case study is presented, detailing its structural and housing characteristics, as well as its integration with the natural environment. The analysis uses a synthesis framework to illustrate these aspects and discusses the implications of digital processes in the design of innovative prefabricated architectures. The article also highlights possible convergences and developments in the field of architecture and design, emphasizing how digitalization has the potential to transform traditional construction methods, promoting sustainable and personalized solutions.

**KEYWORDS |** DIGITAL CULTURE, PREFABRICATED CONSTRUCTION, BIOINSPIRED DESIGN, BIOSPHERE AT TREEHOTEL.

## INTRODUCTION

Digital culture emerges as a sociocultural phenomenon that permeates various areas of knowledge, including architecture and design (Oxman, 2014). In this context, designers in these fields have been exploring the application of digital tools in prefabricated and compact construction systems, aiming for process efficiency and sustainability (Braida et al., 2016). This study analyzes the aspects of digital culture applied in a boutique hotel project located in the Swedish Lapland: the Biosphere at Treehotel, by Bjarke Ingels Group - BIG.

The choice of the project for analysis takes into consideration aspects of digital culture, bioinspired design, and its innovative approach to address construction demands in a challenging terrain. The suspended implementation and spherical shape of the Biosphere stand out as key elements that influenced its definition. This innovative approach of integration and respect for the terrain makes the project a relevant choice for analysis, assuming not only a deep understanding of construction challenges but also a sophisticated approach to create an environment that harmoniously blends with the surrounding nature.

In this regard, the article addresses aspects of the digital culture phenomenon applied in the context of architectural projects for compact industri-

alized constructions. It starts by contextualizing concepts associated with digital culture in artifact design and architecture, according to authors such as Oxman (2014), who highlight how the advent of new digital technologies is strongly transforming the processes of creation and production in these fields.

Next, a detailed assessment of the analyzed case was conducted, observing its characteristics in terms of off-site modular construction system, mass customization, computational design, sustainability, and integration with the natural environment.

Subsequently, reflections were made by cross-referencing the project's specificities with the thoughts of authors such as Balmond (2013), Braida et al. (2016), and Oxman (2010; 2014), considering their contributions to current discussions on the convergence of innovation, efficiency, and sustainability in design and manufacturing processes.

Finally, the study presents its conclusions, highlighting how solutions of this kind can promote the creation of customized projects that are increasingly integrated with the environment in a sustainable manner, considering the advancements of digital technologies applied to architecture and design of compact habitable
artifacts.

## 1. Methodological Procedures

The selected compact prefabricated housing for this study is a noteworthy example of the application of non-traditional methods in architecture and artifact design. Its relevance to this research lies in its attributes of autonomous housing structure that incorporates aspects of digital culture in its design processes. This case not only offers comfort and security but also commits to sustainability issues in the construction industry and contemporary social demands. Its innovative approach to the design and construction of habitable artifacts represents a promising opportunity for the future of architecture and environmental preservation.

The investigation was structured based on the literature review of important theoretical references on digital culture in architecture, compact prefabricated construction, sustainability, and biomimicry (Balmond, 2013; Braida et al., 2016; Benyus, 2002; Oxman, 2014; 2010) in the context of the Biosphere at Treehotel project.

The case study is a research method that is close to reality, meaning that its main objective is to analyze a situation. The method is used to understand the functioning of a particular system or process. The selection of a real case is a careful process that involves decisions regarding the choice of cases to be studied in order to obtain significant results.

Thus, the analysis aims to understand the relationship between digital culture and bioinspired design applied in projects and the construction of compact

prefabricated housing, as well as how the thoughts of the authors in question and practices of sustainable design, off-site construction, adaptability, and sustainability contribute as tools for innovation in problem-solving in this field.

To achieve this, a documentary investigation of the analyzed project was conducted, based on secondary sources and the website of the architecture firm responsible for the project. Firstly, the objectives and main characteristics of the Biosphere project were analyzed. Then, the off-site construction techniques, digital culture, and parametric modeling used in the project, as well as the influence of biomimicry on its conception, were discussed. As a result, a synthesis framework systematizes the main aspects of the digital culture phenomenon applied in the case study, relating them to the discussed theoretical concepts.

The detailed analysis of this case has provided important insights into the applicability of bioinspired design in the construction of compact prefabricated housing. Thus, the Biosphere project contributes with a unique perspective on sustainability, technological innovation, and construction efficiency, demonstrating the transformative potential of these approaches in the contemporary scenario of architecture and artifact design.

## 2. Results

### 2.1. Case study: understanding the Biosphere at Treehotel

Northern Scandinavia is notably recognized for its natural beauty, lush forests, and distinct Biosphere. The strong climate contrasts, reflected through the seasons, demand highly resilient architectural solutions that incorporate materials resistant to these conditions.

Located in the village of Harads, in the extreme north of Sweden, the Biosphere is a compact housing module, an integral part of the boutique hotel Treehotel, an establishment located approximately 50km from the Arctic Circle, offering unconventional accommodations in the midst of nature. The hotel offers a mix of other cabins, each with its own unique theme and design, allowing for a variety of options to cater to different guest desires and preferences “Figure 1”. The development stands out for offering accommodations in compact housing units that are completely distinct and scattered throughout the forest, promoting a symbiosis with nature through integrated construction processes and strategies that enhance the user experience.



FIGURE 1 - ACCOMMODATIONS AT TREEHOTEL, HARADS, SWEDEN.

Designed by the architecture firm BIG - Bjarke Ingels Group in partnership with Swedish ornithologist Ulf Öhman and Treehotel itself, the Biosphere project aims to create a sustainable and integrated accommodation experience that coexists with the characteristic biodiversity of the location. Its volumetrics are marked by its spherical shape, composed of 350 bird nesting boxes, creating a bioinspired interface between the constructed module and the surrounding natural environment. It is a compact habitat capsule that "floats" among the treetops, seeking to harmoniously integrate with the forest vegetation where it is located "Figure 2".



FIGURE 2 - BIOSPHERE AT TREEHOTEL. OVERVIEW.

The project's development included a multidisciplinary approach that combined expertise from fields such as architecture, design, environmental engineering, biology, and construction technology. Biosphere's goal in creating a tree cabin with a facade made of bird nests is to address the decline in bird populations in Swedish forests while also enhancing the natural habitat and biosphere. According to Öhman, forestry practices have led to a decrease in the availability of natural tree cavities

where birds nest. Inventories conducted by ornithologists and the County Administrative Board of Norrbotten indicate a decline in the numbers of various bird species “Figure 3”.

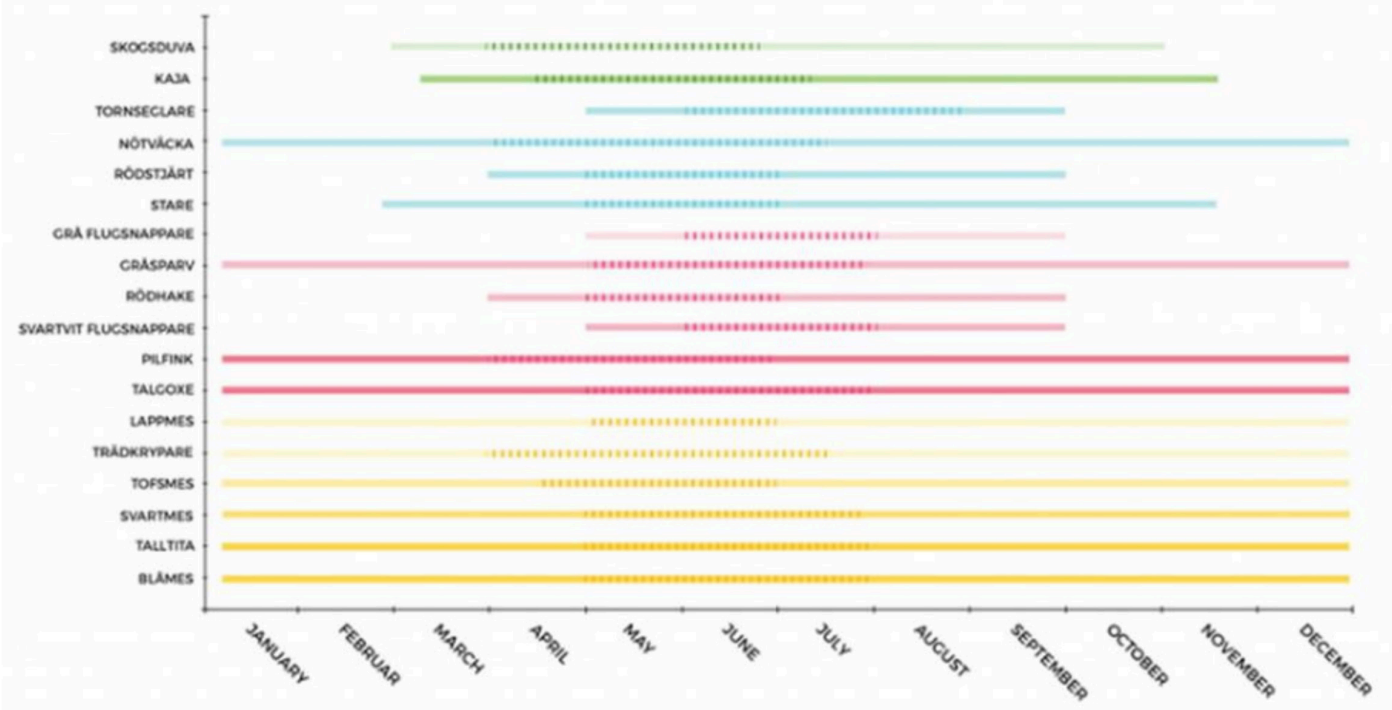


FIGURE 3 - GRAPH OF THE BIRD MIGRATION PROCESS DURING THE BREEDING SEASON.

According to Oxman (2014), the integration of man and nature in architectural projects requires the application of integrated processes to address contemporary project demands. In the case of Biosphere, collaboration between different fields of knowledge allowed the project to create an innovative solution that meets functional needs while respecting and integrating with the natural environment, considering various facets involved in the project “Figure 4”. Through this strategy, the final product achieved combines the knowledge from different areas in order to create integrated and adaptive solutions. According to Balmond (2013), this interdisciplinary approach allows for the exploration of new possibilities and innovative solutions for architecture and artifact design projects.

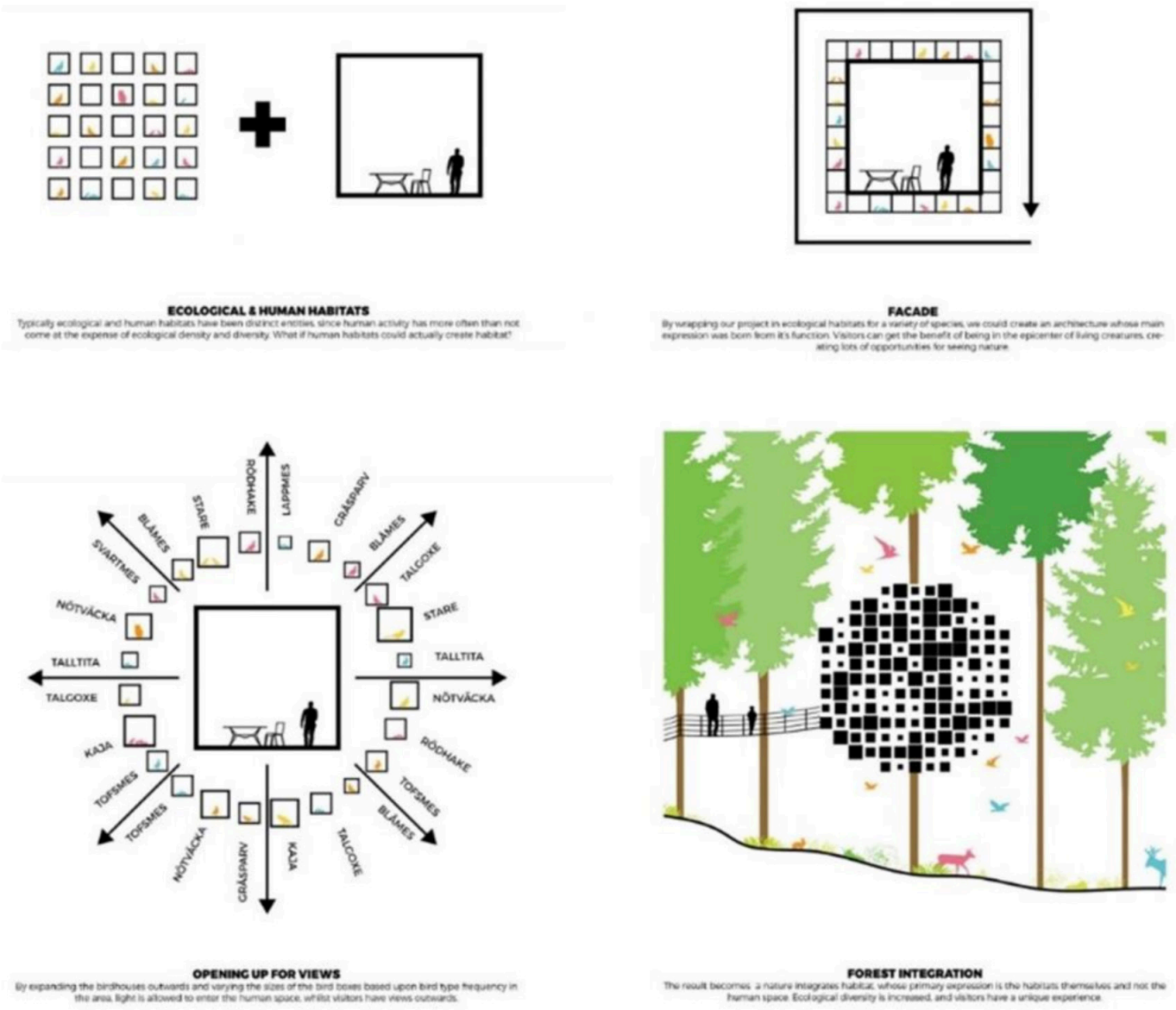


FIGURE 4 -DIAGRAMS ILLUSTRATING THE MULTIDISCIPLINARY APPROACH OF THE BIOSPHERE PROJECT.

The project exemplifies the application of this design premise, aided by computational design techniques that utilize digital tools to allow for the creation of a highly personalized architectural and design solution, adapted not only to human conditions, but especially to the specific needs of the local fauna, considering the diversity of species inhabiting the region and the typologies of their nests “Figure 5”. Thus, the Biosphere cabin was designed to collaborate and contribute to the preservation of the local ecosystem, motivated by the intention to protect the bird population of the region and the entire local ecosystem.

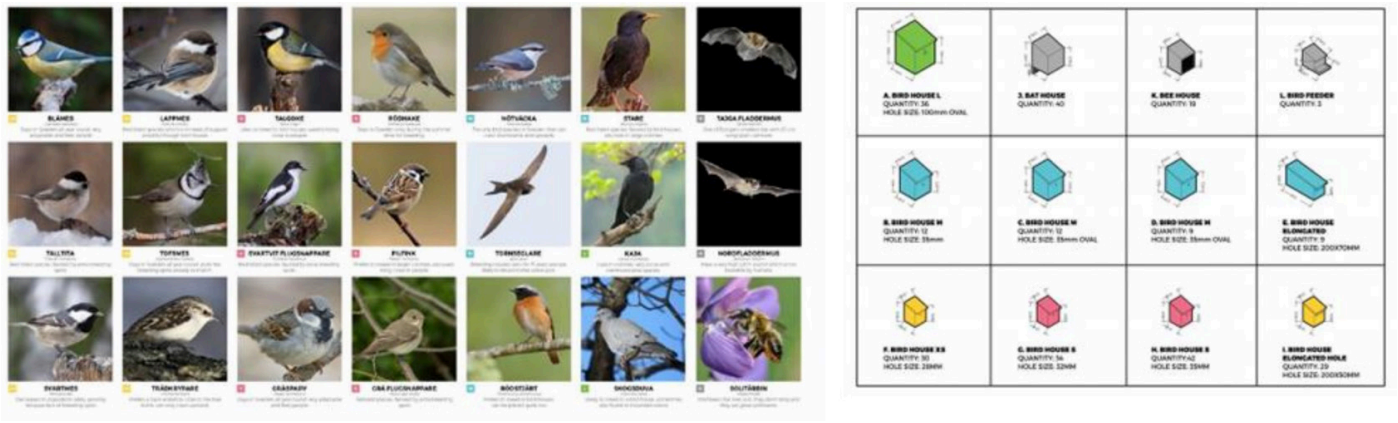

FIGURE 5 - SPECIES OF LOCAL BIRDS AND CUSTOMIZED NEST TYPES FOR EACH SPECIES.

For the application of these contemporary concepts, the architectural approach prioritized sustainable construction processes such as off-site manufacturing of components and prefabricated modular construction. This strategy allowed for time and material optimization, as well as reducing impacts on the natural environment, according to biomimetic concepts (Benyus, 2002). In this sense, the terrain and tree canopies were digitally mapped, allowing for adjustments in the implementation and integration with the surrounding forest environment, reflecting an important approach adopted in the cabin project. The module's facade, covered with 350 bird nesting boxes, establishes a symbiotic and functional relationship with the local biodiversity "Figure 6". The application of nature-inspired design is a clear example of how biomimetic principles and biophilic patterns can be translated into innovative and sustainable architectural solutions.

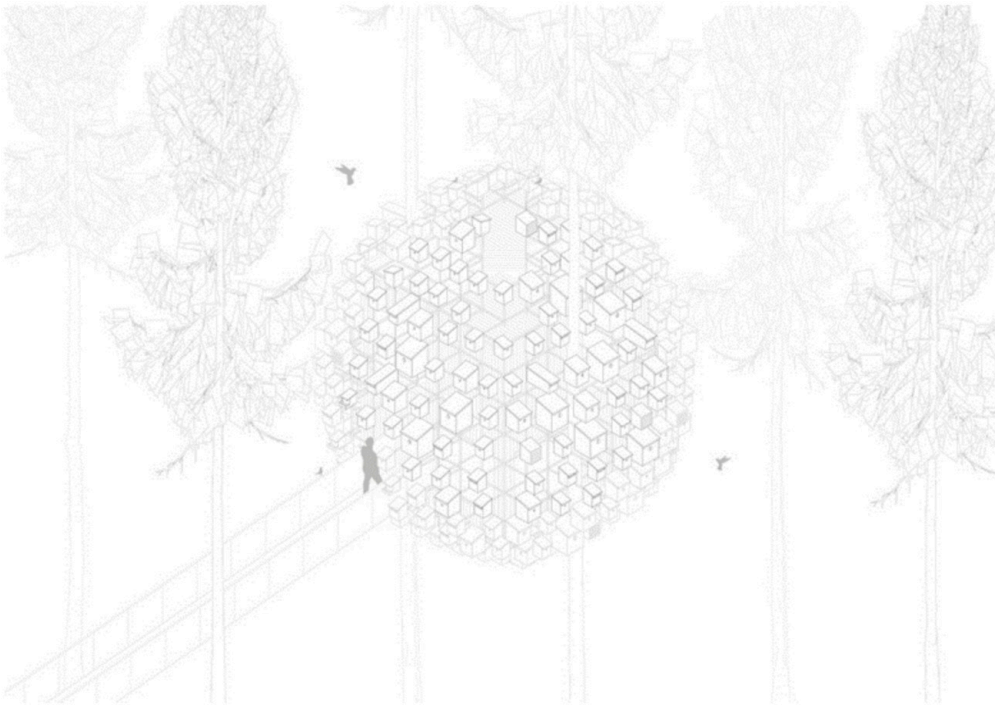

FIGURE 6 - SCHEMATIC AXONOMETRIC PERSPECTIVE.

Firstly, the choice of location reveals a concern for the preservation of the natural ecosystem, indicating a commitment from the designers to sustainability principles. Located amidst dense vegetation, the project seeks a harmonious integration with the surroundings, minimizing the impact on the forest and local fauna. This approach aligns with Balmond's ideas (2013), emphasizing the importance of a holistic relationship between the building and its context. Sustainability is undoubtedly one of the pillars of Biosphere, revealed through the integration with nature and the promotion of local biodiversity. The terrain and tree canopies were digitally mapped, allowing for adjustments in the implementation and integration with the forest environment, reflecting an important approach adopted in the cabin project "Figure 7".

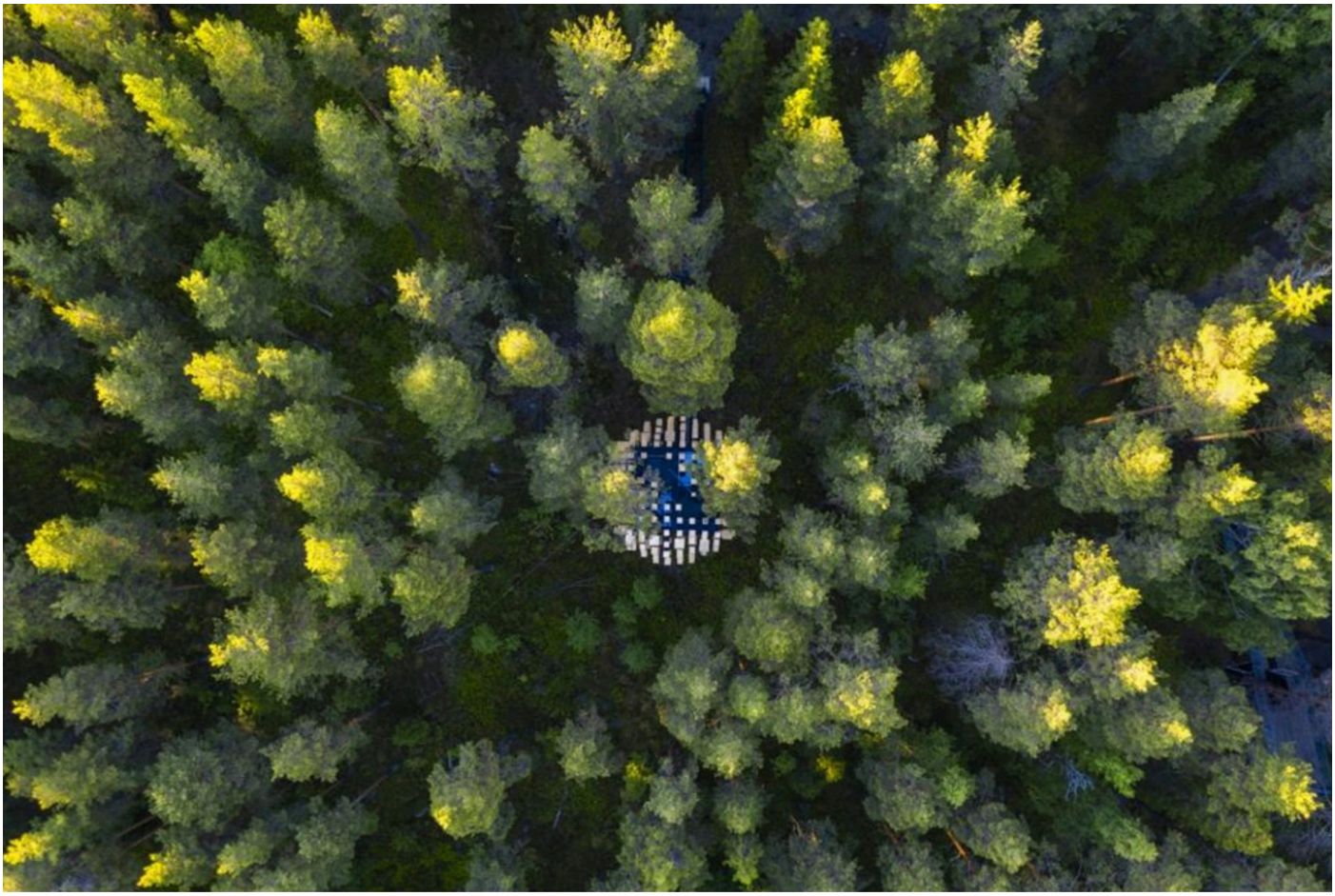

FIGURE 7 - BIOSPHERE AT TREEHOTEL SITE DEPLOYMENT PLOYMENT

The hotel was designed to integrate harmoniously and subtly with the natural landscape of the surrounding forest. The concept behind the Biosphere project is to strengthen the local biosphere, providing a habitat for birds and encouraging the preservation of wildlife. The morphology of the Treehotel itself demonstrates a sustainable projection of the architectural artifact as the structures are suspended above the ground, reducing interference with the terrain. In this sense, the project stands out for its careful imple-

mentation, avoiding the destruction of trees and minimizing interference with the local ecosystem.

Environmental sustainability is a determining premise for Biosphere, manifested through various architectural and design strategies. The choice of local materials also reflects the project's commitment to reducing environmental impact. Its structure consists of a glass prism surrounded by wooden nests that make up a sphere-shaped cabin, suspended among the trees, providing a panoramic and welcoming view of the surrounding landscape "Figure 8".



FIGURE 8 - BIOSPHERE AT TREEHOTEL. CLOSE-UP VIEW OF THE CABIN.

The choice of glass as the main material allows for natural light to enter and visual connection with nature, while the wooden boxes provide thermal and acoustic insulation for the interior of the building. Furthermore, the configuration of the cabin, suspended among trees, minimizes the impact of the construction on the ground while preserving the existing vegetation. This structural solution also visually harmonizes with the forest surroundings, in addition to reducing environmental impact. The housing unit is elevated by a lightweight and slender structure that distributes the weight of the construction to avoid damaging the tree roots "Figure 9". Additionally, the choice of materials prioritized the use of certified wood, reducing the building's carbon footprint.

FIGURE 9 - VIEW OF THE CABIN AMONG THE TREE CROWNS.



The principles of bio-inspired design and biophilia are central to the Biosphere project as it draws inspiration from natural patterns, mimicking bird habitats and creating a structure that harmonizes with the local ecosystem throughout the four seasons, reflecting a significant respect and integration of the built artifact with nature. To achieve this, the architectural approach prioritized sustainable processes such as off-site manufacturing of construction components and modular coordination in the design stages. The choice of this system aimed, among its main objectives, to ensure efficiency in the construction process and to minimize environmental impact during implementation, according to biomimetic concepts advocated by Benyus (2002). The prefabricated modules were digitally produced in controlled environments and subsequently transported for quick assembly on-site, minimizing waste and consequently reducing environmental impact “Figure 10”. The method encompasses construction and sustainability criteria, such as off-site industrialized systems and resource optimization (Schmidt; Austin, 2016; Author, 2017), contributing to an improvement in the quality of design and construction processes in general.

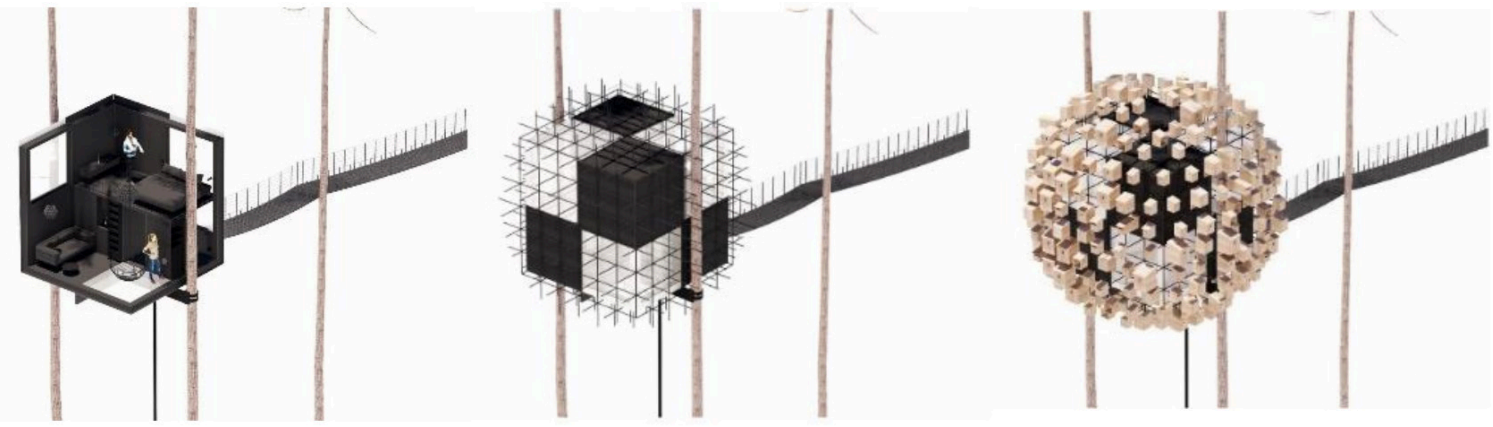

FIGURE 10 - MODULAR SYSTEM OF THE BIOSPHERE AT TREEHOTEL.

The design solution, oriented towards the system, was of great importance in reducing material waste, optimizing construction time, and increasing spatial flexibility, aligning with the ideas of Braida et al. (2016). In this way, the project used a structural grid onto which the elements that configure the unique morphology of the Biosphere were attached, characterizing the application of the concept of mass customization to the project (Balmond, 2013). Thus, the Biosphere at Treehotel stands out for its use of the system and its ability to produce a personalized solution for the project based on a standardized base of its construction components. Computational design and industrialized modular construction allowed for the precise creation of complex components, enabling quick and efficient on-site assembly.

Through the off-site modular system, the project also demonstrates a commitment to sustainability and the prolongation of the building's life cycle through the possibility of disassembly and reutilization of the elements. This approach is a significant advantage as it allows for maximizing material use and minimizing waste, contributing to the reduction of environmental impact. As pointed out by Braida et al. (2016), the use of renewable and low-impact materials, such as wood, is a relevant trend in contemporary architecture. The choice of wood as the predominant material in the Biosphere project reflects this commitment to sustainability and the aim to reduce the ecological footprint of the construction.

The system also incorporates the possibility of disassembly and reutilization of the elements, linking this aspect to the prolongation of the building's life cycle. This sustainable approach, combined with bio-inspired design and the use of renewable materials, contributes to the creation of structures that not only coexist with nature but also promote and protect it. By adopting sustainable solutions, such as the use of natural materials and a bio-inspired approach to structure, BIG demonstrates its commitment to sustainability and the integration of human habitat with the local ecosystem.

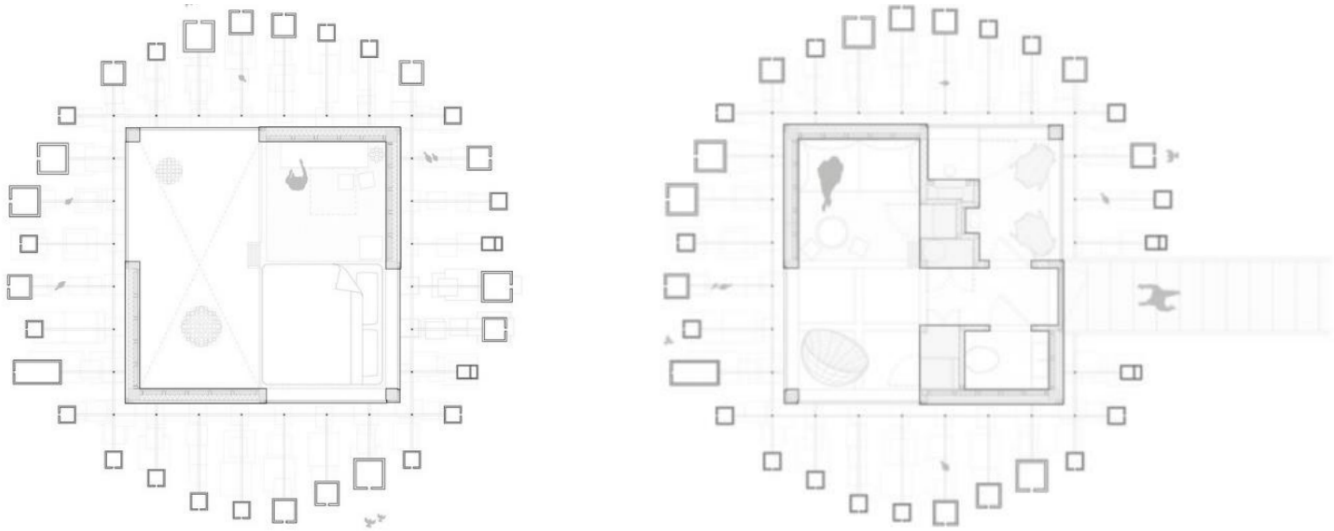

FIGURE 11 - BIOSPHERE AT TREEHOTEL SCHEMATIC FLOOR PLANS.

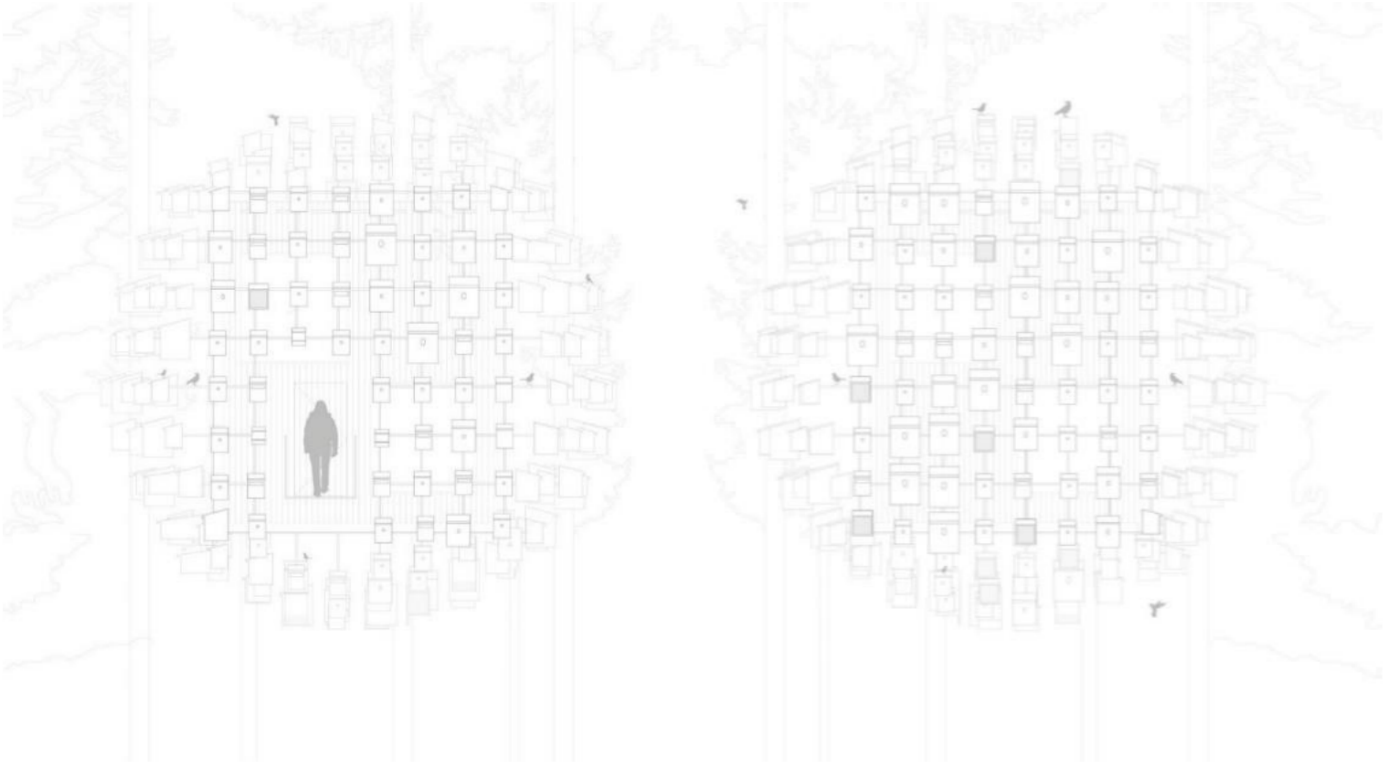

FIGURE 12 - BIOSPHERE AT TREEHOTEL. SCHEMATIC ELEVATIONS.

Balmond (2013) highlights that digitalization in architecture opens new horizons for artistic expression and innovative structural solutions. This is evident in the Biosphere project, where the use of advanced computational design tools was essential to model and simulate the interaction between the architectural structure and the natural forest environment. These tools were crucial in developing a structure that maximizes integration with the forest landscape. By using complex algorithms and digital simulations, the BIG team was able to predict and adjust the arrangement of birdhouses, optimizing natural light input and external views, as well as providing shelter for various bird species.

In the context of the Biosphere project, the computational simulation process involved exploring a series of critical parameters to ensure maximum efficiency and harmonious integration with the natural environment. The main parameters considered include:

**1. Topography and Site Geometry:**

• The terrain and topographic characteristics were digitally mapped to create an accurate model of the space, allowing for adjustments to the structure to minimize interference with the existing ecosystem.
• Distribution and Size of Birdhouses: Using complex algorithms, the distribution of the 350 birdhouses was optimized to accommodate a variety of bird species, respecting their behaviors and biological needs.
• Natural Lighting and Ventilation: The simulations considered natural light input and air circulation, using the geometry of the birdhouses as modulating elements to balance internal lighting and ventilation, increasing occupant comfort.
• Structural Stability: Structural stability analyses were conducted, considering wind loads, snow loads, and the weight of the birdhouses themselves, to ensure the safety and durability of the construction.

• Modeling Bird Behavior: Data on the behavior of local birds were used to determine the ideal sizes and positions of the birdhouses, ensuring that the structure would function as an efficient refuge for various species, contributing to biodiversity.
• Simulation of Environmental Impacts: Digital tests simulated the impact of the construction on the local flora and fauna, allowing for design adjustments to minimize negative impacts.
• Integration with Biomimicry: Inspired by nature, the project used principles of biomimicry to create a facade that not only visually harmonizes with the forest but also serves as a functional habitat for local avifauna.

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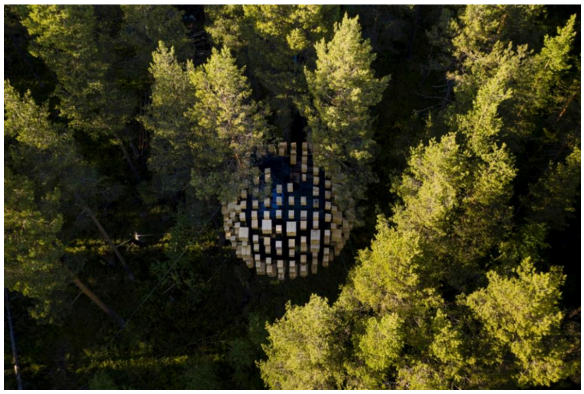
• Integration with Biomimicry: Inspired by nature, the project used principles of biomimicry to create a facade that not only visually harmonizes with the forest but also serves as a functional habitat for local avifauna.
• The Biosphere project, influenced by bio-inspired design and biomimicry, incorporates principles and strategies observed in nature for the design and architecture. According to Balmond (2013), the integration of form, structure, and building systems is crucial for optimizing the energy performance of buildings. This influence is evident in the choice of treehouse typology and the form of the cabin.

According to Braida et al. (2016), the use of advanced technologies allows for the creation of customized and highly precise building components, resulting in greater efficiency in the production and assembly of prefabricated modules. In the case of the Biosphere, these technologies are applied in an integrated manner to the design process, enabling the creation of organic forms and the production of customized components. The integration of computational design strategies is evident in the intricate and highly personalized form of the Biosphere “Figure 13”. The architects of the project used advanced parametric modeling techniques to generate the unique organic shape of the structure, allowing for a high degree of customization and adaptability to the specific environmental conditions of the site.

FIGURE 13 - AERIAL VIEW OF TREEHOTEL, HIGHLIGHTING THE INTEGRATION OF THE BIOSPHERE WITH THE FOREST.



The concept of prefabrication in architecture enables the operational implementation of housing structures in hard-to-reach locations, such as the Treehotel, contributing to the creation of more subtle buildings adapted to environmentally sensitive contexts, thanks to their lightweight construction and minimal impact on the natural ground “Figure 14”.



FIGURE 14 - BIOSPHERE AT TREEHOTEL. VIEW OF THE LOWER PART AND ACCESS WALKWAY.

The strong climatic contrasts called for a resilient architectural solution, which incorporated materials resistant to the challenging conditions imposed on the “Figure 15” project. Sustainability is achieved through the use of alternative materials and construction practices that minimize environmental impact. The project’s adaptive capacity ensures its relevance and resilience in the face of climate and ecological changes.





FIGURE 15 - BIOSPHERE AT TREEHOTEL IN WINTER.

The installation of birdhouses in the trees of the hotel is an important measure to combat the decrease in bird population in the region “Figure 16”. The solution, developed in collaboration with the ornithologist, directly addresses the need to increase local biodiversity. The strategy reflects on the importance of diversity and the integration of different knowledge in the design process.



FIGURE 16 - DETAIL OF BIRD NESTS.

By incorporating multiple creative voices from various fields of knowledge, Treehotel is able to generate unique and personalized solutions without sacrificing productivity. Data on the behavior of local birds was used to determine the ideal sizes and placement of birdhouses. In this way, the structure was designed to serve as an effective refuge for different species, promoting biodiversity.

In the case of Biosphere, this connection between multiple disciplines is tangible and beneficial, where collaboration between different areas of knowledge provides users with an immersive and regenerative sensory experience. The structure of Biosphere was conceived to replicate natural environments, offering an engaging experience to guests while also protecting the local ecosystem “Figure 17”. Thus, both Treehotel and Biosphere exemplify how the combination of different areas of knowledge and the application of specific data can result in environmentally sustainable and enriching projects for the human experience.

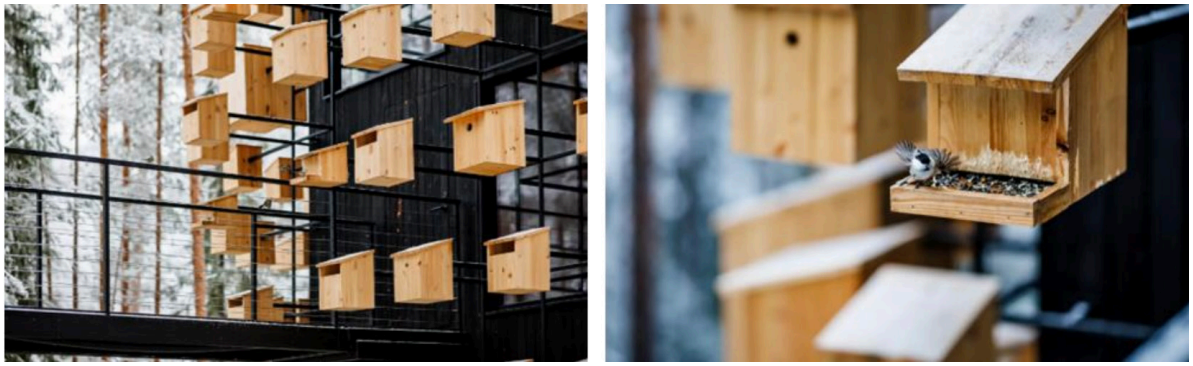


FIGURE 17 -DETAIL OF BIRD NESTS IN WINTER.

This custom-made approach, combined with industrialized production techniques, has resulted in an unconventional hospitality project that adds value to the development through its innovative design, aimed at enhancing the user experience. The adoption of a treehouse as a housing unit directly references nature, exploring the relationship between humans, the forest, and tree habitats.
The design solution aims to create a “second nature,” where architecture and design establish a profound connection with the natural environment. “Figure 18” clearly illustrates the harmony between the architecture and the forest, achieved through bioinspired design and the integration of the module with the forest vegetation. This is accomplished through a metal walkway, allowing users to experience a journey among the tree trunks.



FIGURE 18 - ACCESS TO THE BIOSPHERE VIA THE WALKWAY.

Inside the cabin, this coherence is evidenced by the way the organic shape of the housing unit relates to the airflow and the capture of natural light. The organic biomorphic configuration of the artifact, resulting from a generative design process, establishes a symbiotic relationship between the construction and the surrounding nature, carried into the interior of the cabin “Figure 19”.



FIGURE 19 - BIOSPHERE AT TREEHOTEL. INTERIOR OF THE CABIN.

The decision to neutralize the internal rooms chromatically with dark tones enhances the natural beauty of the exterior, which is framed by the glass skin, further enhancing the synergy between the user and the environment “Figure 20”.



FIGURE 20 - BIOSPHERE AT TREEHOTEL.CABIN INTERIOR.

The application of computational resources allowed for the simulation of various scenarios of implementation and functional distribution for its implementation, guiding designers towards the best decision-making process, in line with the views of Oxman et al. (2010) and Bohrer (2019). Therefore, the structure could be modeled in harmony with the local natural and cultural context (Ingold, 2000; Vitruvius, 1999).

The precision and efficiency brought by these digital processes are exemplified in the Biosphere, where the integration with the forest landscape was optimized through complex algorithms and digital simulations. This type of approach not only enhances the symbiosis between humans and nature but also demonstrates the potential of computational design as a powerful tool for projects in the field of contemporary architecture.

**2.2 Synthesis Table**

In the context of contemporary architecture, projects that combine digital culture, bioinspiration, and sustainability have gained significant relevance. This chapter provides a summary of the concepts and data previously discussed, focusing on the case of the Biosphere at Treehotel project. The different sections highlight the relationship between technological integration and respect for the natural environment, in line with the thoughts of the referenced authors.

The Biosphere at Treehotel project stands out as a remarkable example of how digitalization in architecture can open up new horizons for expression and innovative structural solutions. Balmond (2013) argues that digitalization in architecture brings unprecedented possibilities for creation and structural innovation, a concept that is clearly manifested in the design of the Biosphere project.

The BIG (Bjarke Ingels Group) team employed advanced computational design tools to model and simulate the interaction between the architectural structure and the natural forest environment. This use of digital technologies not only allowed for greater precision in simulations but also enhanced the creation of a structure that maximizes its integration with the forest landscape.

In the development of the Biosphere project, various critical parameters were considered to ensure maximum efficiency and harmonious integration with the natural environment. The following “Table 1” presents a summary of the main aspects of digital culture identified in the Biosphere at Treehotel project, correlating them with theoretical references:

TABLE 1 – SYNTHESIS TABLE.

| **Aspects of digital culture in the *Biosphere* project at *Treehotel*** | **Theoretical References** |
|---|---|
| Multidisciplinary approach combining architecture, engineering, biology, and technology in the design process. | Oxman, 2014. |
| Use of computational design tools for parametric modeling, performance simulations, and optimization of deployment. | Oxman, 2014; 2010. |
| Mass customization of components based on a modular and standardized structural core. | Braida et al., 2016. |
| Digital production of components with high precision and customization. | Braida et al., 2016. |
| Off-site construction of modules to reduce waste and expedite the building site. | Braida et al., 2016. |
| Biomimicry as a strategy for environmental integration and biophilic functionality. | Benyus, 2002. |
| Sustainability reflected in the choice of materials, subtle deployment, and promotion of biodiversity. | Balmond, 2013. |

The principles advocated by Balmond (2013) emphasize the integration of form, structure, and building systems to optimize the energy performance of buildings. This perspective is clearly visible in the Biosphere project, where the harmonious interaction between architecture and the surrounding ecosystem has been a central focus from the beginning. Akadiri et al. (2012) argue that industrialized building systems demonstrate better energy performance and lower carbon emissions over their life cycle compared to traditional methods. This observation is supported by the Biosphere project, which employs off-site prefabrication techniques to reduce waste and enhance efficiency.

## 3. Discussions

This case study allowed for an understanding of how compact industrialized building designs can facilitate the convergence of aspects of Digital Culture, sustainability, and construction efficiency. The analysis of Biosphere at Treehotel demonstrated how computational design tools, off-site modular systems, and mass customization approaches enabled the creation of a highly customized housing solution that is responsive to the natural environment.

The study offers insights into the implications of digital culture for the design of bio-inspired compact modular constructions, incorporating aspects of efficiency and sustainability. Biosphere illustrates how computational tools enhance the synthesis of form and function, allow for mass customization of components, and qualify the construction process.

Additionally, the multidisciplinary approach and biomimicry of the project

highlight the convergence of technology, design, and nature, a hallmark of new architectural paradigms (Oxman, 2014). This premise suggests potential pathways to optimize processes and integrate artifacts into the landscape in a respectful and functional manner. From a technological standpoint, there is potential for series construction systems to incorporate concepts such as adaptability, disassembly, reuse, and recycling (Schmidt III; Austin, 2016).

Reflecting on theoretical frameworks presented by Balmond, Braida, and Oxman, it can be concluded that design and construction models supported by digitalization, as observed, have the potential to disseminate increasingly sustainable solutions that are responsive to their contexts. Furthermore, they enable the customization of projects through the mass production of construction elements, while simultaneously reducing environmental impacts through prefabrication and construction optimization.

## 4. Conclusion

The analyzed project highlights the potential of digital culture to enhance the design of compact modular constructions by utilizing collaborative processes, computational tools, and bio-inspired strategies. This showcases a convergence of technological innovation, sustainable design, and respect for the natural environment. Proposals like Biosphere demonstrate more sustainable construction paths by optimizing processes, reducing waste, and promoting a qualified symbiosis with nature. However, it is imperative to evaluate these systems in light of sustainable development principles.

Industrialized building systems are generally considered more energy-efficient and lower in carbon emissions throughout their life cycle compared to traditional construction methods (Akadiri et al., 2012). In summary, projects like Biosphere signal an effective convergence between digital culture and the principles of sustainability in compact modular constructions. It is important to note that the Biosphere at Treehotel project is a specific case, and each context presents unique challenges and opportunities. Therefore, the application of these concepts and principles in other projects should be carefully analyzed and tailored to local specifics and user needs. The Biosphere at Treehotel project exemplifies an innovative and holistic approach to contemporary architecture, integrating sustainability principles into compact prefabricated constructions. By merging digital culture and bio-inspired design, the project creates structures that not only coexist with nature but also promote and protect it. The adoption of sustainable solutions, such as the use of natural materials and bio-inspired construction techniques, demonstrates a clear commitment to sustainability and the integration of human habitat with the local ecosystem.

The use of computational design in the “Biosphere” demonstrates the potential of technology in creating efficient, adaptable, and customizable architectural solutions. This approach allows for the creation of complex forms that fit the specific context, addressing individual user needs without compromising construction efficiency. Such a modern approach enables the design of unique projects that promote biodiversity and human well-being while minimizing environmental impact.

Concepts of “Performative Architecture” suggest a deep integration of form, structure, and materials, aiming to optimize performance and interaction with the natural environment. This relationship is evident in the Biosphere project, which illustrates how the combination of advanced technologies and biological principles can result in sustainable, adaptable structures that harmonize with nature. The use of off-site modular design and construction techniques allows for rapid building and reduces material waste, significantly contributing to environmental sustainability.

The case study of the Biosphere at Treehotel reveals that a deep understanding of the interactions between form, structure, performance, and environmental impact is crucial for successfully merging bio-inspired design with modern technological processes. This case serves as a model for future endeavors, demonstrating the viability of reconciling the challenges of sustainability, customization, and technological innovation. By valuing user experience and environmental preservation, the project illustrates how architecture supported by digital tools can actively promote environmental conservation and biodiversity.

This specific example underscores the importance of adapting these concepts to unique contexts and local needs. Although the Biosphere at Treehotel offers a beacon of innovation and sustainability, each new project must be carefully analyzed to adapt principles to local specifics, ensuring relevance and resilience in the face of climate and ecological changes. The conclusion suggests that through a holistic approach that unites design, engineering, and construction technology, contemporary architecture has the capacity to efficiently respond to socio-environmental challenges, promoting a balanced integration between the built artifact and the natural ecosystem.

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CHAPTER

# 04

# NATURE-BASED SOLUTIONS

# (35) “Dialoguing Between Ex-Votos” utilizing discarded objects and waste as awakening tools. Gaston Uriel Lisak Zabotinsky (FA ULisboa - ELISAVA Research - TGRAF ISEC Lisboa.).

**ABSTRACT |** In the recent exhibition “Dialogant Entre Exvots” (Dialoguing Between Ex-Votos) artists Josep Guinovart and Gastón Lisak explore using religious artifacts in the form of votive offerings as tools for social and environmental activism. The show, first held at the Fundació Espai Guinovart in Agramunt, Spain, presented an intergenerational dialogue between two artists who both use discarded materials and mixed techniques in their work. Understood in the context of the anthropocene, the exhibition underscores the relevance of rethinking traditional art paradigms and mining its capacity to criticize the dynamics of overproduction and consumption of our time. This paper outlines key works in the exhibition, the artists’ creative processes, using participatory design practises and the importance of the public interaction.

**KEYWORDS |** EXVOTOS, ANACHRONISTIC, DISCARDED WASTE, ART THINKING, DESIGN TECHNIQUES

## 1. Introduction

### 1.1 Historical context of ex-votos

In Christianity, ex-votos are devotional objects offered to saints and divinity in gratitude for favours received. They serve as “tangible expressions of gratitude and supplication, bridging the human and the divine. Its forms are infinitely diverse: crutches, bandages and moulded limbs and internal organs in wax or metal” (Garnett, & Rosser, 2018). Ex-votos have been a significant part of religious and cultural heritage in several countries. The following images (Fig.1A/1B) are two examples found in Spain.

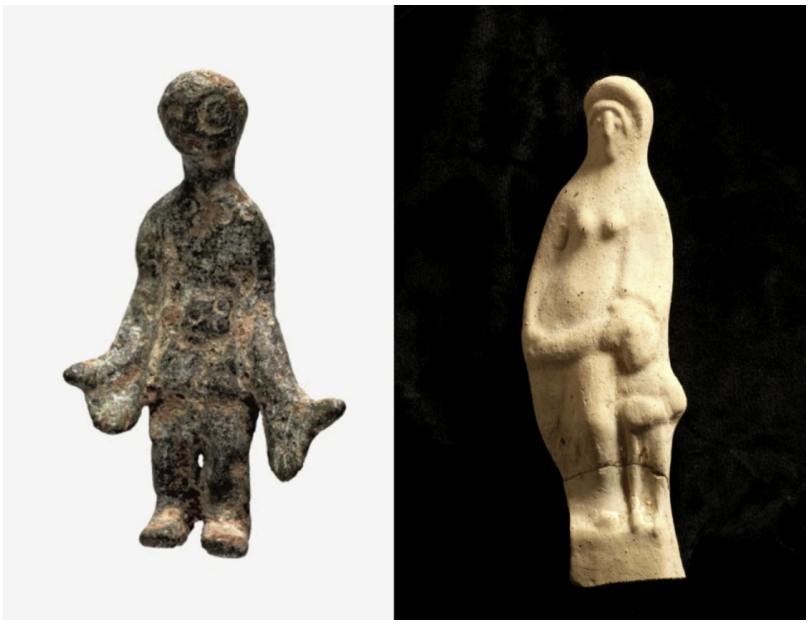

FIG. 1 A/B BRONZE VOTIVE FIGURES, DATED FROM 400 - 201 B.C. AT CASTELLAR, JAÉN, 2024. SOURCE: GOOGLE ARTS & CULTURE.

### 1.2 Objective of the article

The objective of this article is to analyze the exhibition “Lisak i Guinovart: Dialogant entre exvots” and explain how artists Josep Guinovart and Gastón Lisak use ex votos as vehicles for their social and environmental activism. It examines their techniques, creative processes, and impact on the audience. In light of the current environmental crisis, it’s crucial to develop new narratives in the design field that can help promote more sustainable and equitable “futures”. Adopting the plural meaning of “futures”—a concept proposed by researchers Andrés Colmenares and Lucy Black-Swan in their “Everything Manifesto (2019),”—encourages us to be less fixated on one solution and understand the many ways designers can act, change, transform, adapt, and contribute to the creating a better world. This approach advocates for thinking as a collective rather than as an individual.

## 2. The Exhibition “Dialoguing Between Ex-Votos”

### 2.1 Concept and Curation

The exhibition was conceived as a collaborative “dialogue” between two artists from different generations (Fig.2), where Lisak created new ex-votos based on the previous work that Guinovart made in the 1970’s. The word dialogue purposely used in quotation marks because there was no actual verbal exchange between the artists as Guinovart passed away in 2007.

The exhibition was a space where past and present converged. By showing connections and contrasts in their work, the show allowed visitors to experience the enduring efficacy of design and artistic practices in addressing today’s challenges.




FIG. 2 INVITE DESIGN FOR THE EXHIBITION: AUTHOR & GUINOVART, DIALOG BETWEEN EXVOTOS, AGRAMUNT, 2024. SOURCE: AUTHOR

Here, votive offerings are used as a means of representing social and environmental destruction, in a society characterized by overproduction and consumption. Votive offerings serve several purposes: a cultural and social evidence, an artefact, an aesthetic language, and an artistic link between generations. In religious countries like Spain, ex-votos are regularly saved in churches and sacred spaces. But, what happens when we transform an object that was discarded and imbue it with a divine or privileged status? Could design storytelling and literary techniques such as comparison, parallelism, metaphor, help us connect with a wider audiences and pierce through the fatigue and disengagement over environmental matters? Could satire, irony, humour, word play or exaggeration connect the worlds of trash and discarded materials with the realm of devotional objects like ex-voto?

The “dialogue” between Josep Guinovart and Gastón Lisak began with the discovery of a shared social consciousness between the two artists. Curator Maite Machado and Maria Guinovart, daughter of the artist, found this link and set the stage for the exhibition. Lisak then began studying the different connections between his own practice and Guinovart’s and ultimately presented the results in the exhibition held at Fundació Espai Guinovart in Agramunt from 30 June, extended to 06 October 2024.

The exhibition offered discoveries not just for the public but also for the curator, Guinovart’s family, and everyone who took part in the making it, including , a participatory process with designers, photographers, video makers, and students who took part in gathering materials and producing the pieces. The industrial process of thermoforming was used to create well-defined finishes.
Across different eras, the exhibition seeks to transmit sensations with the representation of what has been (dis)carded, using everyday objects and materials to provoke emotional experiences, with a creative process that goes from the idea to the image, from rhetoric to aesthetics. Guinovart died in 2007, and his ex-votos had been never previously shown in Agramunt, the city he was from. Returning his devotional objects back to the space that Guinovart created in 1994 was a unique and emotional experience. A lot of his former colleagues, friends, and citizens from Agramunt were surprised and amused to see them in the exhibition.

**2.2 Two generations together and their approaches**

Josep Guinovart (1927–2007) was a Spanish artist known for his abstract style and use of diverse materials. His compositions often incorporate everyday objects and elements found in nature (Fig. 3). Guinovart’s works invite audiences to ponder the relationship between humans and their environment.



FIG. 3 LEFT:.ARTWORK BY GUINOVART, “L’ULL DEL BLAT”, . MIXED TECHNIQUE ON WOOD, 75 X 60 CM, 1992. RIGHT: ARTWORK BY GUINOVART. “LA RODA ERA”. MIXED TECNIQUE ON WOOD, 180,5CM DIAMETER, 1993. AGRAMUNT. SOURCE: ESPAI GUINOVART FOUNDATION

Gastón Lisak-Zabotinsky (1989-) is a researcher, artist and designer whose work explores social and environmental themes. Using recycled materials and discarded objects, Lisak creates pieces that criticize consumerist culture and its environmental impact of modern society. He explained his goals in an interview with MetalMagazine: “I try to work with objects where I can connect with either because they are ugly, pretty, useless, weird, immoral or fascinating.[...] I combine objects and artifacts of today, creating new narratives for people to explore and experiment with things differently, using (De)materialisation and (Re)materialisation of the object.” (Lisak-Zabotinksy, 2022).

**2.3 Comparison and contrast of their styles and techniques**

Although Guinovart and Lisak belong to different generations, they share a sensitivity towards the use of everyday materials and a concern for social and environmental issues (Fig.4). While Guinovart uses raw abstraction to express his vision, Lisak’s approach draws from his design background. He uses polished design processes and techniques to convey his criticism of current consumerism and material waste. All the works in the exhibition were made with discarded objects salvaged on fields between Barcelona to Agramunt—the same pilgrimage trips that Guinovart made escaping from the Spanish war.

The director of Contratalla Gallery, Marià Casas (2004, p. 34) said referring to Guinovart: “His art is an approach to freedom, an open door to perception, it is aesthetic because it is ethical” And this is something that connects with the work of the author. In this era of visual pleasing, short attention span, things need to be interesting visually to be able to give attention and then, we can go deeper in understanding the meaning behind.



FIG. 4 LEFT: DETAIL OF THE INSTALLATION CREATED BY GUINOVART AT ESPAI GUINOVART IN AGRAMUNT, 2024. RIGHT: IMAGE FROM THE DISCARDED OBJECT FOUNDED DURING THE TRIP TO AGRAMUNT BY THE RESEARCHER AND ITS TEAM ,2025. IMAGES BY IRENE VILLARROYA AGRAMUNT. SOURCE: AUTHOR.

### 2.4 Exvotos by Josep Guinovart and New exvotos by Lisak

Among Guinovart's highlighted pieces are those that use natural materials and waste, such as wood and metal, to create abstract compositions that evoke landscapes and organic elements. His overflowing creativity, his commitment to plastic language, is linked to the ethical, social and everything that happens around him. For him it is fundamental not to lose the critical sense of his position in the face of injustice (Casas, 2004, p.30). Fernando Gamboa, director of the Museum of Modern Art of Mexico City, said in the catalogue/presentation of Guinovart in the exhibition he held in 1977."He seeks contact with all the life that surrounds him, the most quotidian. He is insatiable. With his hunger for reality, he would enclose in a painting, if he could, the whole world (Logroño, 1997, p.31).



FIG. 5 EXVOTOS [SCULTURE] BY JOSEP GUINOVART DONE IN 1970 . EXHIBITION FROM 2021, ESPAI THYSSEN, SAN FELIU DE GUIXOLS, GIRONA. SOURCE: ESPAI GUINOVART FOUNDATION.

Below can be seen the Exvotos created by Guinovart exhibited at Espai Thyssen, in Girona, made with plastic, wood and pigment (Fig.5). Like the Cabinets of Curiosities of personalities such as Elias Ashmole (Palomar, 2024), which contained manuscripts, engravings, paintings, fossils, and tools from different civilisations and were donated to Oxford as a public museum (the Ashmolian Museum), the exvotos from Lisak, serve as a way of reflecting on the wasteful aspects of our daily lives. It seems we, as humans, are being consumed as we consume. We are tracing our path by leaving traces in form of plastic, metal, broken glasses and outdated technology that end up in land fields and nature spaces. The collection of objects gathered in the shape of window, or frames, as small cabinets of curiosities become a leftovers selfie. Lisak presents works featuring discarded objects (Fig.6), like plastics and industrial waste (Fig.7), which he transforms into pieces that criticise waste culture and the lack of sensibility of the environmental impact our behaviours produce in a participatory process of collecting and exhibiting.



FIG. 6 SELECTED IMAGES OF DISCARDED OBJECTS FOUND DURING THE TRIPS FROM BARCELONA TO AGRAMUNT BY THE AUTHOR AND THE TEAM INVOLVED. PART OF THE NEW EXVOTOS. 2024, DIFFERENT LOCATIONS.. SOURCE: AUTHOR

In the image above (Fig.6) we can see a selection of objects found on the way to Agramunt. With the passage of time, these once perfectly made industrial objects now seem like part of the environment and mimic the colours of their surroundings, making them useless. Some of the waste and discarded materials have become almost invisible to the human eye. This is related to the work presented by Lisak, a rectangular vacuum formed shape structure, where one side is all covered in white color, like a veil or a second skin, and on the back part the audience is invited to see the objects as they are, thanks to the transparent plaque.Those rectangular shapes, with volume that are presented in a white wall, become pieces to be touched, adding curiosity, and strangeness to the viewer. Allowing playfulness to discover and learn while touching them or seeing them closely.

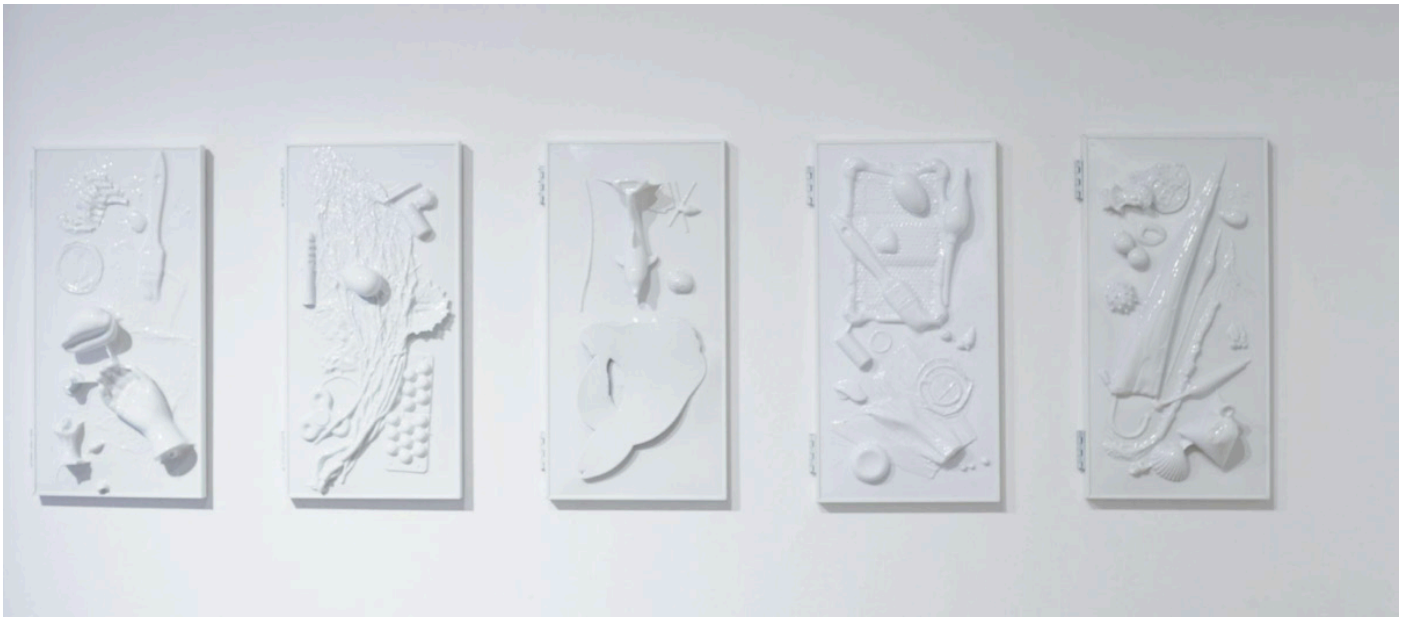

FIG. 7 NEW EXVOTOS CREATED BY THE AUTHOR CREATED WITH DISCARDED WASTE (CLOSED VIEW). 2024, DIFFERENT LOCATIONS. SOURCE: AUTHOR



FIG. 8 NEW EXVOTOS CREATED BY LISAK DONE WITH DISCARDED WASTE (OPEN VIEW). 2024, DIFFERENT LOCATIONS. SOURCE: AUTHOR

On the back side of the new ex-votos (Fig. 8) the raw materials can be seen. Lisak selected the objects from the abundance of scavenged material including leftovers of parties and celebrations, trash from illegal picnics, broken pieces from cars among others in a participatory gathering together with some natural elements and materials from Guinovart. Amid the scarcity of the post-war period, Guinovart used the materials and objects he found around him in his work. In this case, Lisak uses found objects too, but he's chosen to use those discarded by people in today's context such as pieces of lights from the automotive world, single-use food wrappers, yogurts, cans, potato bags, beans, or broken household objects, cables, chargers, broken

dishes, glass,… Taking a sample of each group, although in the trip they found many pieces of each one of the typologies and emphasizing those pieces that were interesting at the level of form, texture and colour, because in this work of decontextualization it is important to, on one hand the texture of the object without colour will be seen and on the other hand the object in all its color and with the marks of use and deterioration. So they had to be interesting both in texture and color to fulfill both needs.

The participatory design process

In the work exhibited at Espai Guinovart, we can find the mixture of the values presented by Andrés Colmenares at the IAM festival in 2019—five key ideas that can help design and redesign our surroundings. In this particular scenario, the empathy towards the planet, not just humans. Tolerance for others, humans and non-humans (Fig. 9).

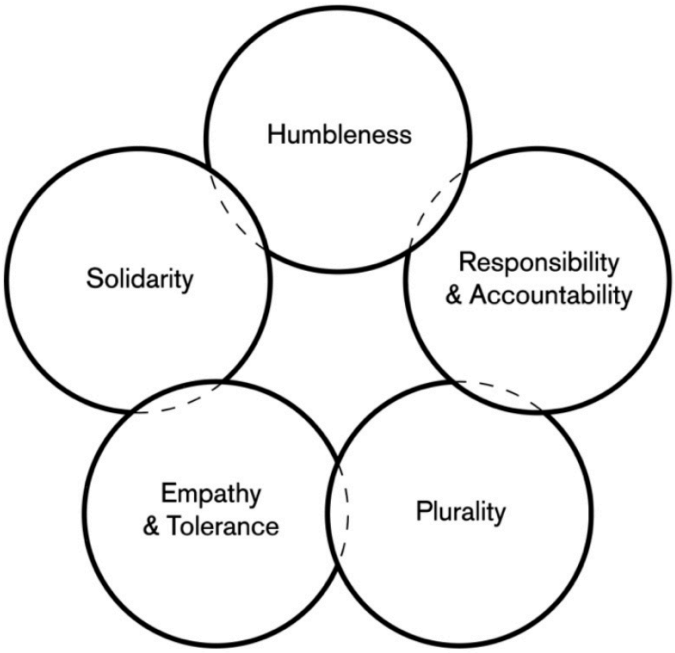


FIG. 9 CONCEPTUAL DIAGRAM: ADAPTED FROM DESIGN FOR HUMBLENESS, THE FIVE KEY VALUES TO DESIGN AND REDESIGN FROM THE EVERYTHING MANIFESTO BY ANDRÉS COLMENARES & LUCY BLACKSWAN. 2019. SOURCE: AUTHOR.

This collaborative process has become a responsible act of consciousness for all the people who were part of making the exhibition and the public who visited the exhibition. Irene Villarroya, the photographer who has been part of the journey said: “I began to observe in more detail all those small objects that are lying around in our daily commute”. Josep Maria Cami, a 77-year old sculptor with more than 50 years of career experience commented that “Mas que verlos los siento con respeto i estima (“More than seeing the objects in another way, I feel respect and esteem for them”). Studying Guinovart’s work closely, I observed that he was able to ignite other senses beyond that of sight that like touch or smell.

## 2.5 Materials and Techniques Used

Both artists share a preference for unconventional and recycled materials. Guinovart uses wood, metal, and other natural elements, while Lisak incorporates plastics and industrial waste (Fig.10). This choice of materials not only reflects their environmental concerns but also adds a layer of meaning to their works.

“The last word comes from the press” (Casas, 2004, p.46). This was an interesting sentence shared by Gallery Director Marià Casas, related to the engravings that Guinovart was doing. You could design, create, combine, but the end comes once the press is applied. Is that moment when you open it, that we will be able to reveal the result. The same happens with the work of the Lisak. Drawing from his A series of questions where made to visitors and people who participate on the creation of this exhibition. Answer by Spanish photographer, Irene Villaroya Answer to the questionnaire after visiting the exhibition by another artist Josep Maria Cami, friend and colleague of Josep Guinovart design background, Lisak has been working with a process method called thermoforming which is typically used in packaging design. Can we use this technique to create artworks? Can we change the way we use the matrix, used frequently to create thousands of copies, to create just one, where the objects from the matrix are wasted materials that will remain inside? They both share the surprise of revelations, happy accidents, and “mistakes” that are more typically present in art than design. Even if Lisak displays and organises the objects as well as he wants, the material, the heat, the humidity, the time left inside the machine will change drastically the end result. This vestige of surprise and the unpredictability of making is valorized in the process.



FIG.10 TOOL USED DURING THE PROCESS OF MAKING THE EXHIBITION THE & GUINOVART, 2024, AGRAMUNT & CASTELLDEFELS. PHOTOGRAPHY BY IRENE VILLARROYA. SOURCE: AUTHOR

## 2.6 Installation and Setup

The spatial arrangement encourages viewers to reflect on the parallels between the two artists' approaches, fostering a deeper understanding of their shared concerns. The exhibition collected four walls full of ex-votos created by Guinovart and the new ex-votos by Lisak. In addition, a video compilation was made showing the artist's and the team's path to Agramunt collecting discarded materials.

## 3. An intergenerational Dialogue

Both artists share a deep social consciousness, reflected in their choice of themes and materials. Through their works, they denounce the impact of overproduction and excessive consumption, inviting the viewer to reflect on their own relationship with the environment. "Guinovart does not need a studio [...], he can work anywhere, at any time and occasion, always with the same frenzy and enthusiasm. Anyone who does not know him, who is not familiar with his work process, would believe that he improvises, that he follows the dictates of an inspiration that comes to him from above. But none of this is true. In Guinovart's passionate temperament, there is a hidden fund of reflection that is set in motion long before any action is taken. The most seemingly minimal and spontaneous work has been long and painstakingly gestated in the painter's mind. He works in a way that is both reflexive and intuitive. That is to say, he makes each work mentally, sometimes for a long period that can last for years, but when he starts to give plastic form to his mental elaboration he works with tremendous speed as if he were short of time". (Borrás, 1997, p.16). As in Guinovart's case, Author's concept of moving from Barcelona to Agramunt is similar, with the workspace becoming the journey. In this case, Author worked with other colleagues, from photographer to designers, from Catalonia to Taiwan, with different ages, collecting discarded objects (Fig.11), and materials during the entire journey, passing through places Guinovart used to be, such as Castelldefels, the beach, or the forest, and then arriving at Agramunt, its gas stations, streets, and wild nature. The fragments collected became little stories, that someone designed and created, that now are trashed and lost in landfills similar concept of offering and divinity. An unusual approach merging the design techniques, including exploratory research, observation and photo studies with the art worlds, to create new narrative using design communication in an art context.



FIG. 11 DISCARDED WASTE FOUND DURING THE TRIP FROM BARCELONA TO AGRAMUNT. GATHERING THE FOUND OBJECTS IN EACH LOCATIONS FROM A GAS STATION TO THE BEACH. 2024, DIFFERENT LOCATIONS. PHOTOGRAPHY BY IRENE VILLARROYA. SOURCE: AUTHOR

“Another aspect that I have always admired about Guinovart and that I have also seen in Lisak’s work, is the use of what I call a three-dimensional collage, (another design technique) the structuring of geometric images that create spatial relationships. We have the opportunity to see two singular representations of the discarded, materials and objects that, without designating them, are also structured and in dialogue with each other, and denounce all that we are capable of discarding and abandoning the environment, revealing with their votive offerings, a common vision of art as a means to recover social awareness in the era of overproduction and consumption” (Machado, 2024).

“Interfered the orthodoxies, diluted the limits, it is not possible to nuance, creativity is not a dichotomous expression; art and life are the same” (Guinovart, 2004, p.46). Guinovart understood the intrinsic connection between art and life and the way both are interconnected. Maria Lluïsa Borras shared the following thoughts about Guinovart: “He first incorporates the object into the canvas. They are objects that seem specially chosen to oppose pop-art, then in vogue. They are also objects of common use, but not shiny and extreme, gaudy, taken from advertising, but found in the trash, old and useless, worn by use, with an emotional charge that has been imprinted on them, inevitably, a long friction with the human being. They are a light bulb or a rocking chair, a piece of wallpaper or gilded plaster that once framed a painting. It may be a bicycle part, a grille back, a bottle or a mannequin”. (Borrás, 1997, p.17) In two different moments those objects have been shared by both creators. It is interesting even that in this “dialogue”, some objects that Guinovart used where incorporated in Lisak’s new exvotos.

### 3.1 Public and Critical Reactions: From an observer-passive to interacting-active behaviour.

Guinovart’s and Lisak’s works provoke a strong emotional response in the viewer, using the familiarity of materials and everyday objects to evoke memories and sensations. The exhibition has received positive feedback from both the public and critics. Viewers have praised the curation and the way the two artists’ works complement each other. Guinovart was an artist who loved his environment, the earth and anything related to the land. He was very sensitive to stimuli and was connected with his surroundings. Following the words of her daughter Maria, “he was not a big fan of Cities, he didn’t like the noise and the mess” . Guinovart 3 needs to establish a dialogue with the public, his work is his own but also for someone else and he knows that for communication to exist, the spectator is as necessary as the creator (Casas, 2004, p. 38). In the case of Author, with the creation of this new exvotos he also place an important role in the user. The creations attached to the wall are not simple frames that needs to be seen from far, instead, the user is able to touch it and move it (Fig.12), to discover what is behind. Little cabinets of curiosities that become conceptual photographies from forgotten memories from humans, that had offered ironically to nature without caring much for the environment.



FIG. 12 INTERACTION OF THE VISITOR WITH THE NEW EXVOTOS CREATED BY THE AUTHOR WITH DISCARDED WASTE (OPEN VIEW). 2024, ESPAI GUINOVART. SOURCE: AUTHOR

Édouard Glissant (Diawara, 2018) left us the concept of Mondialité of "world-mentality", which reformulates being a 'citizen of the world' as a state of mind that recalibrates our existence as at the same level as animals, plants and the Planet as a whole. In this exhibition we share the idea of being part of a bigger ecosystem. We are non just human on the planet, and we need to understand that we get consequences from each movement we do.

## 4. The Role of Design and Art in Shifting Perspectives

Design education plays a vital role in shifting societal perspectives on environmental and social issues. Through collective, creative processes involving art and design, complex ideas and emotions can be communicated in a way that is accessible and engaging including the importance of observation and experimentation. Exhibitions like "Dialoguing Between Ex-Votos" provide educational opportunities, encouraging viewers to think critically about their impact on the world. Weekly visits from schools have been made at the exhibit. "I found a really beautiful intersection between Academy and practice. In my case, my goal is to introduce more artistic processes in the Design Academy, by using the anachronistic object as a tool to understand today's society. Do we really need to create new objects that have no soul? Can we learn from the existing ones?" (Lisak-Zabotinsky, 2022). Maybe we don't need to focus on new products, in a context where humans are surrounded by huge quantities of insignificant artefacts created for trends that will not last.

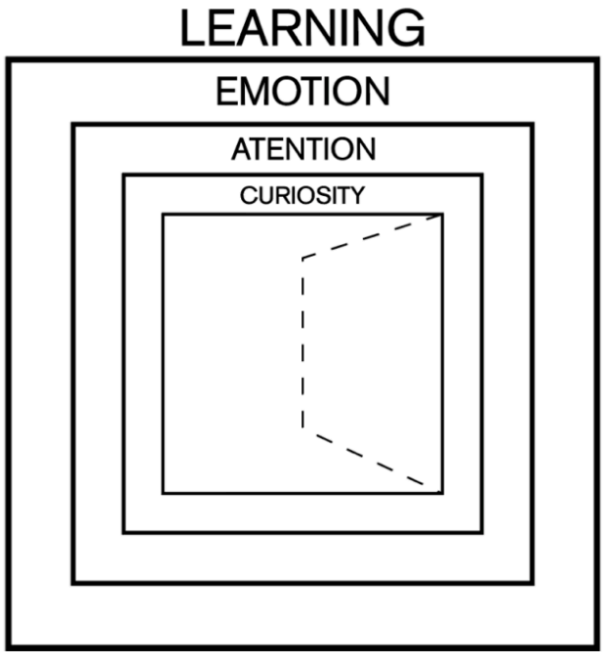


FIG. 13 CONCEPTUAL DIAGRAM: ADAPTED FROM HOW ART CAN TRANSFORM EDUCATION BY RESEARCHERS MARIA ACASO AND CLARA MEJIAS. 2017. SOURCE: AUTHOR.

In academic and exhibit contexts, it is important to understand learning through emotion, attention and curiosity. Without curiosity it is much more difficult to find a way to generate a memory and learning impact in the person who interacts and is part of this type of collaborative experience. As we can see on the conceptual diagram (Fig.13) adapted from the researchers Maria Acaso and Clara Mejias (2017, 121). The place generated curiosity, Espai Guinovart, an old food market transformed into an exhibition space that the municipality gave to the artist in 1994. All the senses are explored in the work of Guinovart, and this creates attention on the visitors. After we experience the main space we enter to the smaller room where the “Dialogue” is created. It is a more intimate space, designed for temporary exhibitions. Lorena, a 47-year old visitor shared that “It has allowed me to connect with something foreign to me, contemporary art, and at the same time feel that I am totally challenged by having objects that have returned the sea, which I love, and to put the focus on the impact that we generate in the environment for many decades, something that I am aware of by studies and profession. The technique from total ignorance has seemed to me shocking and the result incredibly beautiful”. In this case the design production technique becomes surprising and new. Another anonymous shared “Surprising, and even more so knowing how they have complemented each other without knowing each other or interacting”.

Art with design techniques can inspire change by challenging existing paradigms and presenting new ways of thinking using familiar objects in unfamiliar contexts. The use of trash as ex-votos flips the traditional narrative, making offerings from humans to nature rather than the divine. This reimagining, forces viewers to confront the reality of environmental degradation and consider the need for reparative actions. By re-contextualising waste as sacred offerings (Fig.14), artists highlight the urgent need for a more respectful and sustainable relationship with the environment. In this case, exvotos are also created by materials that are found in a specific area a time, giving special meaning to the important of context and time.



FIG. 14 LEFT: DISCARDED WASTE DISPLAYED AT THE ESPAI GUINOVART. RIGHT: ISSEY HUANG AND ALBA GONZALEZ, PART OF THE TEAM, COLLECTING DISCARDED MATERIALS AT THE BEACH, 2024, AGRAMUNT AND CASTELLDEFELS. IMAGES BY IRENE VILLARROYA. SOURCE: AUTHOR

## 5. Conclusion

The exhibition demonstrates how ex-votos can be reinterpreted as a form of contemporary art that denounces social and environmental degradation. It is important to reframe the work of great artists that are commonly stored in famous museums full of dust and hidden to the public. “Age does not exist: what exists is a mental energy, of ideas and an energy of illusion, of curiosity, of the capacity for admiration”. (Logroño,1997, p.31).

In arranging the objects for each piece, Lisak also demonstrates design techniques such as observation, experimentation, experience prototyping and playing with the visual values of composition like tension or symmetry. The dialogue between the two artists offers new perspectives on how to address these issues from the artistic realm. An image from the exhibition can be seen below (Fig. 15)




FIG.15 EXHIBITION VIEW AT THE ESPAI GUINOVART, 2024, LLEIDA. SOURCE: AUTHOR

According to the Italian scholar Ezio Manzini, we live in the “uberization” of everything (Manzini, 2020) and it is a dangerous moment when human beings become defenseless the moment the system stops working. We don’t know how to repair things or how things work. What if we go beyond the selfishness of human centered design methodologies and singularity mindsets, and aim for

more holistic earth-driven-design approaches that lead to plurality and solidarity? (Colmenares & BlackSwan, 2019). This research explores the idea of strangeness and familiarity. The 18th century German poet Novalis calls for a shift in perspective in “making the strange familiar and making the familiar strange.” In this case, the majority of the discarded objects we found are common in our everyday lives, but when we took them out of their original context they transformed into something else. This is one of the experiments led by Lisak who is currently researching the importance of the anachronistic object as a tool for symbolic impact in his doctoral studies. Guinovart said 20 years ago “We are in an urgent crisis…the fundamental commitment is the work, the language, but there is another necessary commitment and you can not be apart from the world around you... I think we are in a tremendously dehumanized moment, and I think that art participates in this crisis of humanization... society only values having, and not being. Everything is bought and everything is sold.” (Guinovart, 2004, p. 46).

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CHAPTER

# 05

# STRATEGIC DESIGN FOR GREEN TRANSITION

# (O2) CULTIVATING SUSTAINABLE PATHWAYS TO AN INCLUSIVE TRANSITION IN DESIGN EDUCATION. Veronica Magno de Moraes (Universidade de Lisboa).

**ABSTRACT |** To confront the complex issues of the twenty-first century, such as climate change, biodiversity loss, natural resource depletion, and a growing wealth disparity, fundamental reforms at all levels of society, as well as new problem-solving approaches, are necessary. These considerations have resulted in a greater emphasis on design research, practice, and education with a long-term perspective and recognition of the need for solutions based on new, more sustainable socioeconomic and political paradigms. Also, design's role in this. This research investigates the transformational power of design education in fostering sustainable futures, and the need to rethink their curriculum structure for it. The study looks at how design curriculum may incorporate cultural, ecological, social, linguistic, economic, and ethnic diversity using case studies from eight institutions throughout the world. Interviews with educators, directors, and students underscore the importance of curriculum variety and alternative pedagogies. Using the Transition Framework Methodology approaches to an inclusive transition entail reorienting design education toward sustainable futures, advocating for a pluralistic approach that prepares designers to face future issues with critical thinking and responsible creativity. Although many higher education institutions are beginning to incorporate inclusion into their curricula, the research emphasizes the significant barriers to achieving full inclusion. In this scenario, this shift requires the implementation of a meaningful strategic design for an inclusive education that promotes emancipatory and plural design, capable of incorporating many perspectives toward a sustainable and prosperous future.

**KEYWORDS |** DESIGN EDUCATION, INCLUSIVE DESIGN, TRANSITION DESIGN, SUSTAINABLE FUTURES, INCLUSIVE TRANSITION

## INTRODUCTION

The world is in transition. The future is a fertile ground for creativity, and it is a way for designers to reimagine worlds that are not yet feasible. Today, design, as a discipline, is centered as a tool to find solutions to capitalism (Pater, 2021). The impact of design on the environment, politics, and society can only be effectively addressed by transcending current limitations. Despite a century since the establishment of the first known European design schools, the values and history of design continue to be taught according to unsustainable principles imposed by a dominant matrix from the Global North. This presiding narrative, as Lupton (2023) points out in her book Extra Bold, dictates the standards of good and bad design, often devaluing the works produced by non-Western cultures and non-industrialized societies.

Consequently, by merely responding to industry demands, the production cycle has constrained critical thinking in design. Forward-thinking in design is crucial to regenerative practices with economic growth, avoiding repeating

past mistakes. Suppose there is a paradigm shift in design practice from the current linear consumption to entire living systems. In that case, design education must alter through a fundamental reorientation, beginning at the grassroots level of design. In these circumstances, discussions on ecological sustainability, and political or social issues might be sparked by design as a means of envisioning education throughout the shift to a green future.

## 1. Methodology

Fortunately, there are currently emerging alternative proposals for this system that reimagine how design can relate to nature, society, and the economy sustainably. This paper employs a two-step methodology, beginning with a literature review adopting the Transition Design Framework Methodology (Irwin, 2015). They are followed by case study analyses, as the overarching method for the research project, using a qualitative approach to explore and analyze how universities are transitioning to diverse curricular structures and pedagogical approaches.
Transition Design is a transdisciplinary process aimed at addressing complex social and economic challenges by understanding, seeding, and catalyzing systemic change at the systems level (Manzini & Margolin, 2018). The methodology framework involves analyzing historical knowledge and past practices that have contributed to present-day challenges, as well as exploring how feasible futures can be achieved through current stakeholder engagement and transitional processes. The ultimate goal is to catalyze social transitions by representing critical opportunities and proposing a new domain of design practice, research, and study, advocating for design-led societal transformations toward sustainability. By applying this methodology, the research aims to challenge the status quo of design education, by reimagining how cultural perspectives can be prioritized in teaching structures and methods, which are strategically integrated to accelerate the transition toward more green futures.

“The perception of the global sameness of the curriculum and the knowledge of what is lost when the richness of specific and local design cultures is marginalized and ignored could make learning more meaningful.” Noel, L. A. (2022).

This study examines the educational practices of the first sixteen universities (Figure 01) offering arts and/or design courses. These institutions were selected for an observational analysis based on higher education universities’ websites and how they present themselves, facing inclusivity and recognizing different knowledge in their curricula. Additionally, to assess the implementation of socially responsible design in education, the study incorporated criteria based on a diverse range of geographical locations, acknowledging the crucial role of cultural context in shaping inclusive pedagogical approaches.

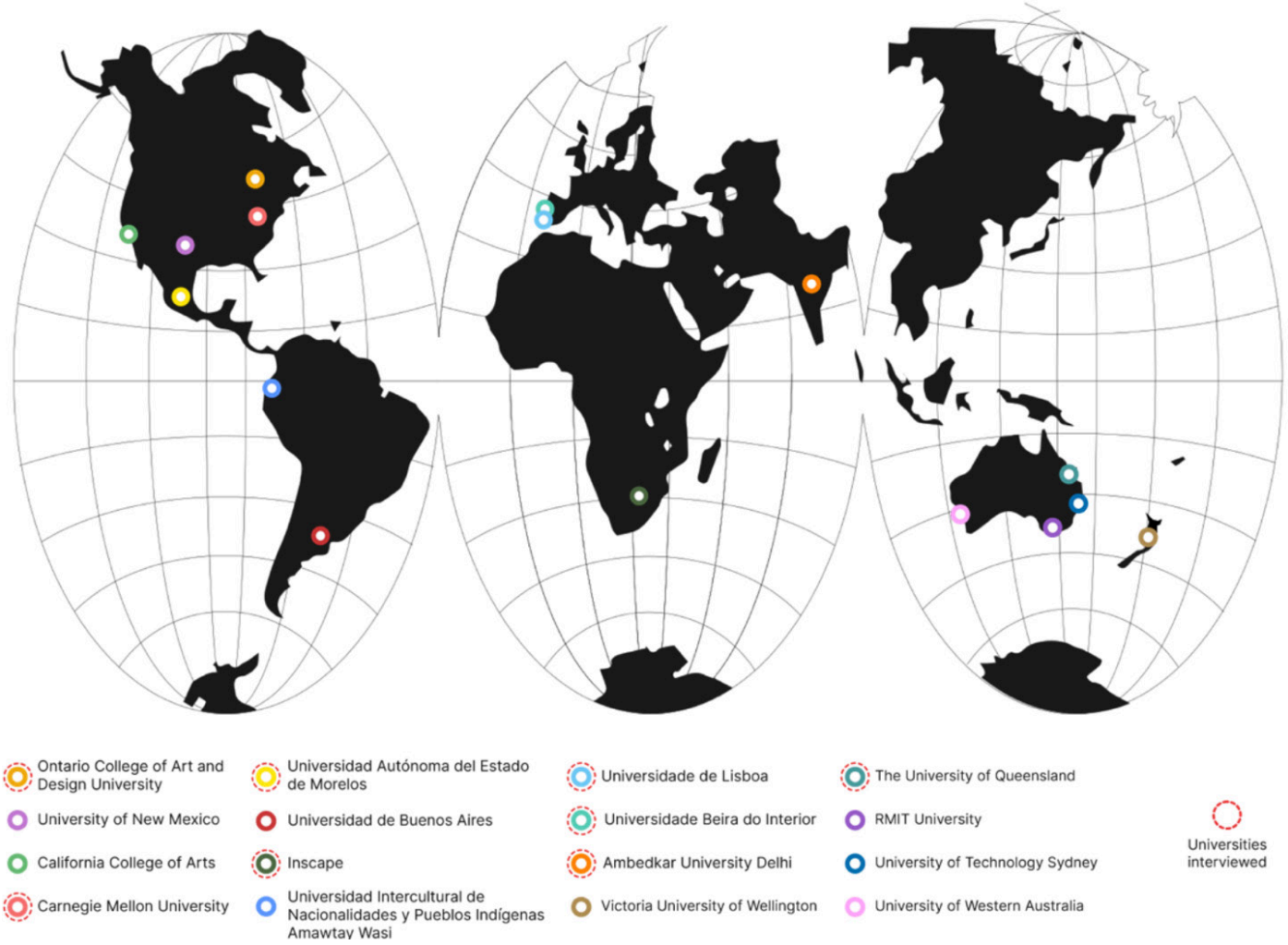


FIGURE 1 : WORLD MAP OF UNIVERSITY POSITIONS

Note: This figure was an adapted design from Abbass Bazeghi, Least Distorted Equal Area World Map (2016) and demonstrates a visualization of the researched and interviewed universities.

To analyze the information collected on the universities and their respective courses, the PESTLE Analysis framework (Perera, 2020) was applied. The highest-rated courses from this framework were selected for a detailed examination of eight design case studies from the original set of sixteen universities. The selection was based on geographic criteria, including institutions from Canada, the USA, Mexico, South Africa, India, Australia, and Portugal, covering both first and second-cycle education programs. This choice stems from the need to understand how to identify and analyze the space for speech and respect for cultural, ecological, social, linguistic, economic, and ethnic diversity and to recognize the unique experiences of students and other stakeholders in the education system.

## 2. Discussion

Following the analysis of the universities, this section presents a discussion of the collected data. The findings are enriched by qualitative research, including interviews with faculty, students, and institutional leaders. The goal is to understand how universities across different global regions perceive inclusive design education, identify key areas of consensus or convergence, and explore the challenges hindering the promotion of innovative approaches for a green future. The analysis is divided into four main areas.

The first area of focus is inclusion in education and the barriers to its implementation. Many universities have begun restructuring their programs to incorporate underrepresented voices into design education. Universities' progress in diversifying their teaching staff and pedagogy by integrating new global perspectives is notable. However, the concept of inclusion at most institutions remains largely centered on providing opportunities for individuals with socio-economic disadvantages, as well as those with physical and mental disabilities, an area where many universities still struggle due to insufficient infrastructure, funding, and training. The challenges of inclusive design education are significant, with financial, and cultural barriers impeding its global implementation. These obstacles underscore the complexity of fostering true inclusion in design education, particularly in light of the varied sociopolitical contexts across different regions.

Second, the study examines course structure and methodology. While design education is evolving, it continues to be influenced by Eurocentric traditions. Many institutions are attempting to decolonize their curricula by integrating local issues and perspectives, such as indigenous knowledge. Some institutions are reimagining new methods of teaching and learning in which technology complements nature, driven by students' desire to create solutions for a safer and more sustainable society. Based on this, the studied courses are building practical solutions that bring together strategies to develop services and products that support the local materials and solutions, to address the significant regional, societal, and global concerns.

Third, the investigation then explores proposed pedagogies that aim to readjust our thinking and practice, supporting critical empowerment to question current historical narratives and understanding the different ways that educational stakeholders learn, absorb knowledge, and teach from each other. Participative design is an emerging discipline that investigates not only classroom relationships but also ways for co-creating curriculum structure and references that incorporate design into an interdisciplinary paradigm.

Finally, the study considers course participants and the international perspective. Sociocultural factors, including socio-economic, linguistic, and cultural diversity, play a crucial role in the educational experience. While some institutions promote greater inclusion, challenges such as social inequality and language barriers persist. The study questions whether design education effectively promotes sustainable awareness, with varying levels of student engagement depending on generational and country-specific factors.

For that, inclusive design is the key process to give space for underrepresented worlds in design education references and classrooms. Not only is the world changing, but so are people, and inclusive approaches to reconceptualizing education structures to include new worldviews in design education are emerging, promoting a more inclusive design practice created by/with/for people of different identities, backgrounds, and abilities.
The research acknowledges limitations, including the reliance on available data from institutional websites, which may not capture the full scope of design programs. Additionally, the study notes potential discrepancies between the intended curriculum and what is taught or learned, suggesting that

communication and structural issues may affect educational outcomes. Although the research focuses on a specific set of regions, it calls for future studies to explore other parts of the world, such as Southeast Asia, the Middle East, and Central Africa.

## 3. Conclusion

As a result, new models and practices that challenge socio-environmental hierarchies serve as curricular frameworks for future design, incorporating long-term thinking as a transformational potential by accepting responsibility for existing crises and understanding design involvement in them. Although the selected institutions around the world are already revising their structures to ensure a more inclusive and sustainable future, economic and social obstacles continue to impede inclusion from being fully realized. On the other hand, major advances in sustainable design actions, with an emphasis on the importance of involving local communities in the creation of nature-based projects that address environmental challenges and promote equity in society, are becoming popular as workshop themes and side disciplines.

Cultivating sustainable ways is a long process that begins with recognizing unfair actions, identifying unsustainable attitudes in design, and reconsidering our histories and beliefs. It entails shifting away from universal structures and procedures and toward pluralistic, local, and global approaches to inclusion, Escobar (2018). Rather than exporting methodologies, design education must vernaculate its structures and utilize technology to envisage future goods and services, responsible approaches that support the development of designers who are better ready to tackle potential challenges. It involves training designers who can think critically, solve complex problems, and anticipate society's future needs. In a future for many, not just a few.

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## Introduction to Distributed Design

In today's rapidly evolving digital landscape, distributed design has emerged as a revolutionary approach to the creation and development of products, services, and ideas. It challenges the traditional, centralized model of design and manufacturing, introducing a more open, collaborative, and decentralized process. Distributed design brings together designers, makers, and consumers from around the world, enabling them to collaborate in real time or asynchronously, often leveraging digital tools, open-source platforms, and local production capabilities.
This new model is not only reshaping industries like manufacturing, fashion, and product design but is also having profound social, economic, and environmental impacts. By decentralizing the design process, distributed design fosters inclusivity, innovation, and sustainability. But what exactly is distributed design? How does it work, and how can individuals and organizations participate in this transformative process?

## What is Distributed Design?

Distributed design refers to the decentralized approach to the creation and sharing of designs, which allows individuals and teams from different parts of the world to collaborate and contribute to the design process. In traditional design models, design decisions and production processes are often concentrated within a single organization or team. Distributed design, however, opens the process up, making it more collaborative, iterative, and inclusive. It leverages digital technologies to break down geographical barriers, allowing anyone with access to the internet and digital fabrication tools to participate.

This method encourages open sharing of knowledge, tools, and resources. In many cases, designs are shared through open-source platforms, where they can be freely downloaded, modified, and adapted to suit different contexts or needs. This openness and flexibility are central to the philosophy of distributed design, where the emphasis is on collaboration and collective problem-solving, rather than on ownership and control.

Key characteristics of distributed design include:

**1.** Decentralization: Design decisions and processes are not controlled by a single entity but distributed among various participants.
**2.** Collaboration: Designers, makers, and users collaborate, often across different locations and time zones.
**3.** Open Source and Shared Resources: Many distributed design projects operate on an open source basis, making resources available for free or for modification.
**4.** Local Production: Designs are often produced locally using digital fabrication tools like 3D printers, CNC machines, and laser cutters, reducing

the need for mass production and long supply chains.
5. Customization and Adaptation: Distributed design allows for products to be customized and adapted to local needs or preferences, offering a personalized approach to design.

**How Distributed Design Works**

Distributed design is made possible by a combination of digital technologies, cloud-based tools, and decentralized production methods. It typically follows these steps:

**1.** Creation and Sharing of Design Files: Designers create digital files, such as 3D models or CAD drawings, that represent the object or product they want to produce. These files are then shared online, often through open-source platforms or digital repositories, where they can be accessed by anyone. Examples of such platforms include GitHub (for software design), Thingiverse (for 3D printing designs), and Wikifactory (for collaborative product development).
**2.** Collaboration and Iteration: Once the files are shared, other designers or users can download them, provide feedback, or make modifications. This creates a cycle of iteration and improvement, where the design evolves through contributions from multiple people. Tools like collaborative CAD software (e.g., Fusion 360) or cloud-based platforms (e.g., Onshape) enable real-time collaboration on design files.
**3.** Digital Fabrication: After the design files are finalized, they can be produced using digital fabrication tools. These tools, such as 3D printers, CNC machines, or laser cutters, can be found in makerspaces, Fab Labs, or even home workshops. Because the production is local, distributed design often supports decentralized manufacturing, reducing the need for mass production and long supply chains.
**4.** Customization and Local Adaptation: One of the major advantages of distributed design is that it allows for customization. Since users can download and modify design files, they can adapt them to meet local needs or preferences. For example, a 3D-printed chair design can be adjusted to fit specific ergonomic requirements, or a device designed in one part of the world can be adapted to use locally available materials.
**5.** Local Use or Further Distribution: Once the product is produced, it can be used locally or shared further within the distributed design community. This process creates a networked ecosystem of design, production, and innovation that is constantly evolving and adapting.

**How Distributed Design Connects People and Ideas**

Distributed design thrives on the concept of interconnectedness. At its core, it builds bridges between designers, makers, and users from different cultures, industries, and geographies. Several key technologies and systems help facilitate this connection:

• Online Platforms and Communities: Platforms such as Fab Labs, Hackaday, Instructables, and Wikifactory host designs and serve as hubs where individuals can collaborate on projects, exchange feedback, and build upon

each other's ideas. These communities foster a sense of shared purpose and collective creativity.
• Communication Tools: Tools like Slack, Discord, and Zoom are frequently used to coordinate projects, discuss ideas, and manage teams spread across multiple time zones. These tools help maintain open channels of communication, allowing distributed teams to work seamlessly as if they were co-located.
• Version Control Systems: In projects where multiple contributors are making changes to a design, version control systems (e.g., GitHub) ensure that all changes are tracked and managed. This is particularly useful in software design and other collaborative environments where multiple iterations of a design may be created.
• Digital Fabrication Networks: Networks such as the Fab Lab and Maker Movement provide access to physical resources for production. These global networks are composed of labs and workshops equipped with digital fabrication tools. Individuals or teams can upload their designs, which can then be produced locally at any Fab Lab or makerspace equipped with the necessary tools.

**Benefits of Distributed Design**

Distributed design offers several benefits, including:

**1.** Greater Innovation: By involving a larger and more diverse group of people in the design process, distributed design fosters creativity and innovation. Different perspectives and experiences lead to more creative solutions and faster problem-solving.
**2.** Democratization of Design: Distributed design breaks down barriers to entry, allowing anyone with access to the internet to contribute. This democratization opens up the design process to a wider range of people, leading to more inclusive and accessible products.
**3.** Sustainability: Distributed design promotes local production, which reduces the environmental impact associated with long supply chains and mass manufacturing. It also supports the use of locally sourced materials and promotes the creation of products that are customized for local conditions, reducing waste.
**4.** Empowerment of Makers and Consumers: In the distributed design model, consumers become co-creators. They can customize products to meet their needs, giving them more control over the design and production process.
**5.** Resilience and Adaptability: Distributed design systems are often more resilient than centralized ones. By decentralizing production and design, these systems can adapt more quickly to changes in demand or disruptions in the supply chain.
Challenges of Distributed Design

While distributed design holds great promise, it also faces several challenges:

• Quality Control: Ensuring consistent quality across multiple locations can be difficult when designs are being adapted and produced locally. Without centralized oversight, there may be variations in the final product.
• Intellectual Property Issues: The open-source nature of many distributed design projects can create tensions around intellectual property and owner-

ship. Designers must navigate questions of who owns the rights to a design and how it can be used.
• Access to Tools and Resources: While digital fabrication tools are becoming more widely available, access to these tools is still limited in some regions. This can create inequalities in who is able to participate in distributed design projects.

**How to Participate in Distributed Design**

Participating in distributed design is accessible to anyone with a passion for creativity, innovation, and collaboration. Here are a few ways to get started:

**1.** Join Online Communities: Platforms like Wikifactory, GitHub, and Thingiverse are great places to find and contribute to distributed design projects. By joining these communities, you can collaborate with other designers and makers, share your work, and gain inspiration from others.
**2.** Learn Digital Fabrication Tools: If you're new to digital fabrication, there are plenty of online resources and tutorials available to help you get started with tools like 3D printers, CNC machines, and laser cutters. Many makerspaces and Fab Labs also offer workshops and courses.
**3.** Contribute to Open-Source Projects: Many distributed design projects are open-source, meaning anyone can contribute. Whether you're a designer, engineer, or simply a creative thinker, your input can help improve and evolve these projects.
**4.** Share Your Own Designs: If you have a design or idea that you'd like to share with the world, you can upload your files to platforms like Thingiverse or Wikifactory, where others can download, use, and adapt them.
**5.** Participate in Hackathons or Design Jams: Events like hackathons and design jams are great opportunities to get involved in distributed design. These events often bring together diverse groups of people to work on creative solutions to specific challenges.

**Conclusion**

Distributed design represents a paradigm shift in the way we approach creativity, production, and collaboration. By decentralizing the design process and leveraging digital technologies, it empowers individuals and communities to take control of the creation and production of goods, fostering innovation, sustainability, and inclusivity. With the rise of digital fabrication tools and online collaboration platforms, more people than ever can participate in distributed design, contributing to a more interconnected and creative world. Whether you're a seasoned designer or a curious beginner, the distributed design ecosystem offers countless opportunities to get involved and make an impact.

# SHORT PAPERS

# CHAPTER 01 - BIODESIGN

## (70) Biophysical mechanisms of morphogenesis as tools for bio-inspired design. Filipa Alves (UNIDCOM, IADE, European University) and Eduardo Gonçalves (UNIDCOM, IADE, European University).

**EXTENDED ABSTRACT |** We can observe an extraordinary diversity of forms in the natural world. From nearly regular patterns to complex three-dimensional geometries, these organised spatial structures are not designed following a blueprint. They are shaped by the properties of their materials, by the interactions between their components and by evolution. Biological form and function are intrinsically associated and result from the interaction of different biological mechanisms and physicochemical processes and constraints, together with their interactions with the external environment.

The emergence of spatially organised biological structures can be analysed from different points of view: from the construction of form during embryonic development and growth to the evolutionary origin and diversification of morphologies. Complex spatial and temporal patterns also characterise the collective behaviour of groups of individuals, such as colonies, populations and whole ecosystems. In this project, we draw knowledge and inspiration from the mechanisms that generate form and function in nature, exploring various ways to integrate them into the creative design process.

The first phase of our approach focuses on identifying and describing a key sub-set of these mechanisms and abstracting their fundamental principles:

**1.** Definition of symmetry axes. The regulation of cell division, growth and differentiation can lead to the definition of different types of organ or body symmetry (e.g. spherical, radial, bilateral, helical, scale, fractals)

**2.** Formation of branching structures (symmetrical or non-symmetrical)

**3.** Shape organisation into minimal surfaces. When several pliable structures (e.g. cells, coral polyps) adhere or are subjected to packing, the resulting geometric shapes minimize their surface area and surface tension.

**4.** Active deposition and removal of material, leading to continuous structural remodelling and the formation of porous trabecular structures (e.g. animal bones)

**5.** Surface breakdowns induced by mechanical forces of expansion or shrinkage (cracking)

**6.** Surface instabilities induced by mechanical forces of expansion or shrinkage (wrinkling, buckling, folding, creasing)

**7.** Temporal patterning mechanisms coupled with growth

**8.** Reaction-diffusion mechanisms (interaction of molecules, or other components, that react with each other and diffuse through space, leading to stable patterns like stripes, spots, and spirals).

**9.** Regulatory networks (genetic, metabolic, ionic)

Although biological growth and morphogenesis depend on important properties of living matter that are absent from inert material, such as active responses to stimuli or self-replication, many of the underlying mechanisms can be abstracted and modelled while still maintaining their key dynamical behaviour. Selected mechanisms are computationally described, so that variant forms can be generated by changing the models' parameters. For these cases, we are implementing and testing generative design algorithms, together with finite element methods, to iteratively evaluate and select the best form variants depending on a set of predefined design requirements and constraints.

Some of the described mechanisms can also be abstracted and explored with non-digital approaches, such as physical modeling and prototyping. The process of self-organisation into minimal surfaces, surface breakdowns and surface instabilities are probably the most suitable mechanisms worth exploring with this type of approach.

The described biophysical mechanisms (and their respective digital and analog representations) can behave as complex systems, leading to nonlinear responses to changes in parameter values, and generating functional dynamics and organised form as emergent properties. In contrast to linear parametric methods, our approach can therefore take advantage of the dynamical properties of these systems, such as self-organisation, non-linear behaviour, sensitivity to critical parameters, resilience and robustness to perturbations.

In this way, we expect to expand the conceivable design morpho-space by performing rich and unpredictable explorations of possible design variants that are capable of meeting a predefined set of requirements and constraints. In proof-of-principle applications we will further discuss how form and function may be associated in these emergent morphologies, and highlight the essential creative role of the designer in the process.

**KEYWORDS |** BIODESIGN, PRODUCT DESIGN, COMPLEX SYSTEMS, GENERATIVE DESIGN

## (13) REGENERATIVE PRACTICES APPLIED TO DESIGN FOR HOSPITALITY: sustainable paradigms for future hospitality spaces. Elena M. Elgani (Politecnico di Milano - Department of Design), Umberto Monchiero (Politecnico di Milano - School of Design) and Francesco Scullica (Politecnico di Milano - Department of Design).

**EXTENDED ABSTRACT |** The contemporary tourism industry and the related hospitality system cause significant emissions and have a considerable impact on natural ecosystems (U.N., 2023); however, after the COVID-19 pandemic, new paradigms for sustainable re development of tourism are arising through the redefinition of the role of Design in the complex system of spaces-products and services for hospitality. In particular, the overcoming of a detrimental extractivist approach and the development of regenerative methodologies and strategies to the design and fruition of hospitality spaces can help restore biodiversity and repair damage in complex ecosystems caused by human actions: in this way, the tourism initiatives can not only achieve a zero impact on the territory and local communities, but can also be 'net positive' by creating places with renewed biodiversity and suitable for multi-species coexistence.

It is of specific interest the practical application of these new regenerative methodologies in support of territories in which the effects of environmental and social challenges are tangible: for instance, on the Italian sides of the Alps, in practice, one can observe both an ever-increasing depopulation of inhabited centers and, in some localities, an ever-expanding flow of visitors due to new urbanisations directly linked to over-tourism phenomena (Degani, 2015).

This paper will therefore, through a preliminary desk-research, define theoretically new design-oriented frameworks of regenerative hospitality, while at a second stage it will demonstrate their applicability through the analysis of case studies. Additionally, the regenerative strategies applied to design for hospitality will be analysed by presenting the reactivation projects of spaces for hospitality that have long been awaiting repurposing, such as the Hotel Savoia in San Martino di Castrozza (autonomous province of Trento, Italy) or the former Convent of San Lorenzo in Sondrio (Lombardy, Italy); these teaching projects, whose concepts were developed with students of the Interior Design Bachelor's Degree at (authors' affiliation), aim to prototype innovative systems of spaces and hospitality experiences in order to actively support the Alpine ecosystem.

Through the definition of new design paradigms and the analysis of case studies, the objective of this research therefore is to outline ways of

sustainable development for the tourism industry, with particular attention to design for hospitality, which is able to renew itself through the spaces-products-services of hospitality in a manner that is both innovative and regenerative, respectful of the local natural and built environment but also able to engage the communities that live in it to define new sustainable scenarios for future generations.

**KEYWORDS |** REGENERATIVE SPACES, DESIGN FOR HOSPITALITY, SUSTAINABLE TOURISM, ALPINE ECOSYSTEM, INTERIOR DESIGN.

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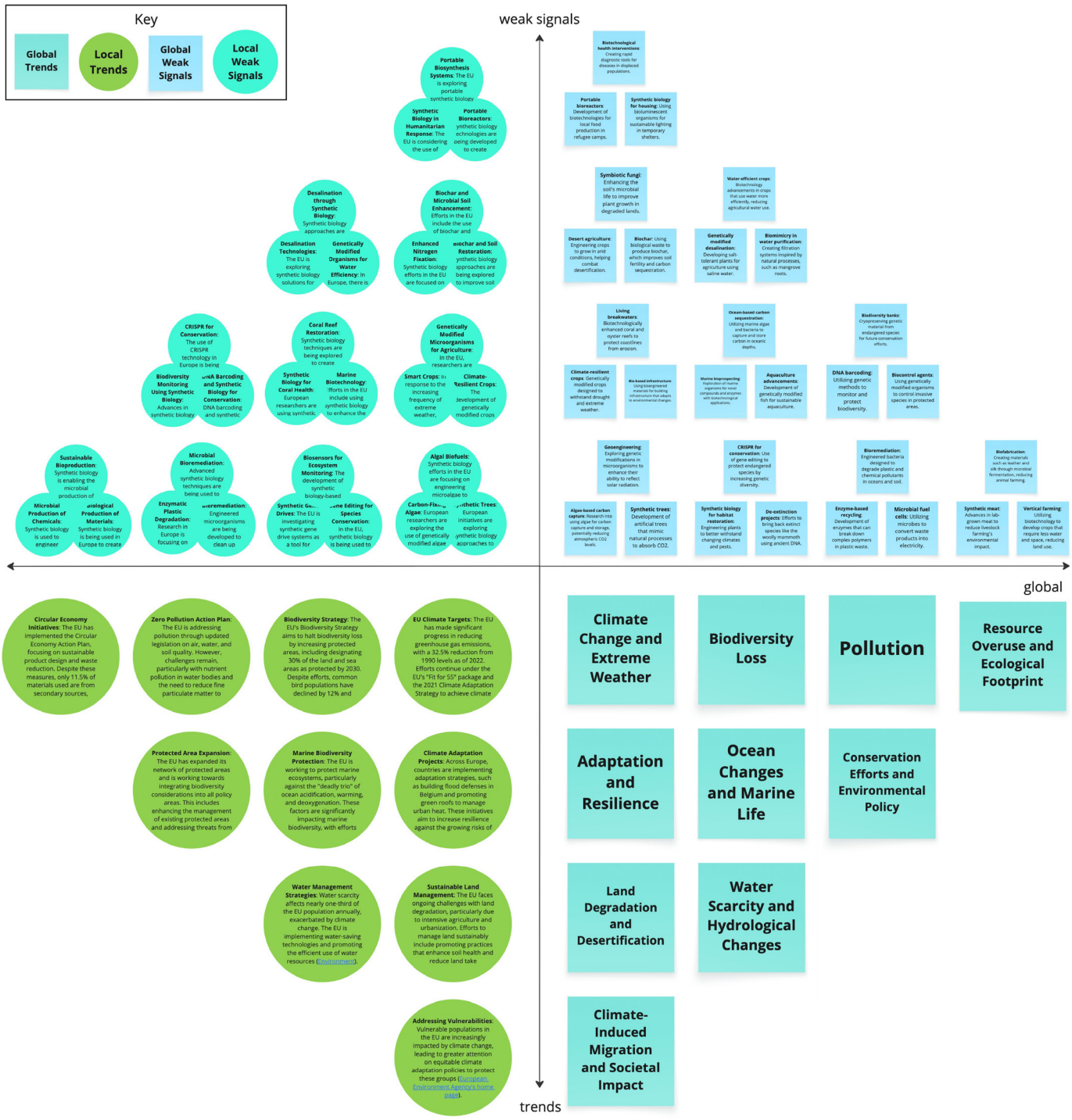
# CHAPTER 03 - SPECULATIVE BIOFUTURES

## (43) Biofutures in Flux: Navigating the Intersection of Biotechology and Society. Trisha Mehta (Royal College of Art) and Taline Frantz (Independent Researcher and Designer).

**ABSTRACT |** Biofutures in Flux delves into the speculative futures that lie at the crossroads of biotechnological innovation and shifting societal values. This study takes its cue from the cloning of Dolly the sheep in 1996, a pivotal event that not only redefined the possibilities of life sciences but also ignited a cascade of ethical debates still resonating today. As biotechnology continues to push the boundaries of what it means to be human, this research examines how these advancements might shape our collective future—for better or worse.

To chart these potential futures, the study employs a combination of future studies methodologies. Horizon scanning identifies the global trends that are steering both biotechnology and society, offering a broad contextual framework for what lies ahead (Voros, 2003). Building on this, weak signal mapping detects the early, often overlooked indicators of emerging shifts that could disrupt current trajectories, hinting at futures still on the fringes of our imagination (Ansoff, 1975). To inform the following preliminary scenarios, global and local (to the EU) drivers and trends were mapped, as per the illustration below.


Key
Global Trends
Local Trends
Global Weak Signals
Local Weak Signals
weak signals
global
trends
Portable Biosynthesis Systems: The EU is exploring portable synthetic biology
Synthetic Biology in Humanitarian Response: The EU is considering the use of
Portable Bioreactors: ynthetic biology echnologies are eing developed to create
Desalination through Synthetic Biology: Synthetic biology approaches are
Desalination Technologies: The EU is exploring synthetic biology solutions for
Genetically Modified Organisms for Water Efficiency: In Europe, there is
Biochar and Microbial Soil Enhancement: Efforts in the EU include the use of biochar and
Enhanced Nitrogen Fixation: Synthetic biology efforts in the EU are focused on
iochar and Soil Restoration: ynthetic biology approaches are being explored to improve soil
CRISPR for Conservation: The use of CRISPR technology in Europe is being
Biodiversity Monitoring Using Synthetic Biology: Advances in synthetic biology
vrNA Barcoding and Synthetic Biology for Conservation: DNA barcoding and synthetic
Coral Reef Restoration: Synthetic biology techniques are being explored to create
Synthetic Biology for Coral Health: European researchers are using synthetic
Marine Biotechnology: fforts in the EU include using synthetic biology to enhance the
Genetically Modified Microorganisms for Agriculture: In the EU, researchers are
Smart Crops: n response to the increasing frequency of extreme weather,
Climate-Resilient Crops: The levelopment of genetically modified crops
Sustainable Bioproduction: Synthetic biology is enabling the microbial production of
Microbial Production of Chemicals: Synthetic biology is used to engineer
iological Production of Materials: Synthetic biology is being used in Europe to create
Microbial Bioremediation: Advanced synthetic biology techniques are being used to
Enzymatic Plastic Degradation: Research in Europe is focusing on
ioremediation: Engineered microorganisms are being developed to clean up
Biosensors for Ecosystem Monitoring: The development of synthetic biology-based
Synthetic Ge… Drives: The EU is investigating synthetic gene drive systems as a tool for
…ne Editing for Species Conservation: In the EU, synthetic biology is being used to
Algal Biofuels: Synthetic biology efforts in the EU are focusing on engineering microalgae to
Carbon-Fix… Algae: European researchers are exploring the use of genetically modified algae
…ynthetic Trees: European initiatives are exploring synthetic biology approaches to
Biotechnological health interventions: Creating rapid diagnostic tools for diseases in displaced populations.
Portable bioreactors: Development of biotechnologies for local food production in refugee camps.
Synthetic biology for housing: Using bioluminescent organisms for sustainable lighting in temporary shelters.
Symbiotic fungi: Enhancing the soil's microbial life to improve plant growth in degraded lands.
Water-efficient crops: Biotechnology advancements in crops that use water more efficiently, reducing agricultural water use.
Desert agriculture: Engineering crops to grow in arid conditions, helping combat desertification.
Biochar: Using biological waste to produce biochar, which improves soil fertility and carbon sequestration.
Genetically modified desalination: Developing salt-tolerant plants for agriculture using saline water.
Biomimicry in water purification: Creating filtration systems inspired by natural processes, such as mangrove roots.
Living breakwaters: Biotechnologically enhanced coral and oyster reefs to protect coastlines from erosion.
Ocean-based carbon sequestration: Utilizing marine algae and bacteria to capture and store carbon in oceanic depths.
Biodiversity banks: Cryopreserving genetic material from endangered species for future conservation efforts.
Climate-resilient crops: Genetically modified crops designed to withstand drought and extreme weather.
Bio-based infrastructure: Using bioengineered materials for building infrastructure that adapts to environmental changes.
Marine bioprospecting: Exploration of marine organisms for novel compounds and enzymes with biotechnological applications.
Aquaculture advancements: Development of genetically modified fish for sustainable aquaculture.
DNA barcoding: Utilizing genetic methods to monitor and protect biodiversity.
Biocontrol agents: Using genetically modified organisms to control invasive species in protected areas.
Geoengineering: Exploring genetic modifications in microorganisms to enhance their ability to reflect solar radiation.
CRISPR for conservation: Use of gene editing to protect endangered species by increasing genetic diversity.
Bioremediation: Engineered bacteria designed to degrade plastic and chemical pollutants in oceans and soil.
Biofabrication: Creating materials such as leather and silk through microbial fermentation, reducing animal farming.
Algae-based carbon capture: Research into using algae for carbon capture and storage, potentially reducing atmospheric CO2 levels.
Synthetic trees: Development of artificial trees that mimic natural processes to absorb CO2.
Synthetic biology for habitat restoration: Engineering plants to better withstand changing climates and pests.
De-extinction projects: Efforts to bring back extinct species like the woolly mammoth using ancient DNA.
Enzyme-based recycling: Development of enzymes that can break down complex polymers in plastic waste.
Microbial fuel cells: Utilizing microbes to convert waste products into electricity.
Synthetic meat: Advances in lab-grown meat to reduce livestock farming's environmental impact.
Vertical farming: Utilizing biotechnology to develop crops that require less water and space, reducing land use.
Circular Economy Initiatives: The EU has implemented the Circular Economy Action Plan, focusing on sustainable product design and waste reduction. Despite these measures, only 11.5% of materials used are from secondary sources,
Zero Pollution Action Plan: The EU is addressing pollution through updated legislation on air, water, and soil quality. However, challenges remain, particularly with nutrient pollution in water bodies and the need to reduce fine particulate matter to
Biodiversity Strategy: The EU's Biodiversity Strategy aims to halt biodiversity loss by increasing protected areas, including designating 30% of the land and sea areas as protected by 2030. Despite efforts, common bird populations have declined by 12% and
EU Climate Targets: The EU has made significant progress in reducing greenhouse gas emissions, with a 32.5% reduction from 1990 levels as of 2022. Efforts continue under the EU's "Fit for 55" package and the 2021 Climate Adaptation Strategy to achieve climate
Protected Area Expansion: The EU has expanded its network of protected areas and is working towards integrating biodiversity considerations into all policy areas. This includes enhancing the management of existing protected areas and addressing threats from
Marine Biodiversity Protection: The EU is working to protect marine ecosystems, particularly against the "deadly trio" of ocean acidification, warming, and deoxygenation. These factors are significantly impacting marine biodiversity, with efforts
Climate Adaptation Projects: Across Europe, countries are implementing adaptation strategies, such as building flood defenses in Belgium and promoting green roofs to manage urban heat. These initiatives aim to increase resilience against the growing risks of
Water Management Strategies: Water scarcity affects nearly one-third of the EU population annually, exacerbated by climate change. The EU is implementing water-saving technologies and promoting the efficient use of water resources (Environment).
Sustainable Land Management: The EU faces ongoing challenges with land degradation, particularly due to intensive agriculture and urbanization. Efforts to manage land sustainably include promoting practices that enhance soil health and reduce land take
Addressing Vulnerabilities: Vulnerable populations in the EU are increasingly impacted by climate change, leading to greater attention on equitable climate adaptation policies to protect these groups (European Environment Agency's home page).
Climate Change and Extreme Weather
Biodiversity Loss
Pollution
Resource Overuse and Ecological Footprint
Adaptation and Resilience
Ocean Changes and Marine Life
Conservation Efforts and Environmental Policy
Land Degradation and Desertification
Water Scarcity and Hydrological Changes
Climate-Induced Migration and Societal Impact

From this foundation, the research constructs a 2x2 matrix that serves as the scaffolding for four distinct scenarios. These scenarios do not aim to be predictions but provocations, designed to challenge our assumptions and spark critical reflection (Schwartz, 1991):

**1.** Technological Renaissance: In this future, biotechnology is harnessed to drive positive change, with society focusing on improving human and planetary conditions. Here, innovations address global challenges like climate change and health disparities, leading to a world that is both harmonious and sustainable.
**2.** Consumerist Utopia: A world where biotechnology radically transforms ways of living, yet society remains fixated on consumer culture. The result is a landscape of luxury and convenience, but one where environmental degradation and social inequality are the prices paid for unchecked technological progress.
**3.** Dystopian Retreat: Biotechnology succeeds in driving positive change, but societal focus remains on consumerism. This creates a fragmented world where the benefits of biotech are unevenly distributed, exacerbating inequalities and pushing the environment to the brink of collapse.
**4.** Radical Reformation: A future where biotechnology not only transforms ways of living but also reshapes human identity and our relationship with nature. This scenario envisions profound shifts in societal values, presenting both opportunities and challenges for maintaining social cohesion in a world where the old rules no longer apply.

To make these futures tangible, the study leverages Speculative Design, bringing each scenario to life through provocative visual and conceptual representations (Dunne & Raby, 2013). These designs are tools for reflection, making the abstract concrete and challenging stakeholders to confront the implications of our current trajectory.

The study's implications are clear: the future is not a predetermined path but a landscape we shape with every decision. Biofutures in Flux calls on policymakers, scientists, designers, and the public to actively engage in this discourse, stressing that the choices we make today will reverberate for decades. Ultimately, the report advocates for a future where technological innovation is balanced with societal well-being, ensuring that the promises of biotechnology contribute to a more equitable and sustainable world rather than deepening divides or creating new ethical dilemmas.

**KEYWORDS |** BIOTECHNOLOGY, SPECULATIVE FUTURES, ETHICAL IMPLICATIONS, BIOTECHNOLOGICAL IMPACT, SPECULATIVE DESIGN

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# CHAPTER 04 - NATURE-BASED SOLUTIONS

## (64) A comparative analysis of ecocentric design approaches: Nature based solutions, biomimicry and ecodesign. Gabriela Madureira (University of Aveiro), Sérgio Tavares (University of Aveiro), Sílvia Soares (University of Aveiro) and João Dias-de-Oliveira (University of Aveiro).

**EXTENDED ABSTRACT |** Challenges in climate change mitigation and adaptation reveal the limitations of existing sustainable design approaches. Researchers advocate shifting from “Anthropocene” to “Ecocentric” design principles. Nature-Based Solutions (NbS), biomimicry, and ecodesign each offer unique, complementary methods for creating sustainable systems, products, and infrastructures. Defining these approaches, categorizing their applications, and exploring their potential synergies is crucial. This extended abstract presents a dissection to identify three ecocentric design approaches and develop a database to support designers in selecting and building adapted mixed methods for sustainability to their professional needs. To structure this research, the following questions were addressed: 1) What fundamental principles define NbS, biomimicry, and ecodesign, and how do these principles shape their design approaches? 2) How do their methodologies, practical applications, and results address environmental and societal challenges? 3) What potential synergies and integration points exist among those three approaches? The review involved searching electronic databases (Scopus, Wiley) for relevant studies, applying criteria focused on sustainability-oriented design aspects, and selecting 42 key documents from an initial pool of 521. The information was then analysed, categorized by definition, methodology, application, and sustainability, and recorded in a digital database.

The findings indicate that, despite differing scales of action, as seen in Error! Reference source not found., these design approaches share a common goal of fostering sustainable human-built environments and can be complementary. Both ecodesign and biomimicry focus on integrating environmental aspects into the design process, but with different objectives: ecodesign aims to minimize environmental impacts, while biomimicry challenges designers to create products that benefit the environment (Speck et al., 2017; Spreafico & Landi, 2022).

Ecodesign, shaped by academia and industry, uses well-established, quantitative sustainability tools, reducing the risk of adverse impacts. In contrast, biomimicry, a newer practice-driven strategy, lacks such tools, increasing potential unintended impacts (Aamer et al., 2020; De Pauw et al., 2014; Hoyos & Fiorentino, 2016). Nonetheless, despite their differing scales, ecodesign’s assessment tools could provide a foundation for evaluating biomimicry’s sustainability.

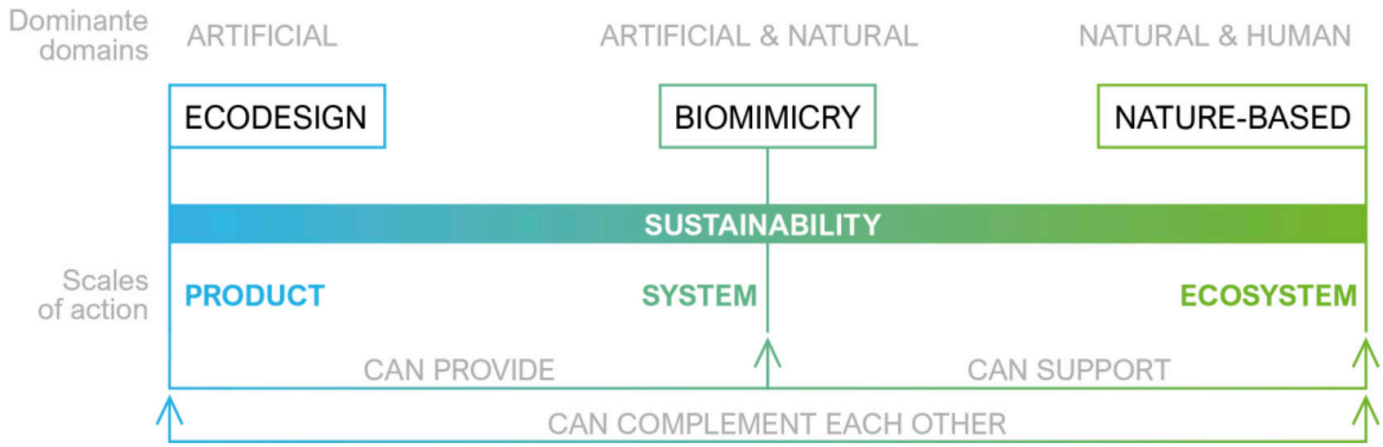


Figure 1. Graphical results

Biomimicry can further support NbS through tools such as the Life Principles, a bio-inspired design framework that proposes overarching natural principles to guide and evaluate the design process (Bianciardi et al., 2023). These principles have been utilized to abstract guidelines for improving the NbS project cycle, with specific NbS guiding principles identified for each Life Principle. The sharing of biological strategies, tools, multidisciplinary knowledge and transdisciplinary collaboration is vital for the successful implementation, design, and evaluation of NbS, providing a bio-inspired foundation from learning from nature that can strengthen the development of NbS frameworks (Butt & Dimitrijević, 2022).

Finally, NbS and ecodesign can complement each other in the creation of products and systems that support ecosystem services, thereby adding a holistic dimension to ecodesign. This integration not only benefits the industry but also promotes environmental sustainability. NbS are meant to be an alternative to technological solutions, however, a balanced approach that includes both nature based and technological solutions is necessary to address current complex challenges. Ecodesign within circular economy strategies is a particularly effective framework for NbS to build upon, where the reuse and recycling of materials, coupled with reduced energy demand and associated CO2 emissions, are prioritized (Seddon et al., 2021).

The comparative analysis highlights that NbS, biomimicry, and ecodesign each bring unique strengths to sustainability efforts. NbS tackles large-scale environmental challenges with direct ecological benefits (Linder & Huang, 2022), biomimicry provides innovative nature-inspired solutions but requires extensive research (2022), and ecodesign focuses on minimizing environmental impacts throughout the product lifecycle integrating also social metrics to support its decision-making process (Campos-Carriedo et al., 2024). These approaches can be synergistic: integrating NbS with biomimicry can enhance urban resilience while combining ecodesign with NbS can improve product sustainability through ecosystem services, integrating ecodesign in all three dimensions of product, nature and social aspects. Applying biomimetic principles within ecodesign can also lead to more sustainable products. Future research should develop frameworks to integrate these strategies and evaluate their real-world effectiveness, promoting more sustainable design practices.

**KEYWORDS |** NATURE-BASED SOLUTIONS, BIOMIMICRY, ECODESIGN, SUSTAINABLE DESIGN

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## (30) Mindfulness Parks: Designing Urban Green Spaces for Pro-Environmental Behavior Change. Uglješa Stankov (Univeristy of Novi Sad, Faculty of Sciences, Department of Geography, Tourism and Hotel Management) and Miroslav D. Vujičić (Univeristy of Novi Sad, Faculty of Sciences, Department of Geography, Tourism and Hotel Management).

**EXTENDED ABSTRACT |** The term "mindful" is increasingly used to describe the practice of focusing one's awareness on the present moment, particularly in therapeutic medicine or meditation (Stankov et al., 2022). A mindful person becomes more attuned to their inner self, recognizing their thoughts, feelings, bodily sensations, and the environment around them in real-time. Various mindfulness-based psychotherapy methods encourage integrating mindfulness into daily activities, such as walking or eating. In these practices, individuals concentrate on specific aspects, like their breath or bodily sensations, for a designated period to cultivate a state of "everyday mindfulness" (Thompson & Waltz, 2007).

Some environments are more conducive to cultivating mindfulness than others (Porter et al., 2017). The influence of natural settings on mindfulness is particularly well-documented and supported by research. According to Chen and colleagues (Chen et al., 2017), mindful awareness often emerges from unexpected encounters with visually pleasing stimuli, especially in natural settings. Being immersed in nature facilitates a state of mindfulness (Barbaro & Pickett, 2016). At the same time, mindfulness can alter individuals' perceptions of nature. This seems to be a universal experience, shared by most people regardless of their cultural background or whether they practice meditation (Van Gordon et al., 2018).

Today's environmental pressures create the need for the adoption of new coping strategies, tactics, and mitigation approaches (Vujičić et al., 2022). This includes individual transformation as an agent of sustainability, with mindfulness playing a significant role in achieving these goals (Lengyel, 2015; Seeler et al., 2021). In this context, the need for pro-environmental attitudes and behaviors is viewed as a potential driver for the acceptance and promotion of mindfulness (Panno et al., 2018). Research suggests that mindfulness can help individuals cultivate non materialistic values, enhance their well-being, and engage in pro-social behaviors (Fischer et al., 2017; Stankov & Filimonau, 2021).

Often included under the umbrella of societal well-being, the concept of mindfulness is starting to be promoted in official development policies and plans (Crane, 2017; Stankov et al., 2022). This promotion may aim to reduce stress and healthcare costs or to invest in mindfulness-themed public spaces, such as mindfulness parks and trails. One recent example is the mindfulness trail in the park of Munsbach Castle in Luxembourg. A mindfulness trail was established in the park, featuring nine stations that invite visitors to experience moments of mindfulness along the way. The aim is to assist children and adolescents with unique socio-emotional needs. However, institutional

recognition is still in its infancy within public policies, and most initiatives remain local and, thus, isolated (for example, mindfulness audio trail in Valley Country Park and Forest in Ringwood, UK) (Stankov et al., 2022). Therefore, this presentation aims to begin the conceptualization of "mindfulness parks" as public spaces that showcase emerging mindfulness practices and leverage their potential to promote pro environmental behavior change. To support its arguments, this presentation draws upon both academic and grey literature related to the emerging intersection of mindfulness and sustainability issues.

**KEYWORDS |** MINDFULNESS, PARKS, GREEN URBAN SPACES, PRO ENVIRONMENTAL BEHAVIOR CHANGE, NATURE BASED SOLUTION

Acknowledgement:

This paper is based upon work from HORIZON TMA MSCA Staff Exchanges: ClearClimate (grant agreement No 101131220) and H2020-LC-GD-2020-3 GreenScent-Smart Citizen Education for a Green Future (grant agreement No 101036480) that have received funding from the European Union's Horizon 2020 research and innovation programme

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# (56) Biodesign and Resilience: Rebuilding Post-Conflict and Climate-Affected Communities for a Healthy and Livable Future. Taline Frantz (Independent Researcher & Designer).

**KEYWORDS |** BIODESIGN, CLIMATE CHANGE, CONFLICT, RESILIENCE, CIRCULAR DEVELOPMENT, RECONSTRUCTION

## Introduction

Biodesign offers a profound recalibration of how we rebuild communities fractured by the twin crises of conflict and climate collapse. It is no longer enough to patch over the ruins; instead, we must rethink infrastructure as something that regenerates ecosystems and strengthens social fabrics. This paper examines the convergence of nature-based solutions (NbS) and regenerative design strategies as frameworks to not only recover what has been lost but to create structures and systems that evolve in sync with the natural world. Drawing on Dhyani et al. (2020), NbS—from wetland restoration to urban greening—embody the potential to absorb environmental shocks while restoring ecosystems that are themselves under siege from climate volatility.

## Problem Statement

In places like Aleppo, Syria, war-torn landscapes demand more than just rebuilding—they require a restorative process that marries urban renewal with ecological regeneration. The case study of Aleppo demonstrates how green infrastructure—permeable pavements, green roofs—was used to heal cultural scars and prepare the city for future climate extremes. Here, design moves away from mere functionality toward bioremediation, using materials like mycelium to repair polluted soils and sequester carbon, as evidenced in Saez and Bryant's (2023) critique of short-termism in post-conflict reconstruction. The lesson is clear: infrastructure must grow, not just rebuild.

## Methodology

Central to this regenerative ethos is the participatory process, a practice that shifts power back to the communities at the heart of recovery. Sushchenko and Schwarze (2023) stress the importance of stakeholder mapping, where local voices take precedence in shaping the infrastructures they will live in. Co-design workshops and biomaking spaces engage communities not as passive recipients but as co-creators of solutions tailored to their environments and identities, ensuring projects are grounded in cultural relevance and long-term resilience.

## Obstacles and Solutions

By intertwining biodesign with nature-based solutions, this paper envisions a reconstruction model that is inherently regenerative—one that addresses not only the immediate survival of communities but their ongoing symbiosis with the ecosystems that sustain them. However, as noted by Henderson (2024),

political and logistical challenges—particularly in regions like Gaza, where blockades limit access to resources—can hinder the implementation of renewable energy and biodesign projects. The solution lies in integrating local knowledge and co-creation processes, ensuring that recovery projects align with both environmental needs and community resilience.

## Conclusion/Visions for the Future

As the discussions at COP28 highlight, the future of recovery lies in biodesign's capacity to transcend crisis-driven responses and embrace the potential for ecological and social resilience. This approach offers a blueprint for a future where human settlements and natural systems grow together, continuously regenerating and evolving in response to the threats of both war and environmental collapse.

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## (63) Bridging Knowledge Gaps: A Participatory-Based Permaculture Toolkit for India's Marginal Farmers. Agnivesh Sharma (Indian Institute of Technology Bombay, India), Sugandh Malhotra (Indian Institute of Technology Bombay, India) and Vivek Kant (Indian Institute of Technology Kanpur, India).

### Extended Abstract

### Introduction

Permaculture offers a beacon of hope in tackling the pressing issues of climate change, dwindling resources, and food insecurity, especially for India's marginal farmers, who make up over 80% of the country's agricultural workforce (Ministry of Agriculture & Farmers Welfare, 2020). Despite its potential, many farmers struggle to adopt permaculture practices due to a significant gap in knowledge (Altieri, 2002; Shiva, 1991). This research seeks to close that gap by developing a participatory permaculture toolkit, specifically tailored to meet the needs of these farmers.

### Methodology

We adopted a participatory design approach, inviting the farmers themselves to play a central role in creating the toolkit (Sanders & Stappers, 2012). By involving them directly, we ensured that the toolkit would reflect their real-world experiences and challenges. We gathered insights through structured interviews, interactive workshops, and hands-on sessions, which helped us, understand the unique difficulties and preferences of these farmers.

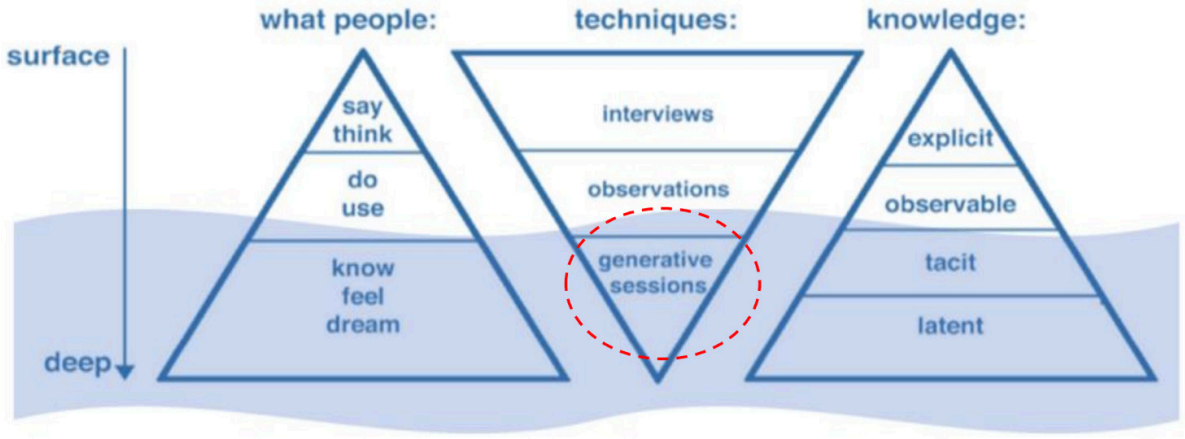


FIGURE 1, ILLUSTRATION SHOWING HOW METHODS THAT STUDY WHAT PEOPLE SAY, DO, AND MAKE HELP ACCESS DIFFERENT LEVELS OF KNOWLEDGE. (SOURCE: CONVIVIAL TOOLBOX: GENERATIVE RESEARCH FOR THE FRONT END OF DESIGN.)



FIGURE 2, LEARNING PERMACULTURE WITH EXPERTS ON FIELD.

**Modeling and Intermediate Results**

The journey began with a deep dive into the existing knowledge and perceptions of permaculture among marginal farmers. Unsurprisingly, we found a significant gap, especially in understanding and applying permaculture principles (Author, 2023). To tackle this, we collaborated with the farmers to co-create a toolkit that included visual guides, interactive modules, and content in their local languages. A key feature of this toolkit is the “Know Your Farm” sensitization kit, designed to help farmers sensitize with their current practices and identify areas where they can improve. Through participatory workshops, we fostered a community-based learning environment, empowering farmers to take ownership of their farm designs.

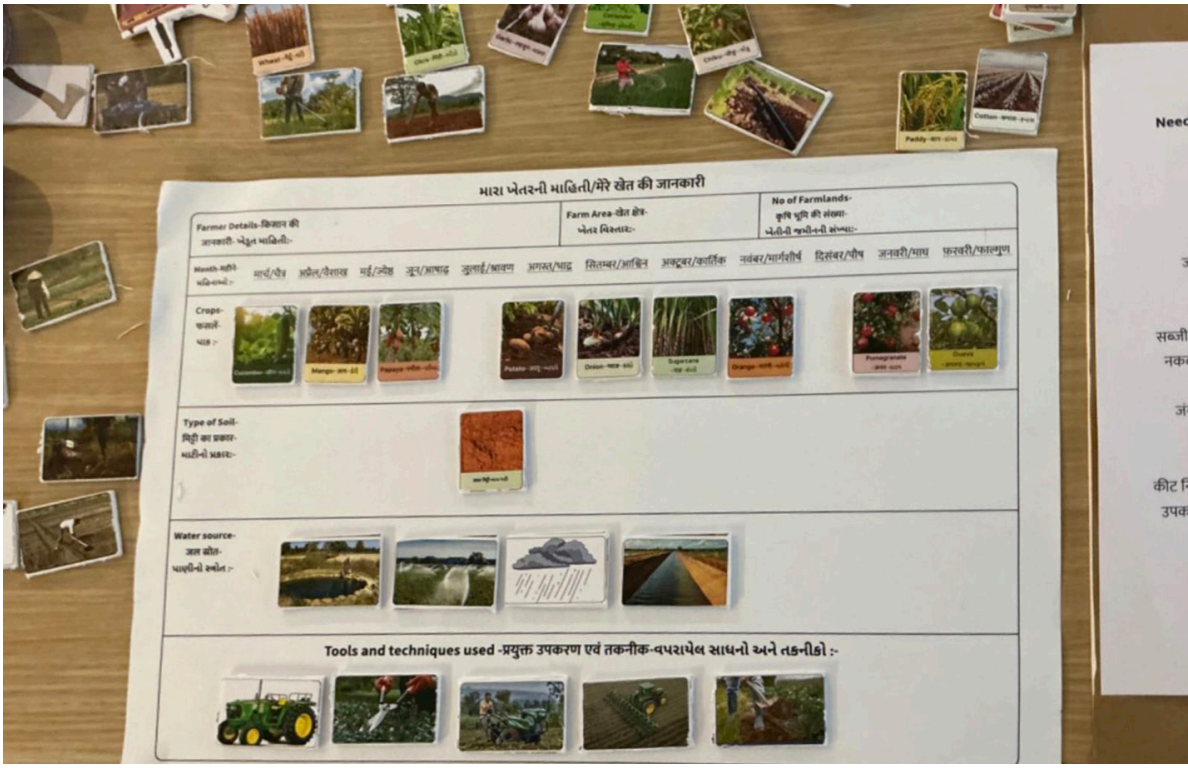


FIGURE 3, SENSITIZATION KIT FOR FARMERS “KNOW YOUR FARM” IN THEIR LOCAL LANGUAGE.



FIGURE 4 PARTICIPATORY WORKSHOP WITH FARMERS USING TOOLKIT.



FIGURE 5, PARTICIPATORY BASED PERMACULTURE TOOLKIT TO DESIGN THE FARM COLLABORATIVELY.



FIGURE 6, TESTING AND ANALYZING THE FARM DESIGN BY THE FARMERS USING TOOLKIT.

## Pains and Gains

As with any new initiative, the project faced its share of challenges. Some farmers were resistant to change, and there were hurdles in accessing resources. But, by making the farmers active participants in the design process, we were able to ease these concerns, leading to a greater willingness to embrace new practices. On the positive side, the farmers who took part in the workshops showed a marked improvement in their understanding of sustainable farming. Also, the toolkit helped to strengthen community ties, encouraging knowledge sharing and mutual support among the farmers.

## Obstacles and Overcomes

One of the biggest hurdles was the farmers' deep-rooted reliance on conventional farming methods, which they often saw as simpler and more reliable. To overcome this, we focused on educating them about the long-term benefits of permaculture, supported by pilot projects and success stories from those who had already made the switch. Another challenge was the wide variation in language and literacy levels. To address this, we designed the toolkit with straightforward language, plenty of visual aids, and interactive elements that don't require advanced literacy skills.

## Conclusion and Future Vision

This research highlights the power of participatory tools in helping marginal farmers adopt sustainable permaculture practices. By closing the knowledge gap and promoting a collaborative learning environment, the toolkit provides a scalable and adaptable solution for building resilience in agricultural systems. Moving forward, our focus will be on refining the toolkit based on feedback from ongoing pilot projects and exploring its potential use in different agricultural settings across India.

**KEYWORDS |** Permaculture, Marginal Farmers, Participatory Design, Sustainable Agriculture, Knowledge Gap

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# (53) MUSEU DO FUTURO DAS ALDEIAS DE MONTANHA. Ana Melo (Faculdade de Arquitetura, Universidade de Lisboa) and Marco Neves (Faculdade de Arquitetura, Universidade de Lisboa).

**ABSTRACT |** Museu do Futuro das Aldeias de Montanha (MFAM) is a funded project by Promove - O Futuro do Interior awarded by Fundação La Caixa and Fundação para a Ciência e a Tecnologia. The project is a consortium between Faculdade de Arquitetura, Universidade de Lisboa (FA-UL) and ADIRAM - Associação de Desenvolvimento Integrado das Aldeias de Montanha, FaunaLab (a design studio), Nest (a tourism innovation center) and Wazo Coop (a spanish cooperative). Research activities focus on engaging local communities, addressing digital literacy among the elderly, and developing speculative design proposals for sustainable futures for the territory.

**KEYWORDS |** DESIGN FOR TERRITORIES, INTERACTION DESIGN, DESIGN FOR SOCIAL INNOVATION, COMMUNICATION DESIGN

## INTRODUCTION

A strategic project for sustainable inland territories
Aldeias de Montanha (AM) is a network of 41 depopulated villages in Serra da Estrela, Portugal, managed by ADIRAM. AM promotes regional development through tourism, environmental and cultural preservation, and aims to attract new residents through community activation and providing possibilities for alternative life projects.

MFAM aims to create a hybrid museum combining digital and physical experiences, featuring: 1) a system with Virtual Reality (VR) and Augmented Reality touchpoints to enable sustainable tourism; 2) a blockchain-based repository to preserve local traditions, and 3) a resource directory to foster entrepreneurship and attract residents. Initially piloting in villages Cabeça, Videmonte, and Alvoco das Várzeas, MFAM plans to expand across the network and explore cross-border opportunities.

The research aims to enable accessibility to cultural heritage, create hybrid interactions, and generate future scenarios within territorial contexts. Research activities with master students from FA-UL will focus on i) launching hypotheses about the visibility, accessibility, and expansion of possibilities for interaction between local communities and MFAM, given the difficulty with digital literacy for a large part of the local population; ii) designing speculative sustainable futures framed by the hypothetical medium and long-term implementation in the territory.

The project asserts itself as a strategic design framework project that enables sustainable transition for depopulated inland rural territories like AM and aims to be the starting point for other design initiatives for reinventing ways of living within the territorial system.

**1. Research objectives**

Accessibility and Interaction: explore how local communities experience MFAM, focusing on overcoming digital literacy barriers for the elderly.
Speculative Design: generate future scenarios for AM, considering social, economic, environmental, and cultural dimensions to ensure sustainable and contextually relevant solutions.

**2. Research activities**

Implement user-research methods with local communities;
Map the territorial system and use exploratory methods for design starting points; Organize, code, and analyze data;
Create digital and hybrid design proposals;
Materialize scenarios through visual tools like sketches and storyboards;
Develop prototypes of progressive fidelity.

**3. Roles and tasks**

FA-UL's role involves research through design practices, fostering close collaboration between researchers from <DIV> Design, Interaction and Visualization group and master students with Faunalab. The design studio manages the content production for the project, including photography, video, and VR content (figure 1-4).

The team is also developing the platform's UX/UI (figures 5-9) and setting up the technological infrastructure using ReactJS, Vite, and NodeJS (figure 10). Also, NFTs are being created to preserve local cultural heritage, involving collecting and minting digital content on a blockchain.

ADIRAM manages the project, while Nest and Wazo Coop advise tourism innovation and cross-border replication strategies.









FIGURES 1 TO 4.CONTENT CAPTURING IN AM. SOURCE: ADIRAM / FAUNALAB.

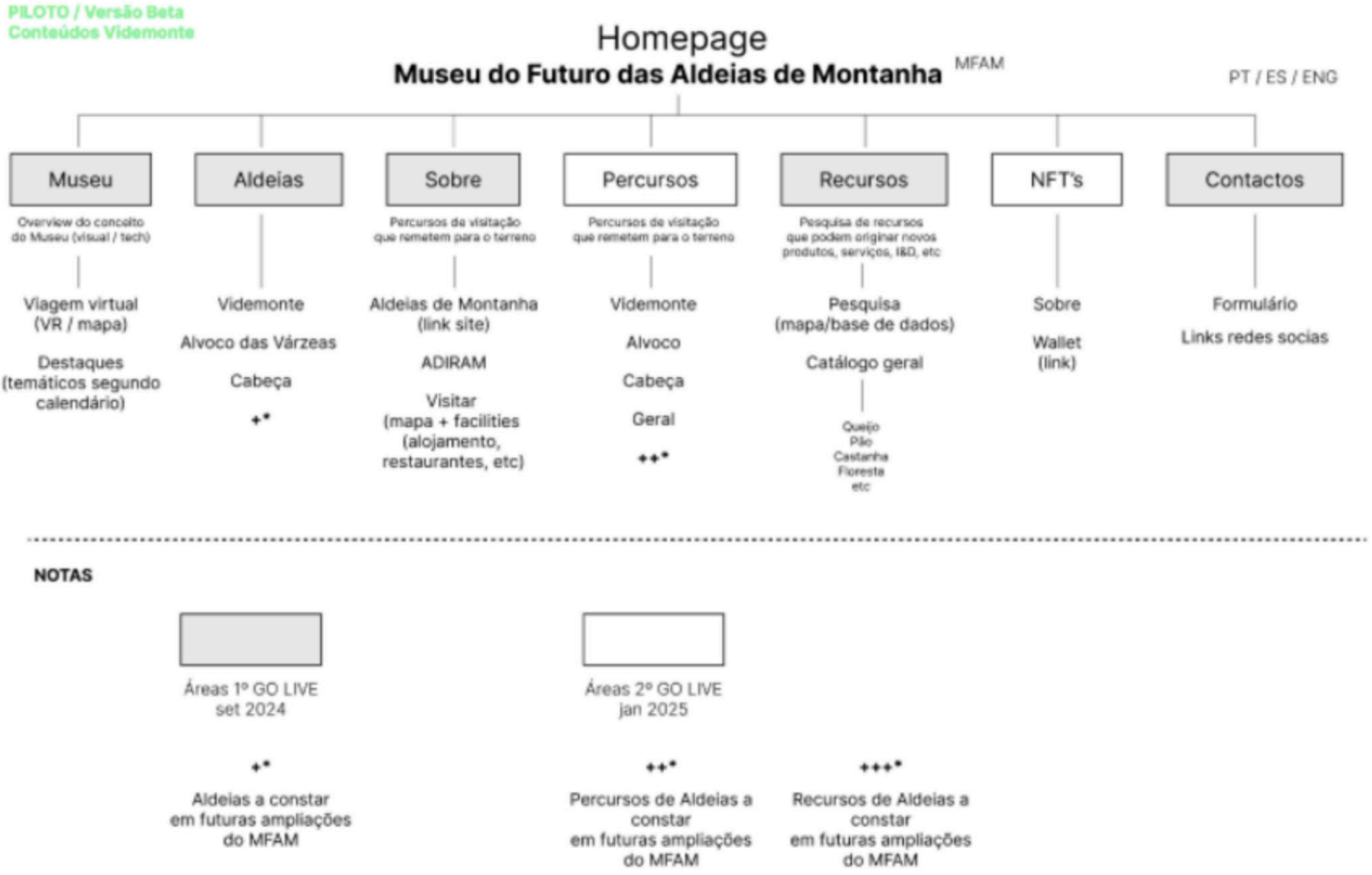


FIGURE 5. INFORMATION ARCHITECTURE. SOURCE: ADIRAM / FAUNALAB.

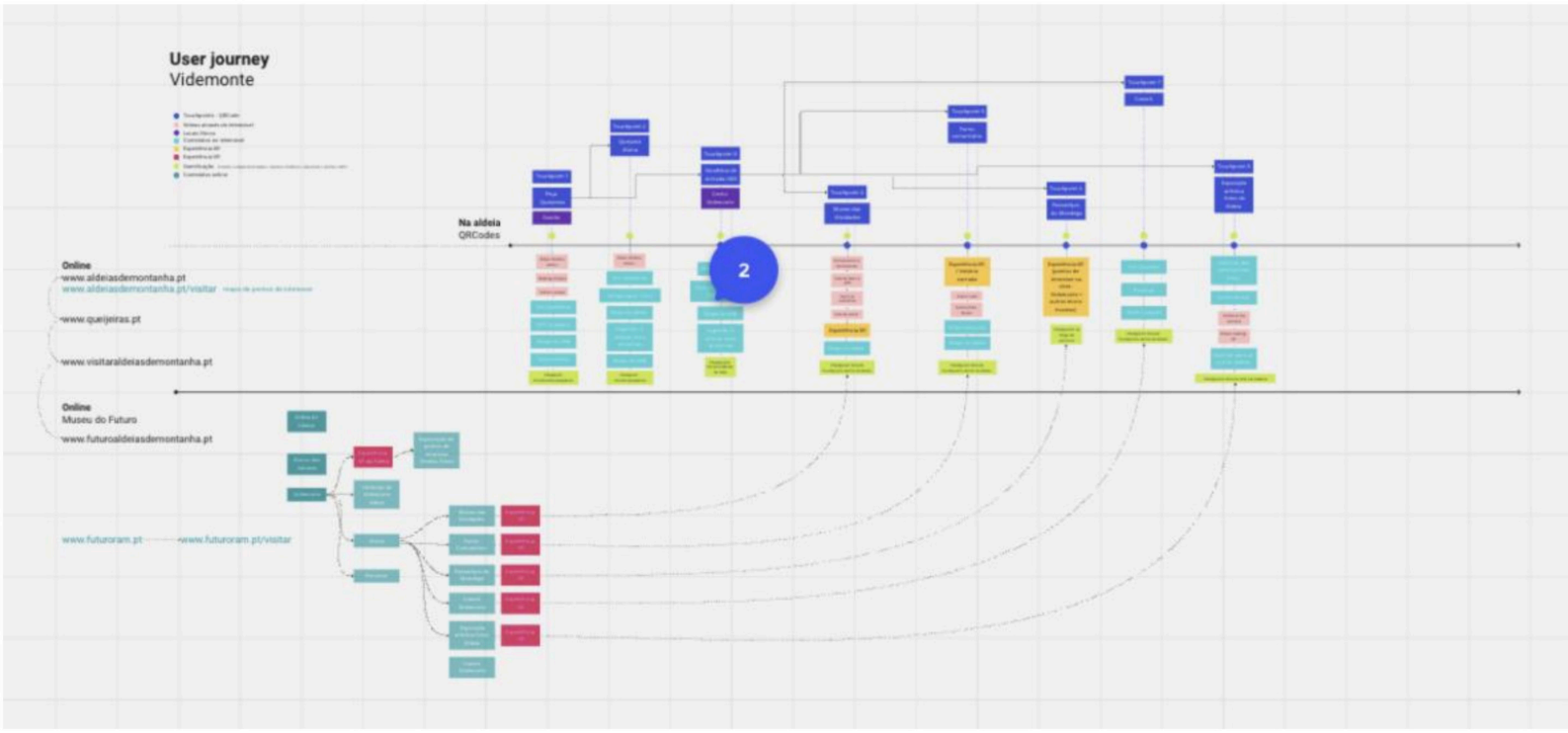


FIGURE 6.USER-JOURNEY MAPPING OF THE HYBRID SYSTEM. SOURCE: ADIRAM/ FAUNALAB.




FIGURE 7.MEDIUM FIDELITY WIREFRAMING. SOURCE: ADIRAM/ FAUNALAB.




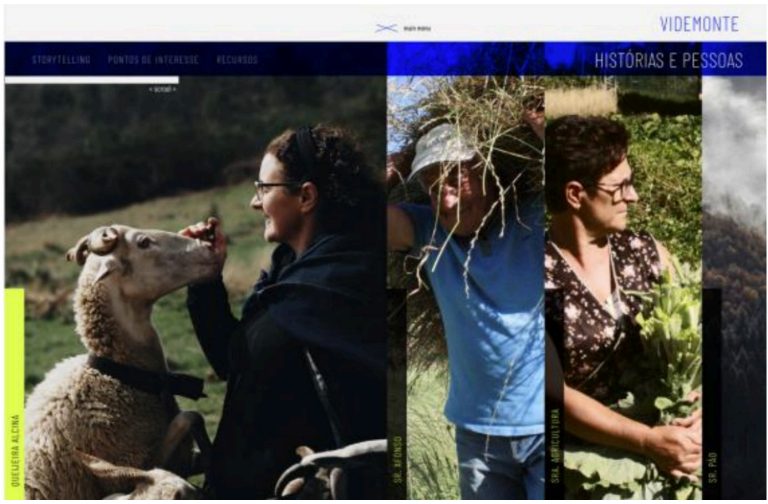


FIGURE 8-9.USER INTERFACE PROTOTYPING. SOURCE: ADIRAM/ FAUNALAB.

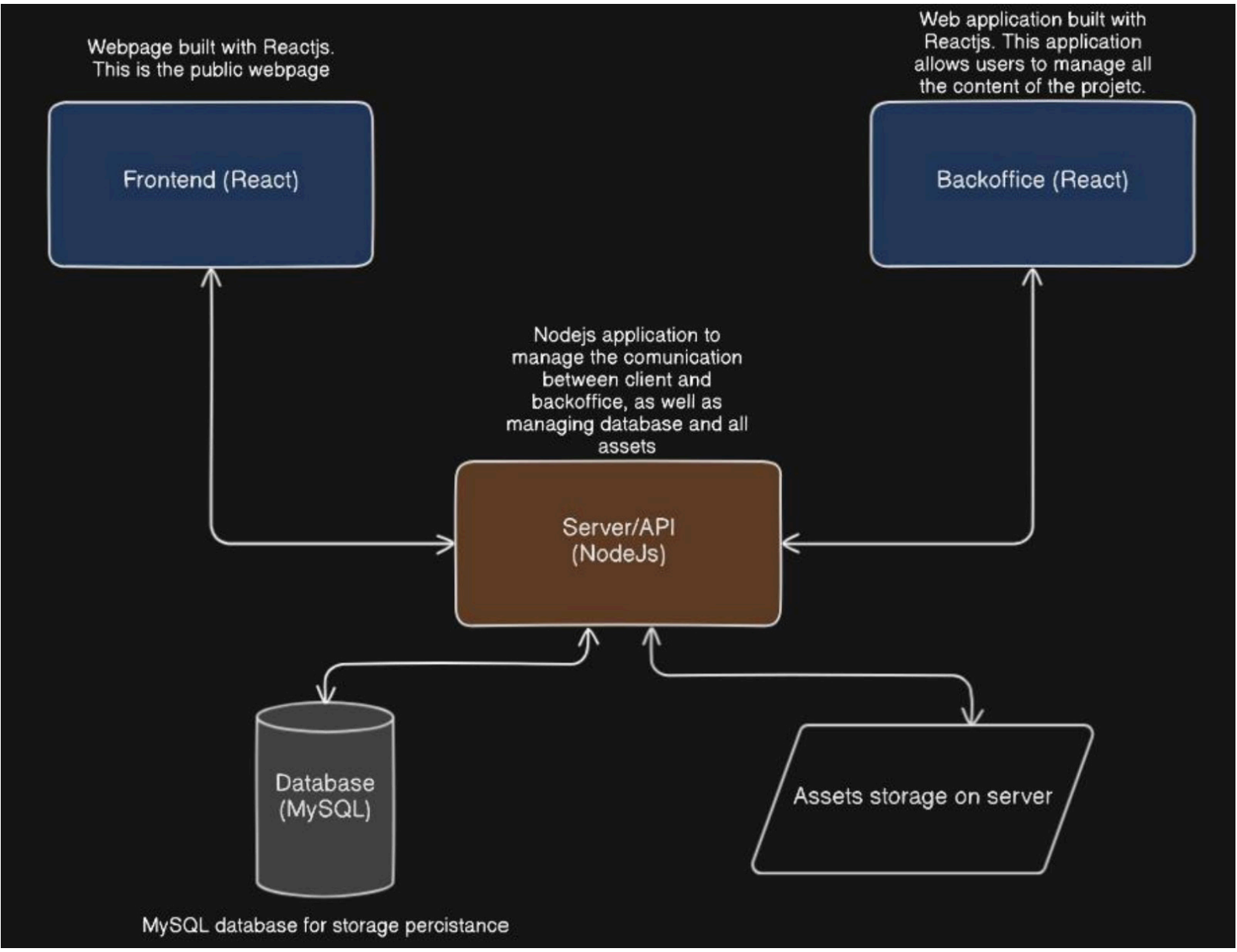


FIGURE 8-9.USER INTERFACE PROTOTYPING. SOURCE: ADIRAM/ FAUNALAB.

## 4. Results and Expected Outcomes

Research aims to improve hybrid interaction models for MFAM, enabling engagement and ownership for local communities. It seeks to generate design solutions that foster future sustainable synergies and enhance the territorial system. Additionally, the project establishes best practices for expanding MFAM to other villages and facilitates cross-border replication.

This work is financed by national funds through FCT - Fundação para a Ciência e a Tecnologia, I.P., under the Strategic Project with the references UIDB/04008/2020 and UIDP/04008/2020.