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WHAT DO YOU WANT (TO BE) YEAST?

EXPLORING EARLY STAGE YEAST-BASED MATERIALS
THROUGH THE LENS OF ARCHITECTURAL MATERIALISMS

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DEPARTMENT OF ARCHITECTURE
AND CIVIL ENGINEERING
M P A R C**

This master thesis project is a part of a contribution to a research project "Resource efficient renovation using a 3D printable material from underutilized biomass" led by prof. Malgorzata Zboinska from the Department of Architecture and Civil Engineering at Chalmers University of Technology, with funding support from Swedish Energy Agency Project ID: P2022-000865.



CHALMERS
UNIVERSITY OF TECHNOLOGY

WHAT DO YOU WANT (TO BE) YEAST?

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In the context of climate change and global warming, the construction sector is among the most polluting industries¹, prompting a critical review of its processes. Although bio-based materials are often proposed as a sustainable alternative, research indicates that their large-scale production can have unintended negative consequences², particularly due to land-use changes that affect natural environments and local communities, escalating social-ecological conflicts³.

One alternative is to reduce the demand for extracted bio-based materials, such as wood, by creating new materials from their by-products, so-called bio-fabricated materials⁴. This thesis investigates the potential of a yeast-based mix, a bio-fabricated material, for architectural applications⁵.

Using architectural materialisms as a holistic framework that integrates community, architectural, and non-

human perspectives, the material is examined through theory-informed design in the robotic laboratory at Chalmers. Additional methods include scientific experimentation, diagramming, material fabrication, 3D scanning, and comparative analysis.

The results highlight the importance of the architect's early involvement in material research, as this enables the adoption of holistic perspectives and ensures a socio-ecological understanding of materials, complementing conventional biological, physical, and chemical performance assessments.

The conclusions are synthesized in a design proposal that demonstrates a potential full-scale (1:1) construction using the material, confirming its capacity to become part of the future construction material palette and to offer sustainable, context-sensitive alternatives to conventional bio-based materials.

Keywords
#bio-fabricated materials
#digital fabrication
#architecture materialisms
#yeast

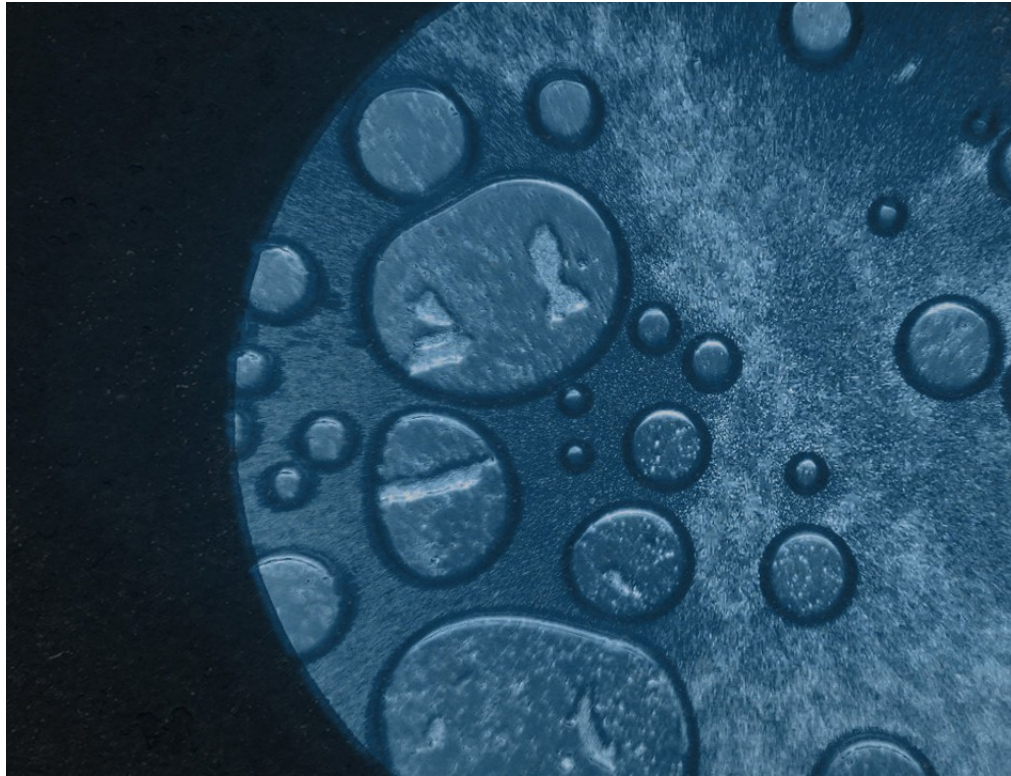
1 In 2022, the sector was responsible for approximately 34% of global energy-related carbon dioxide (CO₂) emissions and 32% of global energy consumption. (UNEP, 2022)

2 "Bio-based materials may exert higher environmental impacts than their conventional counterparts" (Weiss et al., 2012, p. 176)

3 "...plantations are causing a large number of conflicts between companies and local populations" [Gerber, 2011, p. 165]

4 According to Patel et al. (2006, as cited in Weiss et al., 2012), the impacts of land use change can be reduced by producing bio-based materials from crops that provide high yields and useful co-products

5 Based in "Resource efficient renovation using a 3D printable material from underutilized biomass" Research Project, 2022 - 2024, Chalmers.



[Fig. 1]↑
Yeast cell fermentation exhibiting visible CO₂ bubbles under 100× magnification, observed with a SWIFT SW200DL Microscope. Photograph by Constanza Quiroza, 2025..

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To all the friends I have made along this path: infinite thanks for inspiring me and bringing light to the darkest winters.

To my nuclear family, who have supported me vigorously and faithfully. And to the family I have chosen: Juan Pablo, thank you for allowing me to grow in this sea of uncertainty, always anchored by your side.

C U R R I C U L U M V I T A E

CONSTANZA QUIOZA **ANDREA RODRÍGUEZ**



Chilean architect with 10+ years of professional experience, primarily developed within RadarChile, a laboratory of architecture and art dedicated to exploring innovative, social, and ecological design solutions.

Her work spans a wide range of disciplines (just as architecture itself does) integrating community participation, urban interventions, educational infrastructure, and housing. Through a collaborative and experimental approach, she has engaged in projects that bridge academic research with real-world applications, ensuring that her production in architecture remains responsive to societal and environmental challenges.

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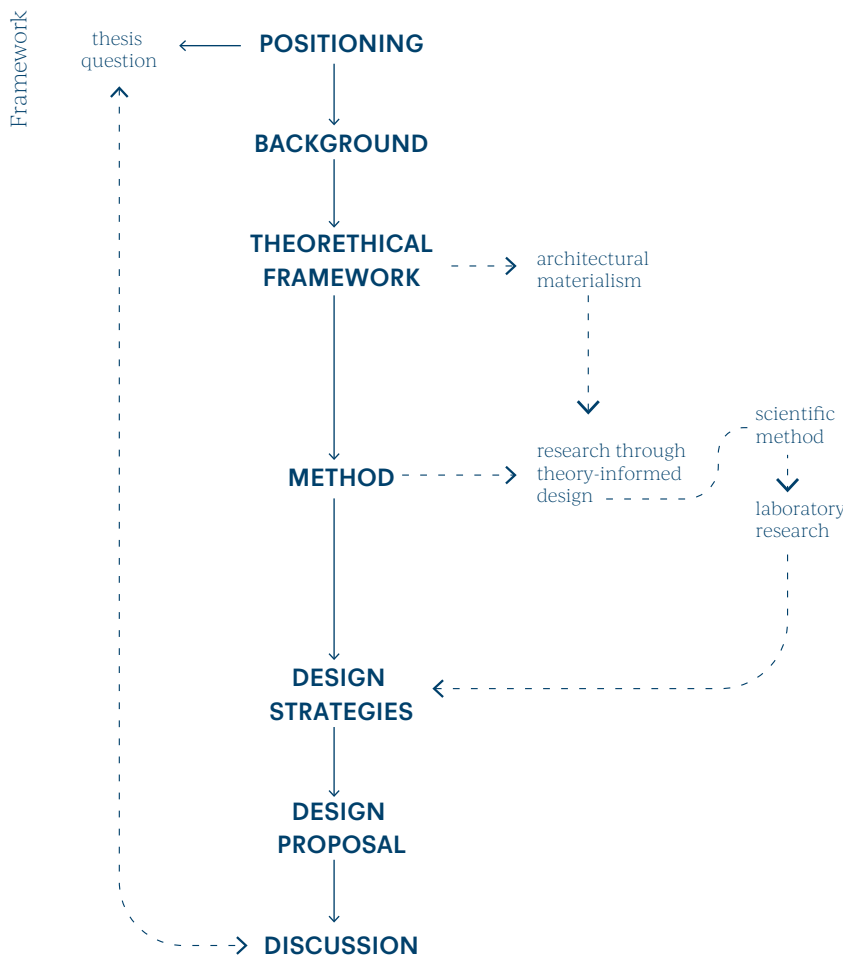
I N T E N T I O N

This thesis aims to **highlight the importance of involving architects in the early stages of material research**. It does so by investigating the architectural potential of a bio-fabricated yeast material through the lens of architectural materialisms and by using laboratory processes with a yeast-based material as a case study.

D E L I M I T A T I O N S

This thesis focuses on yeast-based material research in order to demonstrate a holistic way of approaching it from an architectural perspective.

This thesis does not aim to analyze the material from mechanical, biological, or other scientific perspectives. Instead, it adopts architectural materialisms as its theoretical framework, without attempting to provide an exhaustive review of the theory itself. Finally, this thesis is not intended to represent Indigenous communities, but rather to draw inspiration from and acknowledge their knowledge.



T H E S I S Q U E S T I O N

What could the process of investigating a material through architectural materialisms **highlight** about the importance of architects' involvement in the early stages of research into developing novel sustainable bio-materials?

G L O S S A R Y

Indicated with a (g) in the text

Architectural materialisms

A theoretical framework that understands matter as active and relational rather than passive. It challenges anthropocentric views, emphasizing materials as agents with their own temporalities and capacities to shape architecture. Design occurs through material behavior, not only with it.

Assemblages (in this thesis)

Dynamic systems where material, human, and environmental factors interact. The concept highlights how yeast, robotic fabrication, and cultural context co-produce form and meaning. Assemblages replace static material notions with networks of evolving relationships.

Biocapability

A material's ability to exist within a biological system without causing harmful or toxic effects, such as immune reactions or rejection.

Bio-based material

Is a material that is derived fully or partly from recently captured carbon or biomass (renewable organic material that comes from plants and animals). Bio-based materials are never derived from fossil-based resources.

Bio-fabricated material

A material grown or produced using living organisms or biological processes, rather than being extracted or synthetically manufactured. Bio-fabricated materials often involve microbes, fungi, or cells, and aim to reduce environmental impact by using renewable inputs, low-energy production methods, and enabling biodegradability or circularity.

Cradle to cradle

A circular design approach where materials remain in continuous biological or technical cycles, eliminating the concept of waste and promoting environmental and social regeneration.

Mapuche

An Indigenous people of south-central Chile and southwestern Argentina, the Mapuche have a deep cultural and spiritual connection to the land. They have historically resisted colonization and territorial dispossession, and today continue to assert their rights

in the face of industrial expansion, particularly from forestry and extractive industries.

Principal moments

Principal moments are used to determine the directions of maximum and minimum bending in shell structures. These lines help to visualize and understand the stress flow within a shell.

Ruka

A ruka is the traditional Mapuche dwelling, made of natural materials such as wood, straw, and mud. It is not only a shelter but also a communal and ceremonial space, reflecting the Mapuche world view and relationship with nature, community, and territory.

Socio-ecological

A term used to describe systems, processes, or frameworks that integrate social and ecological dimensions. A socio-ecological perspective recognizes the interdependence between human societies and natural environments.

Yeast

Unicellular fungus used in fermentation and increasingly in bio-fabrication due to its ability to produce cellulose, proteins, or bio-polymers through synthetic biology.

Yeast-based-mix

An experimental composite based in yeast. It is developed for testing structural, chromatic, and temporal properties under non-extractive and regenerative principles. The mix acts as both physical and conceptual material for design speculation.

C H A P T E R I
B A C K G R O U N D

C O N T E X T

CLIMATE CHANGE AND THE DILEMMA

BIO-MATERIAL

When it comes to climate change, the building and construction sector is one of the main contributors to carbon emissions, accounting for about 37% of all yearly emissions (UNEP, 2022). In this context, the industry has recently made great efforts to move toward a greener chain, seeking to shift its energy matrix toward the utilization of renewable sources and to advance toward bio-based materials (g) (Boros & Tózsér, 2023). One of the main focuses is wood as a sustainable material. However, it faces a dilemma: as the demand for wood increases by 54% [Fig.2], land use change (LULUC) will also rise. Some projections suggest that, if a proper framework is not established, this change could be counterproductive, releasing more CO₂ than the fossil fuel industry (Weiss et al., 2012), thereby undermining the original goal of transitioning toward a more sustainable construction matrix.

Deforestation is one of the main multifactorial drivers of climate change. Research shows that deforestation, forest management, and land use change cause a net loss of as many as 15.3 billion trees per year, resulting in a significant release of CO₂ (Crowther et al., 2015). If current consumption rates continue, some researchers predict that all the world's forests could disappear in as little as 100 to 200 years (Bologna & Aquino, 2020).

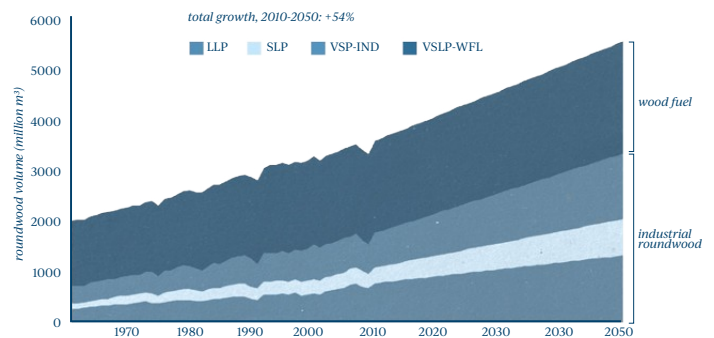
This means that bio-based material research should shift the focus to develop approaches that can mitigate this problem as well, for example by using by-products from the wood industry, thereby creating new materials with minimal wood extraction effort (Patel et al., 2006).

These leftovers, combined with other bio-materials and processed through technologies such as 3D printing, have facilitated the creation of customized, sustainable components, often referred to as bio-fabricated materials (g). But this is not only an ecological problem. In La Araucanía, Chile, the

development of the forest industry has intensified the conflict between the state, companies, and the Mapuche(g) communities, related not only to land ownership but also to the degradation of land and ecosystems following the introduction of non-native trees such as *pinus radiata* (pine), disregarding indigenous knowledge about the land, tempos and material extraction.

This illustrates how global environmental problems intersect with social and cultural dimensions, highlighting the need for approaches that consider both ecological and social-ecological (g) consequences (Schmalz et al., 2023).

This challenge demands systematic thinking from the very outset of material development, aiming to minimize long-term negative repercussions. Architectural design thinking, with its holistic and process-oriented approach, can offer strategies for shaping production processes that endure throughout the material's life span, from cradle to cradle (g), while integrating social, cultural, and ecological perspectives.



[Fig. 2]↑ Historical and projected increases in global wood product production (million m³) between 1961 and 2050. Adapted from Peng et al. (2023) LLP includes sawn wood, wood panels and other industrial roundwood; SLP refers to paper and paperboard products; VSP-IND refers to wastes of other wood product manufactured that are burned for energy; and VSLP-WFL refers to wood harvested to burn for energy.

ARCHITECTS & EARLY APPROACH TO MATERIAL RESEARCH

The Post-Renaissance era confined architects to selecting materials with limited awareness of their impact, due in part to the architect's withdrawal from the construction site process. Architects often engage with materials only at the final stage of their development, once industrial research has already been completed. Louis Kahn's well-known question, "What do you want (to be), brick?" exemplifies this late-stage approach. Yet perhaps an early-stage question should be: "What do you want (to be) clay?". Whereas the late-stage approach focuses on shape, the early-stage approach emphasizes the intrinsic properties and potential of the material itself.

However, as technology advanced, architects have begun to explore areas previously considered peripheral (such as biotechnology), opening new possibilities for interdisciplinary approaches and increased material awareness^{1,2}. The presence of architects in laboratories, where novel materials are being developed, is becoming more common, calling for the embrace of the scientific method as a foundation supported by emerging technologies (Oxman et al., 2015)

Examples of new materials first developed by architects, such as Ginger Krieg Dosier with Biomason [Fig.3], demonstrate a methodology of design-through-research (a common approach among architects and designers). For example, materials that once seemed to be just simple mixes far away of architectural applications are now 3D-printed and examined for their physical properties through design exploration [Fig.4], where aspects such as color and biodegradation are considered strengths (Zboinska et al., 2023).

This approach helps to reduce the knowledge gap between the product and the designer, fostering better development of advanced materials and supporting the industrial production

of more sustainable products. (Bak-Andersen, 2018).

The central idea is that architects can contribute to material sciences primarily through research through design. Their involvement provides feedback for broader application scenarios as architect usually have to locate it project this integrates socio-cultural and ecological dimensions, explores aspects that are difficult to quantify, and offers early-stage design insights that may otherwise remain overlooked in conventional scientific research. This topic aligns with what is identified in material science as a known area of insufficiency: integrate social perspectives (Purker et al., 2023).

An early involvement of architects, applying the architectural research method as a holistic framework for material research, is crucial not only to advance the development of both architecture and the material itself but also to anticipate potential socio-ecological challenges

On the next page, a question is posed to architects working with biomaterials, aiming to understand current perspectives on their role in material research.

¹ "Architects nowadays are undoubtedly more reliant on having a higher understanding of materials than before, as this allows them to take full advantage while digitally fabricating them." (Voyatzaki, 2017, p. 90).

² "The advent of technologies such as digital fabrication, robotics and 3D printing have not only accelerated the development of new construction solutions, but have also led to a renewed interest in materials as a catalyst for novel architectural design." (Bechtold and Weaver, 2017, p. 1)



[Fig. 3]→

Note. Adapted from Biomason [Photograph], LinkedIn (2025). Used with permission.

[Fig. 4]→

Note. Adapted from Zboinska, M. A., Sämfors, S., & Gatenholm, P. (2023). *Materials & Design*, 236, 112472. <https://doi.org/10.1016/j.matdes.2023.112472>. Adapted with permission..

BASED ON YOUR EXPERIENCE WITH BIOMATERIALS AND AS AN ARCHITECT YOURSELF, DO YOU THINK IT IS IMPORTANT FOR ARCHITECTS TO BE INVOLVED IN MATERIAL RESEARCH FROM THE VERY BEGINNING (OR EARLIER THAN THEY HAVE TRADITIONALLY BEEN, WHEN MATERIALS ARE USUALLY ENCOUNTERED AS FINAL PRODUCTS)? AND WHY?

[Fig. 5]→

Photo taken by the author of *MycoMuseum* by Bhakti V. Loonawat, exhibited at Biennale Architettura 2025, Intelligens. Natural. Artificial. Collective.

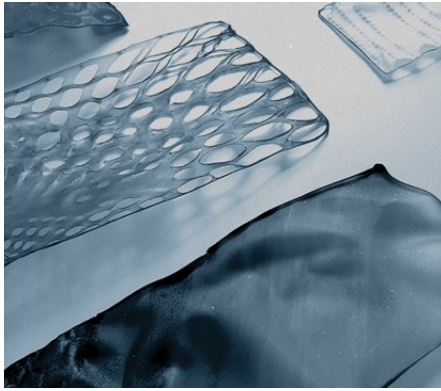


Bhakti V Loonawat
Architect
Partner at Anomalia Studio

Research in Mycelium

"I believe it is becoming increasingly important for architects/ product designers to be actively involved in the early stages of material development, rather than being given a 'finished product' to work with. The way we build is deeply connected to what we build with.

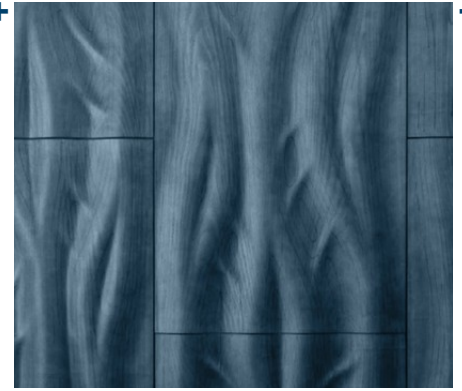
*In the case of biomaterials, it's an act of co-creating with nature and living systems. Therefore, the process of creating the material itself becomes an act of design. If we are to treat bio-materials as conventional materials/ finished products, we lose the opportunity to shape its narrative, its **environmental impact and its sensory value and cultural context.** Being connected to bio-material research, we can really get to the depths of understanding how a material grows, behaves and ages. **Then, design is not restricted to form-making but its about cultivating relationships between people, place and matter."***



[Fig. 6]←
 Note. Adapted from Note. Adapted from “Robotically 3D printed architectural membranes from ambient dried cellulose nanofibril-alginate hydrogel.” by M. A. Zboinska (2023). Adapted with permission from the author.

[Fig. 7]→
 Adapted from Wood-flow Skin Catalogue: Spring 2025 (Strong by Form, 2025).

[Fig. 8]↓
 Adapted from strong by form webpage (Strong by Form, 2025).



Daniel del Río Ortiz
Architect
CTO at strong by form

High-performance biocomposites

"In the current context, it is more valuable than ever for architects to engage at the disciplinary frontier. While traditional practice has focused on spatial design and construction, genuine innovation today occurs at the edges – at the intersection with science and technology. Participating in material research from its earliest stages is therefore a strategic opportunity to expand these boundaries and redefine the scope of the profession..."

...On the other hand, materials engineering often adopts a more pragmatic approach, oriented toward technical performance (strength, durability, efficiency). At times, this pursuit of technical optimization may place socio-ecological variables in the background during the initial phases, even though it is ultimately the engineer who must determine how to make a sustainable vision viable. However, one must be cautious with this distinction, because—particularly in the field of biomaterials—the profile of these professionals may be much closer to the disciplinary perspective of the architect".

Malgorzata Zboinska
Architect

Associate Professor at Chalmers, Architectural Theory and Method, Architecture and Civil Engineering.

*"Yes, I believe it is essential to fully integrate **design thinking** with material expression. A deep understanding of the material, its behavior during shaping and the design expressions that emerge, is crucial, as it enables the full exploitation of **architecture's repertoire: form, color, texture, pattern, and composition in specific built structures**. Influencing these aspects goes beyond the current reductionist approach of selecting ready-made products from material catalogs, which is highly limiting.*

*By incorporating material exploration in the early stages of design and combining it with emerging technologies such as robotic fabrication and 3D printing, we can contribute to more **resource-efficient manufacturing** of architectural products. This approach also allows for a high level of product customization at an affordable cost, meeting the often diverse needs of different end-user groups.*

*This integration of deep material knowledge developed through hands-on experimentation with the ability to tailor materials to meet the goals of **circular design** brings us back to the roots of architecture, where close engagement with materials fosters a dialectical relationship between conceptual vision and materiality. It represents a new mode of digital craft that serves the **goals of sustainability** and the pursuit of the highest quality of the built environment."*



Jorge Christie
Architect
CPO & founder Strong by Form

High-performance biocomposites

*"...architecture training is a good entry door to many different disciplines during masters programs, PhDs or other type of specialization. So, I've met many architects who are interested in scientific research and material development, which brings some of the **creativity needed to make breakthroughs**.*

For architects, in general, a good understanding of the mechanical, fire, moisture, temperature, etc behaviour of materials are key to explore beyond the boundaries of standard materials. I think the most interesting architects do that. But being involved in product and material development (like what I currently do) is quite far from my standard architect training. I had to study a lot and research myself to truly understand how to be a contribution in these processes.

*In summary, architecture training can bring a **holistic understanding of materials** (aesthetic, haptic, interaction with other materials, etc) that specialists might lack. But architects must train themselves to be able to speak with other disciplines with a common language."*

ARCHITECTURAL MATERIALISMS THEORY

For this thesis, an architectural materialisms **(g)** approach is adopted as a theoretical framework to develop a holistic understanding of material research, one that considers not only the physical properties of materials but also their social, ecological, and cultural dimensions. The book used as a reference is *Architectural Materialisms: Non-Human Creativity* (2017) by Maria Voyatzaki.

The perspective of architectural materialisms is influenced from the new materialism perspective, which focuses on shifting away from an anthropocentric view of material (philosophically, scientifically, etc.) toward a broader narrative: material has its own agency, non-human species should be considered, and ancient cosmovisions (worldview) are taken into account (**Gamble et al., 2019**).

Therefore, architectural materialisms focuses on the material itself: not as a contributor serving only to the human-scale body, but in relation to its own nature, interactions, and possibilities. As Voyatzaki states in his book: “We define architectural materialisms as the contemplation that places contemporary speculations on the vitality of matter and materiality at the epicenter of their questioning, ethos, and praxis” (**Voyatzaki, 2017**).

Since this perspective does not provide a step-by-step guide for project development but instead offers a conceptual framework rooted in philosophy, I will highlight some general approaches relevant to the present investigation, drawing on Voyatzaki’s book: *Architectural Materialisms* (2017)

I. Material Vitality **(m)**: Matter is not inert but has its own agency; it has the capacity to affect and be affected.

II. Material Meaning **(c)**: The cultural and causal significance of material (how it

conditions usages and behaviors).

III. Material as Assemblage **(g)(c)**: Material is part of networks; it participates in ecological, social, and technological dynamics, as well as ethics, aesthetics, and politics.

IV. Non-Human Creativity **(nh)**: Creativity is not exclusively human. The research should focus on how creativity emerges from human-non-human interactions.

V. Transversality **(a)**: Material should be studied from a multi-scalar perspective, which requires an interdisciplinary approach.

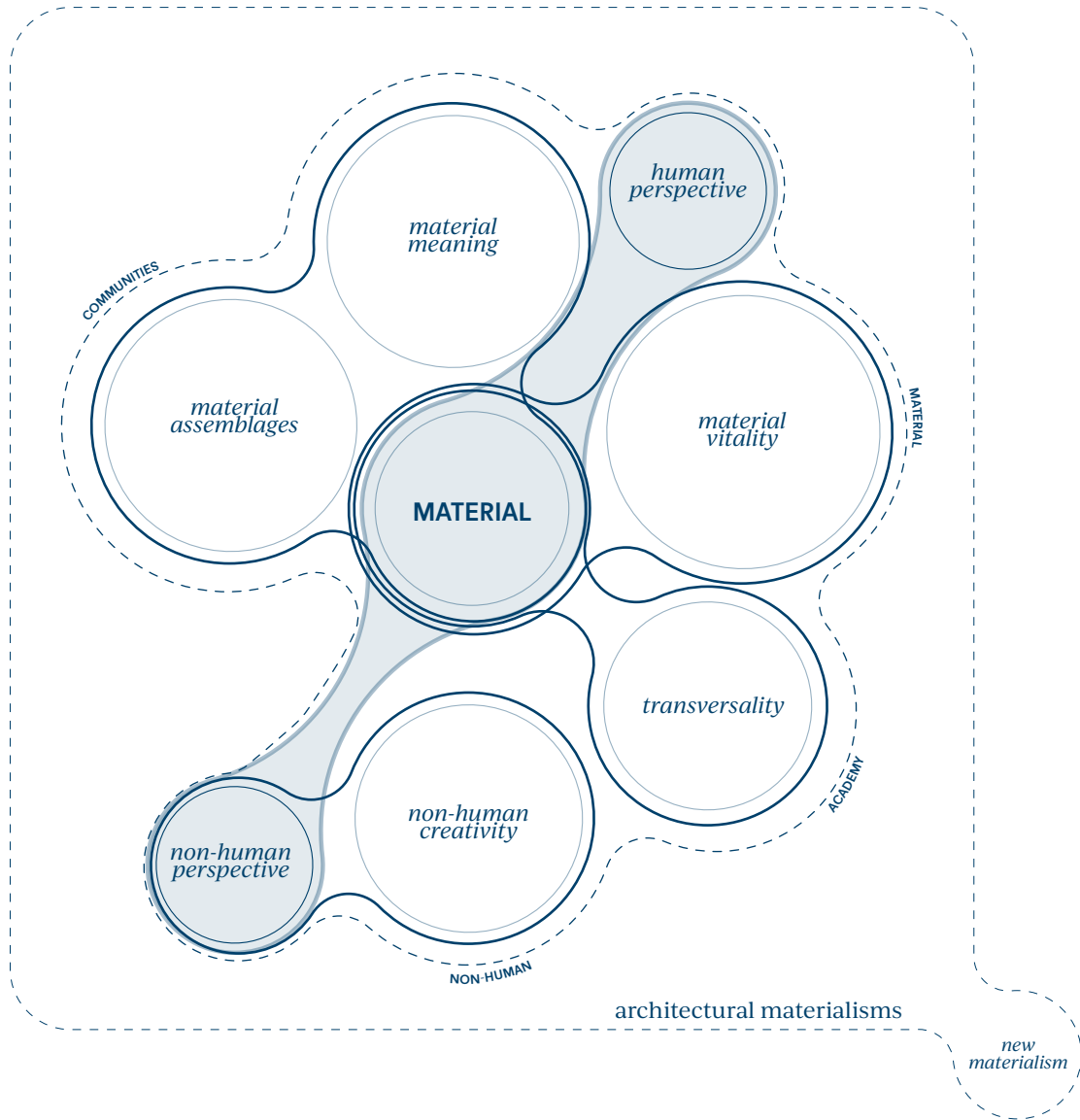
For this thesis, material **(m)** and communities in relation with the material **(c)** are the main drivers of the research. In this framework, **(nh)** stands for non-human, and **(a)** stands for academy, highlighting different perspectives and scales of engagement with the material.

This approach makes room for ancient knowledge as both a cultural and site-based perspective. As **Voyatzaki (2017, p. 18, citing Stiegler, *The Fault of Epimetheus*, p. 152)** suggests, experimentation on the materiality of architecture must combine top-down and bottom-up trajectories, understood as “an abductive inference that synthetically manipulates parameters.”

This framework guides the present research, providing a lens through which the yeast-based material **(g)** introduced in the following section can be studied holistically, considering its physical properties, social relations, and ecological implications.

[Fig. 9]→

Summary diagram of five approaches to architectural materialisms. The family of relations is defined by: material; material and communities; non-human knowledge; and academic knowledge. The theory of architectural materialisms is influenced by new materialist philosophy.



CORE RESEARCH: YEAST-BASED MATERIAL EXPLORATION

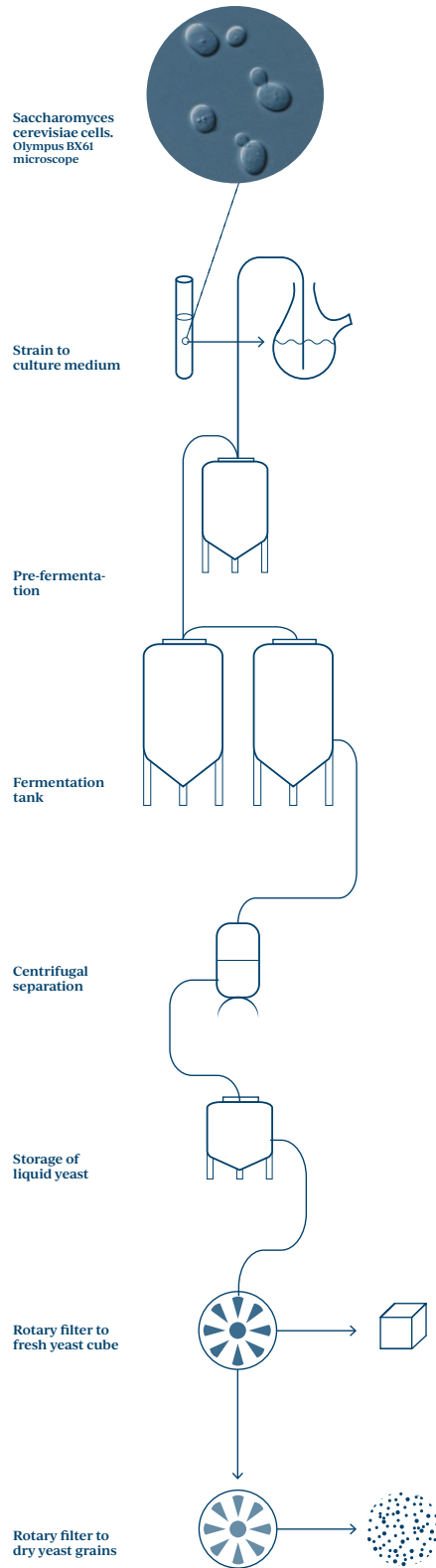
To explore the potential for creating new materials from an architectural materialisms perspective, it is useful to align efforts with ongoing research where materials can be practically investigated. At Chalmers, a new material-based project focuses on this approach: this collaboration centers on the project titled “Resource Efficient Renovation Using a 3D Printable Material from Underutilized Biomass,” funded by the Swedish Energy Agency (<https://research.chalmers.se/en/project/10975>). The project addresses critical sustainability challenges associated with the extensive use of fossil-based, energy-intensive materials in renovation.

The initiative aims to develop a more resource and energy efficient alternative derived from underutilized biomass, such as microorganisms and cellulose. Through a unique intersection of architectural design, biotechnology, and materials science, the project develops multiple formulations of a new material based on yeast. It explores applications in architectural design and 3D printing techniques, producing physical prototypes that demonstrate potential uses in architectural elements.

What is yeast?

Yeast is a natural unicellular microorganism that is abundant, biocompatible, biodegradable, and non-toxic, making it an appealing base material for sustainable products. The kind of yeast used in this experiment is *Saccharomyces cerevisiae*, a common yeast used for bread and beer. Its reproduction occurs through budding, an asexual process.

Yeast grows at an astonishing rate when fed a sugar-rich diet: just 10 milligrams of yeast can expand into a ton of biomass in only one week. Industrial processes are carried out in fermentation tanks that control temperature, pH, oxygen, and nutrient supply [Fig. 10].



[Fig. 10] Industrial process from *Saccharomyces cerevisiae* to baking yeast used in the current research. Diagram based on <https://www.youtube.com/watch?v=PDHb91wIGyg>

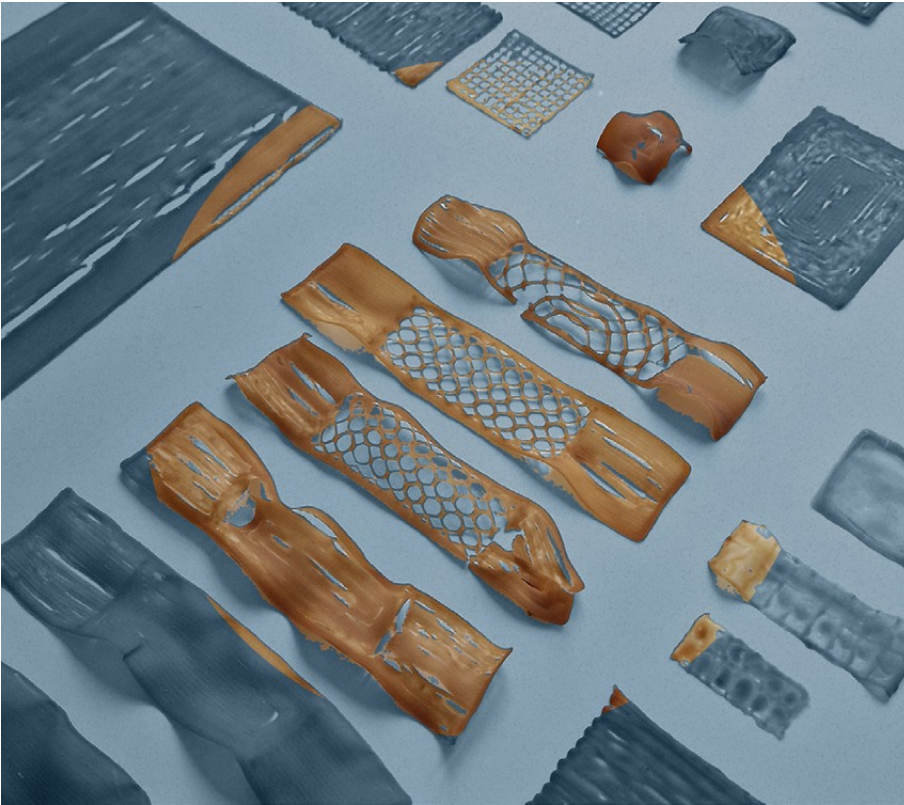
Yeast is commonly found in environments rich in decomposing organic matter, such as forests, fruits, flowers, and soil, and begins to reproduce through budding when provided with suitable nutrients, including sugars. The ultimate goal of yeast is to survive and reproduce, using available nutrients to generate energy and produce new cells.

Why use yeast in architecture?

Yeast has incredible bioavailability. Scientists already know a great deal about it due to its manipulability and rapid growth. It is also inexpensive, which makes data collection and experimentation more feasible. To obtain a stable mix that can be 3D printed, yeast is reinforced with polymers, cellulose, and hydrogels.

Yeast-mix: A printable material

The yeast-mix created has sufficient



[Fig. 11]←
Adapted photo: 3D-printed yeast-material samples. Photo courtesy of Malgorzata Zboinska

fluidity to be printed using a robot equipped with an air-pressure-based syringe extrusion system. The mix used in this thesis is mix B; it exhibits medium to high viscosity and consists on a composed from underutilized biomass upcycled from industry side stream products, comprising microorganisms (yeast) and cellulose (**Bektas et al., 2025a; Bektas et al., 2025b**). All components are low-cost, biocompatible, and biodegradable.

The mix is enhanced with a very relevant component: cellulose taken from forestry scraps, which provides the material with additional mechanical strength, likely due to the distribution of cellulose fibers contributing to increased anisotropy.

Cellulose is frequently used in hydrogel mixtures because of its abundance, biodegradability, biocompatibility, and ability to form strong, water-retaining gels (**Nasution et al., 2022**).

Due to its biodegradable characteristics,

spent yeast is a protein-rich material that can be used for feed and fertilization purposes. According to Raimo Liikamaa, operations manager for the beer process at Spendrups Brewery, "spent yeast is a protein-rich waste stream... used as pig feed or as a soil improver" (**RISE Research Institutes of Sweden, n.d.**).

Why 3d printing?

Printing materials with robotic 3D printers is a highly efficient and sustainable practice that minimizes waste, as it creates only what is necessary for the structure.

Typically, when designing with wooden beams and columns, the stresses do not always correspond to the mass of material, which can result in approximately 23% material waste. The automation and precision of 3D printing optimize the construction process, accelerating project execution and reducing costs (**Green, 2023**). This

approach not only significantly reduces waste generation but also allows for the creation of complex and customized shapes that are difficult to achieve with traditional construction methods.

Yeast is an extraordinary material that has been the subject of extensive research, with a rich historical background and a dynamic presence in contemporary material sciences.

This history is closely linked to ancestral communities as is seen in the next point, highlighting the importance of considering their knowledge and practices in the future development and application of the material.

MAPUCHE AS A RESOURCE OF KNOWLEDGE AND ASSEMBLAGE

Given the ubiquity of yeast, the research conducted in Sweden can be conceptually extended to another context (La Araucanía, Chile, within Mapuche territory) where yeast, forests, and communities form part of an intertwined socio-ecological and cultural assemblage. Research based on Mapuche communities reflects the current complex socio-ecological conflicts, providing a broader, richer, and more contingent scenario.

The Mapuche are an Indigenous people of southern Chile and Argentina, with origins dating back to 500–600 BC. They are the most numerous Indigenous group in Chile, representing approximately 10% of the national population. Known for their deep relationship with the land (Wallmapu), the Mapuche have their own language (Mapuzugun), traditional medicine, agricultural practices, and cosmology.

The Mapuche, like many Indigenous cultures, engaged with yeast through fermentation processes, particularly in the preparation of ceremonial beverages, which the Spanish later attempted to prohibit during colonial times, without success (Pardo and Pizarro, 2020).

The assemblage (g) in this case is drawn from the way the Mapuche approach materials, rather than from yeast itself, since no native community has worked with yeast cells or with yeast as a material, due to technological reasons. Therefore, we do not know its direct assemblage behavior in relation to yeast extraction or laboratory culture.

However, we can draw parallels from previous examples of material extraction. For instance, wood extraction among the Mapuche is guided by an approach to nature based not on domination but on reciprocity; a perspective that challenges conventional Western notions of control over materials: harvesting times are aligned with natural cycles, extensive areas are considered sacred, and various trees possess spiritual significance

(Curivil Paillavi, 2024).

On the other hand, forestry monocultures in southern Chile are not merely a background condition but active participants in the assemblage: they displace communities, and promote the degradation of the land and ecosystems since the introduction of non-native trees such as *Pinus radiata* (pine) (Schmalz et al., 2023).

Indigenous knowledge and cosmologies contribute necessary perspectives to architectural materialisms, introducing non-human agencies (time, soil, water, microorganisms) that shape how architecture and materials come into being.

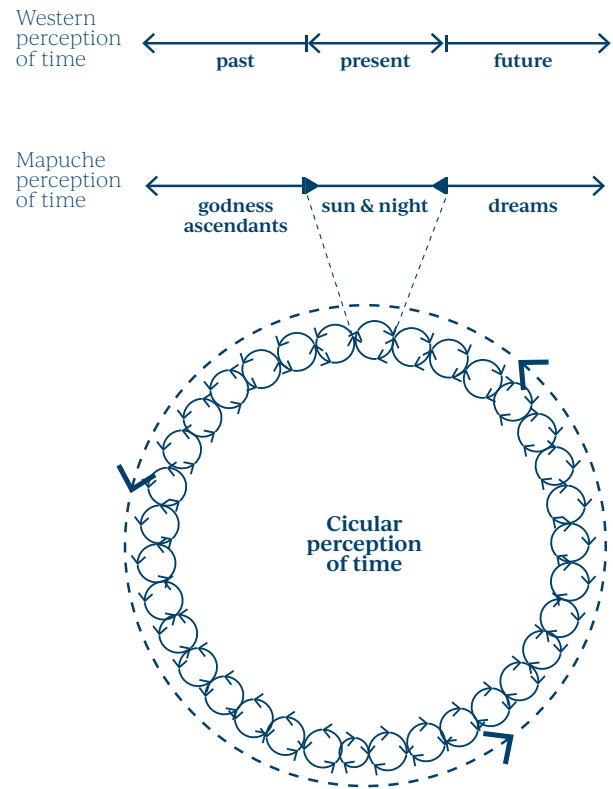
In Mapuche cosmology, time is conceived not as linear but as dynamic and cyclical (Loncon Antileo, 2019), implying that long-term planning beyond the span of the seasons is unnecessary [Fig. 12].

This can be seen in their architecture: the ruka (g), a building previously used as a house and now serving as a community gathering center, is built from biodegradable materials, mainly wood, even though they already knew how to work with stone [Fig.13].

The building is repaired by the community whenever necessary and is blessed according to ceremonial

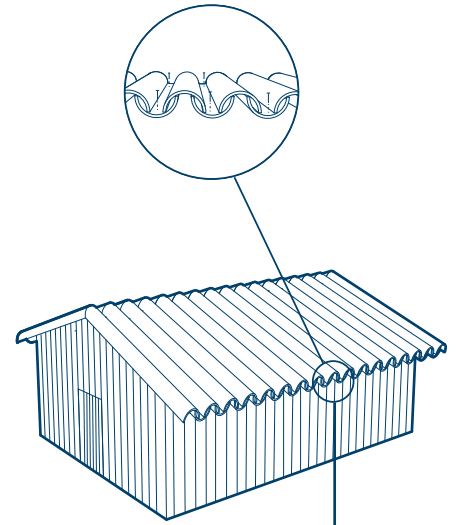
practices. In Pehuenche's rukas (Mapuche communities in snowy regions), the natural concavity of the tree trunks is used to assemble the components of the roof (C.J. Whitma et al., 2014), taking advantage of the existing curvature instead of shaping a new curve (as in a tile), which provides greater stability through form [Fig. 14].

Yeast, ritual practices, Indigenous knowledge, and forestry industries can be seen as heterogeneous elements



that, when assembled (even though at different scales) co-constitute the idea of material as Assemblage.

The value of working with assemblages lies precisely in allowing this crossing of scales: from the microbiological level (yeast) to the territorial (Mapuche) and the cosmological (time, water, earth).



[Fig. 12]↖
Diagram illustrating the Mapuche conception of time and temporality

[Fig. 13]↑
Photographs by the author during a visit to a Mapuche ruka in the Araucanía region.

[Fig. 14]↗
Detail of the concave roof, following the natural curvature of the tree trunk for its fitting.

CHAPTER

II

M E T H O D S

RESEARCH THROUGH THEORY-INFORMED DESIGN METHOD THROUGH THE LENS OF ARCHITECTURAL MATERIALISMS: MAPUCHE, CLIMATE CHANGE, AND YEAST.

The previous chapter reinforces the idea that, in order to legitimize the research of a new material and uncover novel perspectives, viewpoints beyond the conventional scientific study of the material itself must be considered. Research through theory-informed design offers a specific approach to the design process, guided by the theoretical framework (Gehlert et al., 2009), in this case, of architectural materialisms.

To guide the laboratory research, five statements [Pag.18] were derived from architectural materialisms theory. From these, three concepts are selected as the most relevant within the laboratory constraints, and are presented in the following paragraphs.

1.- Material Vitality (m):

What does yeast want to be? Yeast is a machinery of transformation. The inertia that follows yeast is the decomposition of organic matter, even when that matter is itself (*autolysis*). This statement challenges what architecture has sought for centuries: to last, yeast represent **temporality**.

2.- Material Meaning (c):

Yeast has long been associated with food. Mapuche used fermentation to produce sacred beverages, but Spanish colonizers delegitimized this practice by prohibiting fermented drinks. Today, for the Mapuche, the ability to produce their own "*chicha*" represents an act of resistance.

In any case, yeast in culture represents a reaction: fermentation, something that extends beyond architecture. Incorporating this perspective allows us to uncover the **novelty** of this approach, in which yeast has traditionally been manipulated by communities solely for its effects, rather than studied as a cell or material in its own right.

3.- Material as assemblage (c):

As stated before in Chapter I, new materials need to be created; materials that are non-extractive, regenerative, and derived from forest industry by-products. In this way, land-use change can be reduced, and with it, socio-ecological problems can be addressed. Forest management for the Mapuche is closely tied to time, and time is understood in relation to natural processes; it is not linear, and endurance is not a value in itself (Loncón, 2019).

As far as we know, yeast-mix is biodegradable in short times, for Mapuche the time that nature allows (Rodríguez and Saavedra, 2008).

In summary, **temporality** and the possibility of ephemerality must be considered as part of a cultural and situational context.

4.- Non-human creativity (nh):

Yeast is a unicellular fungus that interacts with many animals, which take advantage of it and help disperse its spores (Becher et al., 2018). In nature, color (whether in fruits or during the fermentation process) may attract or repel animals. During fermentation, color changes can occur in the surrounding organic matter, reflecting the metabolic activity of yeast.

These instinctive strategies observed with **color** in nature can be integrated into the yeast-mix in a non-toxic and purposeful manner, preserving the material's biocapability (**g**). Additionally, non-human behaviors will be systematically examined during the laboratory research.

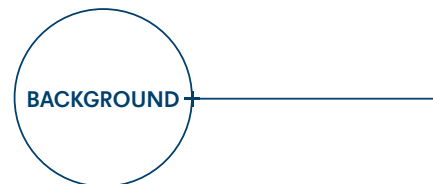
5.- Transversality (a)

The base research "Resource efficient renovation using a 3D printable material from underutilized biomass" is situated at the intersection of bioscience, chemistry, and architecture, with an emphasis

on architectural applications. Insights from Mapuche design and architecture may inform these applications, while research into Mapuche strategies for volumetric creation could potentially guide the **geometric** / form exploration of the material.

Geometrical / form research is not about a pre-defined architectural space; rather, it concerns the material's ability to support itself and maintain its shape, minimizing deformation to allow the creation of a functional space. In this sense, "space" emerges from the material's structural behavior rather than being an predetermined architectural typology.

Therefore, in the development of yeast-based mix printing within the robotic laboratory, the research through design is guided by three key concepts: **temporality, color, and geometry**.



[Fig. 15]→
First part of the workflow: from background information gathering to the research through-theory-informed design method, and its resulting output as input for the laboratory research.

SCIENTIFIC TEMPORALITY,

COLOR

AND

METHOD GEOMETRY

To prepare for the robotic laboratory work, two sets of information are outlined: first, the existing knowledge about yeast derived from previous research and Studios (ACE510 Mediated material interfaces 2024) at Chalmers; and second, the insights obtained through the theory-informed design research process, which will now be translated into scientific hypotheses for laboratory testing.

The key findings from previous research are as follows:

- The yeast mixture has only been printed in planar forms.
- The yeast-mix can accept color tinting, but further research is required.
- The yeast-mix cannot be applied through additive manufacturing, as the fluid mass cannot support the addition of subsequent layers without collapsing, which increases shrinkage.

- Yeast-mix Type B will be used due to results from previous research showing better performance under structural stress.

- Yeast-mix components and composition cannot be changed.

In relation to the points mentioned above, it is necessary to emphasize that they constitute the initial conditions under which the lab experimentation will begin.

Color, temporality, and geometry are the conceptual catalysts of this research, as illustrated in [Fig. 15]. The scientific method is adopted to guide the laboratory process.

1. Temporality (Material Meaning, Material Assemblage)

Observation: Previous findings indicate that the mix dissolves when submerged in water [Fig. 17]. However, the extent

and specific conditions under which this occurs remain unclear. To investigate this phenomenon, both a submerged test and an outdoor exposure test will be conducted.

Question: How can temporality as a design value be addressed in the design proposal?

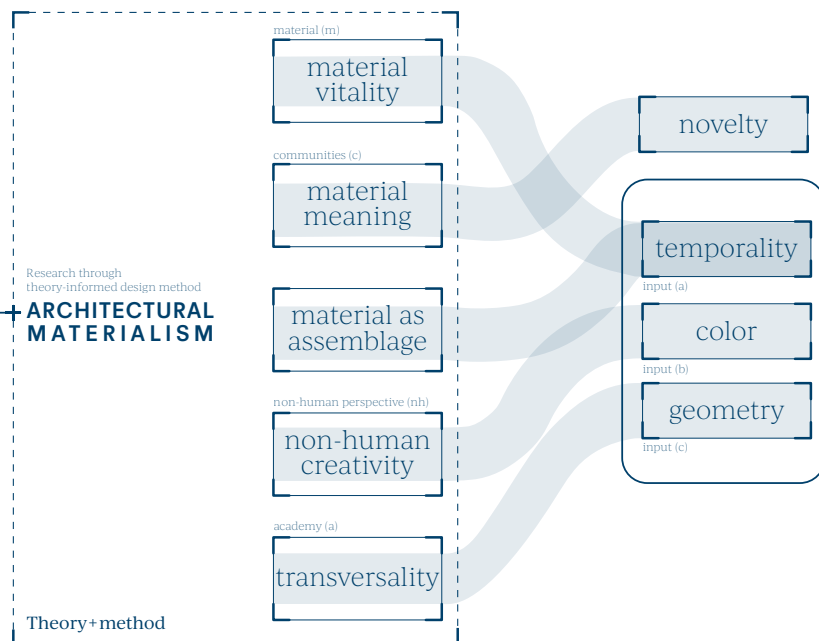
Hypothesis: Temporality may open novel perspectives on how an architectural application is materialized.

2. Color (Non-Human Creativity)

Observation: While previous research included color, it did not develop a systematic investigation. Its incorporation in this study therefore represents a new contribution.

Red, black, and white are chosen based on their relevance to Mapuche cosmivision (Alvarez Saavedra, 2020), their status as the first three basic colors recognized

Through the lens of architectural materialisms: Mapuche, climate change, and yeast



by humans (Collier et al., 1973), their aposematic (colors to ward off predators) effect within animal perception, and their availability as biodegradable and edible powders [Fig. 16].

It is important to note that, in this experiment, colors are not used as symbolic or ritual elements.

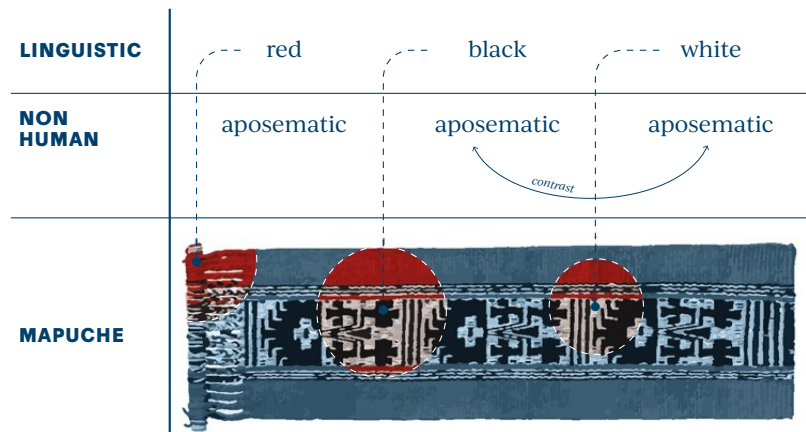
Question: Can adding color to the mix reveal correlations with its disposition?

Hypothesis: Colors may exhibit correlational patterns in their behavior depending on their layering order

3. Geometry (Transversality)

Observation: It is already known that shrinkage occurs during the drying process. However, if the goal is to create spatial configurations with the material while minimizing additional manual and structural interventions [Fig. 18a], the material must be challenged to sustain itself structurally into a non planar geometry.

Since the material cannot be permanently stacked via 3D printing due to its high water content, the layer height decreases dramatically and the material becomes significantly thinner as the water evaporates during drying under ambient room conditions, an alternative approach is explored: applying form-finding principles to experiment with curved geometries. These geometries, particularly those with simple curvature, are also observed in traditional Mapuche



[Fig. 16]↑
Color selection: red, white, and black. The choice correlates with three themes: the first linguistic approaches to chromatics, non-human behavioral responses to color, and the presence of these colors within Mapuche textiles.



[Fig. 17]←
Sequence of three photos showing the partial dissolution of a 5x5 piece of yeast in 200 ml of water. The dissolution occurs after 15 minutes with manual intervention every 2 minutes.

architectural systems **[Fig. 18b]**.

Question: Can a yeast-based, non-planar printed shape maintain its shape?

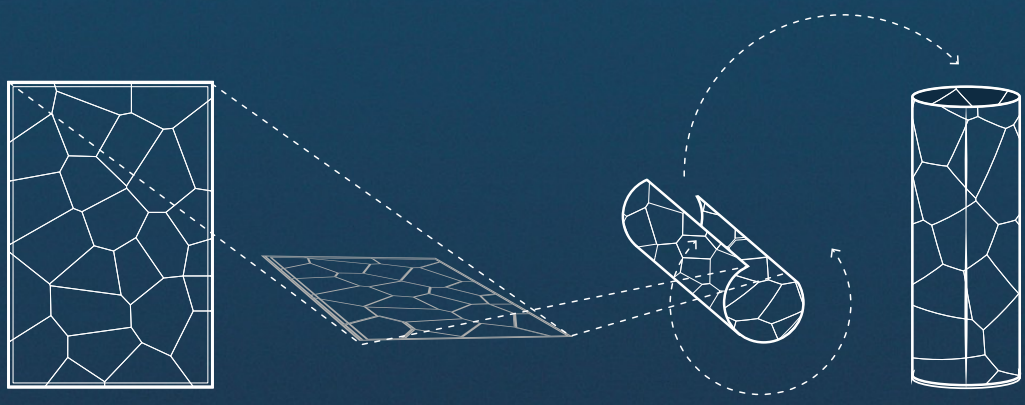
Hypothesis: Double-curvature geometry may enable the mix to sustain its shape due to the redistribution of internal forces, thereby reducing deformation.

The canoe-like geometry provides structural support due to its inherent stiffness. Therefore, continuing to explore curvature (and particularly double or closed curvature) allows the structure to gain geometric rigidity, distribute loads more efficiently, and develop a membrane-like behavior that enhances its stability **[Fig. 18c]**.

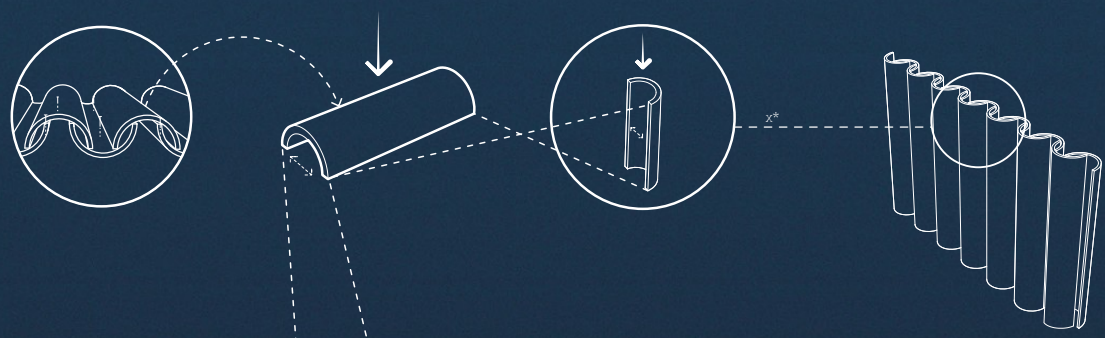
Integrating the scientific method within research through theory-informed design provides a clearer framework for transitioning into laboratory practice, translating theoretical insights into specific hypotheses to be tested.

[Fig. 18]
a) From planar surfaces to a pillar through mechanical manipulation.
b) Inspiration from Mapuche's architecture components in leveraging the inherent geometry.
c) Different curves to explore the geometric hypothesis.

a) Folding tile

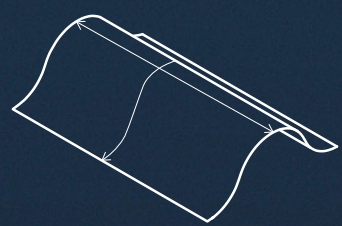


b) Non-folding tile

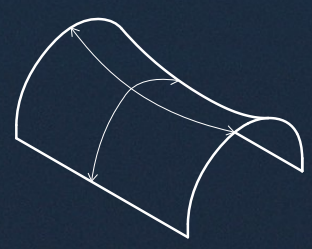


c) Geometry transition

Simple curvature



Double curvature



Closed curvature



RESEARCH BY DESIGN

L A B O R A T O R Y E X P E R I M E N T A T I O N

The laboratory work constitutes a **research by design** method situated within the research-through-theory-informed-design framework following a workflow that is illustrated in [Fig.19]. It translates theoretical concepts into physical tests, focusing on temporality, color, and geometry.

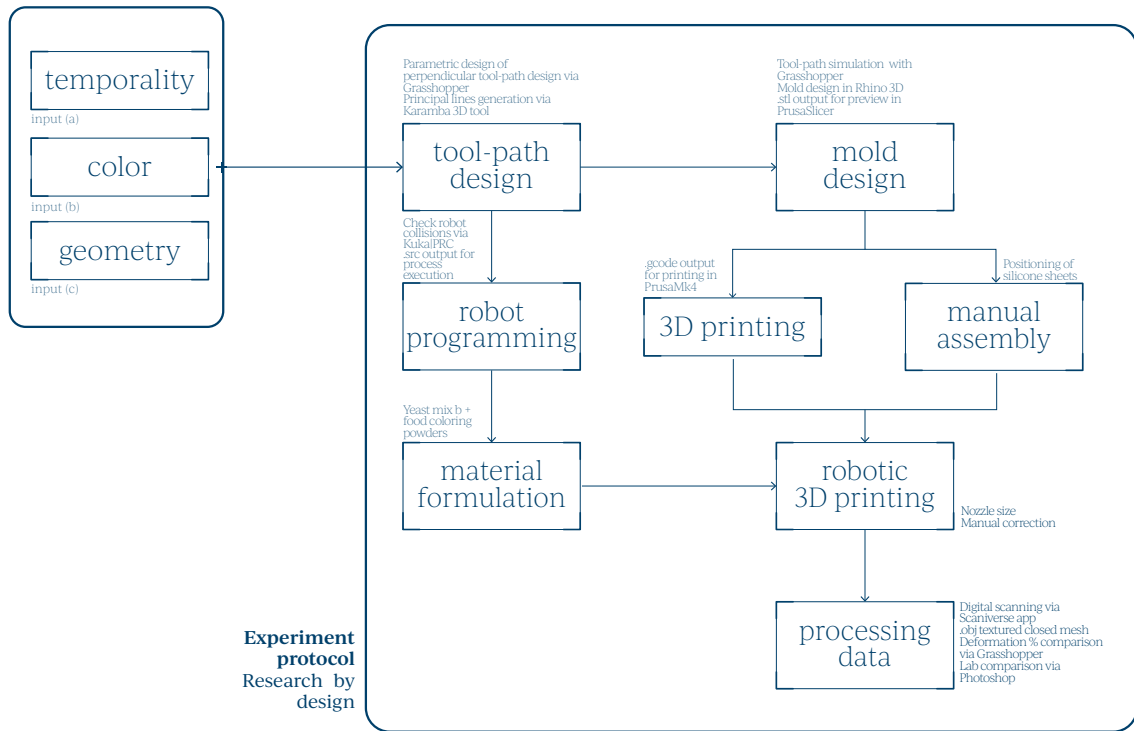
Over a total of three weeks working in the robotics lab, three days of each week were dedicated to printing, while the remaining time was spent preparing the material for subsequent week sessions. "Color" and "geometry" concepts are developed together in the workflow of these three weeks, and "temporality" is observed at the end of the process.

Three types of curves were tested: starting with simple curvature in the first and second week, in the third week double curvature, and closed curvature were tested. The digital toolpaths were customized to emphasize these transitions. To obtain the geometric shapes, molds were created digitally and then 3D printed.

The overall procedure for each week included:

- Toolpath design to generate the G-code file (.src)
- Mold design and printing.
- Yeast-based mix with color preparation
- 3D Robot printing.

For each week, the mixes were prepared in advance by the research team. Food coloring pigments were used to add the selected colors to the mix. The color varied according to the printing results of each week. The outcomes were photographed daily using different digital devices: a Nikon D3200 and an iPhone XR.



[Fig. 19] Workflow of the experimental protocol developed within the research by design framework.

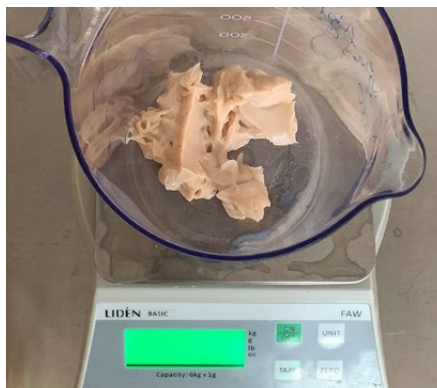
M A T E R I A L & P O S T- P R O C E S S I N G

Mix type B is a fluid, yeast-based composite primarily used for printing linear toolpath geometries. It exhibits low spreading behavior compared to other mixes.

This mix acts as an adhesive that bonds with its own material, meaning it is capable of joining different pieces of yeast-based printed or extruded material. Restoring or adding pieces together is also possible.

Mix type B is prone to forming air bubbles, which can be removed by tapping the syringe. This issue should be taken into account during preparation and extrusion.

The mix can be tinted with edible powdered food coloring, as it accepts the pigment without being significantly disturbed by it. All samples were dried under ambient conditions.



[Fig. 20] Luer-to-Luer connector to transfer the mix.

[Fig. 21] To avoid losses, the amount of mix is calculated beforehand in Grasshopper.

BIOPRINTER SET-UP

The setup used for the robot comes from “Robotically 3D Printed Architectural Membranes from Ambient Dried Cellulose Nanofibril-Alginate Hydrogel” (Zboinska et al., 2023) research.

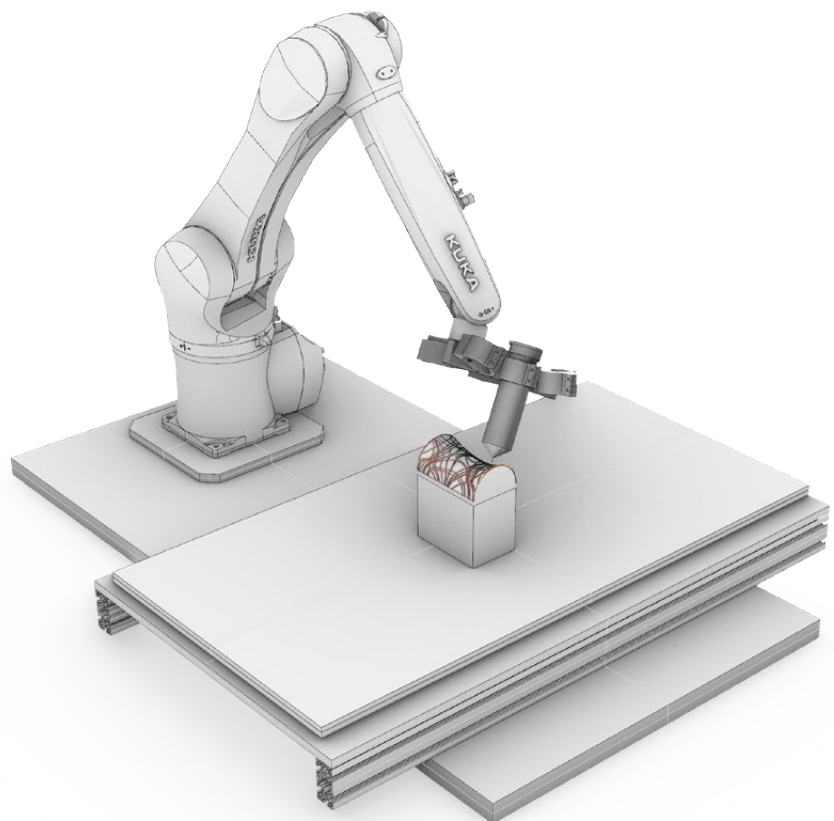
Experiments with the robot KUKA Agilus KR10-1100-SIXX, with 6 axes are held at Chalmers, in the facilities of the Architecture and Civil Engineering Department. The printer features a print head equipped with three material containers and extruders, but only the one in the middle is used.

The container is connected to Air pressure hoses that are linked to air pressure solenoid valves.

Air pressure ranged between 0 and 10 bar, with adjustments made when necessary.

The software used for designing toolpaths as molds is Grasshopper v1.00.007, within the free-form 3D modeling software Rhinoceros 3D v7.0, compatible with the robot’s programming language.

In Grasshopper, a .src file is generated to convert the toolpath data into a robot-readable format. For the amplitude of the robot head rotation, zones where possible collisions could occur are integrated into the robot toolpath as danger zones. Therefore, the preview displays potential collisions, which are then avoided. The toolpath for printing is developed based on the Chalmers MPARC Studio Mediated Material Interfaces 2024; however, changes in the rotation of the planes are produced uniquely for this thesis.



[Fig. 22]↑
Arrangement of the work cell for robotic 3D printing with the yeast mix.

E X P E R I - M E N T A T I O N F R A M E W O R K G E O M E T R Y

RESEARCH QUESTION: CAN A YEAST-BASED, NON-PLANAR PRINTED SHAPE MAINTAIN ITS FORM?

HYPOTHESIS: DOUBLE-CURVATURE GEOMETRY MAY ENABLE THE MIX TO SUSTAIN ITS SHAPE DUE TO THE REDISTRIBUTION OF INTERNAL FORCES, THEREBY REDUCING DEFORMATION.

Exploring new geometrical ways in which yeast-based mix can be printed, and stepping away from planar surfaces, is a strategy to transform the same area (m^2) into volume (m^3) by adding the Z-axis parameter. The non-planar surface is conceived as an object with space-making potential.

Toolpath strategies

Three types of curves were printed (simple curvature, double curvature, and closed curvature [Fig. 18] with the aim of, first, determining whether the geometry

could be retained after printing and drying, and second, whether different types of geometry affect the range of deformation. Three types of parametric lines were also printed: design lines, principal moment and test lines.

The design lines, inspired by Mapuche textile patterns (T4, T7, T12), also aim to provide stability by reinforcing (increased line density in the offset) the highest points of the curve.

The principal moment lines (T9, T10, T11, T14) are intended to retain the shape of the material, calculated using an extension of Grasshopper (Karamba 3D) through the generation of principal stress lines. Karamba 3D 2.2 generates the principal lines as a representation of the

principal stress directions (tension and compression), allowing the visualization and utilization of the flow of forces within a structure.

Additional tests (T6, T8, T13), were conducted as test for strength lines iteration. Test 5 (T5) aimed to demonstrate the effect of layering and to examine how color design is reflected across the printed surface.

Printing strategies

The preparation of the mix was determined by the total length of the toolpath (Main [Fig.26]). Depending on the layer, the mixture was prepared with or without color pigment.

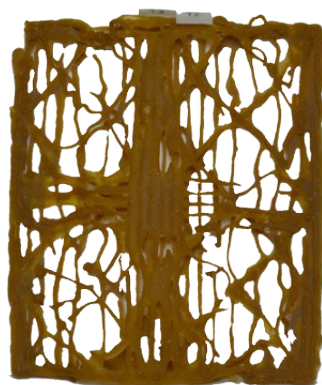
The final nozzle used was 2.8 mm in diameter, replacing the smaller 2.5 mm nozzle used during the first week, which proved inadequate for the required material flow [Fig.25].

Toolpaths were set with a 1.5 mm upward offset to create sufficient space between the material's thickness and the nozzle.

During printing, manual adjustment was required to correct printing-layer height variations. This need was significantly reduced in the final printing week.

The average printing time per sample was approximately 22 minutes, as shown in [Fig. 26].

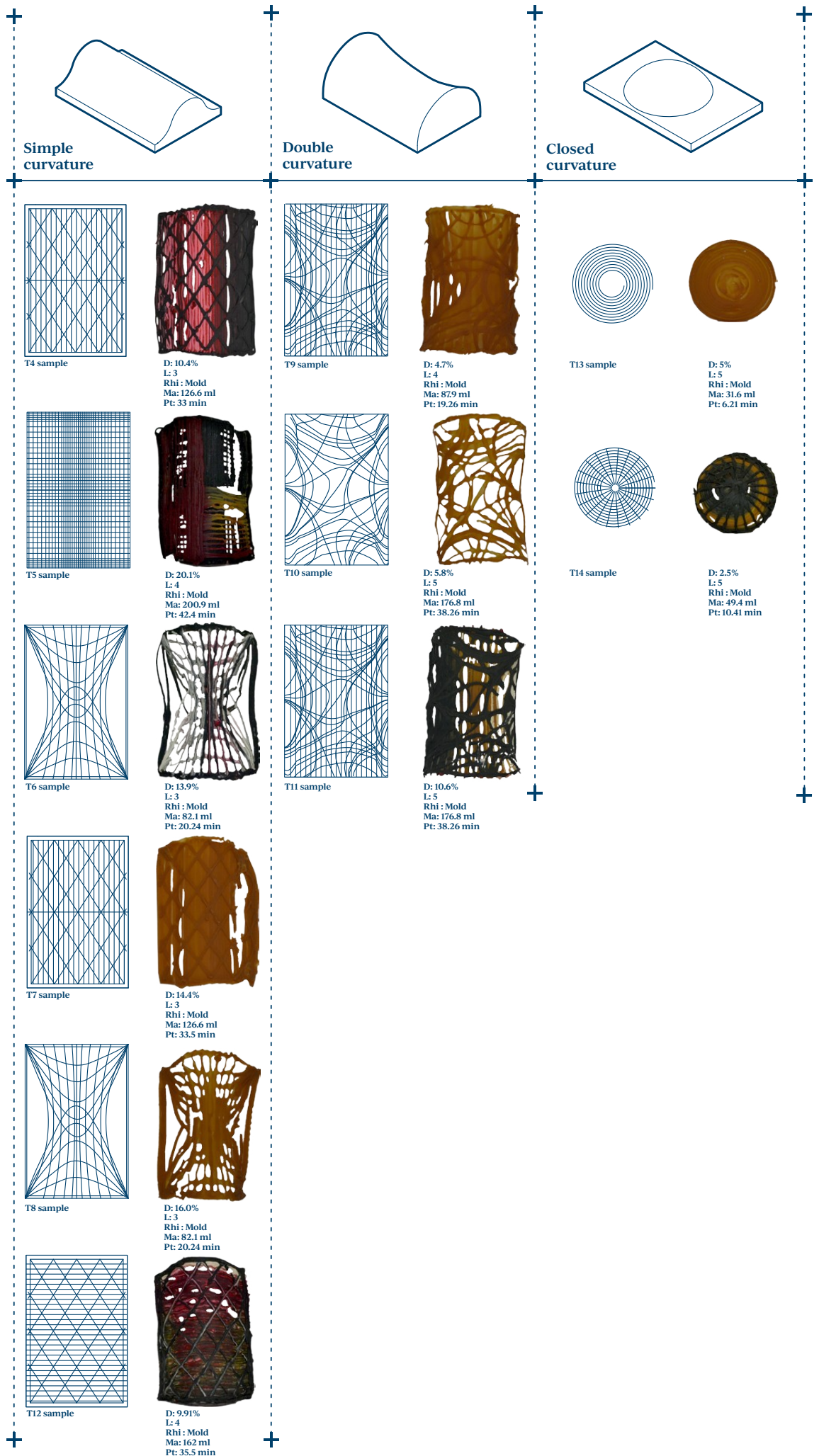




[Fig. 24]↑
The 11 samples scanned in 3D, shown in an isometric view.

[Fig. 25]←
A smaller nozzle and variations in the homogeneity of the material led to weaker printed lines, resulting in thin and fragile outcomes. Another factor was the robot head incidence; in this case, the syringe moved perpendicular to the XY plane (or the robot table). Photo corresponds to T1 and T2 glued together.

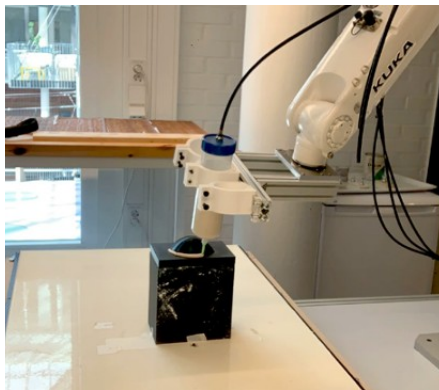
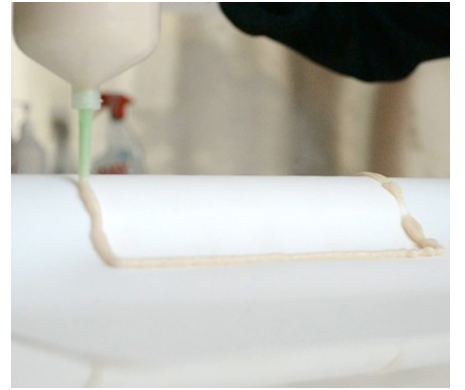
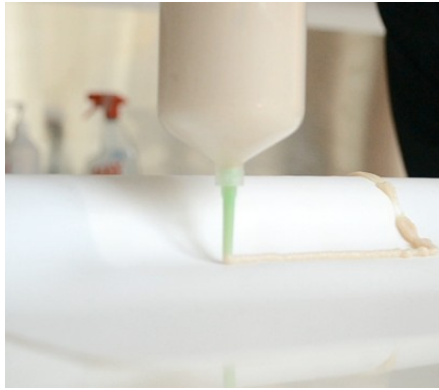
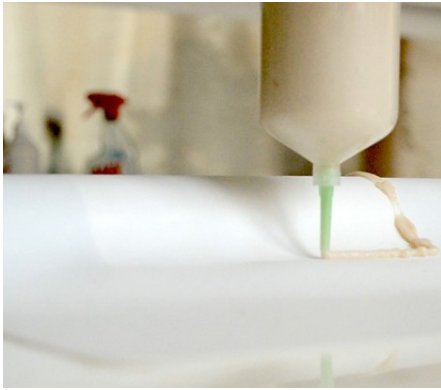
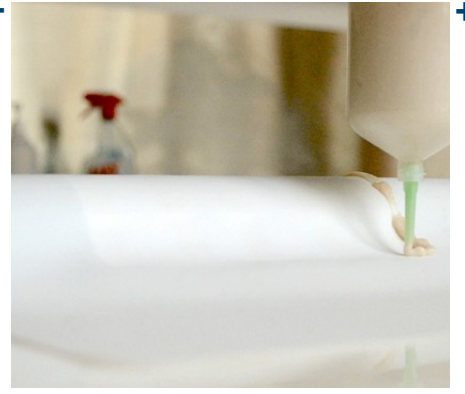
a) Type of curvature & mold.



[Fig. 26]→ Comparative table of all studied samples and their parameters:

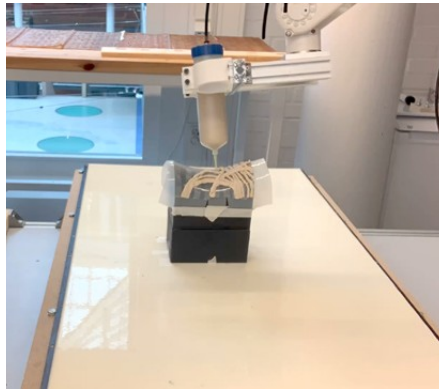
D: Deformation percentage
 L: Number of layers
 Rhi: Robot head incidence (perpendicularity)
 Ma: Total Material amount
 Pt: Total Printing time

[Fig. 27]→
Syringe (and nozzle)
running perpendicular
to the XY plane

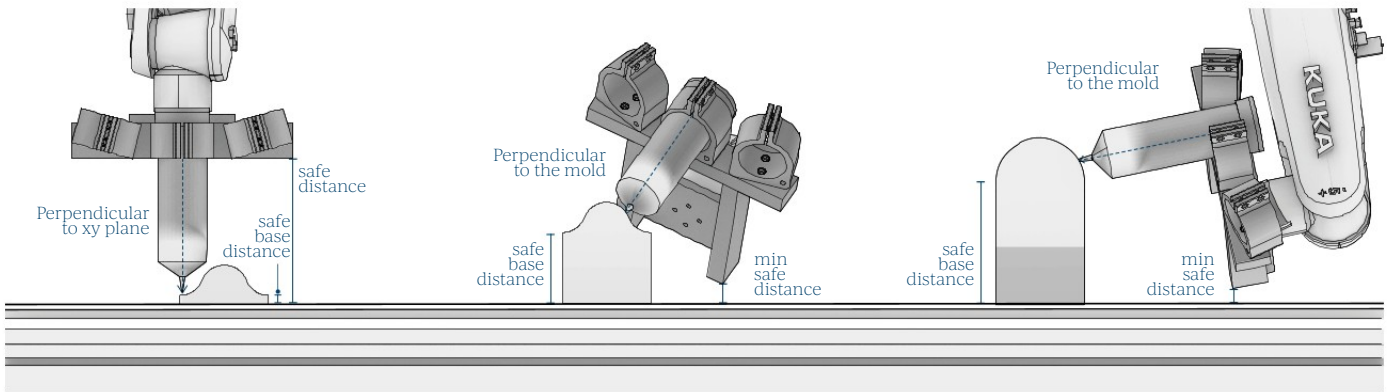
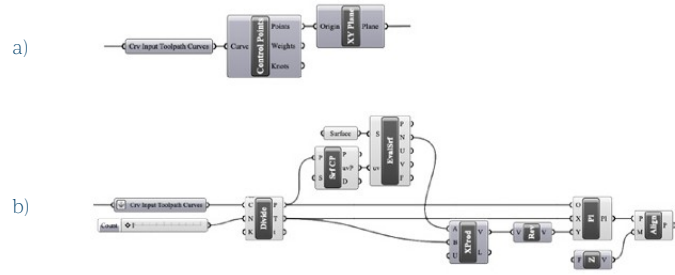


[Fig. 28]←
Robot head movements
when the syringe (and nozzle)
runs perpendicular
to the mold, with a controlled
angle to avoid robot head
collisions.





[Fig. 29]→
Robot head movements when syringe (and nozzle) runs perpendicular to the mold



[Fig. 30]←

Grasshopper component for controlling the robot's head relative to the XY plane or perpendicular to the robot table (a), and for positioning it perpendicular to the mold (b).

Molds

Molds (base dimensions 100 mm × 150 mm) for each of these geometries are printed using a Prusa MK4s 3D printer kit. Using PLA filament the focus was to print the most difficult geometries plus a 15% to 25% of a plint. For taller plinths, a cardboard parallelepiped was built to avoid using too much PLA filament..

The toolpath was adjusted to prevent collisions between the table and the robot head. For this purpose, a component was added in Grasshopper to the toolpath definition, identifying all potential collision areas. When a collision is detected, a red component appears, indicating that the mold position needs to be changed.

An important learning from the first week was that, when the nozzle was oriented perpendicular to the xy (or robot table), some material fell from a higher altitude (due to the difference between the silicone surface and the nozzle's angle), resulting in lower accuracy. Consequently, the nozzle orientation was corrected, and greater precision was achieved **[Fig.31]**. The adjustment was made in Grasshopper. All toolpaths included a rectangular frame, a lesson learned from a previous studio at Chalmers (**ACE510 Mediated Material Interfaces, 2024**).

[Fig. 31]←

The rotations of the robot head relative to the toolpath indicate certain height characteristics for the mold.

Processing data

To examine the deformation of each piece, all printed tiles were 3D scanned after drying using the Scaniverse app.

The resulting geometries contained an average of 37k vertices and 56k triangles. For greater accuracy while scanning, samples were suspended using transparent fishing line. Photographs were taken with an iPhone XR, equipped with a 12 MP camera and an f/1.8 aperture. The resulting files were cleaned and edited in Rhinoceros 7.

Afterwards, in Rhino, each scanned piece was positioned on top of its corresponding digital mold and anchored at its closest vertex. To quantify the deformation, a mesh of several points was extracted from the upper surface of the mold and subsequently projected onto the underside of the scanned piece. The average distance obtained from this projection was then compared with the average distance between the mold points and the mold centroid, and the resulting difference was expressed as a percentage of deformation [Fig.32].

Conclusions

Laboratory testing demonstrated that the 3D form could be preserved due to the stability achieved through double and closed curvatures, supported by the incorporation of principal force lines maintaining its shape fidelity.

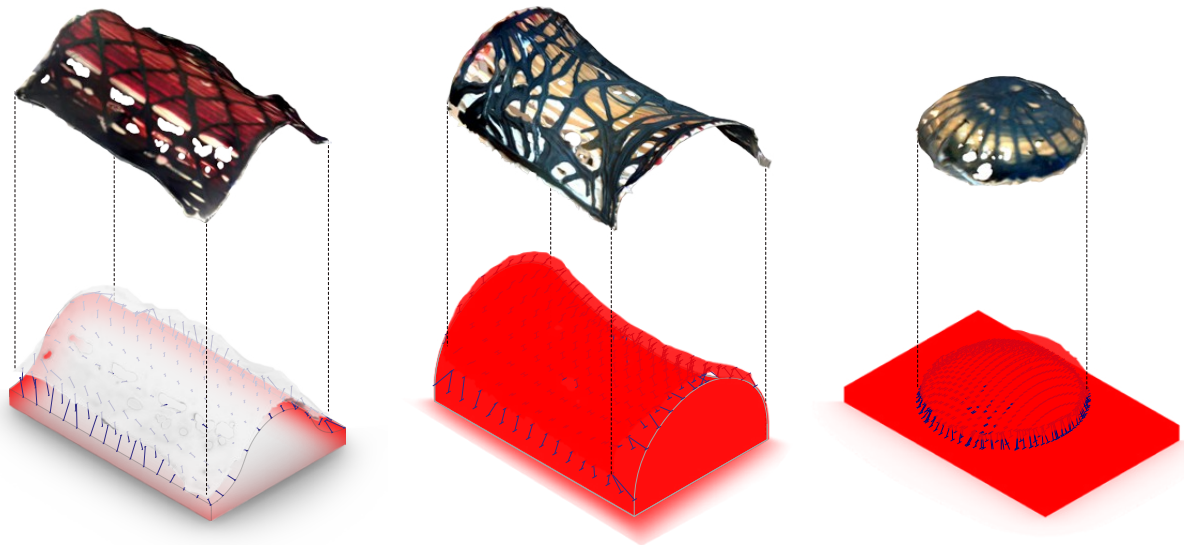
In the final iteration, where principal lines were applied within both double and closed curvatures, deformation was noticeably reduced. As indicated in [Fig.33], these curvature types proved significantly more effectiveness at preserving shape than simple curvature.

[Fig. 32]->

Diagram showing the process of comparing the 3D-scanned sample with the digital mold using Rhino and Grasshopper.

[Fig. 33]->

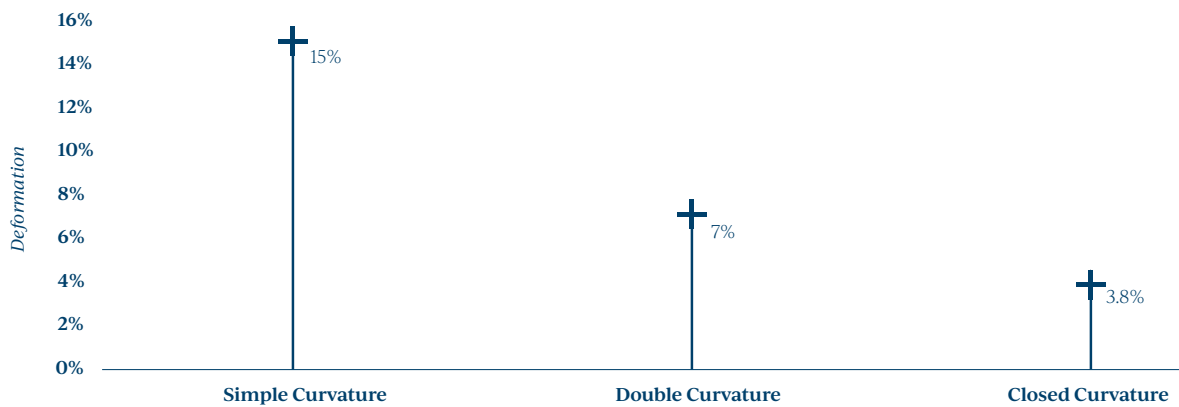
Percentage of deformation obtained through digital comparison.



Deformation $\frac{d1}{d2} \times x$

d_1 = average distance between dry sample points and mold points

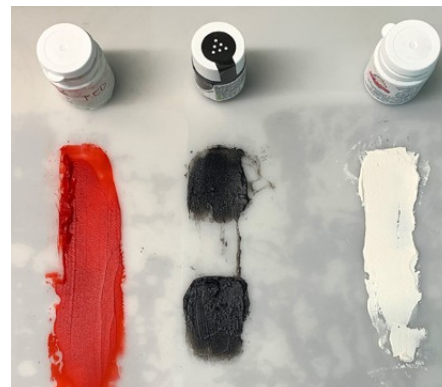
d_2 = average distance between mold points and the center of the mold (centroid)



C O L O R

Color was introduced through the addition of edible color powder (Squires Kitchen, QFC) in varying quantities, as detailed in **Fig. 26**. The introduction of color was primarily used to compare each sample with its natural color printed version (**T1, T2**) or to examine layer behavior, as in **T6**.

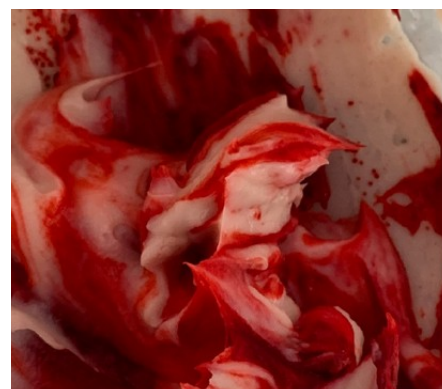
Red, black, and white pigments were used in different weight ratios according to the behavior observed each week. For instance, black pigment exhibited high stability (almost no fading) and was suitable for defining boundaries, whereas red and white pigments blended



[Fig. 34]↑
Different tests using the color and Mix B proportion from the first week.

[Fig. 35]↓
Image showing the preparation process of Mix B with red food coloring incorporated.

[Fig. 36]→
Sample T4 in a wet state close-up



QUESTION: CAN ADDING COLOR TO THE MIX REVEAL CORRELATIONS WITH ITS DISPOSITION?

HYPOTHESIS: COLORS MAY EXHIBIT CORRELATIONAL PATTERNS IN THEIR BEHAVIOR DEPENDING ON THEIR LAYERING ORDER.

more rapidly with other colors and were more reliable for creating gradient effects.

Consequently, a reduction in pigment weight was applied during the third week, as shown in **[Fig. 26]**. While black and white maintained their stability, the red mixture required an increased pigment weight; therefore, it is recommended to return to the second-week proportion.

Samples **T6** and **T12** indicate that the red pigment exhibits a higher migration tendency toward adjacent white and black samples, whereas the reverse transfer was not observed. For this reason, red was primarily used as a base layer.

To assess color variation, both wet and



dry photographs of each sample were taken. Color comparison was performed digitally using Adobe Photoshop CC 2017.1.1, analyzing HSB, as these provide a more accurate representation of potential color decay **[Fig.37]**. Both images were white-normalized prior to analysis following the method published in **Zboinska et al., 2023**.

Conclusions

Shifts in color were observed in relation to both the layering sequence and the variation in pigment weight.

Black pigment begins with low saturation but reaches nearly full intensity once dry. The quantity of pigment powder has little influence on black's final tone, which darkens consistently across all methods. Red behaves differently: greater pigment weight leads to stronger initial saturation and a smoother desaturation process. White maintains steady desaturation, showing minimal variation through the drying phase.

Both red and white exhibit interaction with nearby colors : red, in particular, tends to be absorbed by others, mainly black line layers.

The data **[Table 1]** shows that red tends to lose saturation when drying, unlike black, which gains saturation. White also tends to lose saturation as it dries. Overall, the data show a clear pattern: lower pigment amounts lead to greater variability in color response, making samples more sensitive to wet/dry conditions.

[Fig. 37]↗

Sample photos comparison, images taken in both dry and wet conditions for saturation analysis.

[Fig. 38]→

Table 1 in relation of color change saturation.



| Sample - Curve type-Ncolors* | Color Powder (gr) | | | Color Change (HUE (S)) % | | | | | |
|---------------------------------|-------------------|-------|-------|--------------------------|-----|-----|-----|-------|-----|
| | black | red | white | black | | Red | | white | |
| | | | | wet | dry | wet | dry | wet | dry |
| T4-sc-color 3 | 0.7 | 0.116 | 0 | 7 | 29 | 100 | 85 | 0 | 0 |
| T5-sc-color 2 | 0.7 | 0.116 | 0 | 8 | 22 | 98 | 23 | 0 | 0 |
| T6-sc-color 3 | 0.7 | 0.116 | 0.18 | 10 | 15 | 40 | 43 | 2 | 43 |
| T12_sc_color3 | 0.3 | 0.05 | 0.08 | 71 | 55 | 81 | 52 | 45 | 28 |
| T11-dc-color3 | 0.3 | 0.05 | 0.08 | 18 | 54 | 74 | 60 | 29 | 3 |
| T14-cc-color 2 | 0.3 | 0.05 | 0 | 4 | 14 | 49 | 42 | 0 | 0 |

* Only colored samples are compared

TEMPORALITY

Chapter II Methods

QUESTION: HOW CAN TEMPORALITY AS A DESIGN VALUE BE ADDRESSED IN THE DESIGN PROPOSAL?

HYPOTHESIS: TEMPORALITY MAY OPEN NOVEL PERSPECTIVES ON HOW AN ARCHITECTURAL APPLICATION IS MATERIALIZED.

Due to the scope of the work conducted in the robot lab, *temporality* was addressed through visual research. Two different experiments were made:

In the first, a manually extruded sample (13 cms diameter) was placed outdoors for one week [Fig.40]. The weather conditions are summarized in; temperature, humidity, wind and rainfall. As shown in the photographs, the sample deformed gradually, sagging downward due to gravity.

The second visual observation involved three tubular samples: one made from natural (non-colored) yeast (8 cms tall), one black (4 cms tall), and one red (2.5 cms tall) [Fig.39]. Despite the environmental conditions of those days, the natural pillar showed minimal deformation, whereas the colored samples exhibited more noticeable changes, likely due to their thinner geometry.

After several days, the natural-colored pillar attracted birds, which pecked at small areas of the surface (a). The presence of mold growth at the base of the sample also appeared to draw their attention. Smaller birds were observed entering the

hollow structure, possibly in search of food. Ultimately, the experiment concluded when a Pica pica (Eurasian Magpie) carried the sample away.

Conclusions

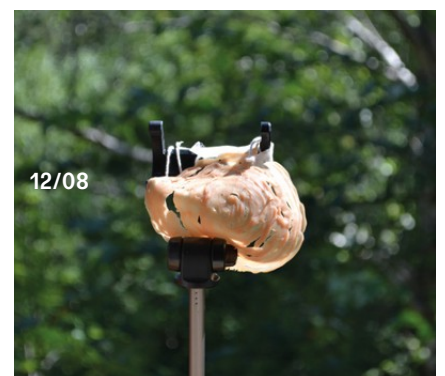
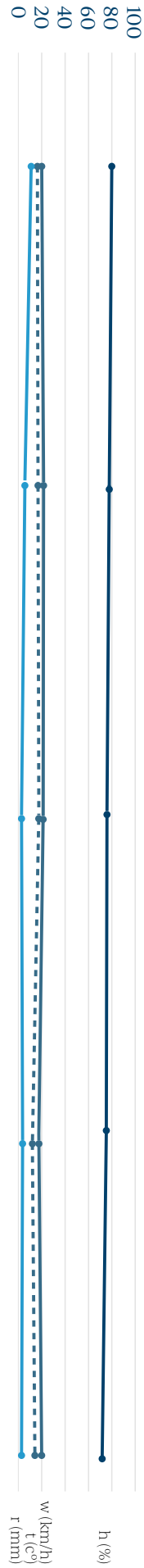
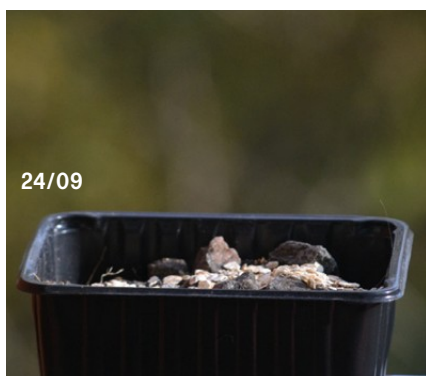
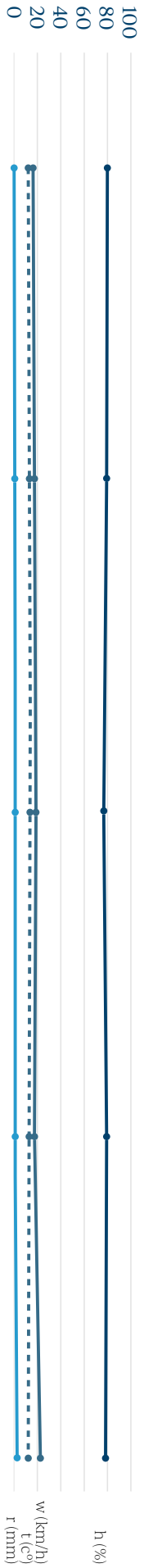
Observations indicate that the material lacks long-term stability to preserve its form under natural environmental exposure. However, this limitation may offer new opportunities in relation to temporality and adaptive design.

Its biodegradability makes it particularly suitable for temporary structures or iterative pavilion prototypes. Moreover, the material's natural decomposition aligns well with circular economy principles and cradle-to-cradle (g) design, reinforcing its potential for sustainable life-cycle applications.

The laboratory phase provided valuable insights into the design potential of yeast-based materials, revealing their relevance as a foundation for future architectural experimentation and material-driven innovation.

[Fig. 39]→→
Sequence of the yeast Mix B material sample, left outdoors on a small stand. Corresponding climatic parameters are presented in their respective units of measurement.

[Fig. 40]→
Sequence showing three pillars made of yeast Mix B: the main one in its natural coloration and two smaller ones in black and red. Corresponding climatic parameters are presented in their respective units of measurement.



Temporality

D E S I G N S T R A T E G I E S

The work carried out in the laboratory provides the foundation to continue with a design proposal.

The concepts that guided the lab work (geometry, color, and temporality) are translated into design strategies: Shape fidelity (geometry), Color Shift, and Biodegradation (temporality).

Based on their capacities and conclusions, a set of design strategies is established:

Pillars (shape fidelity):

It is possible to successfully retain double curvature, and even simple curvature.

Scaling up the double-curved pieces suggests the potential for a 1:1 construction. The union between pieces could be achieved using glue or other biocompatible systems that preserve their biodegradability

The geometry conceives a skin; this skin, depending on the design, could become a translucent linear solid, a force-line mesh, or a rhomboid-type pattern of designed lines.

There is also the possibility of exploring layering: either double layering or a single, toolpath-designed skin.

Color Shift (color) and Layering:

The stability of the color depends on its density, layering, and proximity. Certain design rules must be applied, as described in [Pag. 48].

Since layering is necessary, creating offset layers could be an interesting

strategy, separating the layer from the main skin may generate ecological value by allowing other forms of life to grow.

For instance, insects could proliferate or vegetation could grow, possibly attracted by color, as observed on page 50.

Biodegradation

Its durability is related to the surrounding environment. Decay can be understood as a value : particularly when applied to specific spatial conditions, for example, in testing scenarios.

As observed, material degradation may occur over time; therefore, the pillars will be diversified into different types: Some will include support systems that enable repair, while others will not, allowing them to decay according to their biological and physical time lines.

There is a high likelihood of interaction between the pillars and animals. The possible destruction caused by animals becomes part of the living structure; a way to express its bio-friendly and time-dependent characteristics.

[Fig. 41]→
Diagram illustrating scanned pieces and their strategies for pillar assembly, color usage, and biodegradability considerations.



CHAPTER

D E S I G N

III

P R O P O S A L

DESIGN PROPOSAL

A POSSIBLE SITE

The project's conception is rooted in itself; however, a possible site is necessary to establish spatial and environmental constraints.

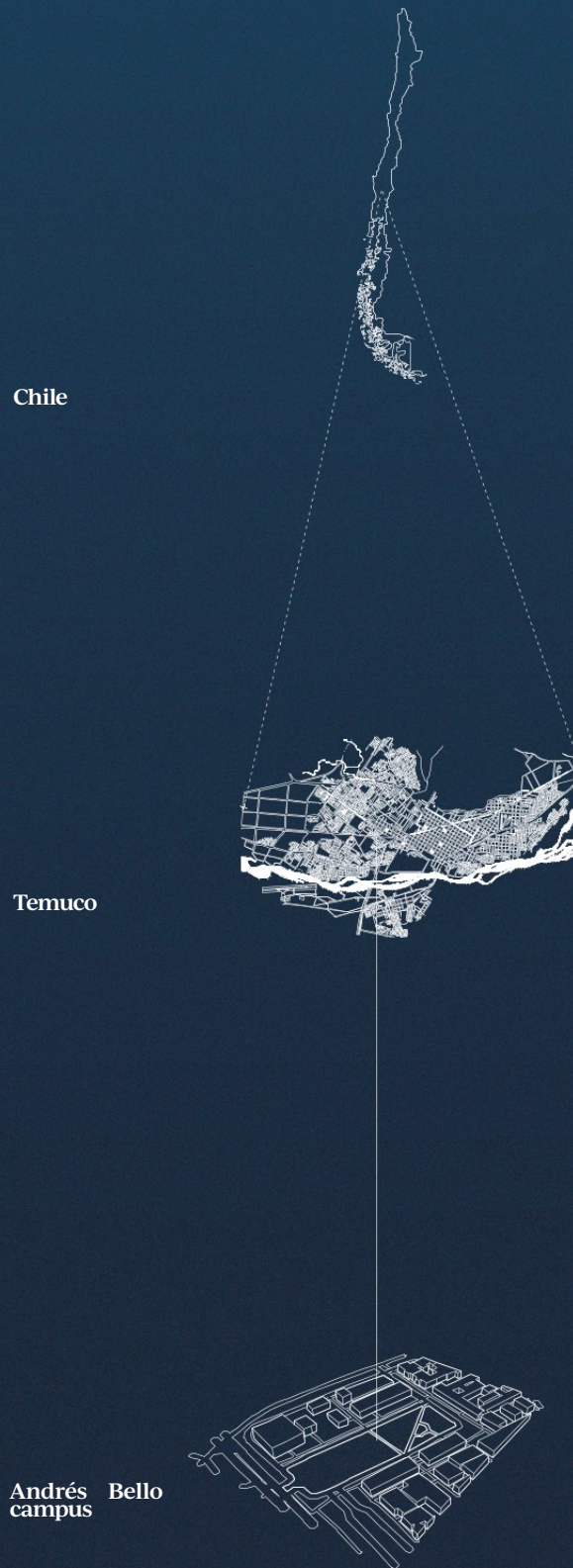
Selecting a location for this first attempt to build with yeast requires identifying agents aligned with the project's main findings: biodegradation, color shift, and stiffness.

Therefore, the chosen context should bring together both researchers who can work with the material and communities capable of engaging actively with the project.

In this case, a potential site is located within the public green areas or forest surrounding the University of La Frontera (Andrés Bello campus), in the Araucanía region, Temuco, Chile.

Temuco has a high percentage of Mapuche population (23,97%) (INE, 2018), many of whom study or work at the university. The institution itself promotes interdisciplinarity and hosts the Indigenous Technological Congress every year.

No specific site has been selected; instead, the chosen location will serve to contextualize and reference the ongoing project.



[Fig. 42]→

The site is conceived more as a triad of conditions: Mapuche communities, academia, and the ecological environment. Therefore, Temuco is proposed as a potential location for the project, and the context of local flora and fauna in the project's development is anchored in this setting.

AN OPEN PAVILLION FOR YEAST

How can something that has never been shown before be revealed? One possible approach is through a pavilion: a free and open space where people can interact and researchers can observe.

The initial architectural gesture is inspired in budding, the reproductive motion of yeast [Fig.43].

It begins with a single point (O) that multiplies according to the spatial requirements needed for circulation [Fig.44]. To define boundaries, tangential circles are generated between two tangent lines.

The resulting composition forms a floor plan that anchors the pavilion to the site.

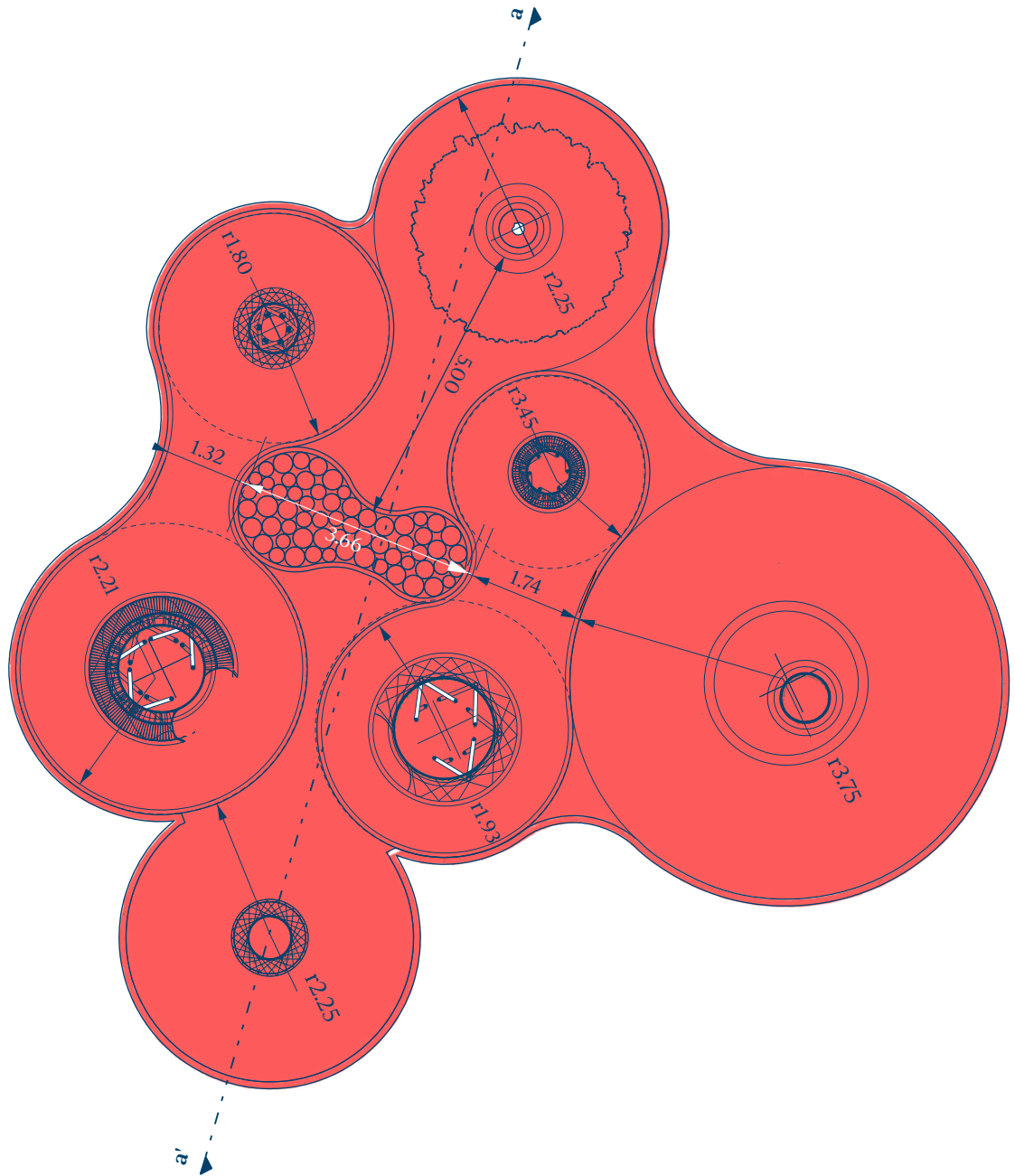


[Fig. 43]← Schematic representation of yeast budding, illustrating the logic of reproduction and repeated multiplication used as a conceptual basis for creating the pavilion.



A=1 mts
B= A x 1.25 mts

[Fig. 44]← Two different dimensions (A and B) are used to define the pavilion's size. Circles without marked dimensions result from tangential circles to those marked with dimensions.



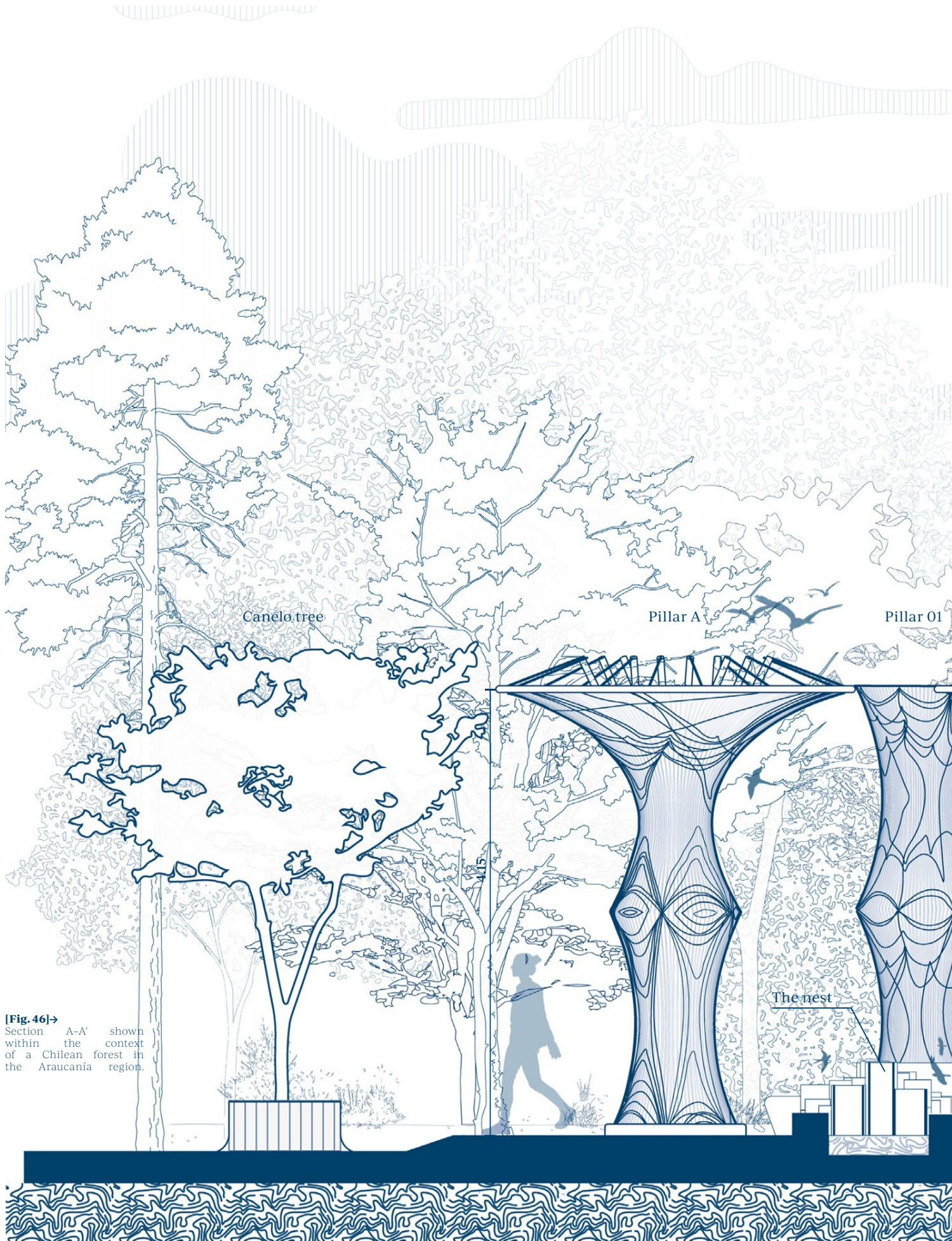
[Fig. 45]
Floor plan of the
Yeast Pavilion project.

Floor plan

The pavilion's floor plan emerges from the multiplication of a single point and its capacity to expand according to tangent relationships, governed by the minimum circulation distance. This distance, defined as A (1 meter), is preserved as long as the geometry allows the circulation path to bifurcate or connect to another route. This generative behaviour closely resembles the asexual reproduction of *Saccharomyces cerevisiae*, where a single cell produces multiple offspring through budding, resulting in exponential multiplication.

In terms of how the pavilion is spatially configured through the design strategies, each circle's centroid hosts a set of programmatic and material elements: one canelo tree (the sacred tree of Mapuche), two biodegradable non-structural pillars, and four biodegradable pillars with an internal structure. This arrangement introduces a temporal dimension to the pavilion, as certain pillars will gradually degrade and disappear while others will require periodic maintenance or replacement.

Each pillar originates from a fully double-curved base (specifically, a hyperbolic paraboloid) meaning that its longer edges terminate not in straight lines but in continuous curves. This geometry enables the formation of a doubly curved enclosure, providing both spatial coherence and structural intention.



[Fig. 46]-> Section A-A' shown within the context of a Chilean forest in the Araucanía region.

Section

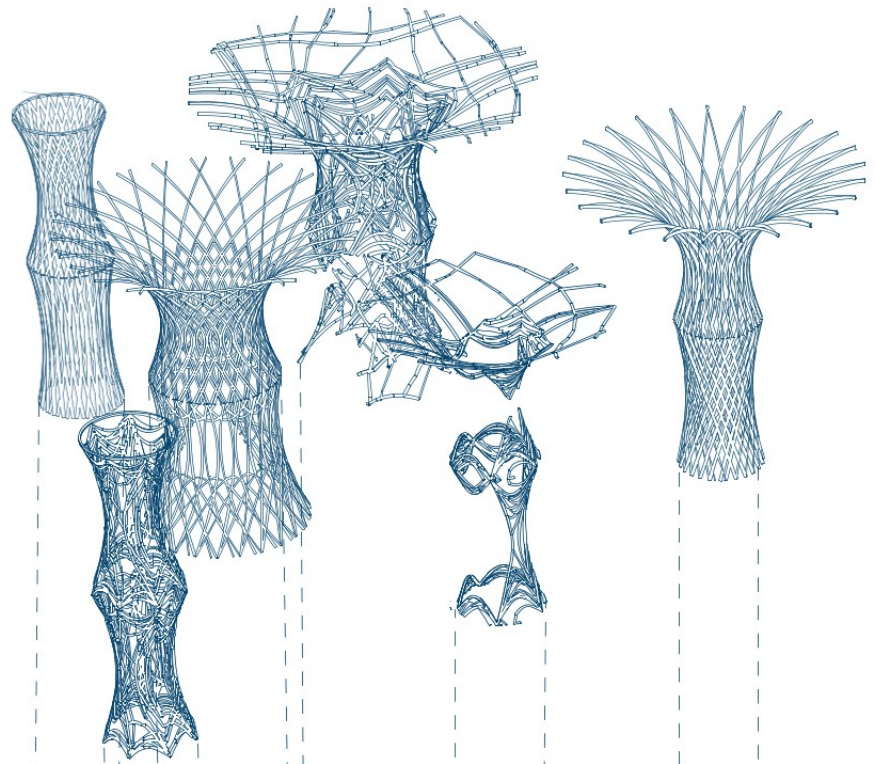
In section A-A', two non-structural pillars (**pillar 01 & pillar 02**) and two structural ones are shown (**pillar A & pillar B**). The structural pillars are allowed to expand more dramatically at their crown, reaching the same diameter as the projected circle in which they are inscribed. Some of these structural pillars may remain open, allowing visitors to enter and observe the interior: where, for example, plants may grow or sunlight may filter through. Both the principal lines (derived from the structural behavior of the pillar) and the design lines (inspired by Mapuche geometry) can be observed.

The circulation, generated through the system of tangent circles, creates a fluid and dynamic movement through the pavilion. At the center, **the nest** can be found, composed of several non-structural pillars that recall the manual experiments shown on page 51. This cluster is expected to attract small birds and insects, activating the space just as observed in the material prototyping phase.

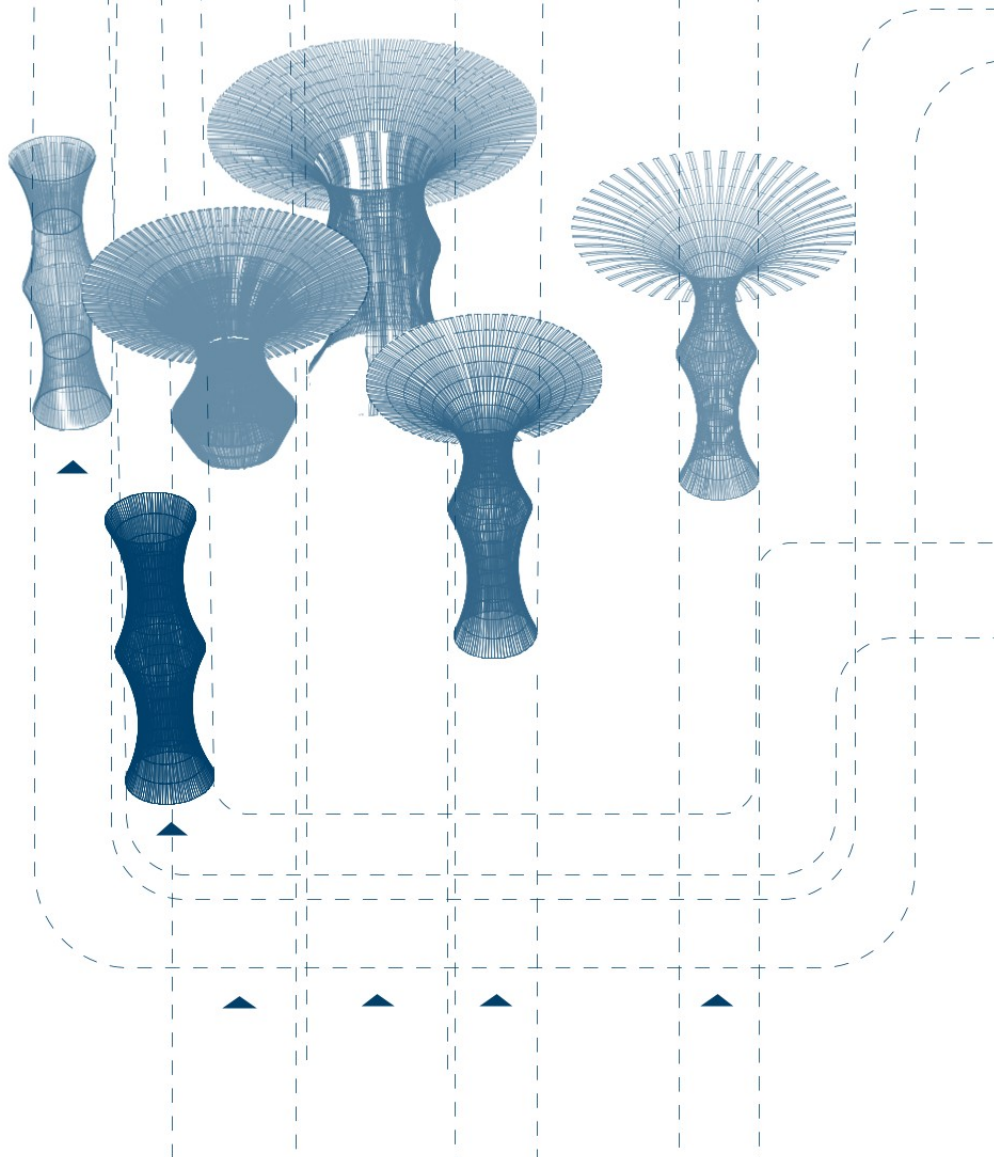


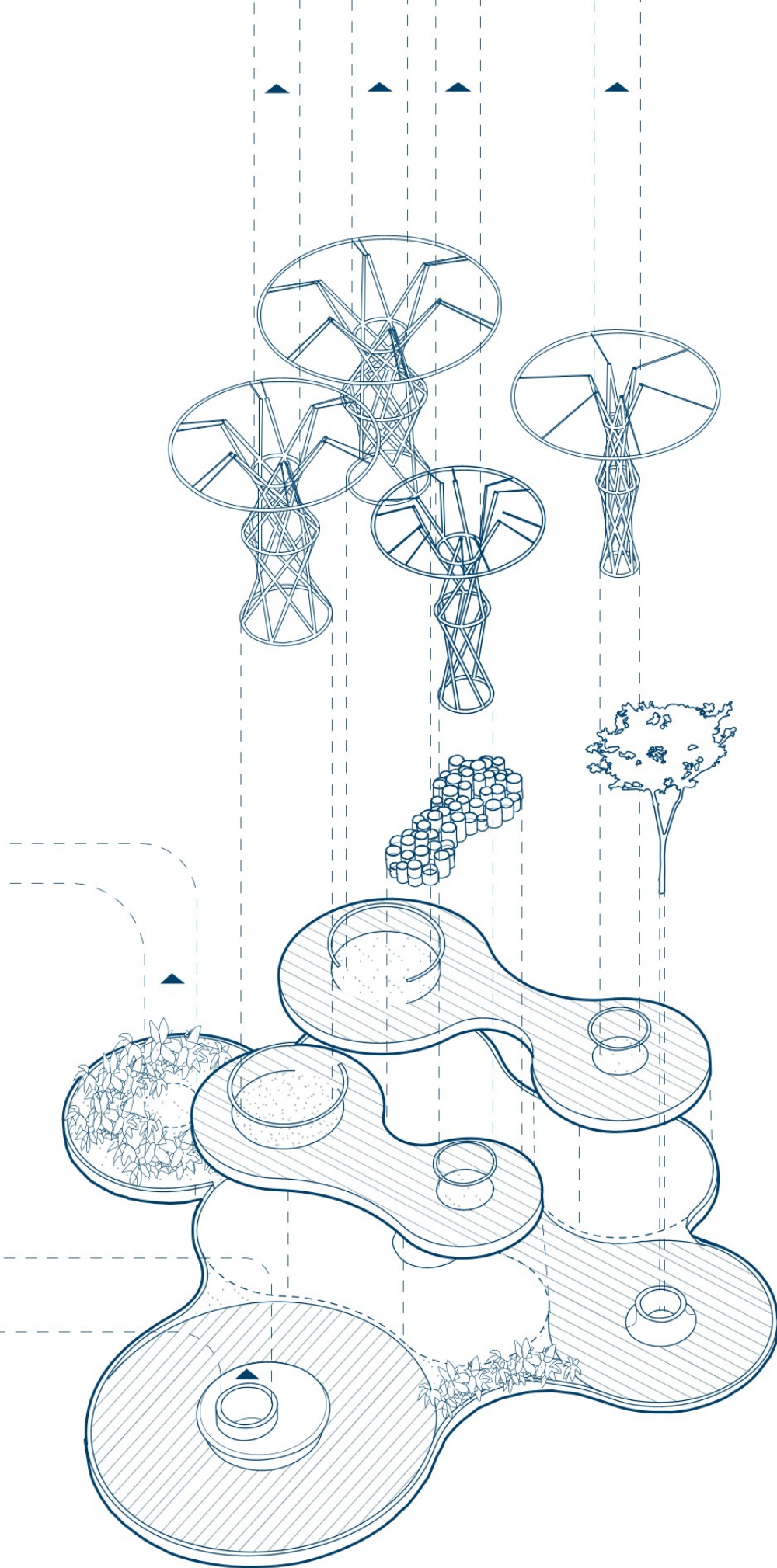
Exploded isometric

→
The final layer (either printed on top of the second sub-layer or produced as a separate printable component) corresponds to the principal lines or the design lines. These are generated from a single toolpath printed twice along the same trajectory, with sufficient offset to provide structural thickness..



→
A first printing layer of the yeast-based mix is applied in linear toolpaths to provide an initial structural membrane. This first printed component is composed of two sub-layers: the first formed by vertical lines and the second by horizontal lines, following the geometry of its mold.





←

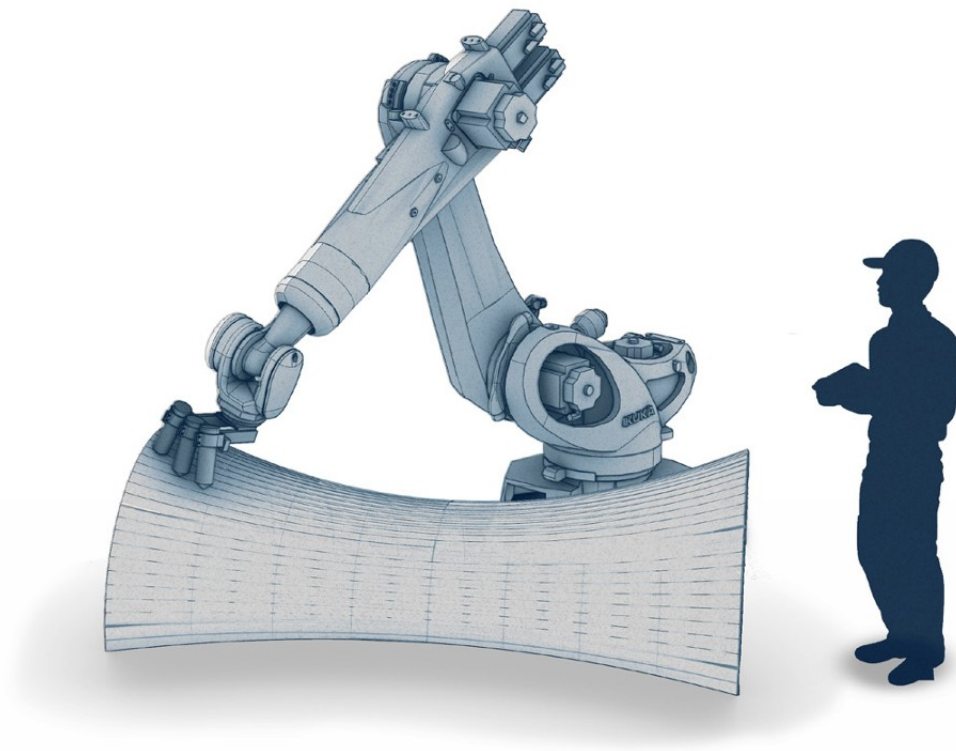
A helicoidal structure made of curved coligüe is proposed for the superstructure, with all joints secured using organic rope ties (cañamo). The upper ring is supported by 3 mm recycled steel tension cables.

←

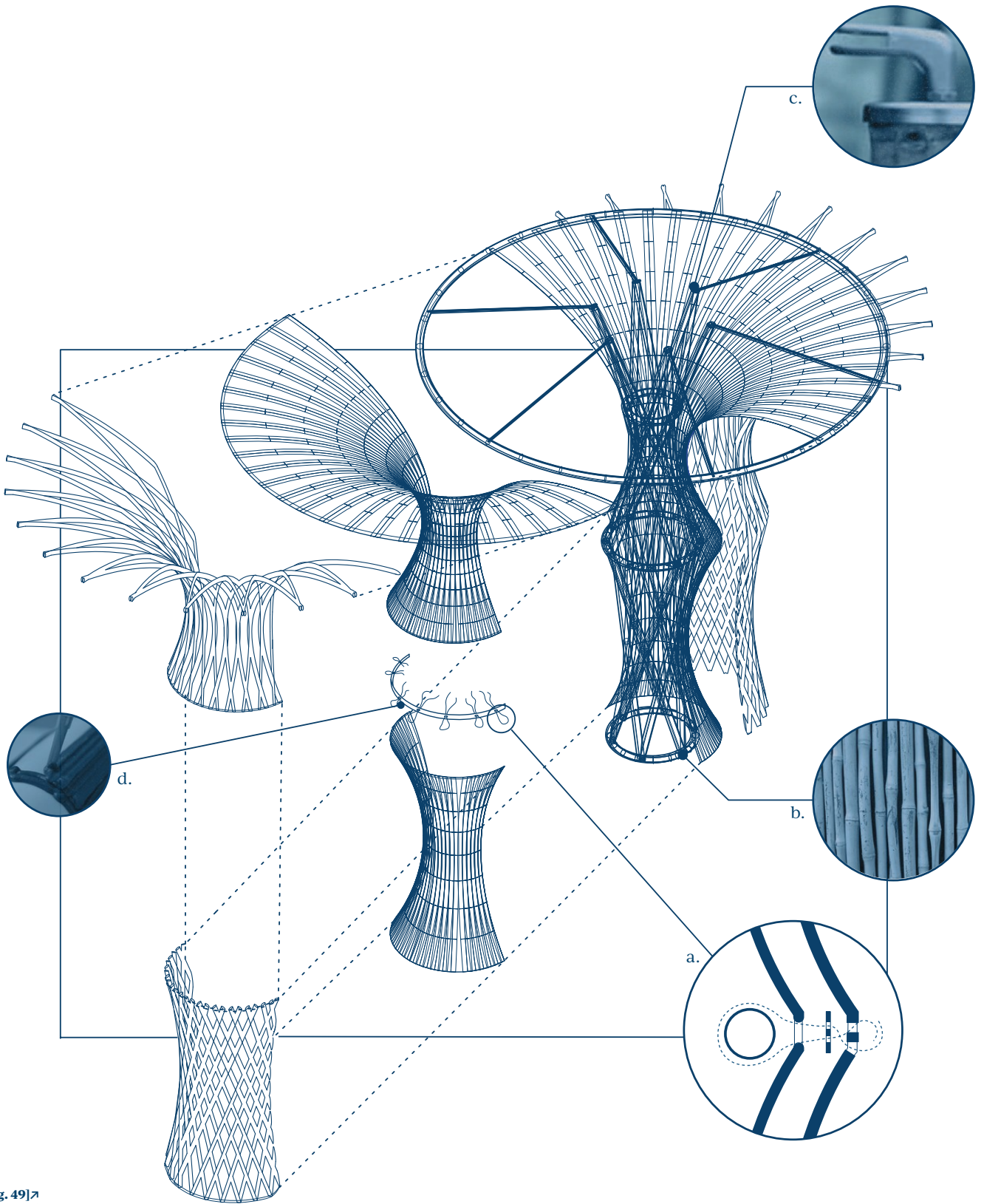
The base of the project consists of a deck made of sustainably sourced, certified pressure treated pine from local sawmills. It is stained with a black plant-based dye. The foundation uses pressure-treated pine posts embedded 60 cm into the ground, upon which the deck's grid structure is established.

[Fig. 47]←

Exploded axonometric view showing four distinct layers: floor, structure, printing layer A, and printing layer B.



[Fig. 48]↑
Diagram illustrating the feasibility of printing a 2.05-meter component using the KR 120 R2700-2 robot currently operating in the Robotic Fabrication Laboratory at the Department of Architecture and Civil Engineering at Chalmers University of Technology.



[Fig. 49] Exploded axonometric view showing four distinct layers: floor, structure, printing layer A, and printing layer B

- a.** Proposed rope-anchoring system designed to avoid drilling holes into the piece after printing.
- b.** Chilean coligüe (Chusquea culeou), a native bamboo-like species with structural properties similar to bamboo.
- c.** Steel-tension cable anchoring system.
- d.** Double-toolpath reinforcement used to create a structural belt for securing the assembly.



[Fig. 50]↑
Diagram illustrating the potential for non-structural pillars (top) to fully biodegrade, and for structural pillars (bottom) to be repaired, support plant growth, and interact with animals.







[Fig. 51]←
Image of the pavilion with-
in the context of a Chilean
forest in the Araucanía
region, a dense forest typi-
cal of areas surrounding
Temuco. The pavilion is
designed to biodegrade
over time, contributing to
the enrichment of the soil.



[Fig. 52]↑
Image of the pavilion and its potential behavior with light. As observed, when the material is not colored, light tends to pass through it, in contrast to the red-colored pillar in the foreground.



[Fig. 53]↑

Image of the nest, located at the center of the project. This nest is intended to replicate the outdoor experiments described on page 50. Small animals may be attracted to its spatial form, color, and potential scent.



[Fig. 54]↑
The pavilion is designed as an interactive architectural installation, intended to be touched and explored; its texture, form, and material novelty are meant to engage visitors.



[Fig. 55]↑

It functions as an educational space, not only about this specific project but also about sustainable architectural materials and the potential of yeast as a viable construction material.

CHAPTER

IV

D I S C U S S I O N

CONCLUSION AND REFLECTIONS

AGENCY, MATERIALS, AND ARCHITECTS

Conclusion

“*What do you want (to be), yeast?*” was the provocation that triggered this research, opening a broader perspective on how to position oneself when approaching the study of the material. If the initial question served as the spark, then the thesis question¹ guided the in-depth exploration of the material, using architectural materialisms theory as the primary tool for shaping the framework for the laboratory research. Through this process, the thesis sought to highlight the importance of the architect’s role in the early stages of material research.

A connection between the answers to architects on page 16 and the thesis workflow diagram is established [Fig. 56]. Using this as a matrix, it becomes possible to observe that architects make a unique contribution to material research due to the following points:

1.- Architectural design logics

Architects work with characteristics that are visible, such as geometry, color, degradation, light, and other aspects of spatial design. This approach is uncommon in material research, where the capacities (mechanical, chemical, or physical) are tested rather than what the material is capable of in an architectural context (Purker et al., 2023). Therefore, novel perspectives emerge from this distinction; for example, biodegradation, shrinkage, deformation, gaps in the mixture, or printing errors might initially appear as flaws, but from an architectural perspective, such faults can be reinterpreted as opportunities for exploring uses beyond permanence.

In this thesis, decay is considered a value; geometry is treated as an opportunity to increase volume; and

colors are considered a possibility to engage non-human creativity.

2.- Socio-ecological perspective

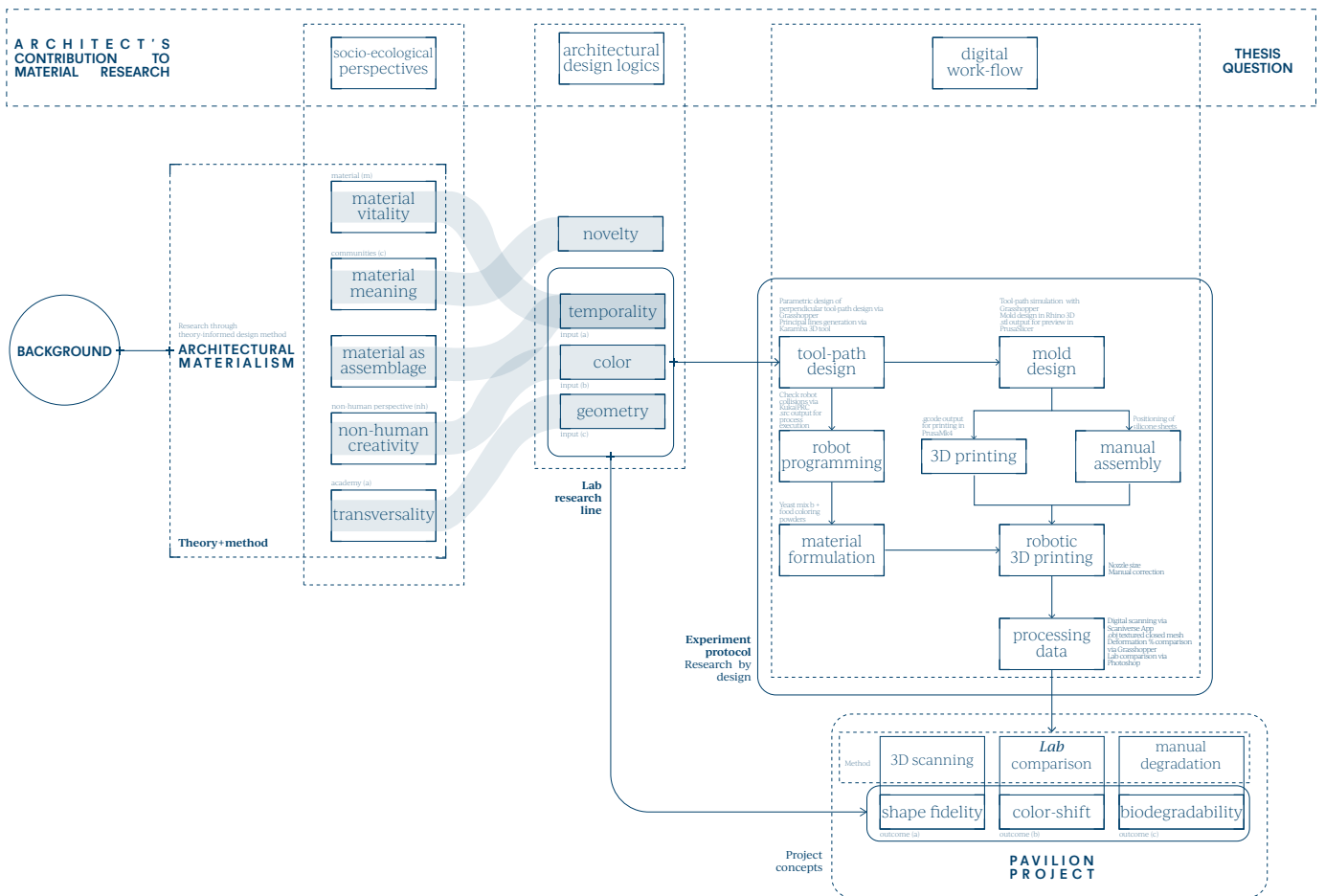
In architecture, research through design is traditionally at the core of the architectural method. However, this thesis proposes the use of a research-through theory-informed design method. In this approach, theory provides the necessary conceptual groundwork that precedes and enables the subsequent research-by-design phase and its practical experimentation in the laboratory. The theoretical framework (in this case, architectural materialisms) offers a holistic lens for material research, helping to position and situate materials within broader contexts. Ecological considerations (such as sustainability) have long been incorporated into architectural discourse, but architectural materialisms extend this approach by emphasizing relational, socio-ecological, historical, and non-human dimensions of material agency.

- Digital workflow

This thesis also revealed the current state of material investigation in architecture. As digital development increasingly permeates the discipline, architectural practice is shifting from working with forms as final states to programming and analyzing the processes through which those forms are created. New technological tools enable architects to work in a more data-driven and analytical way.

For instance, biomimicry is no longer focused on copying biological shapes but on analyzing the physical dynamics underlying geometric behavior. It is well documented that the use of digital scanning and visual programming languages (such as Grasshopper) serves as a bridge between architects and other disciplines, including biology, fostering interdisciplinary collaboration and shared modes of analysis (Oxman, 2021).

‘WHAT COULD THE PROCESS OF INVESTIGATING A MATERIAL THROUGH ARCHITECTURAL MATERIALISMS HIGHLIGHT ABOUT THE IMPORTANCE OF ARCHITECTS’ INVOLVEMENT IN THE EARLY STAGES OF RESEARCH INTO DEVELOPING NOVEL SUSTAINABLE BIO-MATERIALS?’



Conclusion

[Fig. 56]↑
 Diagram illustrating the complete workflow of the thesis, showing inputs and outputs leading to the thesis question resolution and the project design.

The future of bio-fabricated materials in architecture is promising, especially if we, as architects, take a serious and proactive position, one that assumes responsibility and agency in shaping how these materials will be developed and implemented. This thesis represents one way of exercising that agency, through a theory and a procedure that remain flexible enough to support a complex and wider material research.

Limitations and future work

Throughout the development of this thesis, it became evident that several issues must be addressed in future work. For instance, one limitation of applying architectural materialisms through a non-human perspective is that the personification of nature ultimately relies on human interpretation, which inevitably brings the discourse back to a human-centered standpoint. A more comprehensive and rigorous understanding of this approach is therefore required.

Similarly, if the aim is to develop a new material while connecting it with communities (as this thesis approached with caution and respect, explicitly avoiding speaking on behalf of any community) future research should include structured community participation processes, integrate these groups as active contributors to the investigation and work, and hopefully engage with processes that allow for alterity (**Labra Mocarquer, 2024**).

This aligns with the delimitations stated in the thesis, which acknowledge the need for deeper engagement beyond the scope of this project.

From its very beginning, this thesis did not aim to bypass the importance of the material science perspective; on the contrary, it sought to open up the workflow to integrate architecture as a way of thinking. It acknowledges that parallel, previous, and subsequent steps should be carried out through a multidisciplinary, back-and-forth

process, as is happening nowadays with the PhD research mentioned previously. Knowing that the material has shape fidelity, it is now possible to explore other approaches. For example, it is possible to digitally design a workflow that interacts with weather phenomena to improve performance outdoors. The material could even be shaped by humidity behavior or light behavior.

One of the advantages of robotic printing and additive layer manufacturing is that no molds are typically required. However, for this type of yeast-based material, a scaffold was necessary. Further research into non-planar geometries should therefore explore alternative methods that eliminate the need for scaffolds or, ideally, investigate how the material itself could be enhanced to function as its own structural support.

Architectural materialisms is not the only framework capable of providing a background that encompasses socio-ecological concerns to material research. LCA-based self-assessment tools for materials have also recently been developed to integrate socio-ecological perspectives (**Stoycheva et al., 2022**). Both approaches can operate in parallel, enriching material-related decision making.

This thesis engaged deeply with novelty: novelty in the material and novelty in the theoretical approach. For this reason, the expected contribution to architectural discourse is the provision of a flexible methodological tool and theoretical approach that establish a strong conceptual foundation. This foundation provides a coherent and unified framework for material research in architecture, highlighting the importance of architect's involvement in the early stages of material development.

AI DISCLAIMER

In this thesis, the use of AI was limited to non-creative modes. Images enhanced with AI were generated from images provided and processed for the author through Rhino, Grasshopper and V-ray, enhanced in relation to light, greenery, and people, and all final results were post-processed in Adobe Photoshop CC 2017 1.1.

**[Fig.50], [Fig.51], [Fig.52],
[Fig.53], [Fig.54], [Fig.55].**

No AI was used to generate text; AI tools such as Linguee.es or ChatGPT were only employed for corrections. All written content is original creation of the author.

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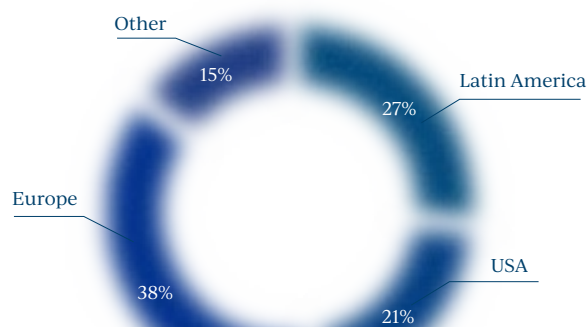
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Regional Distribution of cited Literature (in %) *



*References according to the main location of the study or institution/journal.

Image References

[Fig. 2]

Peng, L., Searchinger, T. D., Zions, J., & Waite, R. (2023). The carbon costs of global wood harvests [Figure]. Adapted from Nature, 620(7972), 110–115. <https://doi.org/10.1038/s41586-023-06187-1>

[Fig. 3]

Biomason. (2025). [Photograph of Biomason material] [Photograph]. Adapted with permission. https://www.linkedin.com/posts/biomason_innovation-techforgood-futureready-activity-7336461928782852123-_Bjp?utm_source=share&utm_medium=member_desktop&rcm=ACoAAA4s6TEB4sGprjOZVeY3rkQOQMBnuZmilyw

[Fig. 4] & [Fig. 6]

Zboinska, M. A., Sämfors, S., & Gatenholm, P. (2023). Robotically 3D printed architectural membranes from ambient dried cellulose nanofibril–alginate hydrogel [Figure]. Adapted with permission. Materials & Design, 236, 112472. <https://doi.org/10.1016/j.matdes.2023.112472>

[Fig. 7]

Strong by Form. (2025). Woodflow Skin Catalogue: Spring 2025 [Figure]. Adapted with permission from the author.

[Fig. 8]

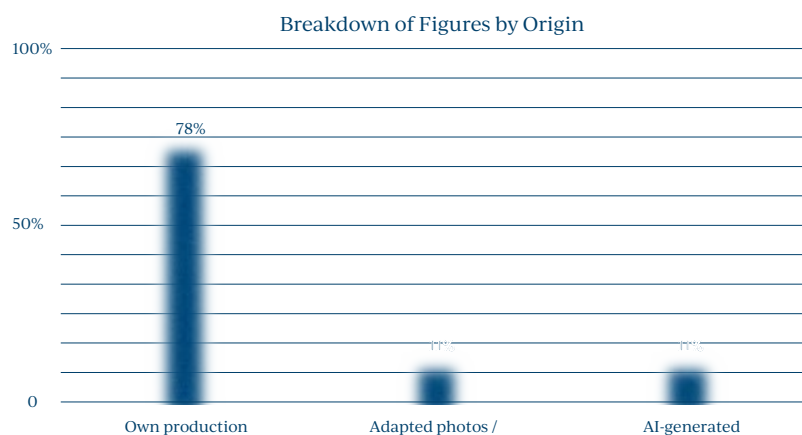
Strong by Form. (2025). Company web page surge: Spring 2025 [Figure]. Adapted with permission from the author.

[Fig. 11]

Zboinska, M. (2023). 3D-printed yeast-material samples [Photograph]. Adapted with permission. Photo courtesy of Malgorzata Zboinska.

[Fig. 50–55]

Author-generated images. (2025). [AI-generated figures based on original design] [Figures].



A N N E X

In the final presentation, all samples were displayed on a 12 mm CNC-milled plywood base. At one end of the plywood, a model produced with a Prusa MK4 XL was presented.

This model was intended to illustrate different layering strategies of a pillar (1), combining a real double-curvature yeast-based bio-material sample (T11) with a PLA-printed layer (7). Vegetation was also incorporated into the model (6).

The novelty of this printing process lies in the fact that the layers corresponding not to structural or physical lines, but to planar surfaces, were printed at the minimum thickness allowed by the 3D printer nozzle (4). This decision aimed to emphasize and visually communicate the concept of decay (5).

Annex





CONSTANZA A. QUIOZA RODRIGUEZ

CHALMERS SCHOOL OF ARCHITECTURE
DEPARTMENT OF
ARCHITECTURE AND CIVIL ENGINEERING

2 0 2 5

WHAT DO YOU WANT (TO BE) YEAST?

EXPLORING EARLY STAGE
YEAST-BASED MATERIALS
THROUGH THE LENS OF
ARCHITECTURAL MATERIALISMS