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Designing Bio-based Materials

for Lightweight Aircraft Seating and Engineering them to meet the Functionality Requirements

Master Thesis Research

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ABSTRACT

Airbus Cabin Vision 2035 aims to transform the future experience of air travel with a focus on sustainability through its three pillars: Transparency, Decarbonization, and Circularity (Airbus, Airspace Cabin Vision 2035+). As part of this initiative, the current thesis explores the potential of bio-based materials to replace conventional fossil-based thermoplastics in aircraft seating trims. By investigating whether nature can provide lighter and more environmentally friendly alternatives, this study seeks to reduce the aviation industry's carbon footprint (during the usage phase of aircraft) while enhancing the circularity of the materials.

This research is structured in a three-phase iterative framework. The initial phase involves problem analysis and the development of design specifications. The next phase, material exploration, identifies a list of potential bio-based materials suitable for design exploration, followed by a literature review to understand their flammability and moisture resistance properties, which are critical for compliance with the rigorous standards of aircraft applications.

From the material exploration, a family of hardwood, natural fibers, and mycelium emerged as potential materials for further design exploration. Lightweighting method was employed to optimize their geometry and meet the required mechanical strength established in the design specifications (Load bearing strength up to 100kgs). This method led to the development of a more practical option: the Designing of Composites. Static load-bearing capacity calculations were conducted to assess the feasibility of the composite design with the variations in facesheet materials. The pretreated Baxis Sinica wood panel with a mycelium core emerged as a feasible solution, primarily due to its weight-to-strength ratio, ability to meet the functional requirements of aircraft, and its circularity.

In the pursuit of material optimization, studies were undertaken in exploring bio-based coatings, to enhance the flammability and moisture resistance properties ensuring its suitability for the stringent requirements of aircraft applications. With established research on enhancing the flammability and water resistance of wood-based composites, the focus was to improving the properties of mycelium. Initial post-treatment methods using inorganic flame retardants like sodium silicate effectively demonstrated flame-extinguishing properties; however, further research is required to further enhance the material's water resistance. Additionally, there is promising potential for utilizing bio-based coatings to simultaneously improve both the flame retardancy and moisture resistance of mycelium. As it is well-established that bio-derived materials can degrade over time, it is crucial to develop strategies and treatments to ensure this does not compromise the product's lifespan. Current efforts also focuses on understanding the long-term behavior of these materials and their coatings under extreme conditions. However, as these materials have not yet reached full maturity, further optimization and enhancement remain within the scope of future research.

Positioned within the framework of Circular R-strategies, this study proposes an ambitious design, utilizing a wood and mycelium to develop a composite, with textile serving as the adhesive layer. The proposed design not only eliminates the need for fossil-based materials but also reduces weight by up to 50% compared to conventional thermoplastics in seat trims. This weight reduction is significant, as even a single kilogram less can lead to a decrease of 5,000 to 15,000 kg CO2 emissions over the aircraft's lifetime.

TABLE OF **CONTENTS**

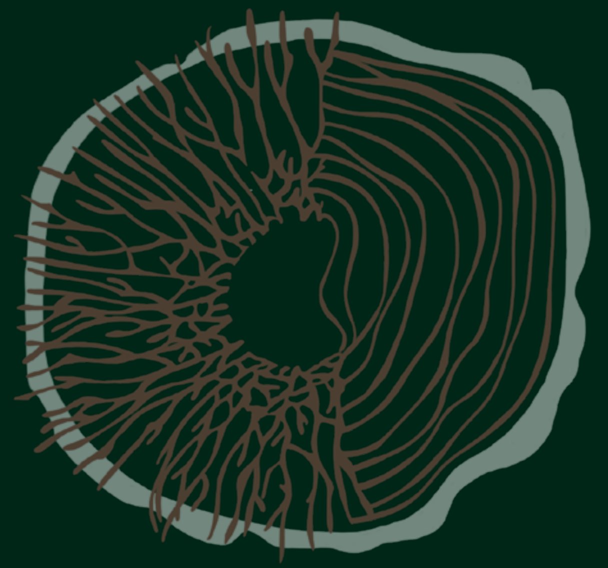
Problem Description

Material exploration and Selection

Concept Designing

Material optimization

Thesis Conclusion



PROJECT DESCRIPTION

1 PROJECT INTRODUCTION

This chapter presents the initial assignment provided by the Central Research and Technology Division of the Airbus Group. It reviews the components that contribute most to the aircraft cabin's weight, analyzes the CO2 emissions per kilogram of aircraft weight, and determines the design direction while outlining the scope of the research.

1.1 Assignment brief

Bio-derived materials are emerging as promising sustainable alternatives for traditional materials in packaging, automotive, and building industries. Airbus, in line with similar efforts, is exploring renewable materials as replacements for conventional materials. Airbus 2035 re-imagines passengers future travel experience while prioritising sustainability. The vision is built on three pillars: Transparency, aiming to provide full visibility on the environmental impact of cabin components; Decarbonization, focusing on using low-CO2 impact materials; and Circularity, targeting zero landfill waste by promoting reuse, and recycling (Airbus. (n.d.). Airspace Cabin Vision 2035+).

This thesis is a case study provided by the Central Research and Technology division of Airbus, exploring the potential of bio-derived materials in the aircraft cabin structures and how to make them the materials of choice for tomorrow's aerospace.

Assignment statement:

"Design bio-based materials to meet the functional requirements of aerospace, ensuring they contribute to aircraft weight reduction and enhance the circular economy."

1.2 Key Research Questions:

Design Development:
How can bio-based materials be designed to replace existing materials and be weighted, positioning them as the materials of choice for the future, given that weight can significantly reduce fuel consumption and, consequently, environmental impacts.

Technology Development:
Which methods and treatments can be used to improve their functionality requirements such as reducing the flammability, and improving moisture resistance of these materials?

Image Source: The C-Suite - The Business Class Concept Seat, 2023, https://aircraft.airbus.com/en/airspace-cabin-vision-2035.

1.3 Project Scope

The initial assignment from the company provided an opportunity to explore a variety of bio-based materials in the early stages of this thesis. Based on a comprehensive literature review and prior experience with bio-derived materials, the project initially considered all potential types of bio-based materials. This exploration helped on identifying materials that could meet sustainability goals while also fulfilling the performance requirements of the aerospace industry.

At the outset of this thesis, two potential approaches were considered: selecting an existing product and substituting its material, or choosing a specific material and integrating it into an aircraft component. This decision required balancing design pull and design push strategies. Given the emphasis on reducing carbon emissions, a design pull approach was chosen. This involves identifying the component that contributes most significantly to the aircraft's weight and replacing it with a lighter, more sustainable material.

The weight of the seats is a significant factor in the overall weight reduction of aircraft, as outlined in figure 1. Seats, at 1,601 kg, are the heaviest single item among the listed components cabin components. The flyzero targets a 20% reduction in seat weight by 2030. This substantial weight reduction in seats alone represents a major contribution to the overall goal of reducing the aircraft's total interior weight by 16%. (Fly zero, sustainability in the cabin, New approaches in Sustainable Aircraft Interior Design, 2022)

Item	2020 weight, kg	2030 weight target, kg	2020-2030 weight reduction
Seats	1,601	1,290	20%
Linings	363	340	5%
Stowage bins	188	220	-20%
Passenger Service Unit (PSU)	172	130	20%
Services (lavatories and galleys)	563	450	20%
Insulation blankets	418	310	25%
Carpets	240	210	10%
Floor panels	376	330	10%
Total	**3,919**	**3,320**	**16%**

Figure 1: A320 in low cost carrier (LCC) configuration, weights analysis. (Fly zero, sustainability in cabin, New Approaches in Sustainable Aircraft Interior Design, 2022)

CO2 Emissions of per kg Weight during lifetime of an aircraft:

The Airbus A320 (reference model for the study) consumes approximately 2430kg jet fuel/hr (Saurabh, 2023). Given its estimated operational lifespan of 60,000 hours, this results in a substantial total fuel consumption. (M.Durgut, 2024) Since burning 1 kg of jet fuel emits approximately 3.16 kg of CO2 (CO2 Emissions - Carbon Offset Guide, 2020), an Airbus A320 operating for its full lifespan is estimated to emit around 460 million kg of CO2. This immense carbon footprint underscores the environmental impact of aviation. Furthermore, it is calculated that the aircraft emits approximately 5983 kg of CO2 for every 1 kg of its weight over its operational lifetime, highlighting the critical importance of lightweighting strategies in aircraft design to reduce overall emissions. These emissions are for a low cast carrier and the emissions for bigger flights are to be pictured twice to thrice of these numbers.

End-of-Life (EoL) considerations:

Figure 2 provides a detailed breakdown of the recycled versus unrecycled mass for various aircraft components. Insulation padding, crucial for the airframe's structural integrity, is primarily made of melamine or polyurethane, materials that are not easily recyclable. These insulation paddings are mainly structural components of aircraft fuselage ceilings. Next to that The seating structure consists of multiple components, where metal forms the core structural support, while thermoplastics and foam are employed for aesthetics and passenger comfort.

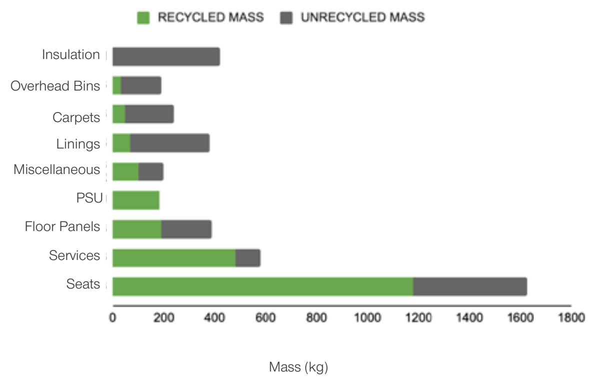


Figure 2: Recycled and unrecycled mass breakdown (Fly zero, sustainability in cabin, New Approaches in Sustainable Aircraft Interior Design, 2022).

The scope is narrowed to replacing the thermoplastics used in seating trims. Thermoplastics are selected due to their design versatility, which offers greater scope for product designers. In contrast to foams, which require a deep understanding of chemistry and materials science for development and modification.

The initial focus is on business-class and Premium Economy seating structures, specifically the armrests and side panels, due to the relative ease of design modifications in these areas. While Economy Class backrests could also be considered, they present greater moldability challenges. Initially targeting Business Class side panels, the design process is simplified, with the potential to expand to seat-back shell trims in future work. Figure 3 envisions the design of structures, likely where straight and flat geometrical structures can be used.

Figure 3: AI Generated image

1.4 Final Deliverables:

1. A comprehensive list of requirements and desired attributes for the current thesis on designing bio-based components for aircraft seat trims.

2. An overview of bio-derived materials suitable for use in the aircraft cabin, highlighting their potential advantages. (Density and Weight to Strength ratio)

3. Methods and treatments aimed at enhancing the flammability and moisture resistance properties of bio-based materials.

4. Testing on the developed samples, ensuring their potential to meet the necessary requirements for aircraft industry.

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5. Structural Calculations for the New Design: Performing calculations to evaluate the weight-to-strength ratio of the new design, thereby demonstrating its effectiveness in reducing the overall weight of the aircraft components.

6. Developing an 'R' Strategy for Circular Economy Benefits:This involves creating a strategic framework based on the 'R' principles (e.g., Reduce, Reuse, Recycle, Refurbish)

7. Concept Design and Prototype Development The prototype serves as a final demonstrator to showcase the practical application of the design in a real-world context.

Design Vision Statement:

" To design bio-based materials which can potentially replace thermoplastics (fossil-based) in aircraft seating trims. These materials should enhance weight properties to reduce carbon emissions and contribute to circular economy practices. Additionally, they must comply with functionality requirements of the aircraft industry."

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2 **PROBLEM** INTRODUCTION

This section investigates the waste generated at an aircraft's end-of-life, highlighting the need of researching bio-based materials for future aviation. It discusses the Global Market Forecast, which raises industry concerns about the need for sustainable aviation. Additionally, the section includes insights from interviews with companies introducing circular materials in their product lines.

2.1 Background

Airbus, in its latest edition of its Global Market Forecast (GMF) for the period 2023-2042, (2023 Global Market Forecast, 2023) has established a view of future air traffic and fleet evolutions. The forecast reveals several key trends and drivers shaping the aviation industry over the next two decades.

2.1.1 Key Drivers

A projected world Gross Domestic Product (GDP) increase of 2.5% from 2019 to 2042 is expected to boost disposable incomes, enabling more people to afford air travel. Additionally, the expansion of the middle class will contribute to a higher demand for air travel, as more individuals are wanting to fly for the first time. During the same period there is an increase in global trade, projected to grow by 2.9%. The Global Market Forecast, 2021 report highlights future traffic growth and aircraft demand for cargo aircraft (for aircraft > 10 tonnes payload). (2023 Global Market Forecast, 2023)

2.1.2 Key Trends

Forecast, indicates a demand for 40,850 new passenger and freighter aircraft between 2023

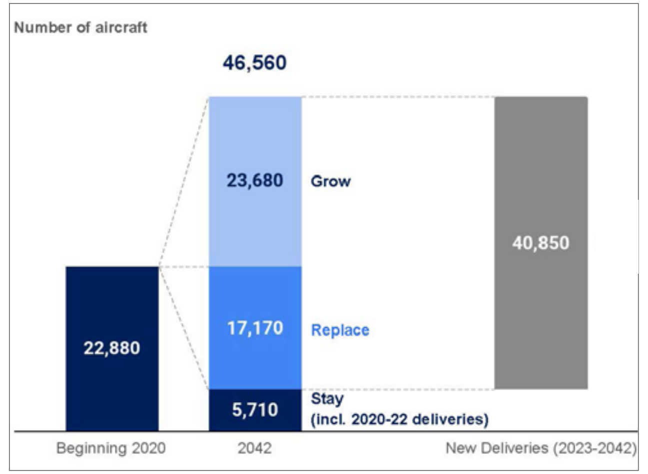


Figure 4: Demand for 40,850 new passenger & freighter aircraft (2023 Global Market Forecast, 2023)

Figure 5: Satelite view of Davis-Monthan United States Air Force Base aircraft graveyard (Low Orbit Tourist. (2017))

And 2042. This growth is driven by the need to replace 75% of the existing fleet of 22,880 aircrafts in service as of 2020 and to accommodate market growth, which accounts for 58% of the new deliveries. By 2042, the total number of aircraft is projected to reach 46,560, with 25% of the 2020 fleet remaining in service. (2024 Global Market Forecast, 2024)

2.1.3 Aircraft End of Life

The Figure 5 shows the satellite view of the largest aircraft graveyards in Arizona, United States spread over 10,633 acres. According to the Aerospace maintenance and Regeneration Group (AMRG) the facility stores, on average, 3,200 aircrafts, 6,100 engines, and almost 300,000 line items of tooling and test equipment (Finlay, 2023). These are just the exterior components of the aircraft, however, an interview with a member of the Airbus team, mentioned most of the aircraft interiors are refitted/retrofitted every 3-7 years once. The increase in demand for new aircraft and the demand to replace the parts will inevitably result in an increase in the demand for aircraft materials. This underscores the critical need to carefully consider the end-of-life cycle management of these materials. Also due to competition and ongoing innovations in aircraft seating and cabin design, airlines are increasingly opting for cabin refits as a cost-effective and practical method to update their planes. Airlines are presently competing to outdo each other in cabin development. As long as economic conditions in aviation allow, this competition will ultimately lead to improved cabin conditions for passengers across all sections of the aircraft. The focus for aviation now, is to continue developing the engineering capabilities and innovations which make lower-cost, low weight, more comfortable and more attractive cabins possible. (Garcia en Skift Team (2014) Curran (2020)).

2.1.4 Aircraft Cabin waste

As per the data outlined in the Sustainable Cabin Design report by the Aerospace Technology Institute (Fly zero, sustainability in cabin, New Approaches in Sustainable Aircraft Interior Design, 2022), it is mentioned that the combined weight of cabin components for an A320 low-cost carrier configuration is approximately 3919 kilograms. Considering the need to replace 17,170 aircraft and introduce 23,680 new aircraft by 2042, there would be an average estimation of more than 159 million kilograms of waste generated every 3-7 years starting from 2042 where in current average estimation, waste production of aircraft interior materials stands at 89 million kilograms every 3-7 years. These numbers are just estimated weight keeping with the cabin weight reported in Fly zero, sustainability in cabin report (New Approaches in Sustainable Aircraft Interior Design, 2022) and assuming that all the cabin components will be replaced.

Additionally, aircraft component recycling companies are grappling with challenges related to recycling materials used inside the fuselage, particularly cabin seats and insulation panels. (End of Life, AELS CEO, 3rd April 2024).

Figure 6 visually summarizes the increasing consumption and its effects discussed in this chapter. This awareness for the environmental impacts has led to a growing interest in Circular economy practices. The circular economy is a model of production and consumption, which involves (R strategy) reducing, reusing, repairing, refurbishing and recycling materials and products as long as possible. Within the aircraft industry, the innovation of bio-based materials is being explored to drive circular economy practices. Of that recently, the international collaboration of

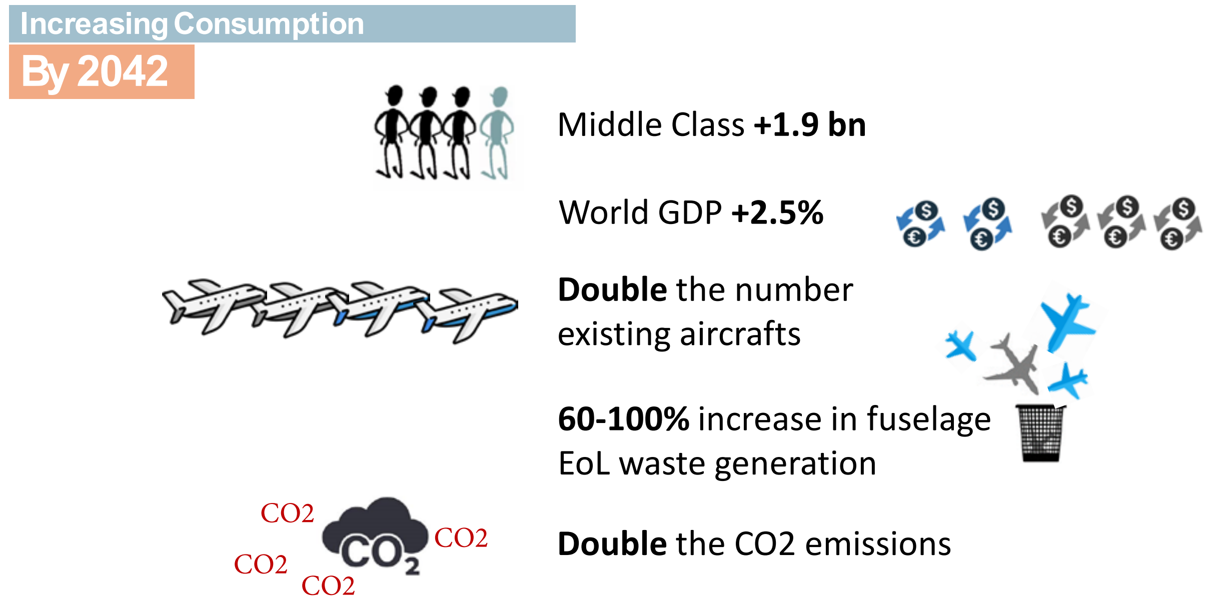


Figure 6: Increase in air travel consumption and its effects.

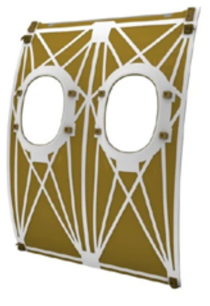
Chinese and European partners in the ECO-COMPASS (Eco-Compass. (n.d.)) project provided an assessment of different eco-materials and technologies for their potential application in aircraft interior and secondary composite structures. Many projects are underway at both university and industry levels, one of which is discussed in the section 2.3.

The next section will highlight bio-based products that have been successfully launched and are in the market, as exhibited/communicated with the companies at the Airbus Aircraft Interior Expo in Hamburg 2024.

2.2 Aircraft industry towards Bio based materials

Lufthansa Technik has introduced AeroFLAX, renewable and eco-efficient pre-impregnated fibers that meet the stringent flammability requirements for aircraft cabins. This innovative material combines ampliTex and powerRibs flax fiber reinforcements with a bio-based resin system, achieving up to a 20% reduction in the weight of cabin components. (discussed with Lufthansa Technik, at Hamburg Aircraft Interiors Expo, 30th May 2024)

RECARO Aircraft Seating products has made its first attempt to adapt bio sourced products in its product line R Sphere. The company announced that its seats inculcates components incorporating materials such as cork, wood, and recycled fishing nets. This demonstrates RECARO's stewardship, with the seat contributing to a reduction of 63 tons of CO_2 emissions per aircraft annually and being fully recyclable at the end of its life .(RECARO, exhibited at Hamburg Aircraft Interiors Expo, on 30th May 2024)



DIEHL has developed eco efficient side walls by fusing sustainable concepts. They have inculcated low emission basalt fiber reinforced in bio based furane resin made from a byproduct of refining sugarcane. Light weight core materials is Kevlar honeycomb structure and the load is optimized by using tapes which are made of unidirectional fibers. The whole provides 10% weight savings (DIEHL, exhibited at Hamburg Aircraft Interiors Expo, 30th May 2024)

Developed by **Mitsubishi Chemical Group**, BIOpreg PFA is a bio-based prepeg material offering a sustainable alternative to the phenolic systems The Furan resin system, which is formaldehyde-free, is derived from sugarcane waste and can be combined with various reinforcement fibers. The material is processable via vacuum bagging, autoclaving, and hot compression molding, using similar cycle times to phenolic-based resin systems. (MCG, exhibited at Hamburg Aircraft Interiors Expo) 30th May 2024)

2.3 Review of Previous Research: (Chaudhury, 2023)

Mrinal Chaudhary's thesis, completed in 2023 in collaboration with the Central Research and Technology Division of the Airbus , was referenced in the current assignment to aid in the exploration of bio-derived materials. The research focused on exploring the potential of mycelium use in aircraft cabins. Mycelium is the vegetative part of a fungus, consisting of a network of fine, thread-like structures called hyphae. These hyphae form a dense, interwoven mat that spreads through the substrates, such as wood or organic matter for a bio-composite. They are regenerative, biodegradable, and lightweight composites having density between 50-600kg/m3. The key findings and insights from this thesis work are summarized below:

Applications Identified: The research identified a range of optimal applications for mycelium materials in aircraft cabins, including hot and cool cases, galley systems, seat shelving, cushions, upholstery, and decorative fillers. These applications take advantage of the material's low weight, mouldability, and sustainable properties The project developed conceptual designs and demonstrators for two specific applications: an optimized bionic partition for Airbus aircraft interiors and a versatile packaging cum meal tray for airlines. These designs leverage the material's properties, such as competitive insulation, damage resistance, and mouldability into complex shapes.

2.4 Review on major challenges in adapting Bio based materials

- **Innovative Material Development:** There is a recognized need to explore new bio-based materials and combinations to enhance the mechanical properties, flammability, thermal and hygroscopic properties of composites. This involves investigating lesser-known natural fibers and bio-based polymers to expand the range of materials available for composite applications. (Andrew & Dhakal, 2022)
- **Processing Techniques:** The aerospace industry has established manufacturing processes optimized for synthetic materials. Bio-based materials may require different processing techniques, such as alternative curing processes, which can complicate their integration into existing manufacturing workflows. (Pickering et al., 2016)-
- **Lifecycle Analysis:** Although these materials are promoted as sustainable alternatives, their overall environmental impact including factors such as energy, water use, and end-of-life management strategy must be carefully evaluated to ensure they truly offer a more sustainable option compared to traditional materials. (Engineering Biopolymers, n.d.)
- **Innovation risk:** Future research should include a market entry strategy of bio-based composites. This involves examining R&D and scale up costs, market demand, and potential obstacles to compete with performance of traditional materials. (Arnau, Collins Aerospace, Interviewed on 3rd May 2024)

Main takeaways

Bio-based materials often encounter challenges in market adoption, largely due to the industry's focus on market demand over environmental considerations. However, as the demand for new aircraft continues to rise, the market potential for certified bio-based designs could grow. This shift could facilitate quicker and easier scaling of these designs. Additionally, the maturity levels of bio-based materials vary, with some still in the early stages of development and lacking the robustness required for certain high-performance applications. By carefully evaluating and optimizing these materials, it can be improved to become viable alternatives that contribute to a more circular economy.

It is important to acknowledge that responsible practices during this stage of development can lead to significant future impacts. However, there is a risk of 'greenwashing,' or by obscuring data. To avoid this, it is essential to ensure that sustainability efforts are genuine and supported by measurable outcomes, rather than superficial marketing. In my thesis, I plan to work with materials that are circular, grounded in the knowledge and understanding I have on their sustainability.

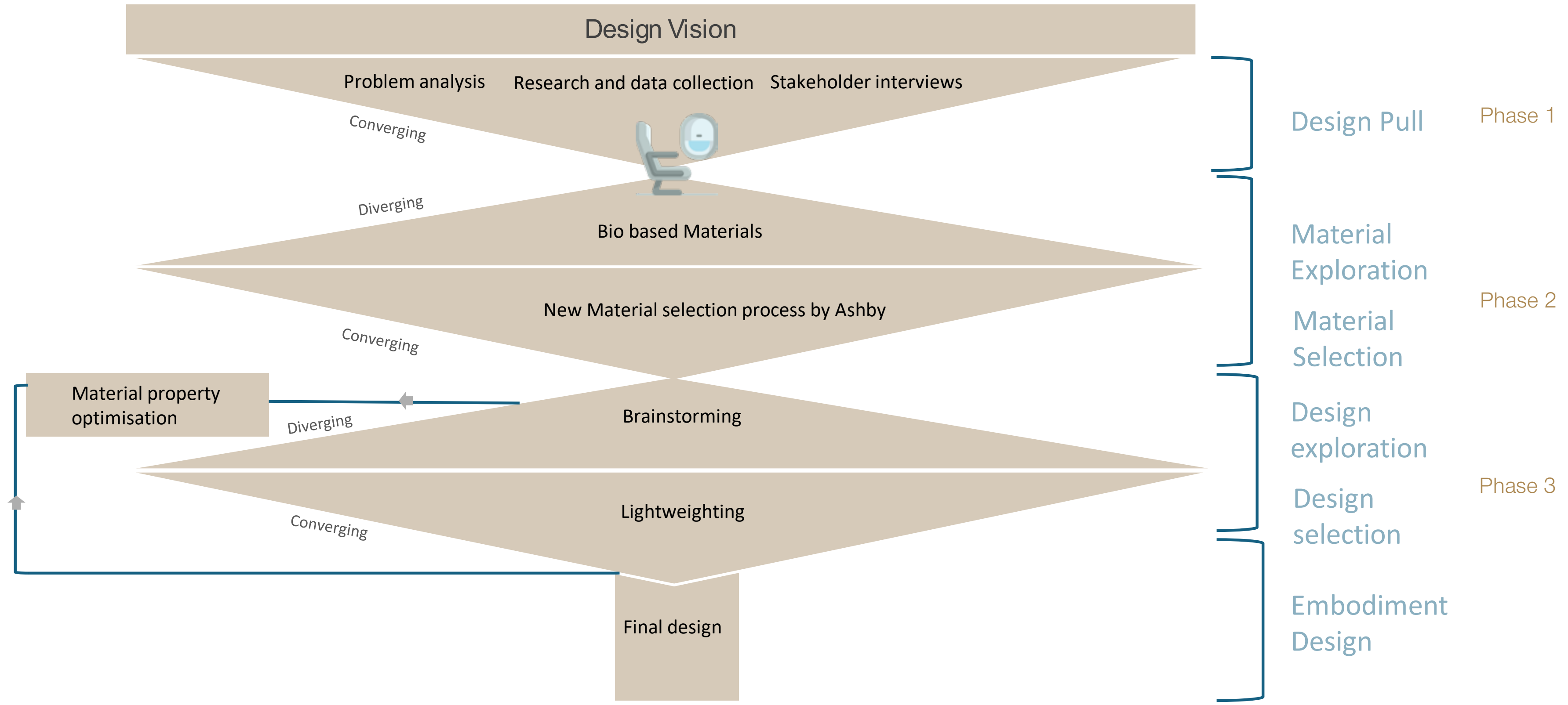
If it can't be reduced, reused, repaired, rebuilt, refurbished, refinished, resold, recycled, or composted, then it should be restricted, redesigned, or removed from production.

Pete Seeger

3 RESEARCH AND DESIGN METHODOLOGY

3.1 Design Methodology

The project is carried out at 3 main phases:
1. Problem analysis and design pull
2. Material exploration and selection
3. Concept Design and Embodiment design



3.2 Research Objectives

The research objectives lay out the aims that will direct the entire research process as there is an overlap of designing and engineering going simultaneously. The objectives not only define the scope of the research but also ensure that the tasks are actionable, particularly given that this is an emerging area of study with intensive research gaps.

Objectives of the steps	Expected outcome/ understanding
1. What are the crucial requirements that a material should pass to be able to be replaced with the existing materials.	Sufficient understanding of aircraft functionality requirements.
2. Benchmark the material properties of the current materials to draw the program of requirements for the new class of bio-derived materials.	Understand how the properties of bio-based materials compare to those of existing materials and identify areas where they require improvement.
3. Explore the bio-derived materials and their properties which can potentially be developed to meet the requirements of the aircraft.	Narrow down the selection from thousands of materials and develop a comprehensive understanding of the chosen options.
4. Brainstorm ways to design the bio-derived materials in an aircraft.	A set of unconventional and conventional ideas for the inspiration for concept design
Viability objectives	
6. Is there a demand or market for the product? Will it appeal to consumers or stakeholders?	Interview with stakeholders on their say on bio-based materials in long run and why would industry adopt these materials
Feasibility objectives	
7. Develop ways to improve flammability and moisture resistance properties, testing and evaluating them whether they achieve the functionality requirements.	A comprehensive knowledge about the material properties and optimization.
Sustainability/ Desirability objectives	
8. Aim to reduce the weight of the design which inherently reduces CO_2 emissions (during the use phase) and develop the R- strategies for the design.	Quantification of the new design benefits against the conventional materials.

3.3 Approach

3.3.1 Approach in Phase 1: Problem analysis

Innovation is an iterative process that involves continuous testing, learning, and refining of ideas. For push, or technological innovation, the approach typically involves leveraging new scientific discoveries and technological advancements to create products and services for market introduction. On the other hand, the pull strategy is driven by the market's needs or demands, which inspire the development of new products or services using either new or existing technologies.

As discussed earlier the initial phase of the project employed a design pull approach, guiding the selection of a specific aircraft component for substitution with bio-based materials following by an attempt to push of new innovations in bio materials.

Design Thinking is "Pull"
Technology Innovation is "Push"

2.3.1 Approach in Phase 2: Material exploration and selection

Classifying information is not an easy process. Design involves choice. and choice from enormous range of ideas and data. But to be efficient, the classification and indexing must be adapted to the nature of the population of objects that are to be classified and the purpose of the search. (Ashby en Johnson (2002)

Ashby's material selection process is followed starting from exploration of wide amount of materials, classifying them based on the design requirements and finally selection of the materials and processes is done through logical reasoning and feasibility of the design.

3.3.2 Approach in Phase 3: Concept design

For the concept design, a method called Lightweighting is used followed by developing demonstrator model of the selected design. The method of lightweighting, focuses on reducing the amount of material used in a product, which not only decreases its environmental impact but also enhances efficiency, especially in products in the transport sector where weight reduction can lead to significant energy savings. (VentureWell, 2022g)

Few of the key strategies for lightweighting include:

1. Optimizing Geometry and Structure: This involves removing excess material from non–essential areas and reinforcing parts that bear significant loads. Techniques like using hollow sections, ribs, or trusses help in maintaining strength while minimizing weight.

2. Following Lines of Force: Designing structures to align with the natural flow of forces can reduce material use without compromising integrity. This includes strategic placement of materials where stresses are highest.

3. Using Tensegrity Structures: This concept relies on balancing tension and compression to maintain structural integrity, allowing for lighter and more efficient designs.

Tools like Finite Element Analysis (FEA) are employed to simulate and validate lightweight designs before production. This ensures that the reduced material use does not lead to failure under real-world conditions.

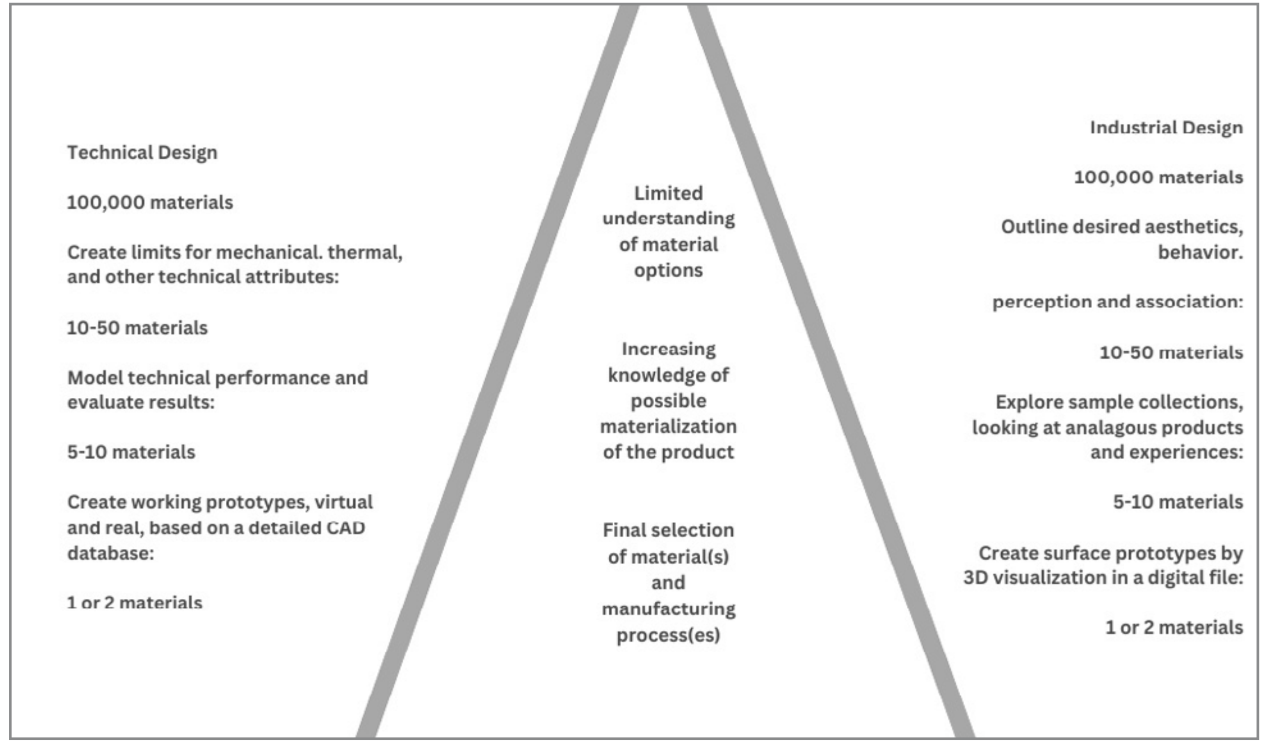
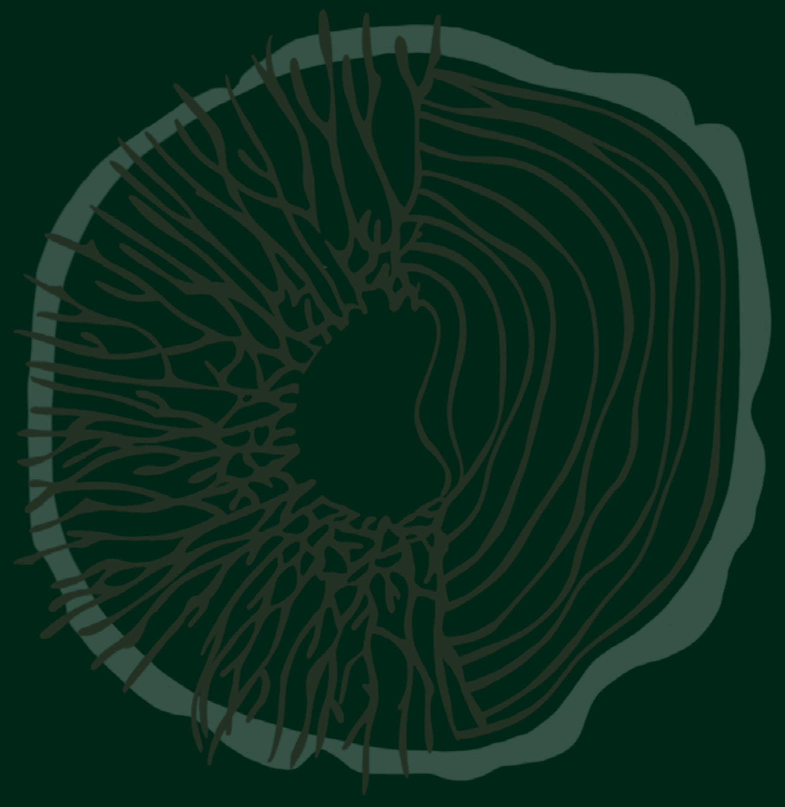


Figure 7: Materials in the design process. (Ashby en Johnson (2002)



MATERIAL EXPLORATION AND SELECTION

4 NEW **MATERIAL SELECTION**

This chapter employs Ashby's material selection strategy, beginning with a broad range of materials and limited information. The process involves systematically narrowing down thousands of materials by prioritizing low-density options. As the selection progresses, the focus shifts to a more refined set of materials, where the available knowledge about each option increases while the number of viable materials decreases. The final phase involves a literature review on optimizing the functionality of the selected materials to meet the specific requirements of the application.

4.1 Ashby new material selection strategy

Studies of problem solving distinguish two distinct problem solving processes, deductive and inductive reasoning. The figure 8 shows the methods which are both inductive and deductive. Traditional engineering education emphasizes analytical methods, often to the exclusion of ideas about analogy and curiosity. The justification is that analysis is an exceedingly powerful tool, but there is evidence that many of the most creative ideas arise from analysis but from inductive thinking from successive guessed solutions (informed guesses, of course on drawing on past experiences), testing one after another until a solution, created by pulling together strands from many past solu

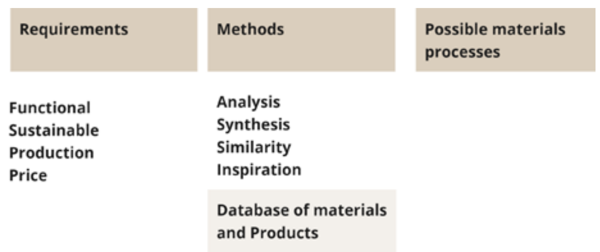


Figure 8: New material Selection Strategy (Ashby en Johnson 2002)

tions, are found that matches the requirements. (Ashby & Johnson, 2002). Each material selection process has its own challenges, so there is no specific prescription for how to tackle it. The design brief is followed by converting the set of inputs into design requirements that are feasible within the scope of the thesis. Between the design brief and the product specifications lie the steps of identification, selection, and implications.

4.2 Identification

This section aims to understand the composition and properties of the conventional materials used in aircraft seat trim components. It focuses on identifying the commonly used thermoplastics employed as shells and concealing parts for the structural elements of the side panels and armrests as shown in Figure 9 and 10.

Figure 9: Image Source: The design Air (Posted by:Jonny Clark, 2019) modified by Chinmayi N

Figure 10: Image Source: The design Air (Posted by:Jonny Clark, 2019) modified by Chinmayi N

4.2.2 Conventional materials used in non structural parts of aircraft seats

Various thermoplastics, such as Polypropylene (PP), Polycarbonate (PC), Acrylonitrile Butadiene Styrene (ABS), and Polyetheretherketone (PEEK), along with their different grades, are used in aircraft seat trims for their lightweight, flame-retardant, and moldable properties. Among these, ABS/PC blends are known for their excellent mechanical properties, including high impact resistance and toughness, making them suitable for aerospace applications where durability is crucial (J et al., 2022). They exhibit excellent thermal stability and flame retardant properties, which are essential for meeting aviation safety standards. (Jinpeng et al., 2019) Figure 11 shows the seat component manufactured with blend of ABS+PC.

Reference materials are necessary for the development of bio-derived materials. In this study, an ABS+PC blend is specifically chosen for its ability to combine the optimal properties of both materials. Future results will allow for a comparative analysis of the bio-derived materials against other

Blend of ABS+PC material which is Vacuum formed and then assembled using a Leather Flap Assembly in Swizz Airlines

Figure 11: Plastic Aerospace Components, Aircraft Seat & Component Manufacturers - Ansini, 2024

4.3 Selection

Establishing a list of requirements is crucial for defining the scope and constraints of the design process for a designer, particularly when developing complex products that must address numerous factors. A program of requirements is established to describe the design goals of the project and criteria concretely.

For the material selection process, the thesis utilises data from Ansys Granta EduPack: Eco Design and Aircraft materials database. Although a material may be under Eco design database, it does not necessarily imply that it is sustainable. This consideration is to be acknowledged in the material selection process, and concept selection process though it is not yet established as a formal criterion in the Program of Requirements An ideal sustainable material would also consider the following points:

- The materials development, use, and disposal processes should be chemically safe and healthy for people.

- Although the use phase of an aircraft material is critically important, as it affects fuel consumption, it must also consider the environmental footprint associated with its production and the energy used in manufacturing.

-The materials/products must be sourced and produced in accordance with ethical standards and promote social welfare, including fair labor practices.

- It not only reduces its own environmental impact but also enhances the sustainability of the entire production and usage cycle, such as minimizing waste and improving energy efficiency.

- It should be durable and resistant to wear and tear/degrade minimizing the need for frequent replacements, which can be economically challenging for the industry's profitability.

- While the aircraft industry has substantial resources, managing material and production costs remains crucial to ensuring long-term financial stability and competitive advantage.

4.3.1 Program of Requirements established for the thesis

Category		Criteria	Requirements/Wish
Technical Requirements	1	Lightweight Construction: Components should be designed to be light-weight or of the same weight as the current materials, therefore reducing the fuel requirement and carbon emission.	Requirement
	2	The material used must be capable of self-extinguishing in the event of a fire, preventing the spread of flames.	Requirement
	3	The material should be hydrophobic and resistant to moisture absorption over the long period.	Requirement
	4	The components should also maintain adequate load-bearing capacity, capable of withstanding operational forces such as those from passengers and luggage.	Wish
	5	Durability: The panel material shall be resistant to wear and tear from regular passenger use. The panel surface should have a minimum wear index.	Wish
Production and Processing Requirements	6	The material is plentiful and can be quickly replenished, ensuring a sustainable supply.	Wish
	7	The production process should incorporate end-of-life strategies. This includes designing for recyclability, promoting biodegradability, and facilitating reuse or refurbishment, ensuring that materials are not wasted and can contribute to a circular economy.	Requirement
	8	Cost-effectiveness: While bio-based materials offer sustainability benefits, they might initially be more expensive than traditional materials. However, as technology advances and production scales up, costs are expected to decrease.	Wish

Category		Criteria	Requirements/Wish
Design Requirements	9	Thermal Comfort: Materials should regulate temperature, preventing seats from becoming too hot or cold.	Requirement
	10	Aesthetic Appeal: The design should reflect the use of sustainable products, and consider user preferences.	Wish
	11	Ease of Cleaning: Surfaces should be easy to clean and resistant to staining, especially in high-traffic areas like seat upholstery.	Wish
	12	Noise Reduction: Panels should contribute to noise reduction within the cabin, enhancing passenger comfort.	Requirement
	13	Attachment: The panel shall be designed for secure and easy attachment to the aircraft structure using approved methods (e.g., brackets, fasteners).	Wish
	14	Interface Requirements: The panel shall interface seamlessly with surrounding cabin elements (e.g., ceiling panels, floor panels) to create a cohesive look. It should have a smooth, finished surface that complements the overall design of the cabin.	Wish
	15	The panel design shall accommodate integration with lighting systems, air vents, and other cabin features as needed.	Wish

4.3.2 Selection by Analysis

Selection through analysis is a fundamental tool for engineers. In this process, the inputs are technical requirements, which are often initially expressed in non-technical terms and subsequently quantified. (Ashby & Johnson, 2002) In this context, the exploration of low density materials are crucial. A systematic screening of materials from the EcoDesign database in Ansys Edu Pack has been conducted, including bio based materials both less dense and denser than ABS+PC blend thermoplastic. As the design process advances, lighter materials may be reinforced with stronger counterparts, whereas denser materials can be optimized to reduce their weight.

Constraints

Density < 1050 kg/m³
Density 1050 > and <1970 kg/m³

Database of products
Possible Materials

Density < 1050 kg/ m³
Mycelium, Cork, Balsa, Poplar.
Density 1050 > and <1970 kg/m³
Natural fibers: Hemp, Kenaf and Flax

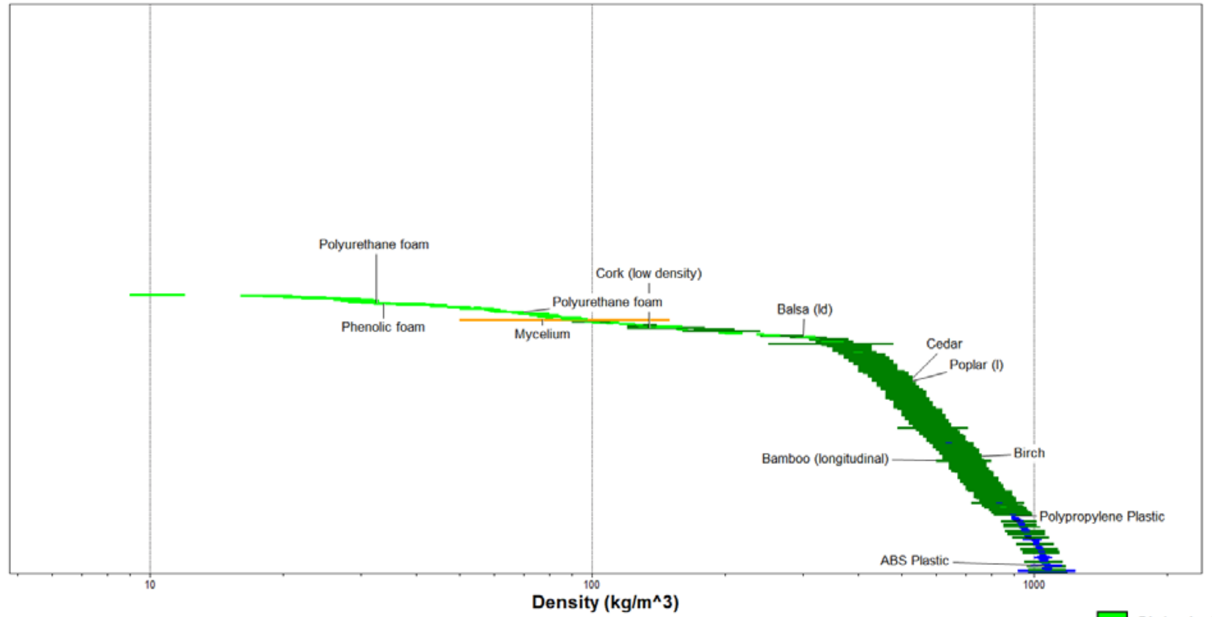
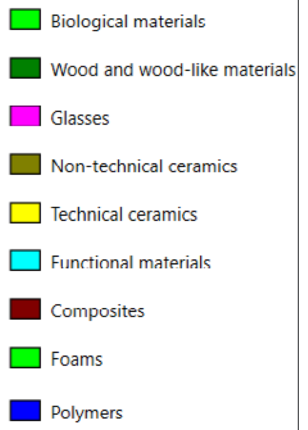


Figure 12: Ashby plot of density from literature against Eco design materials in Granta Edupack



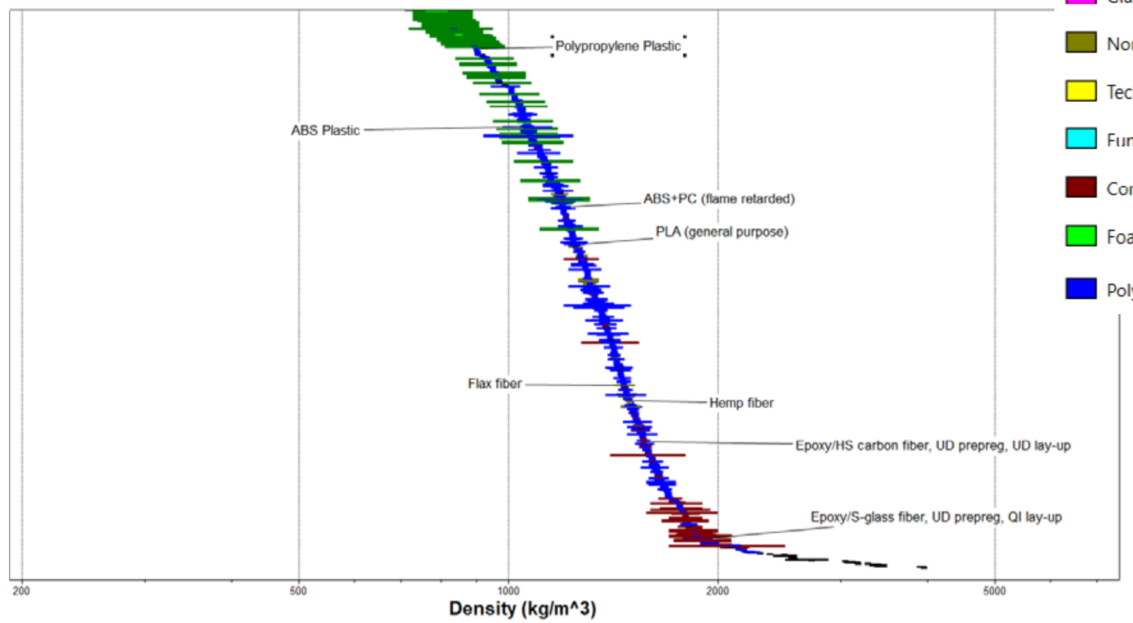


Figure 13: Ashby plot of density from literature against Eco design materials in Granta Edupack

4.3.3 Selection by Similarity

Substitutes are considered when an established material becomes unavailable or fails to meet performance requirements. In this context, the focus is on identifying bio based alternatives to replace thermoplastic blend. The key attributes under consideration are load-bearing strength and stiffness. Flexural strength is assessed to evaluate the material's ability to withstand static loads as well as its resistance to impact loads.

Analogy
(Its a bit like this)
Constraints:
Flexural strength> 60MPa

Bamboo, Cedar.
Natural fibers: While they demonstrate excellent flexural strength, the overall performance ultimately depends on the epoxy reinforcement ratios.

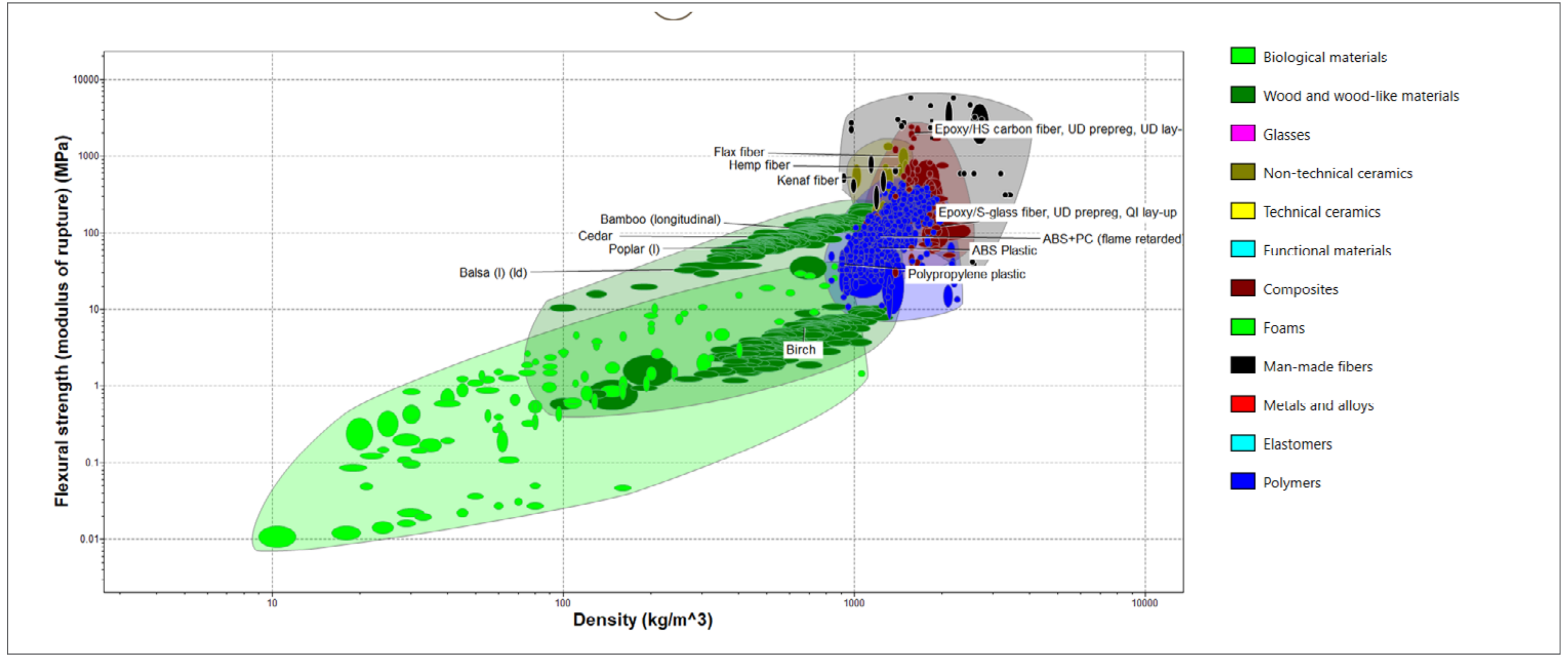


Figure 14: Ashby plot of density vs Flexural strength from literature against Eco design materials in Granta Edupack

4.3.4 Selection by Inspiration

Many ideas created by accident, by an unplanned encounter. It relies on the mental index to search for features and the way they are created. (Ashby & Johnson, 2002) Inspiration can be sparked through interaction with materials, collecting samples, browsing in stores, exploring social media, or observing the natural environment. To further develop concept designs, a mood board is created, and a brainstorming session is conducted to gather and refine ideas.

Curiosity
(I wonder how they)
Inspiration through touch
Inspiration through search

Database of products
Mood Board

4.4 Implications

Based on the results of the selection strategies, the focus shifts back to the design brief, which emphasizes designing lightweight, bio-based materials that achieve functionality comparable to that of currently used conventional materials. At this point, only mechanical strength is being considered. A visual representation of the findings has been created to identify which materials benefit density and which support strength. This mapping helps in determining the suitability of specific materials for particular applications. For instance, low-density, high weight-strength ratio materials like balsa and bamboo can be identified as suitable for lightweight yet strong structural components.

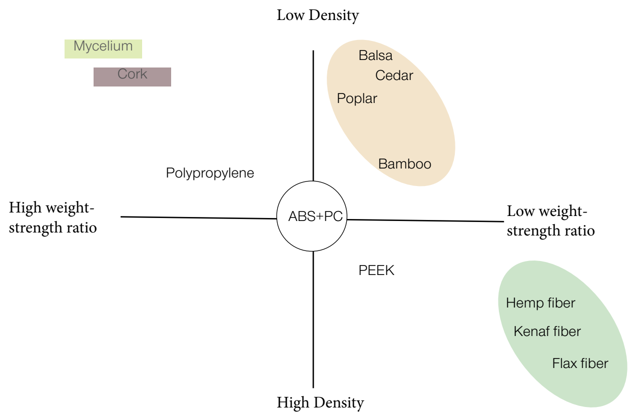


Figure 15: Overview of the material density vs weight to strength ratio against thermoplastics.

The selection process is now categorized into low-density materials and those with a low weight-to-strength ratio. Natural fibers exhibit an excellent weight-to-strength ratio; however, they inherently require reinforcement with epoxy to form composites. Due to the inherent flame and water resistance of epoxies, further examination of these properties is not addressed in this thesis. Although there are products and ongoing research on bio-based epoxies, this represents a separate area of study focused on understanding the sustainability benefits and properties of these alternatives.

The subsequent phase of this research involves a detailed exploration of low-density materials and an examination of methodologies to augment their mechanical strength. With the exception of cork, the composition of materials within the wood and mycelium (lignocellulosic substrate) categories is predominantly characterized by inherent flammability and a propensity for water absorption, typical of lignocellulosic properties. Consequently, further investigation will concentrate on a comprehensive evaluation of the flammability and moisture resistance of wood and mycelium to assess their viability and suitability for the proposed application.

5 MATERIAL **INSIGHTS**

Following the material selection process, a subset of bio-derived materials has been identified from hundreds of potential options. The technical challenge of biomaterials with flammability lies in their inherent susceptibility to fire, along with moisture sensitivity as a significant concern, as it can affect both thermal and mechanical properties (Das et al., 2019) (Simonsen et al., 2023). To address these issues, this chapter delves into a study of the characteristics of mycelium and wood-based materials.

5.1 Mycelium composition and the parameters influencing its properties.

Mycelium, the vegetative part of fungi, is composed of a network of filamentous structures known as hyphae. It consists of hyphae that form a dense, interconnected network, which can bind with organic substrates like sawdust, creating a composite material with a hierarchical porous structure (Zhang et al., 2023).

Flammability Properties: Mycelium exhibits a high carbohydrate content (46.72% to 63.40%), moderate protein levels (14.19% to 26.16%), and significant amounts of minerals like calcium and iron (Sharma & Gautam, 2017) as shown in the figure 16. The presence of lignin and phosphorus in mycelium contributes to significant char formation, which enhances fire resistance (Chulikavit et al., 2023). While the char-forming behavior of mycelium is known, it has not been conclusively demonstrated that it can function as a self -extinguishing material.

Water resistance properties: The chitin, glucans, and proteins in the mycelium cell walls exhibit varying levels of hydrophilicity. This variability can affect the cell wall's interaction with water and other molecules, highlighting the complexity and adaptability of fungal cell walls (Araújo et al., 2017) Ross (2001) Furthermore, extended exposure to elevated humidity levels or direct water contact may lead to enhanced absorption and subsequent degradation of the material, necessitating further investigation to fully understand and mitigate these effects.

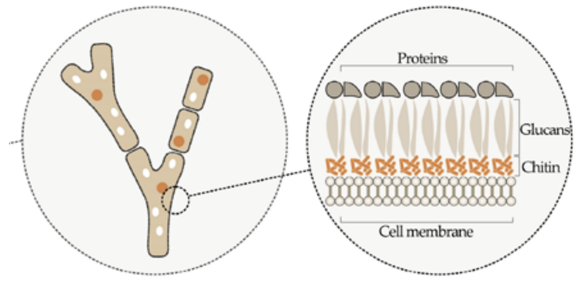


Figure 16: Cellular composition of Mycelium (Mohseni et al., 2023)

Figure 17 illustrates the development process of mycelium, highlighting the stages at which its properties can be modified. Flammability and moisture resistance are influenced by the choice of substrate and the fungal species used for incubation. Also, flame resistance can be further enhanced through the application of bio-based surface coatings

External coatings are a more viable focus for improving flammability properties as they can be applied as a post-processing step, offering flexibility in formulation and application In contrast, tweaking substrates and inoculation conditions involves complex, time-consuming changes to the production process, with less predictable outcomes during the thesis period.

Parameters affecting Mycelium properties

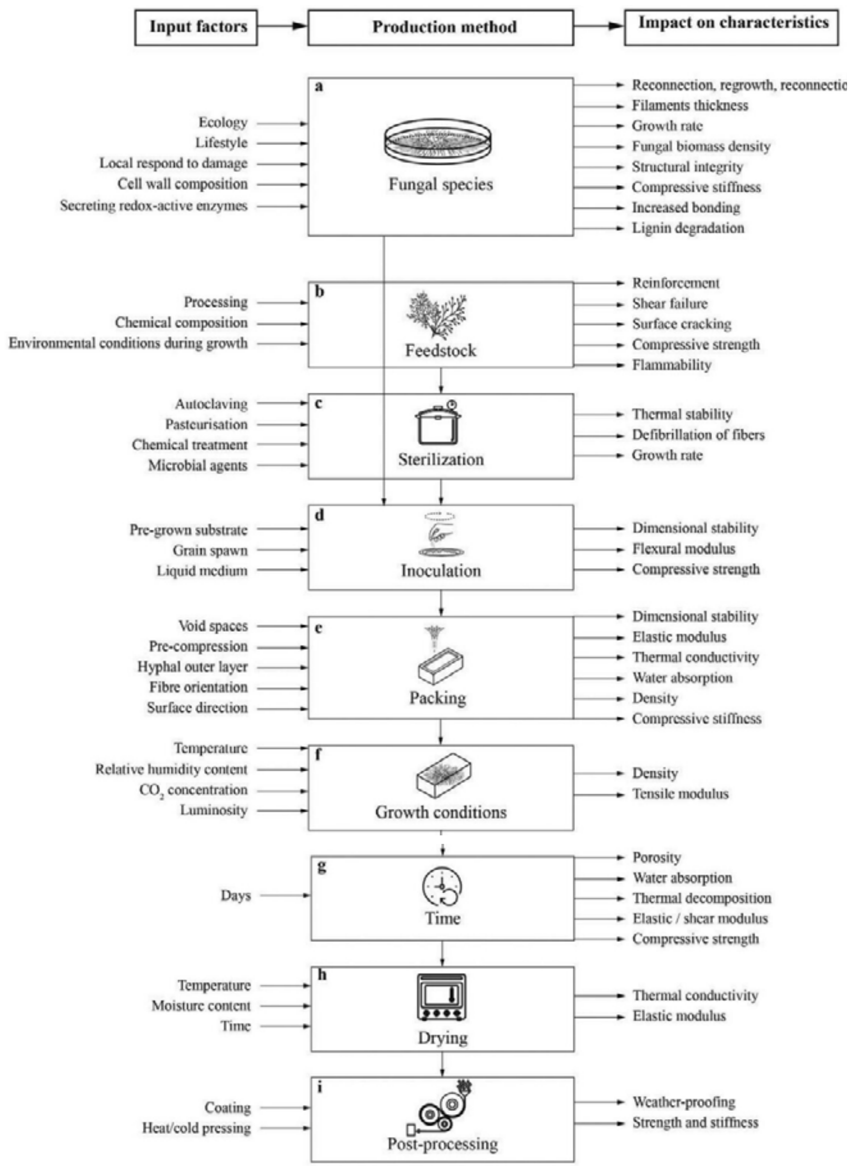


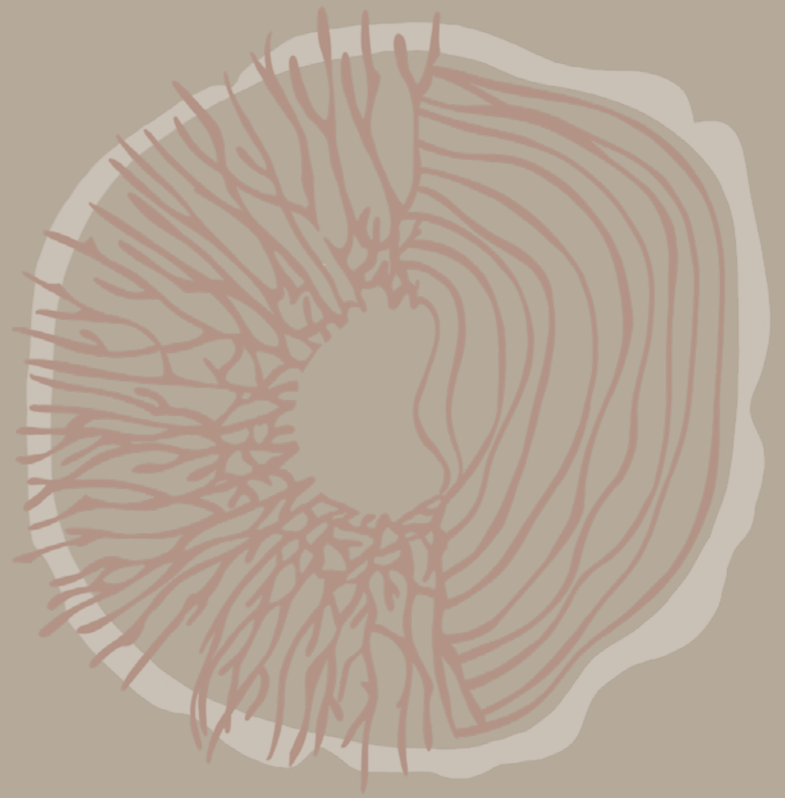
Figure 17: A comprehensive framework for the production of mycelium-based lignocellulosic composites (Elsacker et al. (2020))

5.2 A Comprehensive Literature Review on ways for Enhancing the Flammability and Moisture Resistance of Fungal Biomass.

	Experiment	Results	Discussion
Thermal degradation and flame spread characteristics of epoxy polymer composites incorporating mycelium (Chulikavit et al., 2023)	Objective: Enhance fire retardancy of epoxy using mycelium. Methods: Mycelium sheets consolidated at 60 °C, coated with epoxy/hardener slurry, cured at room temperature for 24 h, and post-cured at 60 °C for 8 h. Testing: UL94 flammability test, TGA, SEM.	Thermal Degradation: Slower weight loss and higher residual mass in TGA compared to pure epoxy. - Flammability: Improved fire resistance with slower flame spread in UL94 test. - Char Formation: Compact char barrier observed via SEM.	Mycelium functions as a char-forming agent, thereby enhancing the flame retardancy of the epoxy matrix. When combined with another thermoset in situ, mycelium demonstrated promising results. Conversely, when considering the inherent characteristics of mycelium, its porous structure and thermal degradation at low temperature makes it susceptible to combustion. To further improve its flame-resistant properties, the application of a flame-retardant coating is a potential strategy that warrants further investigation.
Penetration and adhesion of finishes for fungal materials through solubilization, emulsion, or dispersion in water-soluble materials and the use (Scullin et al., 2018)	Objective: To improve the water resistance of fungal (mycelium) materials using a biodegradable polymer coating. Method: Polymer Dispersion: PLA dispersed in water to create a mixture (0.1%-50% concentration). Mixture is applied to the mycelium surface to allow deep penetration into the fungal matrix and the material is dried to evaporate water, forming a PLA coating.	The coating penetrates at least 1%-10% of the mycelium's thickness, or at least 20 micrometers. - Adhesion: Improved adhesion strength (>2N/10mm) according to ISO 11644:2009. - Wear Resistance: The coating provides enhanced abrasion resistance and water resistance for mycelium materials.	Given that PLA is a thermoplastic, a well-established bio-based coating was utilized in the study. Bio based thermoplastic coatings can be further explored and applied to mycelium to evaluate its moisture resistance and flammability properties.

5.3 Literature Review on the Enhancement of Ligno-cellulose materials Flammability and Moisture Resistance Properties

	Experiment	Results	Discussion
Fabrication of environmentally, high-strength, fire-retardant biocomposites from small-diameter wood lignin in situ reinforced cellulose matrix (Yang et al., 2023b)	Objective: To evaluate the flame resistance of biocomposites made from small-diameter wood powder, and sodium silicate. Method: Wood powder was pretreated with hydrogen peroxide, sodium hydroxide, and sodium silicate, then hot-pressed at 170°C under high pressure (75 MPa) for 60 minutes. Testing: Butane Gun Burning Test: The biocomposite samples were exposed to a butane flame for 30 seconds to observe their burning behavior.	The untreated wood powder (RWP) samples began to burn after 15 seconds of flame exposure and produced a larger amount of ash. In contrast, the pretreated biocomposites (DW samples) showed delayed ignition, starting to burn only after 30 seconds, and retained their shape and size even after burning, indicating a char formation and self extinguishing properties.	The sodium silicate, plays as an effective flame-retardant agent and simultaneously acts as an adhesive. Its dual functionality not only enhances the material's fire resistance but also binds the cellulose fibers together, reducing the presence of pores that could facilitate combustion. By shredding the wood and bonding it with an external binder, the density of the wood increases to up to 1450 kg/m³. Additionally, the paper also reports significant improvement in its flexural strength.
Fabrication of environmentally, high-strength, fire-retardant biocomposites from small-diameter wood lignin in situ reinforced cellulose matrix (Yang et al., 2023b)	Objective: o assess the water resistance of the biocomposites and their ability to repel moisture.	The pretreated biocomposite (DW8%) exhibited a water contact angle of 99.96°, significantly higher than the untreated samples, which had contact angles around 80°. This result indicates a high level of hydrophobicity due to the dense and smooth surface created during the hot-pressing process, which minimized surface cracks and pores, thus limiting water penetration.	This treatment not only enhances the flame resistance of the wood but also improves its hydrophobicity, as indicated by higher water contact angles through the use of inorganic binders. Therefore, this modified wood could serve as a viable alternative to epoxy-reinforced flax fiber panels. Although the density of the treated wood is higher than that of the materials (Balsa,Cedar, Bamboo) discussed in the previous chapter, the subsequent chapter will investigate lightweighting techniques to achieve an optimal weight-to-strength ratio.

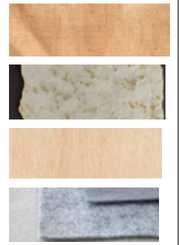


CONCEPT DESIGNING

6 LIGHTWEIGHTING METHOD

Up to this point, the focus has been on the identification of bio-based materials that facilitate circular economy practices and promote responsible end-of-life management. This chapter delves into the concept of lightweighting, a critical aspect of sustainable design, particularly in the aerospace sector. By reducing the overall weight of aircraft, significant reductions in fuel consumption can be achieved, thereby mitigating the environmental impact, which is predominantly attributed to fuel usage.

Lightweighting Method Steps:

Step 1: Identify Components for Lightweighting	
Step 2: Analyze Current Material and Design	Control design Sample: Density of ABS+PC: 1.15e3 kg/m^3 Flexural Strength: 60 MPa (ABS+PC Data sheet from literature against Aerospace materials in
Step 3: Explore Alternative Materials	- Natural fibers: Flax/Hemp - Mycelium Family of - Hardwood - Natural Textile 
Step 4: Optimise the Geometry to reduce weight	Brainstorming session to reduce per gram weight for the same loading bearing strength 
Step 5: Design selection and validation	Calculations and quantification of percentage reduction of weigh 

6.1 Brainstorming session

With a foundational understanding of the materials and their properties, primarily concerning density and mechanical strength, the next step is to develop a concept using these materials.

Session Goal: To develop design concepts that ensures a good strength-to-weight ratio for a space divider in seating structure utilizing the materials provided: flax fiber composite, balsa wood, mycelium, and non-woven fabric

Participants and method: Nine students between 20 and 30 years of age from various disciplines, including architecture, aerospace engineering, mechanical engineering, and industrial design, were involved. This session aimed to harness the collective experiences and academic backgrounds of the participants. Participants were encouraged to explore creative solutions focusing on generating a broad range of ideas rather than refinement. Each participant was tasked with generating at least 10 ideas followed by discussion. After generating ideas, participants were Encouraged to use dot voting to narrow down their ideas to 3/4 top ideas.

This section presents the design ideas, which are numbered and color-coded based on the types of materials used. Pink represents synthetic materials or matrices, while green indicates bio-based materials. Combinations of these materials are shown in both green and pink. As a result, a visual representation in Figure 18 illustrates the combination of materials as matrices and reinforcements, with the corresponding design numbers placed alongside. The ideas selected to further conceptualise are highlighted as shown below.

1. Topology optimization of the Fiber reinforced panel
2. Triangle and hexagonal plywood wood reinforcements to the mycelium panel
3. Magnetic metal pieces for reinforcement of textile
4. Wooden truss inside the mycelium panel
5. Molding of flax panel in the epoxy resin
6. Developing parabolic and hyperbolic structures for strength
7. Metal mesh for the reinforcement of mycelium
8. Bamboo joints for strength reinforcement of Mycelium
9. Knitting textile around the wood piece and growing mycelium as a foam material
10, I beam structure design of Balsa wood and textile filling inside it
11. Bio mimicry inspired bone structure flax panel
12. Create multilayer panel using best properties of each material
13. Bamboo lattice with textile covering
14. Balsa as core material in composites
15. Bamboo weave around the mycelium
16. Flax panel with mycelium as core
17. Growing mycelium on non woven textile mass as an adhesive
18. Utlising Mycelium as an adhesive instead of epoxy for fiber reinforcement
19. Usage of Natural fiber mat for Mycelium growth
20. Knitting textile around wood piece
21. Balsa face sheet and mycelium core
22. Origami folds for strength enhancement of flax and textile

The design concepts have been categorized into fully natural composites and partially hybrid composites to consider its circularity during design selection. Based on the design requirements for weight and strength, three design ideas have been narrowed, integrating one or more ideas developed during brainstorming session. Since this project is focused on aircraft design requirements, practical considerations are paramount. In contrast, for applications such as furniture, a more freedom towards experimenting with aesthetics and form could be more appropriate.

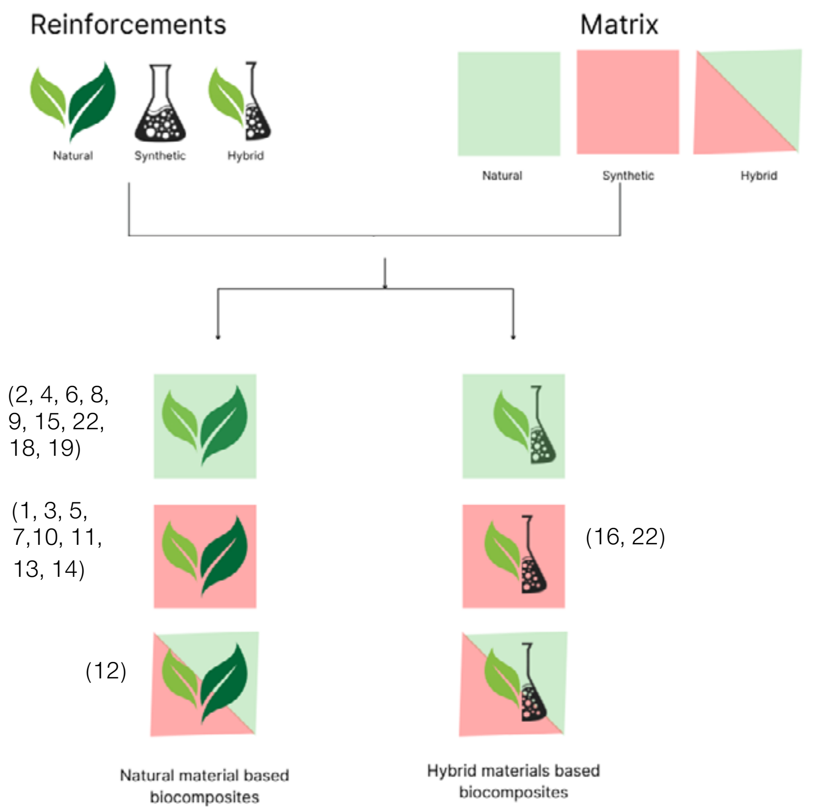


Figure 18: Classification of designs based on reinforcements and matrix Adapted from (Mazlan et al., 2024)

The composite design, employing a core and facesheets, has been selected due to its advantageous combination of high strength-to-weight ratio and the inherent flexibility to tailor material properties to meet precise design specifications. The face sheets provide the composite with its tensile and compressive strength, while the core maintains the structural integrity by resisting shear forces and keeping the structure stiff. This combination results in a lightweight, strong, and stiff composite material. Given the combination of natural and hybrid materials, consisting of both natural and synthetic components, it would be interesting to explore their weight-to-strength ratios and compare them with fully natural and semi-hybrid alternatives. The following are design variations to explore optimal weight to strength ratio:

Composite core: Mycelium (Treated with flame retardant)

Face sheets variations:
A- Balsa wood (Untreated)
B- Pre treated wood (Yang et al.2023b))
C: Flax reinforced Panel

Adhesion Mechanism: Mycelium grows on textiles that are mechanically fastened to the wood using rivets.

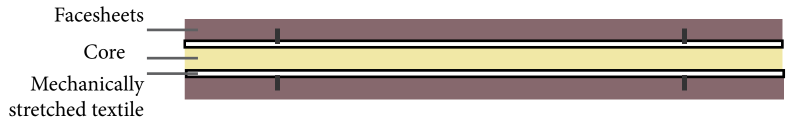
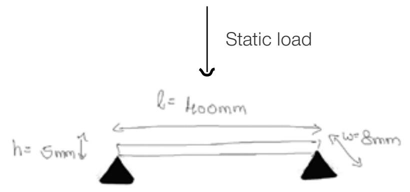


Figure 19: Schematic diagram of sandwich panel

6.2 Identifying the suitable material to achieve an optimal strength-to-weight ratio.

Design statement: To design a panel which is simply supported at both ends using bio derived materials which can withstand 1000N of static load

Design Specifications: The panel dimensions are 400mmx 80mmx 5mm.



The control sample (reference sample to provide a baseline for comparison) here is considered to be a panel made of ABS+PC.
Control design Sample specifications:
Density of ABS+PC: 1.15e3 kg/m3
Flexural Strength: 60 MPa
(ABS+PC Datasheet from literature against Aerospace materials in Granta Edupack)

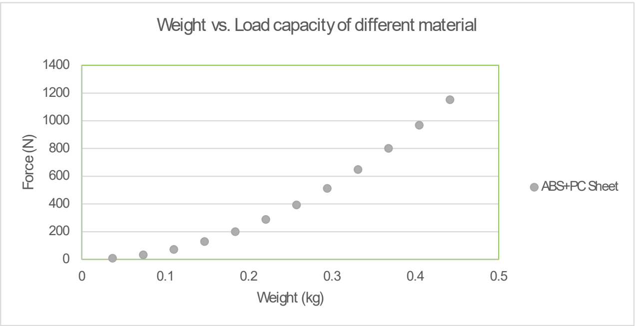


Figure 20: Weight to strength ratio of ABS+PC thermoplastic

Experimental samples:

Balsa wood Panel:
Balsa wood (longitudinal orientation): 300kg/m3
Flexural Strength: 29.7 MPa
(Balsa (ld) Datasheet from literature against Eco design materials in granta edupack)

Pre-treated wood (PTW) panel
(Busxus Sinica wood pretreated with Hydrogen Peroxide, Sodium Silicate and Sodium Hydroxide as mentioned in the section 5.3)
Density: 1460kg/m3
Flexural Strength: 141.98 MPa
(Yang et al., 2023)

Flax fiber reinforced (in bio epoxy) panel (FRP)
Density: 1178 kg/m3
Flexural Strength: 65.5 MPa
(Rana & Evitts, 2014)

Core: Mycelium based Composite (MBC)
Density: 88 kg/m3 (Lab calculated)
Flexural Strength: 2.86 MPa

(Mohammad Aliff Shakir1et.al, 2020)

Assumptions:
- The adhesion between the mycelium and the facesheet is continuous and uniform, exhibiting no signs of deformation in the bonding.

Calculations:

The mass of the each sample is calculated with the density data from the database and volume of the panel

$$m = \rho \times V \quad \text{...(1)}$$

m is mass
V is Volume
ρ is Density

Flexural Strength calculations:

$$\sigma = \frac{3FL}{2bd^2} \quad \text{...(2)}$$

σ_{eq} is the flexural equivalent in the composites

F is the max load (force) at the fracture point
L is the length of the support (outer) span
b is width
d is thickness

σ_{eq} = (Volume fraction of facing sheet x flexural strength of facing) + (volume fraction of core x flexural strength of core) ....(3)

Volume fraction of that component = volume of that component/total volume ....(4)

The above formulas were used and calculations were run on excel to plot a graph between weight and max load at the fracture point of the 3 choosen variations of the composite and the result are as shown in the figure 21,22,23. The final analysis comparing all three composites is shown in the figure 24.

Analysis of the results

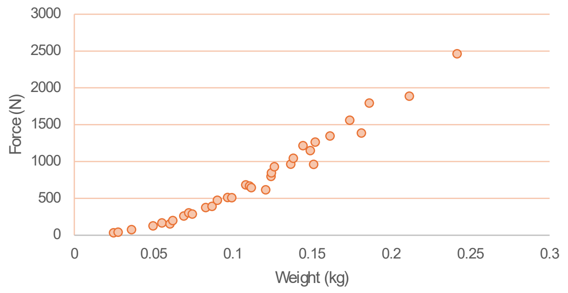


Figure 21: Weight to load performance of Mycelium and Balsa composite

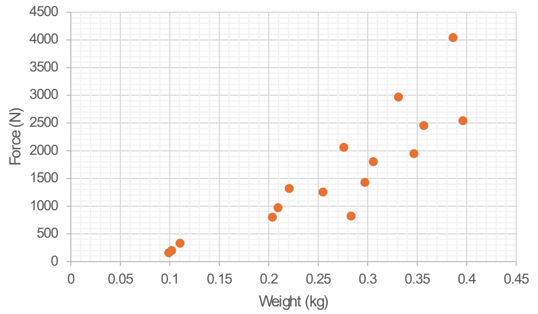


Figure 22: Weight to load performance of Mycelium and PTW composite

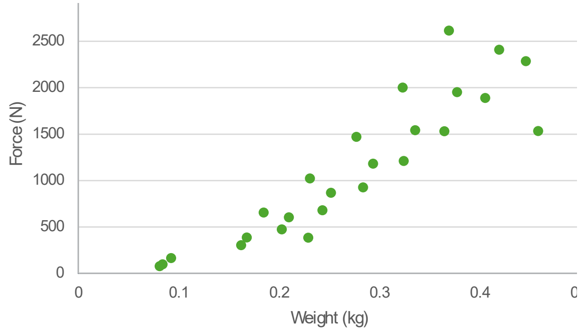


Figure 23: Weight to load performance of Mycelium and FRP composite

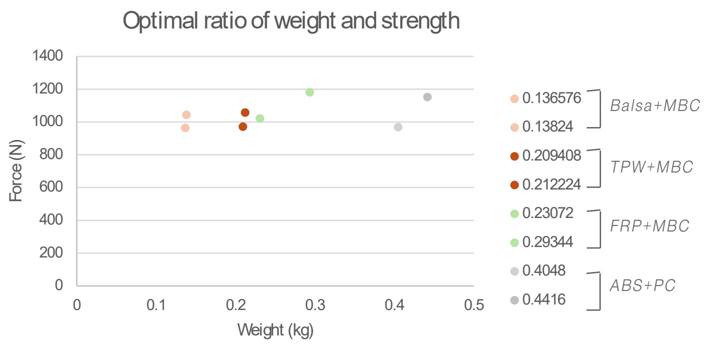


Figure 24: Weight at which all composites can withstand a static load strength of approximately 1000 N.

(Refer Appendix 3 for complete calculations.)

Balsa wood+ MBC composite: This composite has the lowest weight, ranging 0.1-0.2 kg, and can stand forces between 800 N to 1000 N. This shows that balsa wood has a relatively low weight but good strength for its weight. However the thickness of the composite is extremely high upto 22-25mm. Also the current composite considered is not treated with flammability and moisture resistant materials making it not so desirable for the aircraft industry

Treated wood+ MBC composite: This has a slightly higher weight than balsa but achieves 1056N at the weight of 0.209g.

FRP+MBC Composite: At 0.23kg flax panel can handle upto 1021N with thickness of 17-20mm.

6.3 Design Selection: Weighted Criteria Method

Up to this point in lightweighting, we have focused solely on the weight-to-strength ratio of the designs. Now, referring back to the program requirements, it is essential to view the overall picture and assess how well each design meets the critical functional and design criteria. A weighted criteria method has been employed to evaluate the optimal material choices as shown in figure 24. Each criterion is assigned a specific weight and rated on a scale of 1 to 5, where 1 indicates the lowest alignment with the requirements and 5 indicates the highest.

Weightage to each criteria	
Weight	35
Flammability	15
Moisture resistance	10
Hygroscopic resistance	6
R strategy	9
Thermal insulation	4
Acoustic insulation	4
Space management	5
Biodegradability	6
Rapidly renewable	3
Chemically safe	3
Total	100

Figure 24: Weighted Criteria Method, adapted from Delft Design Guide (Van Boeijen et al., 2020)

Balsa + MBC	
5	175
1	15
0	0
0	0
4	36
4	16
4	16
1	5
5	30
3	9
4	12
	320

Flax + MBC	
3.5	122.25
3	45
3	30
3	18
2	18
4	16
4	16
4	20
2	12
2	6
2	6
	309.25

PTW+MBC	
4	140
4	60
3	30
3	18
4	36
4	16
4	16
4	16
5	30
3	9
4	12
	371

Figure 25: Rating of design against weighted criteria's

Conclusion: Based on the weighted criteria analysis, the PTW + MBC composite scored the highest , indicating its balance across key factors like flammability, moisture resistance, and thermal insulation. Balsa + MBC and Flax + MBC scored 320 and 309.25 which are nearly same, showing they are viable options but less optimal compared to PTW + MBC. Here while considering Flax reinforced panel, it is assumed that the epoxies are flame retardant and Moisture resistant. However flax composite is also a potential area to explore in the near future in development and sound knowledge of bio based resins.

As PTW + MBC emerges as the most favorable composite choice. Final design visualisation is created and a modification version of the same is shown for the seat armrest in the Figure 26 and Figure 27 respectively.

Selected concept visualisation

Figure 26: Cross-Sectional View of Composite Structure with Buxus Sinica Wood Facing, Mycelium Core, and Non-Woven Fabric Layer.

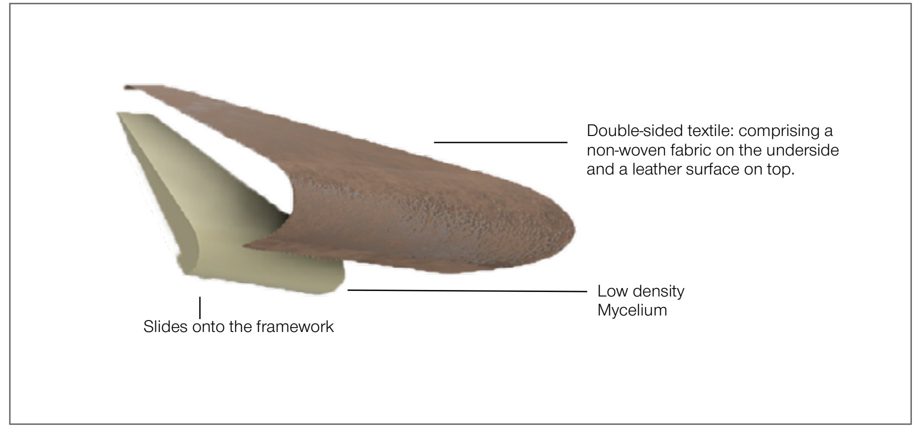


Figure 27: Redesigned for the application of armrest padding

6.4 Design Validation of Mycelium as core structure in composite

All the previously discussed decisions were based on theoretical values. To validate these theoretical assumptions against experimental results, 3 point bending experiment was conducted. Due to the unavailability of treated face sheets and the timeline of thesis, a balsa and mycelium composite was created using commercially available Bison epoxy glue. This test serves as a preliminary validation of the potetntial of using Mycelium as a core materials but does not assess the full range validation of th e proposed design.

Specimen specification:
Dimensions of 70 × 30 × 14 mm, with an average Mycelium core thickness of 6 mm and a Balsa wood layer of 4 mm. A three-point bending test was conducted to determine the maximum force (F) composite can take before it breaks, and the results of theoretical and experimental calculations are presented below for analysis.

Theoretical calculations:

σ_{eq} = (Volume fraction of facing sheet x flexural strength of facing) + (volume fraction of core x flexural strength of core)

σ_{eq} = (8/14 × 29.7) + (6/14 × 2.86)

= 16.97 + 1.22 = 18.19

$$\sigma_{eq} = \frac{3FL}{2bd^2}$$

F = 3 × 18.18 × 2 × 30 × 14² / 3 ×70
= 1018 N

Figure 28: Zwick 3 point bending testing

Experimental Values:

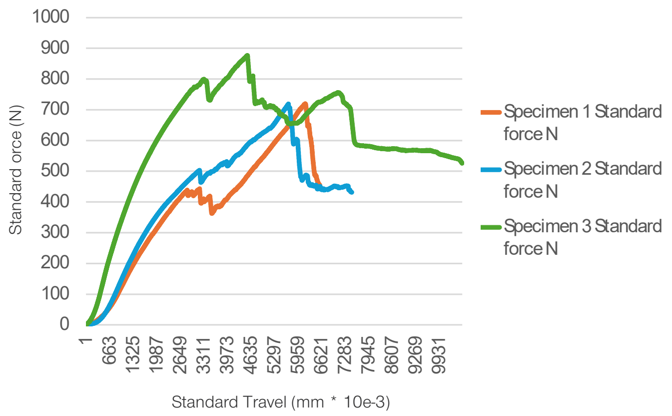


Figure 29: Result of 3 point bending test

Analysis of the results

The 3 point bending test showed values lower-than-expected as shown in figure 29. The reasoning could be:

- The major reason is as shown in the figure 30,

Figure 30: De lamination of the core from the balsa facing sheet

mycelium core was not strong enough for the stress to be distributed evenly, which resulted in weak load transfer across the layers, simultaneously which could also reduce the overall strength of the composite.

- Mycelium compared to other core materials such as polyurethane foam, Nomex honeycomb has less shear strength.

- The presence of voids or inconsistencies in the mycelium could also compromise the structural integrity of the composite, leading to a lower Fmax.

- Optimizing the layup pattern of substrate can distribute the load effectively.

- The current sample was incubated for 7 days, however incubating for longer period can lead to formation of stringer binds and lesser crack formation.

6.5 Design Validation of adhesive nature of mycelium with textiles

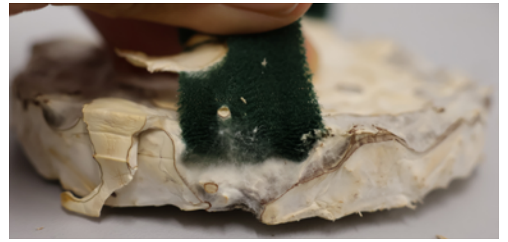
During the initial brainstorming phase, aimed at investigating the interaction between mycelium and various textiles, a preliminary validation of mycelium behavior was conducted utilizing four distinct types of textile substrates. The results of this evaluation yielded positive outcomes, detailed as follows:

1. Mycelium growth on knitted fabric:
Poor adhesion was observed in this sample, as the mycelium might have lacked sufficient support to attach effectively due to the large pore size.

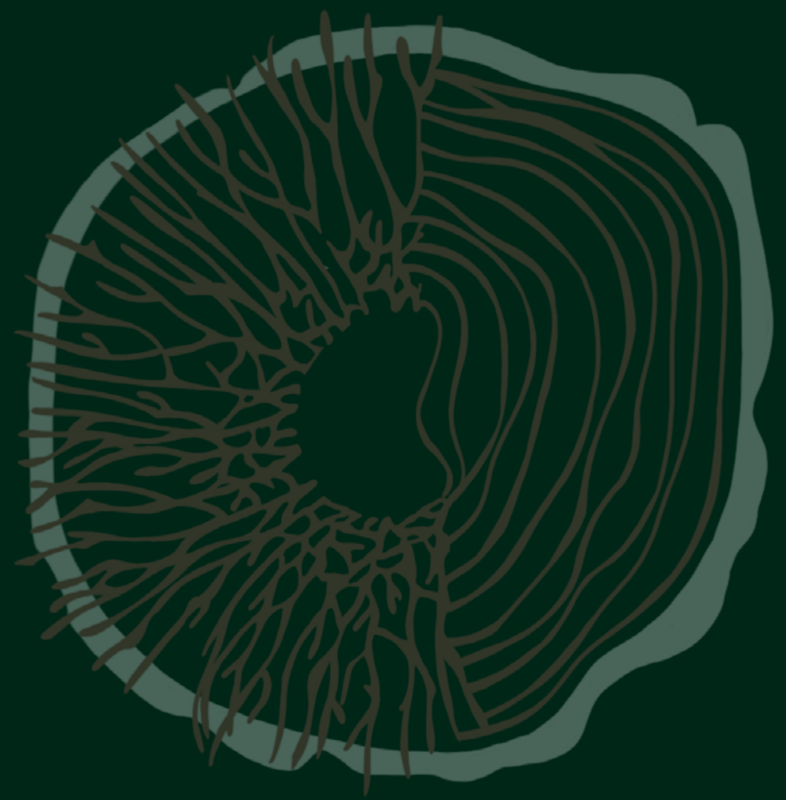
2. Mycelium Cultivation on Non-Woven Fabric: Non-woven fabrics offer a randomly oriented network of fibers that can facilitate mycelium infiltration.

The small porous nature of non-woven fabrics allows for mycelium to easily stick and exhibit excellent adhesive property.

3. Mycelium Cultivation on Small-Pore Woven Fabric: Small-pore woven fabrics presented a structured surface with defined porosity. The porous structures were seen to make a network of interlocked hyphae also exhibiting good adhesive property.



4. Mycelium Cultivation on non porous surface: The adhesion of mycelium on synthetic fabric was very poor, likely due to the fabric's smooth finish and lack of surface porosity, which provided no anchoring points for the mycelium to attach.



MATERIAL OPTIMISATION

7 FLAMMABILITY TEST

This chapter discusses about the selection of coating treatments for enhancing mycelium's flame-retardant characteristics. Following this exploration, a UL94 test, typically employed for plastics, conducted to evaluate its fire resistance. The chapter concludes with a discussion of the test results, providing insights into the material's performance in terms of flammability.

7.1 Flame Retardant Coatings

A chart was constructed to do comparative overview of various flame retardants in terms of their compatibility with mycelium and their toxicity at disposal. Figure 31, is based on previous practical experience with commercial coatings and the literature review on wood coatings rather than directly derived from comprehensive scientific literature. The placement with its compatability with mycelium is informed by personal inferences, it may not fully reflect peer-reviewed studies or empirical data.

Halogenated retardants are most toxic to the environment and health and its toxicity have potential to disintegrate the mycelium structure. Phosphorus- and boron-based retardants offer better flame resistance with moderate toxicity, but they can still pose environmental concerns due to its potential to Eutrophication. Nitrogen-based and inorganic retardants are more balanced options, providing adequate flame resistance with

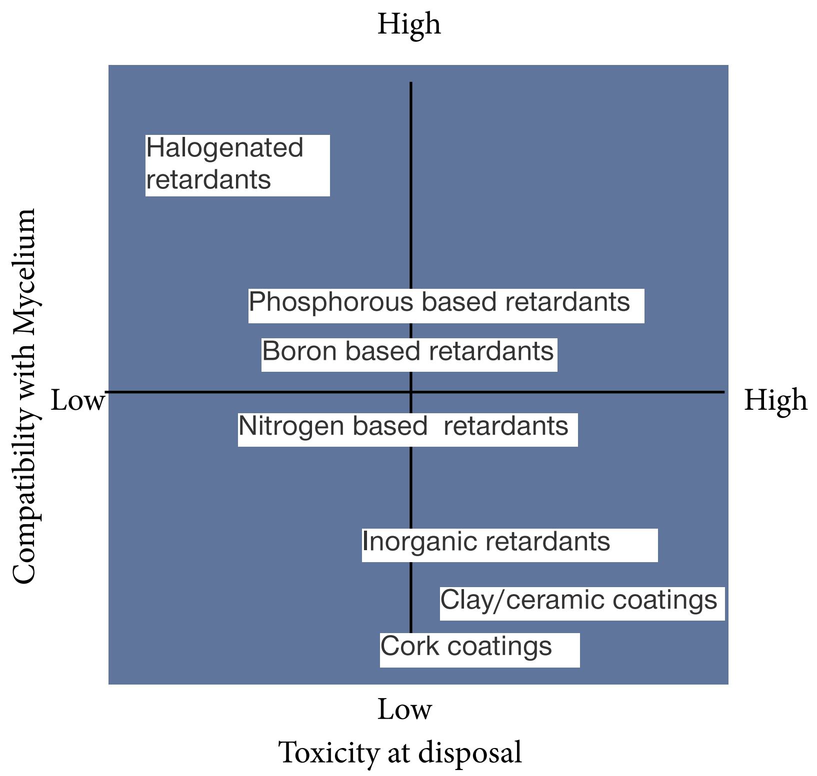


Figure 31: Toxicity of Various Flame Retardants and their Compatibility with MBC

lower toxicity and reasonable compatibility, though they are safe, the melamine compounds stays forever in the landfills and water bodies. Clay/ceramic is seen as favorable choice however it adds up to the weight of the composite. Next to that cork is an amazing option given there is a bio based adhesive which is compatible both with cork and Mycelium. These natural materials do not hinder mycelium's structure or growth, making them ideal for creating environmentally safe, flame-resistant bio-composites.

Based on the insights from Chapter 6 and the literature review of the paper "Fabrication of Environmentally, High-Strength, Fire-Retardant Bio composites from Small-Diameter Wood Lignin In Situ Reinforced Cellulose Matrix" (Yang et al., 2023b), sodium silicate, an inorganic flame retardant, shows potential for use in enhancing the flame resistance of mycelium. Additionally, sodium silicate serves not only as a flame-retardant coating but, when combined with cork, it can function as an effective bio-based adhesive, facilitating the formation of a cork and mycelium composite with enhanced fire-resistant properties.

Furthermore, the study "Penetration and Adhesion of Finishes for Fungal Materials through Solubilization, Emulsion, or Dispersion in Water-Soluble Materials and the Use of Surfactants" (Scullin et al., 2018) demonstrated that PLA thermoplastic was successfully utilized to render fungal material surfaces hydrophobic. However it is established that the PLA is inherently flammable with a limited oxygen index of 18%-20 % Yang et al. (2023b). During the market exploration of mycelium's moisture-resistant coatings, it was

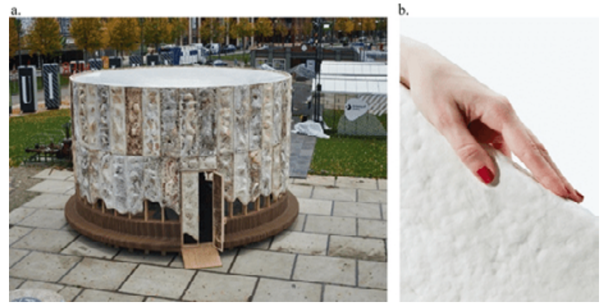


Figure 32: Growing Pavillion during Dutch Design Wekk (DDW), 2019 (Elsacker et al., 2021)

observed that the Growing Pavilion exhibition at DDW 2019 employed a bio-based thermoplastic known as BioSeal (a bio derived thermoplastic) with mycelium as shown in figure 32. Given its established effectiveness, and Moisture resistance properties, BioSeal (BioSeal Mycelium, 2024) was subsequently sourced to evaluate its flammability properties since it's requested material data sheet did not provide the nature of its flammability. The complete Material Datasheet of Bio Seal sourced from the company is in Appendix 2.

Based on the research, four types of samples were prepared, with three specimens for each type:
- Mycelium-Based Composite (MBC): Used as the control sample
- MBC + Sodium Silicate as coating
- MBC + Cork with Sodium Silicate Binder and heat pressed
- MBC + BioSeal as coating

7.2 Test Objective

The test aims to determine the ability of each coated MBC sample to resist ignition and self-extinguish after being exposed to a direct flame. By analysing the burning behavior, after-flame time, and dripping characteristics, the test will provide insights into the effectiveness of each coating in enhancing the fire resistance of mycelium-based materials.

7.3 Test Method:

For this test, UL 94 test is undertaken as it is focused on evaluating the flammability of plastic materials in terms of their ability to ignite and sustain combustion. EASA's regulations encompass a wider range of factors, including not only flammability but also smoke generation, toxicity, and overall performance in real-world aircraft condition which are more stringent to test at this stage.

Test Setup: The sample is secured in a vertical position and ignited using a 20 mm blue flame, positioned at a 45° angle, 10 cm from the lower end of the test strip. Cotton balls are placed 30 cm beneath the specimen to detect any flaming particles that may drip during the test. The procedure consists of two stages: first, the flame is applied to the specimen for 10 seconds, then removed to allow self-extinguishing. After that, the flame is applied again for another 10 seconds before being removed.

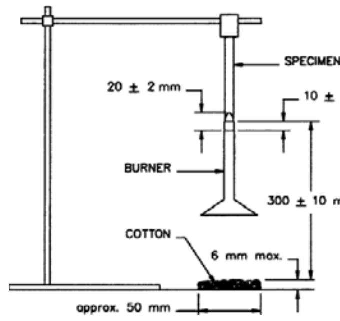


Figure 33: UL 94 test setup

7.4 Sample Preparation

(a) (b)

Figure 34: Preparation of Mycelium composite (a) Vaccum forming the mold (b) Molding the pre incubated mycelium (Appendix 1) and drying at 50 degree Celsius for 24hrs

(a) (b)

Figure 35: (a) Bio Seal Mycelium sourced from Impershield Europe (b) Commercially available Natron Water Glass.

(a) (b)

Figure 36: Preparation of Mycelium and Cork composite using Sodium Silicate as Adhesive. (a) Molding the composite (b) Hydraulic Pressing

The mycelium samples were coated three times with Sodium Silicate and BioSeal Mycelium in the intervals of 2hrs and air dried. The first layer of the coatings penetrated the porous structure of the mycelium, while subsequent layers, as they dried, began to form a surface layer. Both the inorganic and polymer coatings required a high loading to achieve an effective barrier. The weight difference between the coated and uncoated samples ranged from 0.75 to 1.35 grams; however, this variance is not being considered at this stage because the focus is on performance. The percentages of the coatings varied, and the substrates and coatings were inconsistent as it was prepared in lab

The samples were prepared by mixing cork (Particle size of 0.5mm) with a sodium silicate and water solution in a ratio of 1:0.2:0.8. This mixture was then placed between mold plates and heat-pressed at 50°C for 60 minutes at 40bar. Initial attempts at 170°C resulted in burning the samples, so the temperature was subsequently lowered to 50°C.

7.5 Test Results and Analysis:

This table presents the results of a vertical flame test conducted on various materials, focusing on afterflame and afterglow times after flame applications.

Vertical flame test results	MBC uncoated		MBC + Sodium silicate			MBC + Bio seal			MBC + Cork		
Criteria conditions	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Afterflame time after first flame application, t1 (sec)	26	18	0	0	0	7	1	1	0	0	0
Afterflame time after second flame application, t2 (sec)	45	32	0	0	0	16	1	2	0	0	0
Total afterflame time for any condition set, t1+t2 for the 5 specimens* (sec) *Note: *Only 3 spe*	*121*		*0*			*28*			*0*		
Afterglow time, t3 (sec)	30	30	0	0	0	0	11	1	6	0	1
Afterflame plus afterglow time for each individual specimen after the second flame application	75	62	0	0	0	16	12	3	6	0	1
Afterflame or afterglow of any specimen up to the holding clamp	no	no	no	no	no	no	no	no	no	no	no
Cotton indicator ignited by flaming particles or drops	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Comments			foaming	foaming	foaming						
Material Classification	failed	failed	V-0	V-0	V-0	V-1	V-1	V-1	V-0	V-0	V-0
Pictures											
Speciemens after UL94V test											
	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13

Table 1: Results from the UL94 flammability test

MBC uncoated: The control sample, the uncoated Mycelium-Based Composite (MBC), passed the horizontal burning test however passing vertical burning test is hard because of the availability of the substrate for the flame spread. Theoretically, the mycelium should form a protective char layer to prevent flame spread but during the test it turned to ash. Possible reasons for Ignition:
- Presence of gaps or areas where mycelium did not fully grow, or where it has deteriorated, exposing the substrate directly to fire.
- Mycelium degradation at low temperatures, which subsequently exposes the underlying substrate to flames.
- The porous nature of the material allows oxygen to penetrate, facilitating combustion.
- Insufficient formation of a dense char layer to act as an effective barrier against flames.

MBC + Sodium Silicate: The test results were exceptionally positive. When exposed to fire, the sodium silicate forms a glassy, ceramic-like barrier that effectively insulates the underlying material from heat.

MBC + BioSeal: The MSDS of Bio Seal Mycelium (Appendix 2) indicates it is a styrene like bio derived -polymer. The flammability results were varied , while 2 out of 3 samples displayed reasonably good fire resistance, one sample exhibited a high after-flame. This variation may be due to the porous structure of the material, which can create exposed areas that are more prone to catching fire. This suggests the need for further exploration

MBC + Cork Composite: Mycelium coated with cork showed similar flammability results to the sodium silicate-coated samples, displaying equally effective self-extinguishing properties. However, as seen in table 1, flame spread was noticeably greater than in the sodium silicate composites.

8 WATER CONTACT ANGLE TEST

Following the flammability test, it is also important to evaluate the water resistance properties of these composites. This section seeks to examine how various coatings interact with mycelium and improve its wettability.

8.1 Test Objective

To measure the water contact angle on the surface of Mycelium-Based Composites (MBC) with various coatings. This test aims to evaluate the hydrophobicity or hydrophilicity of the coated surfaces by determining how water droplets interact with each surface.

8.2 Test Setup

In this test, a small droplet of distilled water is carefully placed on the material's surface using a syringe. A contact angle goniometer, equipped with a camera and light source, captures the profile of the droplet as it interacts with the surface. The software then analyzes this profile to measure the contact angle, which is the angle formed between the droplet's tangent line at the point of contact and the surface baseline. A higher contact angle (greater than 90°) indicates that the surface is hydrophobic, meaning it repels water, whereas a lower contact angle (less than 90°) indicates a hydrophilic surface that absorbs water.

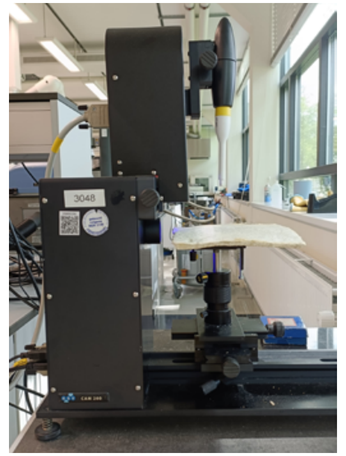


Figure 37: Water Contact angle test setup

8.3 Test Results and Analysis

The MBC composites: MBC initially displayed hydrophobic properties with the first few drops of distilled water. However, with repeated application of water droplets to the same area, the surface began to show signs of hydrophilicity and became wet. The initial hydrophobic behavior of the Mycelium-Based Composite (MBC) can be attributed to the surface characteristics of natural arrangement of chitin, which can create a barrier that reduces the wettability of the surface. However, when water droplets are repeatedly applied to the same area, this initial hydrophobic layer can be compromised as shown in the figure 38. The repeated impact and weight of the water droplets can disrupt the surface tension, leading to the gradual penetration of water molecules into the composite. Over time, water can infiltrate these pores, dissolving surface films or altering the surface energy.

Figure 38: Water Contact Angle Measurement of Mycelium Based Composite (Uncoated)

The MBC+Sodium Silicate: The water droplets slid off within seconds, making it impossible to capture an image. However, it remains unclear whether the material is absorbing the water or if it simply possesses non-wettable properties.

The MBC + Bio seal: When the sample was coated with Bio Seal, the surface became un even. This may be due to the heavy and uneven application of the coating. Additionally, the mycelium may have become wet and soggy, resulting in an uneven surface for the water contact angle test. Despite this, the captured images indicate that the sample demonstrated some extent of hydrophobicity. Its important to note that to get a good test results the sample needs to be flat

Figure 39: High resolution Images of the MBC+Bio Seal surface following the droplet application

The MBC + Cork: The cork composite exhibited extremel high hydrophilic properties and absorbed a significant amount of water. Although images could not be captured, this behavior was primarily due to the porous structure of the developed composite, which allowed water to penetrate. Future research could investigate whether using densely packed cork might prevent water seepage into the mycelium.

Figure 40: High resolution Images of the MBC+Cork surface following the droplet application

9 WATER ABSORPTION TEST

Based on the previous water contact angle measurement test, the hydrophilic and hydrophobic nature of the composites was established. However, it was unclear whether the water was being absorbed or simply flowing off the surface. Therefore, a water absorption test was conducted to clarify this behavior.

9.1 Test Objective

The water absorption test to measures the amount of water a material can absorb under specific conditions, evaluating changes in both weight and appearance caused by water intake.

9.2 Test Setup

The MBC composites coated with sodium silicate and Bio Seal, along with the control sample, were exposed to 5 ml of water applied to their top surface at 20-minute intervals. After each interval, the surface was gently blotted with a cloth, and the samples were subsequently weighed to measure any changes in mass. This test does not adhere to any specific standards, as the typical procedure involves fully immersing the sample in water. Generally, according to ASTM standards, the sample is observed for 24 hours; however, a significant change in weight was noted as early as the 20th minute. Consequently, variations were monitored over shorter intervals, leading to the creation of the graph. The test was performed solely on the top surface, as mycelium growth was denser in this area. This growth resulted from the mold conditions used. When scaling up production, this issue can be addressed by intro ducing air gaps between the molds and the sample, allowing for even mycelium growth on all sides.

Edge Conditioning: Given that the composites were grown at the lab scale and have uneven surfaces, there is a high possibility that water could flow off the edges and wet other faces of the sample, potentially leading to inaccurate results. To prevent this, the edges of the mycelium were masked during testing.

9.3 Test Results and Analysis

MBC after the test

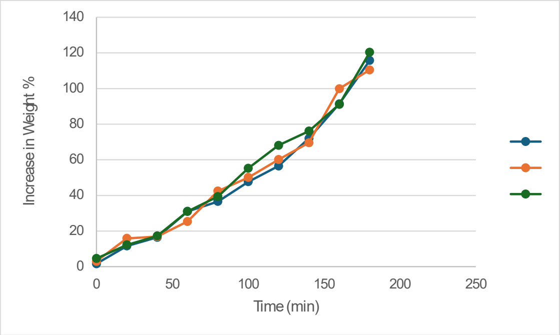


Figure 41: Increase in Weight percentage on the water dispersion of MBC vs time

MBC+ Bio Seal after the test

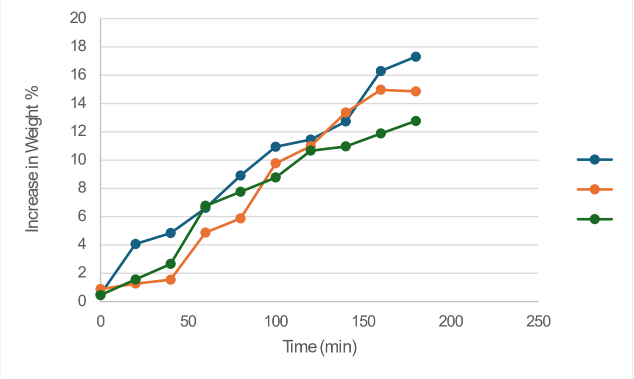


Figure 42: Increase in Weight percentage on the water dispersion of MBC+ BioSeal vs time

Theoretically, the polymer coating should act as a barrier; however, it has been observed that water leaves a mark on the composite. This may be attributed to poor curing of the polymer or an inadequate coating application.

MBC+ Sodium Silicate after the test

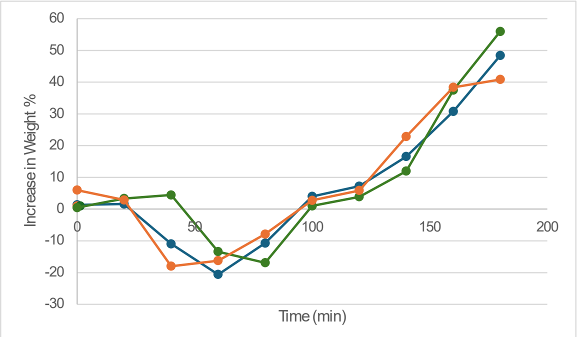


Figure 43: Increase in Weight percentage on the water dispersion of MBC+ Sodium Silicate vs time

The increasing graph suggests that the Sodium Silicate coating is not effectively preventing water absorption over time. Although it may provide some initial protection, the coat tends to peel off and the barrier is broken leading to water absorption of mycelium.

10 HOT WET AGING TEST

To thoroughly assess the coating's durability, the hot-wet aging test is essential. This test simulates prolonged exposure to heat and moisture, revealing how the coating withstands stress over time. It can identify potential weaknesses, such as disintegration or discoloration explaining its behavior in the real extreme conditions

10.1 Test Objective

To evaluate the durability and long-term performance of composite materials under conditions of elevated temperature and high humidity,this test aims to assess how exposure to hot and wet conditions affects the weight, and integrity of the coating over time,

10.2 Test Setup

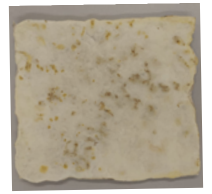
The MBC and MBC + BioSeal composites are to be placed in a climate chamber at 70°C and 85% humidity for 1000 hours (Eco Compass, 1.6 Final Report), here during the thesis timeline it is kept for 720hrs to assess their hygroscopic behavior, thermal expansion, and potential discoloration.

The water absorption test demonstrated that sodium silicate is not water-resistant, as it deteriorated and developed cracks during the test. Given this poor performance, conducting a hot-wet aging test on the sodium silicate-coated MBC was deemed impractical, as the coating would not withstand prolonged exposure to moisture and heat.

10.3 Test Results and Analysis

MBC

Day 1 (0hr)



Weight: 36.19g

Day 10 (240hr)

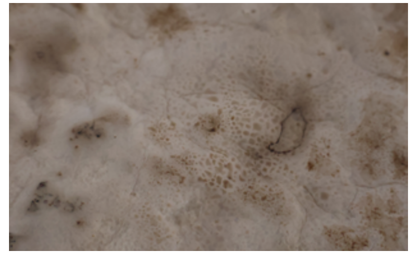
Weight: 36.49g

Day 20 (480 hr)

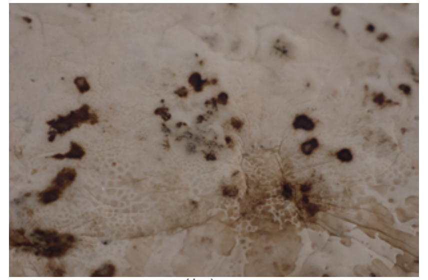
Weight: 36.37

Day 30 (720hr)

Weight: 36.32



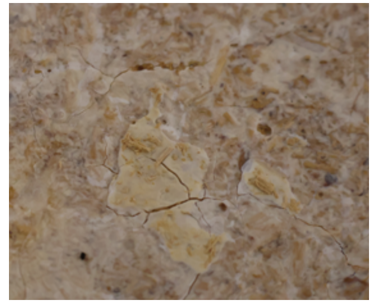
(a)



(b)

Figure 44: Surface modification of MBC after 720 hrs in

The samples exhibited minimal changes in weight, likely due to the simultaneous effects of high humidity and elevated temperature. While the humidity promoted moisture absorption, the high temperature caused moisture loss from the composite, resulting in an overall low net change in weight. However, it was not possible to accurately measure the composite's dimensional changes due to its uneven surface properties. Notably, a significant observation was the change in color and the appearance of dark spots on the surface. These dark spots suggest potential burn-out areas, warranting further investigation using Scanning Electron Microscopy (SEM) for a more detailed analysis.



(a)

(b)

Figure 45: Surface modification of MBC+ Bio Seal after 720 hrs in

Although the weight of the Bio Seal-coated composite remained relatively constant, likely due to the balance between moisture absorption and loss, it was observed that the coating began to develop cracks. This cracking is indicative of thermal expansion within the composite. The high temperature likely caused differential expansion between the mycelium substrate and the Bio Seal coating, leading to the formation of surface cracks and suggesting that the coating elasticity may be insufficient to accommodate the thermal stresses involved.

11 **CONCLUSIONS** FROM MATERIAL OPTIMISATION

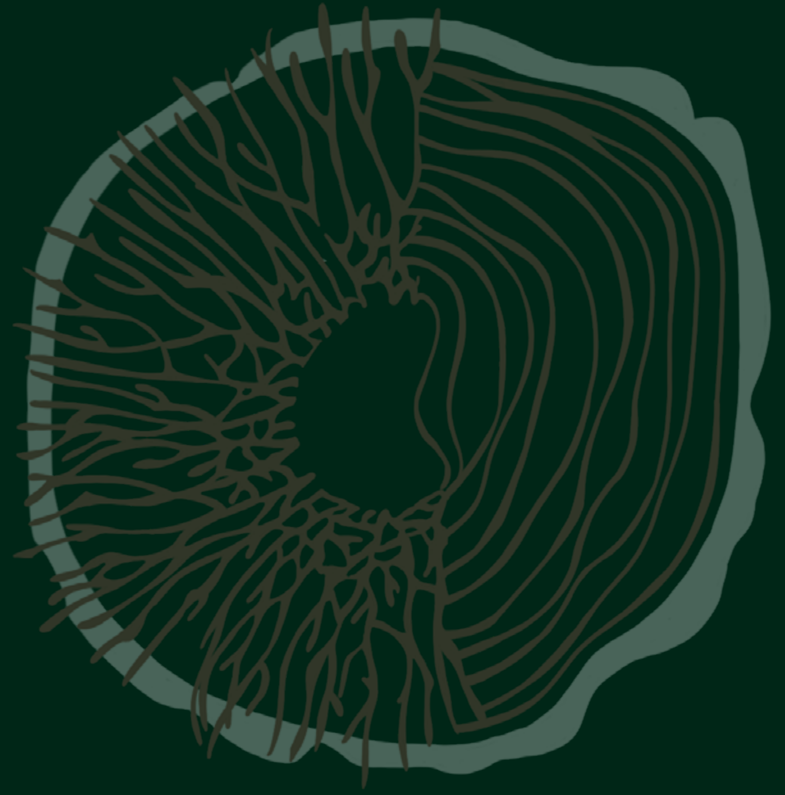
This chapter takes a holistic approach by evaluating all the properties collectively to determine which coating demonstrates the most balanced performance in terms of both moisture resistance and flame retardant. While individual coatings may excel in one specific function, it is imperative that they also fulfill the other essential criteria are also to be met.

1. Self extinguishing behavior:
The flammability tests conducted on various coatings applied to Mycelium-Based Composites (MBC) showed that sodium silicate and cork-based coatings exhibited effective flame-retardant properties. Cork showed promising results, but with higher flame spread and density compared to sodium silicate. Sodium silicate formed a ceramic-like barrier, yet its water-soluble nature undermines its long-term durability in real-world aerospace conditions.

2. Hydrophilicity and Moisture Absorption:
The water contact angle tests demonstrated that while MBC initially showed hydrophobic behavior, repeated application of water droplets caused it to exhibit hydrophilic properties. Sodium silicate coating hydrophilicty and Bio Seal coatings displayed hydrophobicity over the captured image on camera since the samples were not flat to capture it on the water contact angle test setup. Although the samples were developed to be flat under optimal laboratory conditions, the coating caused unevenness on the surface. This requires further research to understand how the coating alters the surface of mycelium.

3. Hot-Wet Aging Test Findings: The hot-wet aging test revealed cracking and surface changes, including the formation of dark spots on the coated composites. This indicates not only the mechanical limitations of the coatings under thermal stress but also a potential chemical degradation of the mycelium. The appearance of dark spots suggests possible thermal degradation or burn-out areas, indicating that the current coatings are unable to protect the mycelium from high-temperature stress. This underscores a critical limitation: current coating solutions are insufficient to withstand the combined thermal and moisture stresses encountered in aerospace applications.

Further Recommendation: As of Sodium Silicate exhibits excellent flammability and none of the samples exhibit absolute water resistance behaviour A recent study by Kandola et al. (2024) investigates the enhancement of water resistance in cellulose-based materials through the incorporation of chitosan. The research reveals that blending chitosan with cellulose significantly improves the moisture barrier properties of these materials. Notably, a chitosan-to-cellulose ratio of 30:70 resulted in a remarkable 65.5% reduction in swelling compared to pure chitosan, indicating a substantial increase in moisture resistance. Additionally, the study proposes the integration of sodium silicate with chitosan nanoparticles. Given sodium silicate's adhesive qualities, this combination has the potential to achieve an optimal balance between flammability reduction and moisture resistance. Future research is needed to explore the surface morphology of this coating on mycelium and to understand the mechanisms by which it adheres to the substrate and also protects it from thermal expansion.



THESIS CONCLUSION

12 Design Demonstrator

12.1 Product Visualization

The proposed design is a composite with face-sheet made of Baxis Sinica, pre-treated with hydrogen peroxide, sodium hydroxide, and sodium silicate, resulting in a material that is both self-extinguishing and possesses a hydrophobic surface which are critical requirements of an aircraft cabin component. The mycelium core is also treated with sodium silicate, further enhancing its flame-resistant properties. Mycelium is cultivated on a textile stretched across the fabric using rivets, thereby eliminating the need for adhesives, such as epoxies, to bind the core and the face sheet.

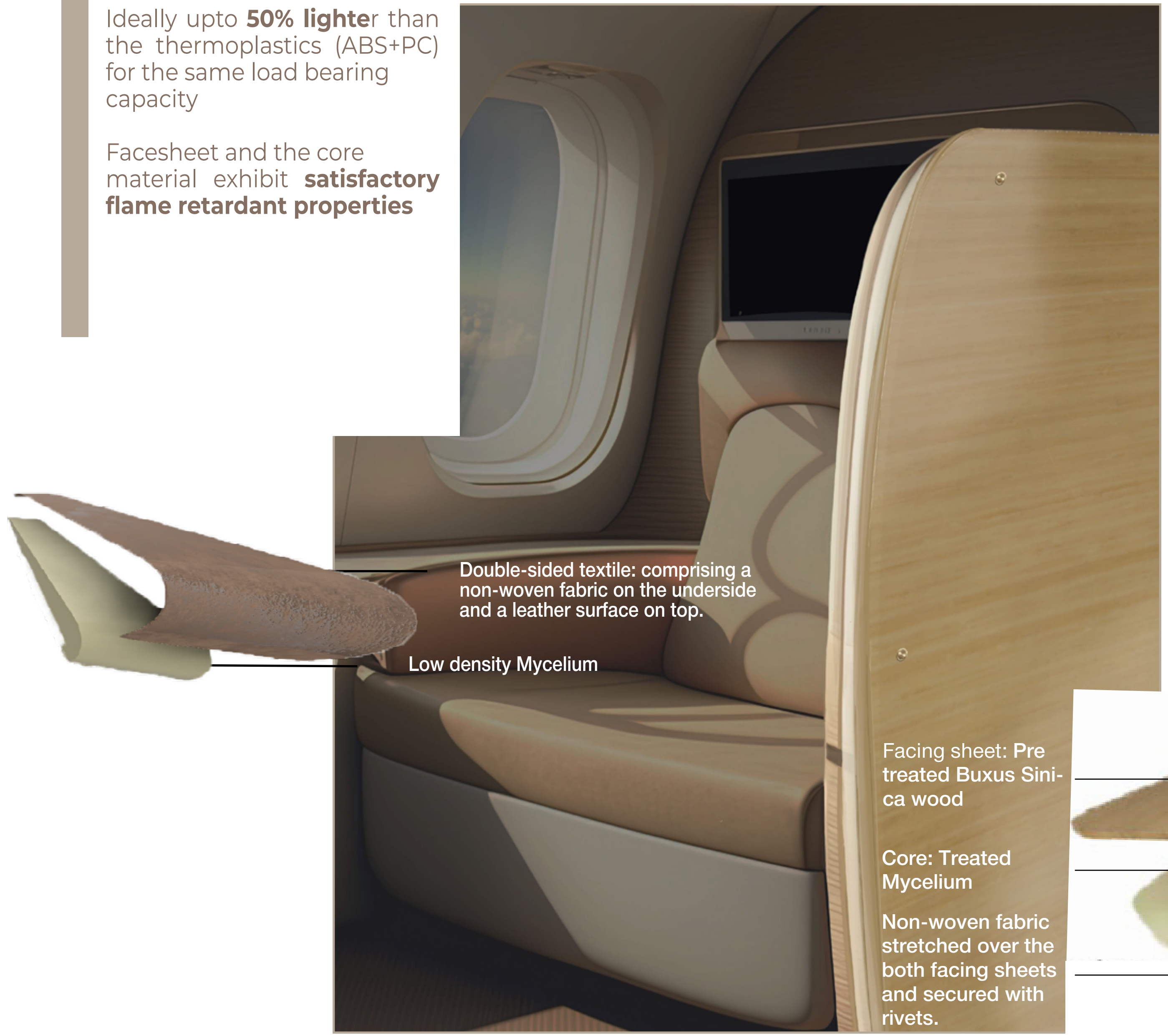
This composite is nearly 50% lighter than a comparable thermoplastic blend with the same load-bearing capacity as shown in the figure 24. Additionally, the composite is made of biodegradable materials. In cases where the core or face sheets require replacement, the rivets can be easily disassembled and reassembled. The mycelium core also provides significant benefits for thermal and acoustic insulation, improving the overall passenger experience.

(Note: The mycelium in the images can be grown densly than shown)

Seat Panels

Ideally upto **50% lighte**r than the thermoplastics (ABS+PC) for the same load bearing capacity

Facesheet and the core material exhibit **satisfactory flame retardant properties**



Seat Panels and armrest cushioning

Completely **Biodegradable**

No fossil based materials used

Circular Product

12.2 Mapping R-strategies for waste management

The "R-ladder" within a circular economy, emphasises waste reduction strategies. It includes 9R's starting refusing, rethinking, and reducing consumption, followed by reusing, repairing, refurbishing, and re-purposing products to extend their life. When a product reaches the end of its usable life, recycling and energy recovery are prioritized to prevent landfill waste. Minguez et al. (2021). This mapping investigates R strategies during the use phase as a the end phase is more of technical solution.

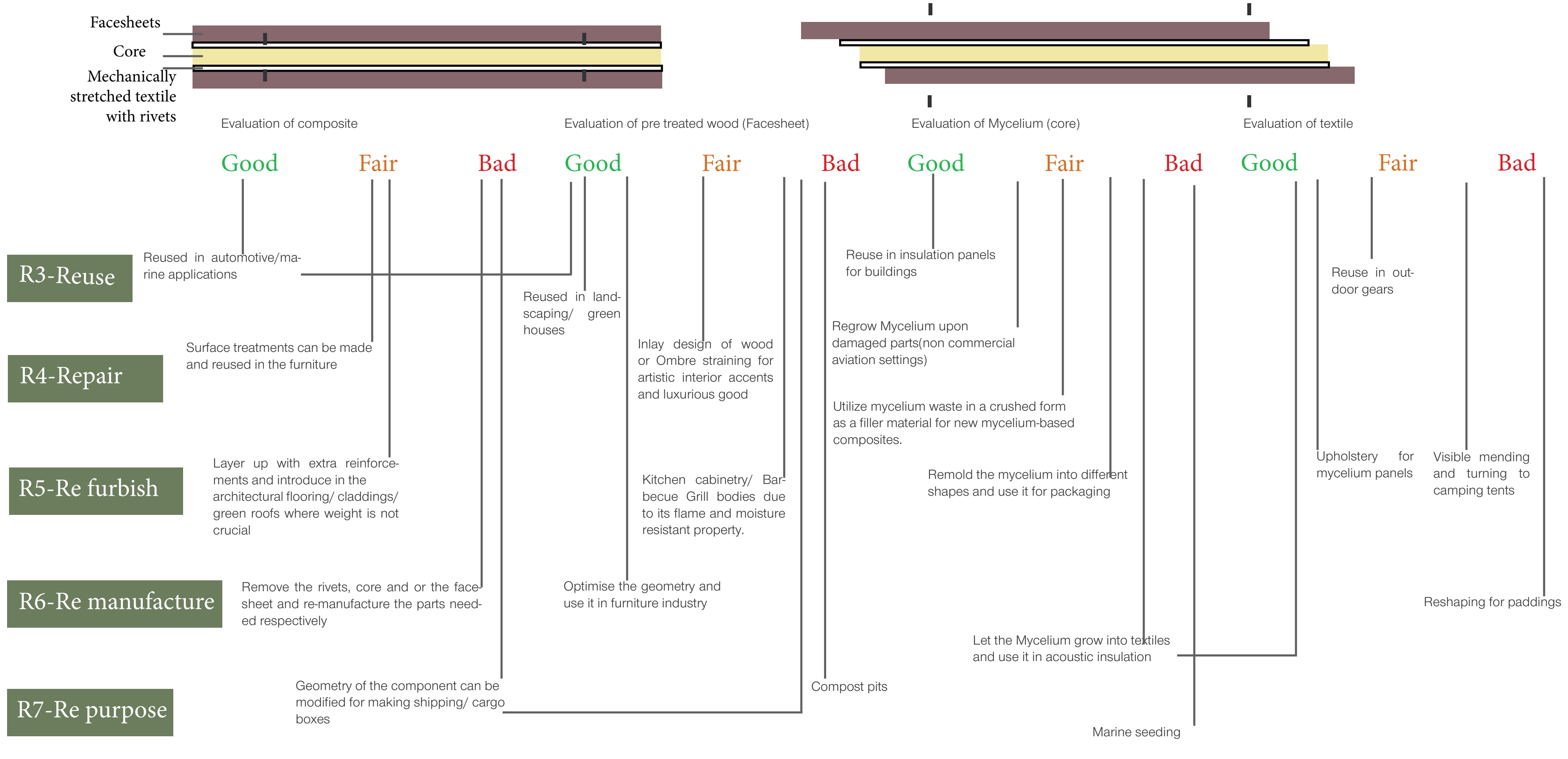


Figure 46: R strategies for the composite panel as a whole and their individual components

13 CONCLUSIONS

13.1 Research Conclusion

The initial assignment provided by Airbus underwent significant evolution as the project advanced. Initially, the focus was on outlining the properties of bio-derived materials and assessing their potential applications within the aviation sector. However, it quickly became evident that integrating such materials into aircraft design presents a far more complex challenge than initially anticipated. While the concept of introducing bio-derived materials into aerospace applications is innovative and forward-thinking, the current maturity levels of these materials remain low, and identifying suitable application spaces proves to be a considerable challenge.

To answer these questions feasibility, viability and desirability objectives were drawn and the outcomes can be concluded as follows:

Viability: Is there a demand or market for the product? Will it appeal to consumers or stakeholders?

This question was explored by examining current bio-based initiatives in the industry, particularly through the visit to the Aircraft Interiors Expo in Hamburg 2024. A personal observation was that only 4 out of 400 exhibitors showcased bio-based materials, indicating that adoption is still limited. This indicates that the current demand for these materials is quite low, primarily due to concerns about meeting the stringent requirements of the aviation industry, as outlined in the section 2.4. However the section 2.1.4 highlights why companies would want to shift towards bio based materials. Challenges in adopting bio-based materials often revolve around the hesitation to invest in innovation and the fear of failure. This master's thesis is a small attempt to highlight the potential of bio-based materials, aiming to encourage further exploration and development in this field.

Feasibility: Develop ways to improve flammability and moisture resistance properties and testing and evaluation them whether they achieve the functionality requirements.

Efforts to explore bio-based coatings were undertaken in this study. A successful finding from the literature review indicates that powdered Buxus Sinica wood, when pretreated, exhibits strong flammability and moisture resistance properties, which is an encouraging result. Attempts were also made to enhance the properties of mycelium. While the flammability tests yielded positive outcomes, challenges with moisture resistance were encountered. Recommendations have been made to address these issues, as there are promising opportunities for improvement.

However, major problem with scaling up fungal biomass is its inconsistent composition. Utilizing 3D printing or machine layup for the substrate could potentially address these issues to a significant extent This thesis demonstrates the potential of the design, but does not yet present a fully functional model. Extensive further work is required to advance these materials to a more mature and practical stage.

Desirability/Sustainability: Aim to reduce the weight of the design which inherently reduces CO2 emissions (during the use phase) and develop the R- strategies for the design.

This was achieved by lightweighting method, ensuring that the weight of the newly designed materials is lower than that of conventional ones. Under ideal working conditions, the weight reduction is nearly 50% than the ABS+PC blend. Additionally, these composites have a high potential for reuse, re manufacturing, and refurbishment, and recycling as demonstrated in section12.2.

As discussed in Chapter 1, an aircraft emits approximately 5,983 kg of CO2 for every kilogram of its weight over its lifetime. Assuming the thermoplastic seating panels in an aircraft weigh around 200 kg, implementing these lighter materials could potentially reduce CO2 emissions by approximately 5.98 million kg over the aircraft's operational life!

13.2 Limitations of the current work

Proposed design limitations:

- The composite material developed and the associated calculations do not account the potential contribution that the textile layers might have on load distribution.

-The drum peel strength between the mycelium and the textile has not been fully investigated, leaving room for potential improvements in this area.

- The load-bearing calculations considers only static loads. Additionally, the simulations were not performed according to the standards required for aircraft certification.

- The shear resistance of the mycelium was not tested, leaving these critical properties unexamined.

- In the proposed design, it is assumed that mycelium has uniform consistency throughout its structure. Possible way of making it to have a consistent composition is through uniform substrate size and laying up in a defined geometry

- The flammability and moisture resistance properties of the textile used in the composite were not examined in this study. It's uncertain whether the internal layering of the composite meets the stringent requirements for aircraft applications. Further ideation and design work are needed to ensure the textiles also comply with these standards.

- This study primarily focuses on the viability needs of aircraft and airline stakeholders, but it does not consider its customer view on bio-based materials, nor does it adopt a design approach to develop form, color, and texture.

Process limitations (during thesis):

- The selection of the textile was based on random inspirations rather than a systematic, scientific approach. This aspect could be explored further to identify the most suitable textile for the intended application.

- The samples grown in lab were incubated for only 10 days, incubating it for longer period might result in stronger bond formation.

- The properties of the wood used in this thesis were sourced from existing literature and were not experimentally validated as part of this research. It would be beneficial to validate these properties, particularly when considering the wood as part of a composite material.

- Figure 31 discusses the types of bio coatings based on prior knowledge rather than a formal literature review, primarily drawing from existing research related to wood. This topic could be further explored in a more structured manner.

13.3 Personal Reflection

This thesis made me realize just how deeply we are addicted to technology and innovation, and how challenging and far from luxurious it can be to reconnect with nature.

Embrace discomfort and uncertainty: Sustainable design does not offer the clear-cut solutions I was once familiar with; instead, it operated in a space of exploration. It required me to accept that there might not always be a single "right" answer and that failure is an inevitable part of the process. This has been difficult, as it goes against the ingrained professional instinct to seek control and clarity. Additionally, the holistic and integrative nature of sustainable design calls for a broader understanding of materials, systems, and their interconnectedness. It pushed me to look beyond the immediate project and accept the fact that the product might not come to life soon. This expansive view can be overwhelming, as it demands a level of responsibility and foresight that is not typically emphasized in conventional design paradigms.

Tension between feasibility, viability and sustainability: In my work, I found that many sustain able solutions are highly context-specific involves a trade-off between aesthetic appeal and environmental responsibility. In conventional design, aesthetics often take precedence, with a focus on creating visually pleasing and marketable products. However, sustainable design sometimes necessitates the use of materials or processes that may not align with traditional notions of beauty or luxury. This raises a dilemma: how do we reconcile the need for aesthetically compelling designs with the imperative to use materials and methods that are ecologically sound? My work forced me to confront this issue, prompting a reevaluation of what constitutes "good design" in a sustainable context. It requires redefining aesthetics to include values like durability, biodegradability, and resource efficiency.

One of the most profound personal learnings was the need to shift my mindset from seeking immediate solutions to embracing a more thoughtful, long-term perspective. Previously, I was accustomed to the conventional design mindset that prioritizes efficiency, speed, and problem-solving within defined parameters. However, sustainable design challenged me to look beyond quick.

This thesis tells the story of my journey into sustainable design a journey marked by experimentation, a willingness to explore new ideas, and the courage to embrace failure. Hope is that, 20 years from now, I will be watching planes fly by, embodying the technologies I once imagined, and knowing that the uncertainties I faced along the way were all part of bringing this vision to life.

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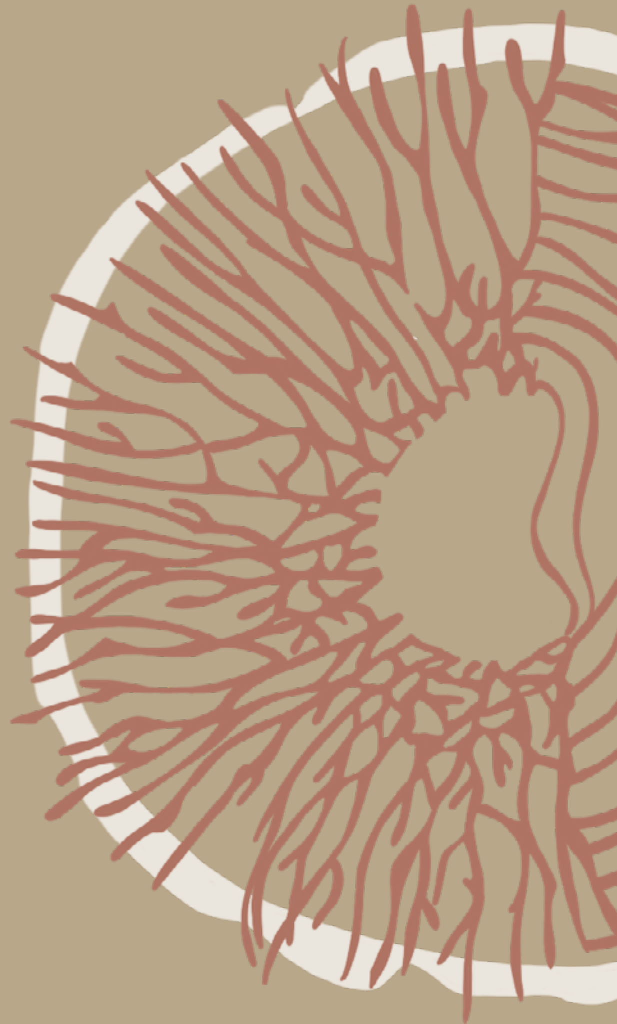

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