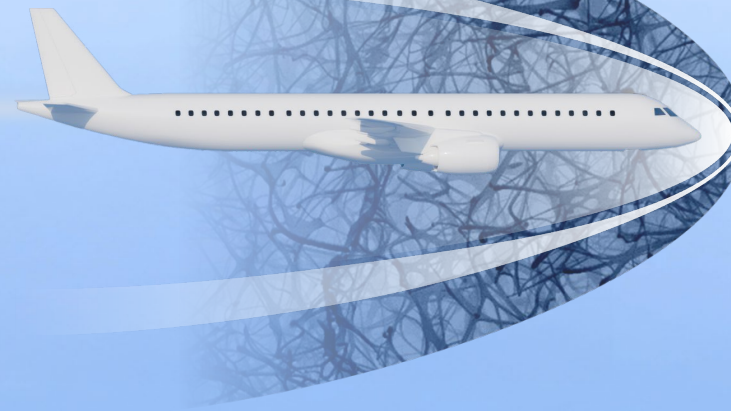


CMF DESIGN FOR A MONO-MATERIAL AIRCRAFT CABIN CONCEPT WITH BACTERIAL CELLULOSE

A CASE OF AIRCRAFT SEATS



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PREFACE

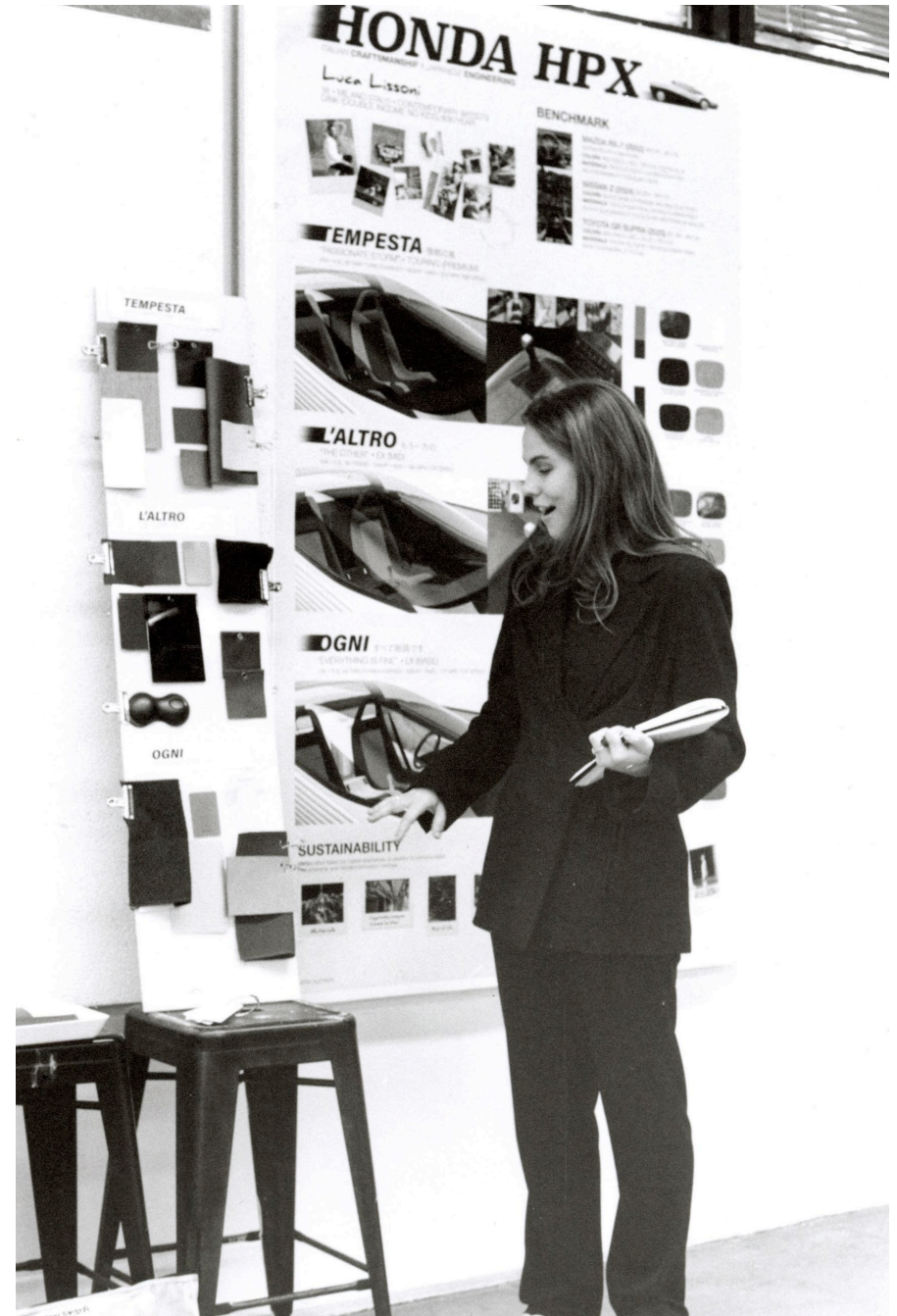
Throughout my studies I developed a strong passion for CMF design, mobility, and sustainability. Growing as a designer throughout my education, linking user experience to material use convinced me that materials do not only support form, but most importantly shape practices, emotions, and identity. That insight guided my choice to focus my graduation project on CMF design in mobility, a user centric design space, while pushing sustainability innovations and awareness of this part of design.

I approached Prof. Dr. Peter Vink, whose work in human centered design encouraged me to link CMF to measurable passenger experience. He greatly helped me shape the opportunity to collaborate with Embraer on this new concept for their 195 E2 Jet. I also reached out to Prof. Dr. Elvin Karana, whose research and experience in the field of on material driven design provided the methodological backbone for this thesis. I am extremely grateful for both of their contribution and support to this project.

I am thankful to my industry mentors. At Embraer, Demetrio Andrade de Campos offered essential insights into aviation constraints, the strategic role of CMF and its sustainability impacts. At Foamlab, Alice Buso supported the project by her extensive knowledge of bacterial nanocellulose foam and its application opportunities. Their feedback sharpened my thinking and kept feasibility and validation in view.

In short, I truly enjoyed this project and I hope it contributes to circular aviation and to a stronger materials focus within design education.

Vera Klerken



EXECUTIVE SUMMARY

This thesis investigates how Color, Material, and Finish (CMF) design can function as a measurable sustainability force in short-haul aviation by integrating bacterial cellulose material variants into aircraft seating. In collaboration with Embraer and Foamlab, a three-class cabin CMF concept was developed for the Embraer 195-E2, combining physical and digital prototyping with passenger perception studies and an operational-phase Life Cycle Assessment (LCA). Two perceptual evaluations, a forced-choice classification test and a within-subject Likert-scale comparison, demonstrate that CMF can effectively communicate cabin class hierarchy and significantly improve perceived passenger experience, with comfort and cleanliness emerging as dominant evaluative drivers. The operational LCA shows that replacing conventional polyurethane-based seat materials with lighter bacterial cellulose alternatives can reduce aircraft weight and yield an estimated operational emission reduction of approximately 355,000 kg CO₂ per aircraft per year under representative short-haul conditions. This thesis demonstrates that material-driven CMF decisions can concurrently enhance passenger experience and reduce operational emissions. The findings indicate that lightweight, bio-based CMF strategies represent a high-impact pathway for advancing more sustainable aircraft interior design.

Design goal

Develop a three-class cabin-interior CMF design for the Embraer 195-E2 (KLM Cityhopper), that improves LCA performance by integrating different bacterial cellulose material variants, while maintaining or improving passenger experience relative to the current KLM Cityhopper interior CMF design.



DUTCH DISCOVERY

Y-CLASS

Evoking the energy of shared exploration, rooted in Dutch openness, directness and movement. The name suggests both place and mindset, discovery as a collective journey. The design invites collectivity, clarity, curiosity, and a humble sense of freedom.



"PLAYFUL MIXING"



CROCUS COMFORT

W-CLASS

Named after one of the Netherlands' earliest spring flowers, this class embodies gentle renewal and tactile warmth. The orange crocus signals optimism, softness, and seasonal transition, mirroring the comfort and brightness this class offers.



"SYMBIOTIC GROWTH"



VERMEER VESPER

J-CLASS

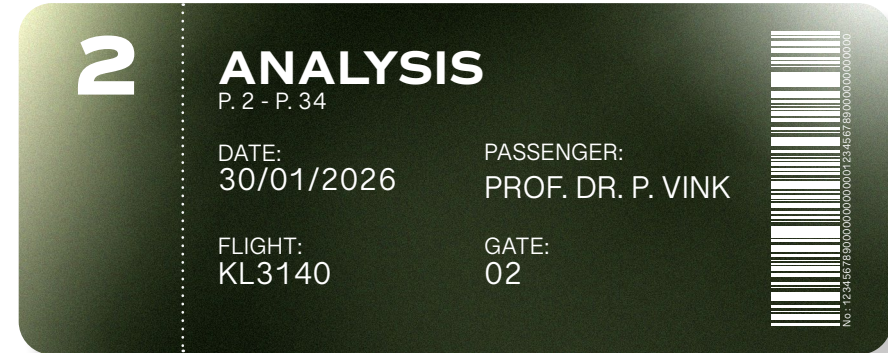
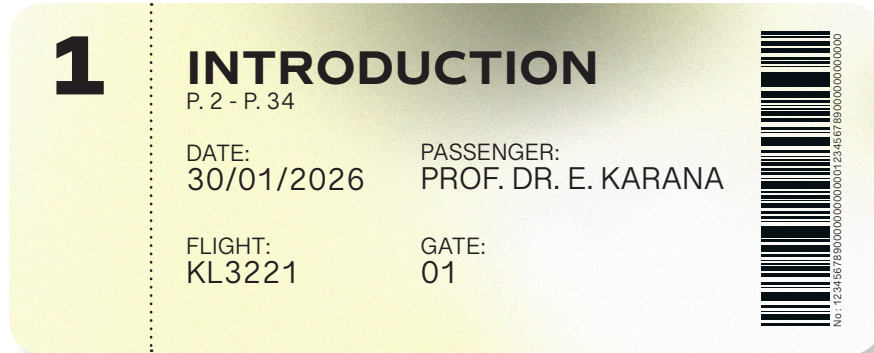
Combining the quiet brilliance of Dutch painter Vermeer with the word vesper, meaning "evening star", the design reflects a moment of flow and focus. Symbolizing a refined, introspective space that supports calmness, privacy, confidence, and presence.



"QUIET HARVESTING"



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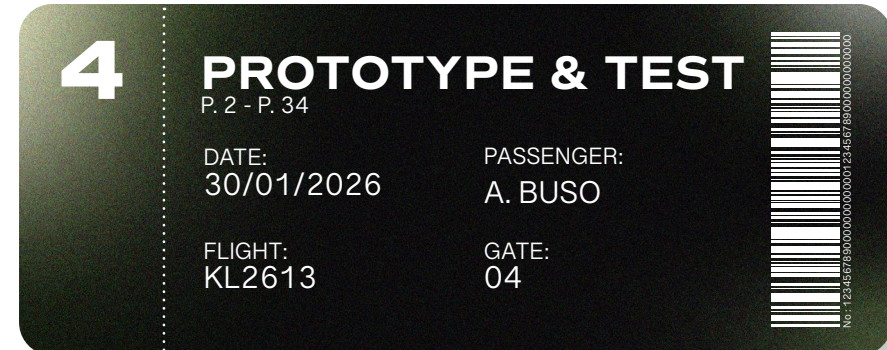
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1

INTRODUCTION



1.1 INTRODUCTION

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1.1. INTRODUCTION

1.1.1 EMBRAER

Embraer is the world's third-largest commercial aircraft manufacturer and a global leader in regional aviation. Founded in 1969 in São José dos Campos, Brazil, the company originated from a national strategy to strengthen technological independence through aerospace innovation (Jewell, 2017). Today, Embraer employs more than 23,000 people globally and operates industrial facilities in Brazil, the United States, Portugal, and Mexico, with aircraft in service in over 100 countries (Embraer website, n.d.).

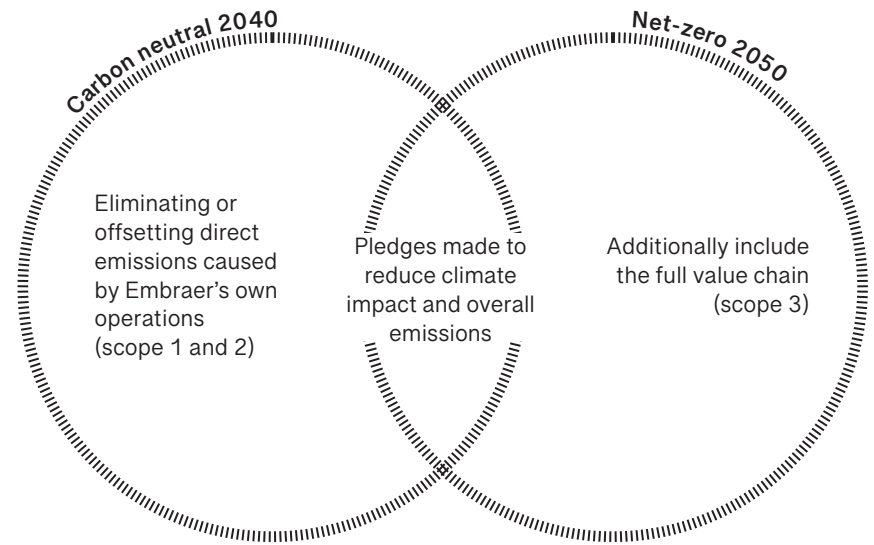


Figure 1: Embraer climate targets: carbon neutrality and net-zero pathways. Source: Embraer sustainability report (2024).

Embraer's commitment to environmental innovation is reflected in its propulsion roadmap. Its latest E2 jets are compatible with 100% Sustainable Aviation Fuel (SAF), enabling full biofuel operation without blending, although regulatory approval currently limits commercial use to 50% blends (Embraer, 2023). SAF reduces life cycle CO2 emissions compared to conventional kerosene and supports immediate climate benefits using existing infrastructure. Beyond regional jets, Embraer is also investing in next-generation mobility through Eve Air Mobility, its eVTOL subsidiary. Eve aims to launch all-electric, zero-emission air taxi operations by 2026, focusing on urban commuting (Aviation Week Network, 2023). Together, these developments position Embraer as a key player in shaping more sustainable air transport.

This thesis focuses on Embraer's commercial aviation division because it has the highest potential for visible and scalable sustainability impact through CMF design. Even though Commercial jets account for only 35% of Embraer's aircraft deliveries in 2024, they have carried over two billion passengers globally, with more than 1,800 E-Jets flying across 100+ airlines (Aviation Week Network, 2024). These cabins are seen by millions of passengers each year, offering significant design exposure. In contrast, executive aviation involves smaller jets used by a narrow group of private or corporate clients, with limited design visibility. Defense & Security aircraft serve military personnel and represent less than 2% of Embraer's annual output (Embraer delivery report and financial results, 2024). CMF innovations, especially those related to sustainable materials and passenger experience, are thus most relevant and impactful in the commercial segment, where volume, visibility, and life cycle usage are significantly higher.

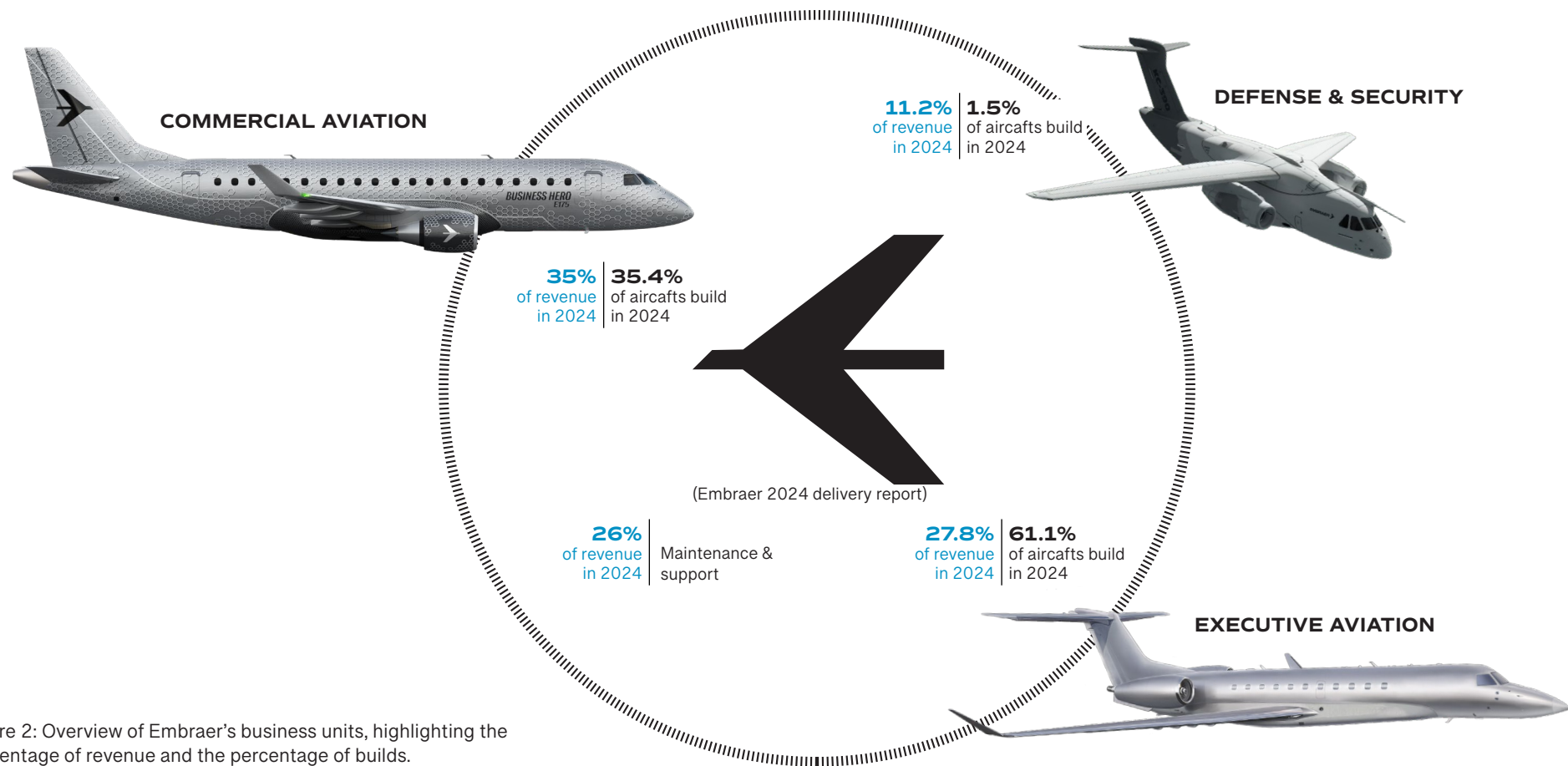


Figure 2: Overview of Embraer's business units, highlighting the percentage of revenue and the percentage of builds. Data source: Embraer delivery report and financial results (2024).

Embraer's sustainability strategy positions the E2 program as a key contributor to reducing aviation's environmental footprint. The company has committed to achieving carbon-neutral operations by 2040 and supporting net-zero aviation by 2050, addressing both operational and life cycle emissions (Embraer, 2025). In line with this roadmap, Embraer targets 100% renewable electricity in its operations by 2030 and continued adoption of SAF. (Aviation Week Network, 2021; Embraer sustainability report, 2024).

Beyond propulsion and operations, Embraer increasingly identifies aircraft interiors as a critical domain for sustainability innovation. Cabin materials influence aircraft weight, maintenance cycles, and end-of-life waste streams, while simultaneously shaping passenger experience. Embraer already invests in several sustainable alternatives that decrease environmental impacts, but there is yet a lot to be improved. Seating systems are of particular relevance due to their material volume and frequent replacement cycles. Despite this, conventional aircraft seats remain heavily dependent on fossil-based polyurethane (PU) foam, a material associated with high embodied emissions, hazardous additives, and poor circularity. These challenges underline the need for alternative seat cushioning materials that can meet tight aviation safety requirements while supporting Embraer's broader sustainability ambitions. This thesis addresses this gap by exploring multiple bio-based bacterial cellulose material variants as a circular CMF alternative within the E195-E2 cabin context.



Usage of water-based primers, paints and adhesives, reducing VOCs by over 75% (Embraer sustainability report, 2024)



Carpet materials made from recycled fishing nets (Embraer sustainability report, 2024)



Curtain materials made from recycled polyester (Embraer sustainability report, 2024)



Building the aircraft with 3D printers (over 60% of the cabin parts, cutting weight by 40% and waste by 65%). (Embraer additive manufacturing, 2023)

CURRENT SUSTAINABILITY LIMITATIONS OF PU MATERIALS IN AIRCRAFT INTERIOR

Polyurethane (PU) foam is the dominant cushioning material used in commercial aircraft seating due to its low density, comfort performance, durability, and cost efficiency. A typical commercial aircraft seat contains approximately 3–5 kg of flexible PU foam, and with more than 25,000 commercial aircraft currently in service and interior replacement cycles of approximately 6–10 years, this corresponds to an estimated 75,000–125,000 tonnes of PU foam entering the aviation interior system per fleet-wide refurbishment cycle (Schwarz, 2011; ICAO, 2022). However, from a sustainability perspective, PU foam presents significant environmental challenges.

Conventional PU foams are synthesized from fossil-based polyols and isocyanates, resulting in substantial greenhouse gas emissions during production (Graham et al., 2017). Life cycle assessments indicate that manufacturing flexible PU foam generates approximately 3–5 kg CO₂-equivalent per kilogram of foam before assembly into aircraft seats (Montaño et al., 2022). Given the large material volumes involved, seat cushioning represents a non-negligible contribution to the embodied emissions of aircraft interior materials.

In addition to its fossil origin, PU foam poses critical safety and end-of-life challenges. To comply with strict aviation fire safety regulations, aircraft seat foams are treated with flame retardant additives, many of which are associated with toxicity, environmental persistence, and potential human health risks (Allen et al., 2013). These additives, combined with multi-layer constructions involving adhesives and textiles, severely limit recycling options. As a result, more than 90% of PU foam from aircraft seating is incinerated or landfilled at end-of-life, leading to additional carbon emissions and long-term waste generation (ECHA, 2021; Roobankumar & SenthilPandian, 2024).

The combination of fossil dependency, hazardous additives, high embodied emissions, and limited recyclability positions PU foam as a critical bottleneck in the transition toward more circular aviation industry and cabin interiors. At the same time, replacing PU foam in aviation remains challenging due to strict certification requirements related to flammability, durability, and lifetime performance (EASA, 2023). These constraints have historically restricted the adoption of alternative materials in certified cabins. Consequently, there is a clear need for novel, bio-based alternative materials that can deliver comparable material characteristics and performance while enabling improved circularity and reduced life cycle environmental impact. This need directly motivates the exploration of bacterial cellulose-based foam alternatives within the scope of this thesis.



Figure 3: Polyurethane foam structure



Figure 4: Shredded polyurethane foam waste

1.1.2. FOAMLAB

Foamlab is a Netherlands-based material innovation start up that develops foams from renewable resources, with a strong emphasis on sustainability, material science, tunability, and multi-sensory qualities. Their vision is that materials are not just functional but also shape how people emotionally and physically experience products. Their flagship material is bacterial cellulose foam. Bacterial cellulose is a natural material made by bacteria during a fermentation process, somewhat similar to how yeast makes bread or kombucha is brewed. Unlike plant-based cellulose, it is extremely pure and forms a fine network of fibers (like a microscopic mesh). This structure makes it lightweight, strong, and in some forms highly porous, which means it can be processed into foams suitable for cushioning, insulation, but also rigid interior parts. The material can be tuned in terms of density, softness, and surface texture, enabling a wide range of applications.

These foams are fully bio-based, biodegradable under the right conditions, and can be produced with relatively low and sustainable energy. In paragraph 2.7.7. the subject of bacterial cellulose. Compared to the petroleum-based polyurethane foams that dominate (aviation) seating today, bacterial cellulose foams could offer a sustainable alternative in the future.



Figure 5: Foamlab product portfolio. Source: Foamlab (2025).

Foamlab's bacterial cellulose foams can be engineered across a wide mechanical spectrum, from soft, sponge like structures that compress easily under light touch to stiffer, cork like or polystyrene like foams that retain their shape under load. At lower densities the foam can twist, fold, or wrap without tearing, enabling conformal cushioning and protective layers, while higher density formulations provide rigid, dimensionally stable structures for load bearing and form retaining interior components comparable to wood based foam or molded fiber. The material can be molded into complex three dimensional geometries with clean edges and fine detail, processed into powders or beads for secondary forming routes, or applied as a coating on existing substrates such as pipes or panels. All of these variants are achieved without synthetic binders or other petrochemical inputs and rely instead on controlled microbial growth and post processing, which is relevant for circular material strategies in aircraft interiors (Foamlab, 2025).



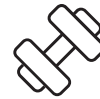
High insulation efficiency

Excellent thermal and acoustic insulation with minimal material thickness.



Ultra-lightweight

Extremely low density, reducing overall product and fuel weight.



High mechanical performance

Strong and resilient structure despite its low mass.



Bio-compatibility and compostability

Fully bio-based, safe for humans, and degradable after use.

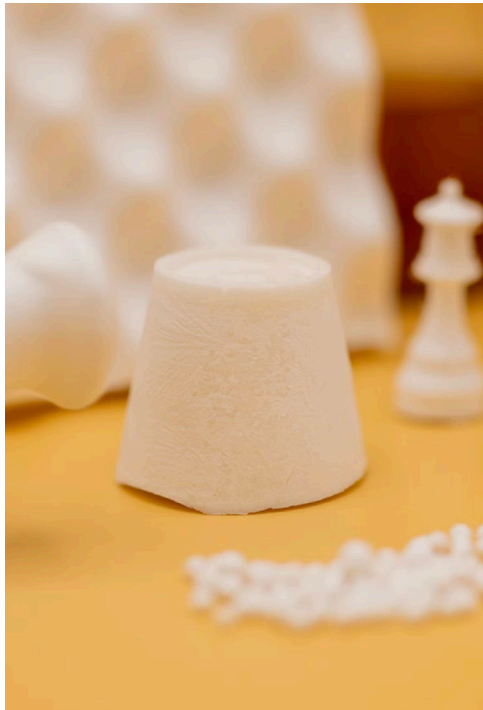


Figure 6: 3D formed BC.
Source: Foamlab (2025).



Figure 7: Rigid BC foam.
Source: Foamlab (2025).



Figure 8: Flexible BC foam.
Source: Foamlab (2025).



1.1.3. CMF DESIGN

Color, Material, and Finish (CMF) design concerns the deliberate integration of color, material, texture, and surface treatment to shape how products are perceived, experienced, and understood. Rather than functioning as a purely aesthetic layer, CMF operates as a holistic and cross-disciplinary practice, connecting product design with engineering, manufacturing, branding, sustainability, and user experience (Ashby & Johnson, 2014; Karana et al., 2015). As a professional discipline, CMF is widely established in industries such as automotive, consumer electronics, furniture and fashion, where material and surface choices play a critical role in product differentiation and user perception. As such, CMF decisions are often negotiated across multiple parts of an organization, balancing technical feasibility, brand coherence, and regulatory constraints. Within design research, CMF has evolved into a strategic tool for shaping product experience by influencing sensory, emotional, and symbolic meaning (Desmet & Hekkert, 2007; Schifferstein, 2011). Users form rapid judgments of quality, comfort, and trust largely through color and material cues, often within milliseconds (Crilly et al., 2004). However, CMF innovation typically operates along a spectrum, ranging from incremental “facelift” updates to more pronounced material or aesthetic shifts. Designers must carefully balance novelty and familiarity, introducing change that signals progress without disrupting recognition or acceptance (Ashby & Johnson, 2014).

CMF also plays an increasingly important role in sustainability. Surface finishes, coatings, and bonding methods directly affect environmental impacts, recyclability and end-of-life outcomes, making CMF a key lever in circular design strategies (Bocken et al., 2016; Karana et al., 2018). At the same time, CMF strongly shapes perceived sustainability, as natural textures and matte finishes are often interpreted as environmentally responsible, regardless of actual material performance (Fella & Bausa, 2024). In aviation, where interiors must meet strict requirements for weight, flammability, and durability, CMF sits at the intersection of engineering performance and passenger experience. Research shows that cabin color and material choices can significantly influence passenger comfort and well-being (Yao et al., 2021). Within this context, CMF provides a framework for integrating new materials, such as bacterial cellulose foam, in a way that balances innovation, certification constraints, and passenger adoption.

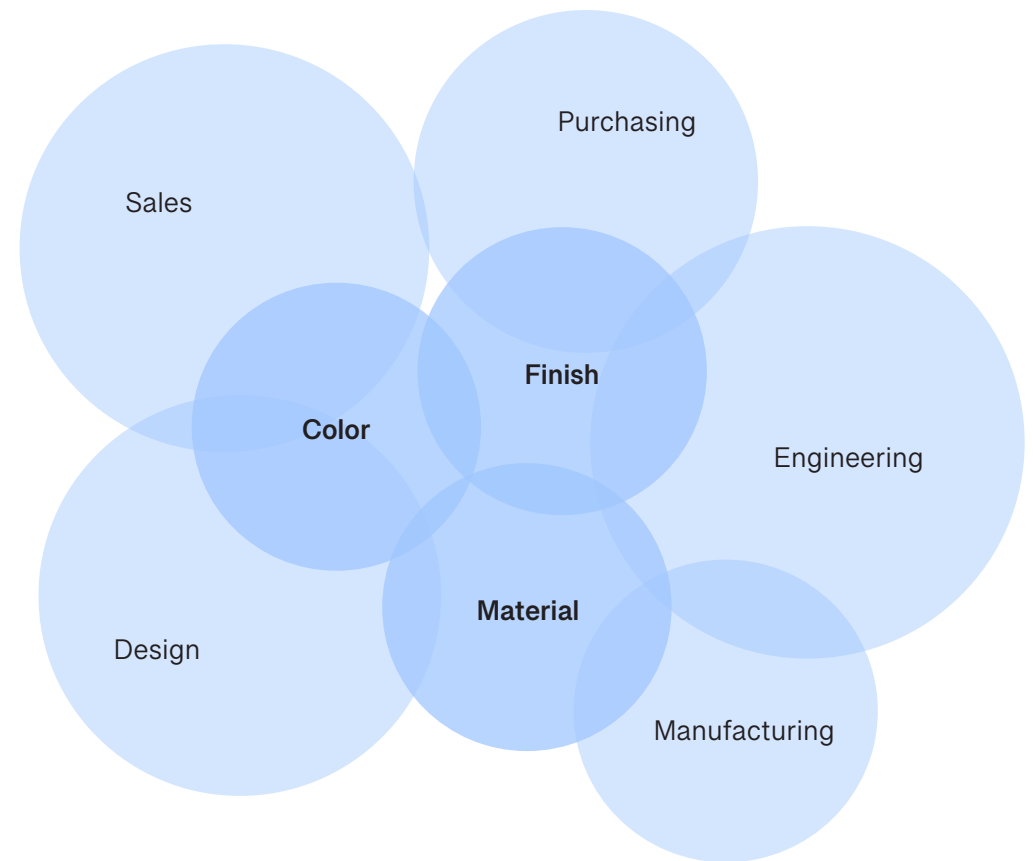
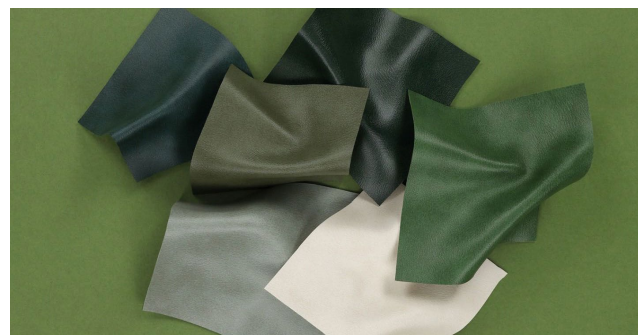


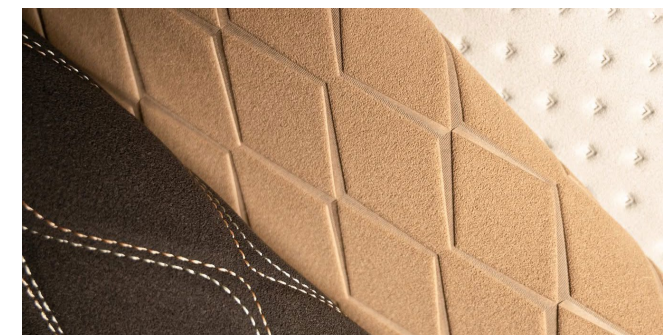
Figure 9: A visualization of the multidisciplinary position of CMF design within an organization, collaborating across design, engineering, manufacturing, sales, and purchasing departments.



Colors: an example of Pantone samples (a commonly used design tool in CMF)



Materials: an example of different material samples to compare for in material trays



Finishes: an example of different finishes on the same material, that can be used in CMF design

1.2.1 THE ASSIGNMENT

The project involves two intertwined scopes: the CMF design scope, focusing on the aircraft cabin's three class design and the Bacterial Cellulose scope, focusing on implementing the material into the cabin interior.

CMF ASSIGNMENT SCOPE

Research and design gaps:

- ✦ **Passenger experience as a competitive driver**
Passenger satisfaction and perceived service quality have become central to airline competitiveness, shifting differentiation toward the cabin experience rather than price alone (Eshaghi et al., 2024).
- ✦ **Underdeveloped CMF strategies in short-haul cabins**
CMF design in aircraft cabins remains under explored and lacks systematic, experience-driven application, particularly when compared to automotive interiors, representing a missed opportunity for competitive differentiation in short-haul aviation (Pan et al., 2019).

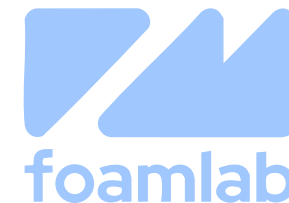
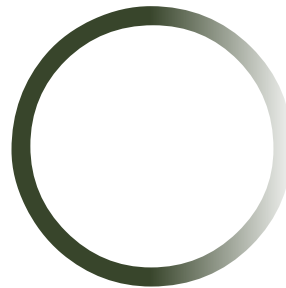
Goal: Improve passenger experience through better CMF design and thereby strengthen competitive advantage.

BACTERIAL CELLULOSE ASSIGNMENT SCOPE

Research and design gaps:

- ✦ **Lack of viable alternatives to PU foams**
Aircraft seating and cabin interiors remain largely dependent on plastic-based and difficult-to-recycle materials, for which no mature, certified alternatives are currently available (Khan et al., 2019; Mrazova et al., 2020).
- ✦ **Insufficient focus on cabin materials in aviation sustainability targets**
Achieving aviation sustainability objectives, including 2030 interim targets and net-zero ambitions by 2050, requires addressing cabin interior materials alongside propulsion and operational measures, due to their life cycle environmental impacts (Dahlmann et al., 2016).

Goal: Demonstrate the potential reduction in life cycle impact of a cabin concept through the integration of bacterial cellulose materials.



The scope of the **CMF-related work** is indicated by an **outlined circle symbol**, reflecting its focus on the outer, visible layers of the design. The scope of the **bacterial cellulose (BC) work** is represented by a **filled circle symbol**, corresponding to the core material of the product. These symbols are also displayed at the bottom of each page, next to the page number, to indicate which of the two thesis scopes the respective chapter primarily addresses. Sections without a symbol are not specifically focused on either scope.

THESIS SCOPE

Demonstrate that bio design goes hand in hand with CMF design and that combining these two disciplines can accelerate innovation and adoption of both.

Value of combined project between CMF and bio design > Value CMF scope + Value BC scope

CMF

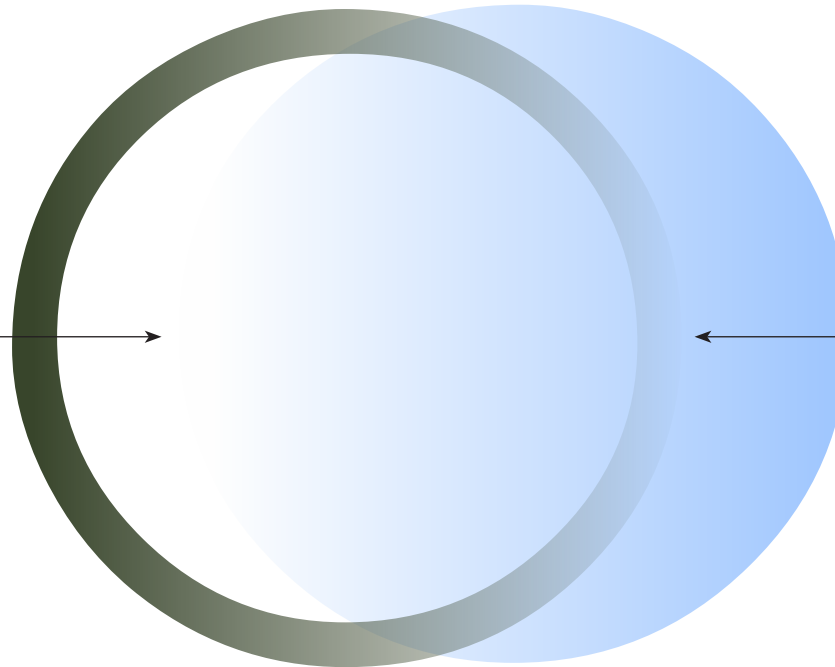


BC



BIO DESIGN
supports CMF storytelling

CMF DESIGN
supports bio designs adoption



The outcomes of this scope include three class-specific CMF concepts supported by a CMF design framework, material boards, renderings, pattern development, and prototyping.

Validation is performed through two perceptual user studies:

- ✧ A forced-choice perceptual classification match task, evaluating the perceived class of each design.
- ✧ A within-subject Likert-scale comparative perception test using renderings, evaluating the significance and difference in perceived user experience between the old and the new design.

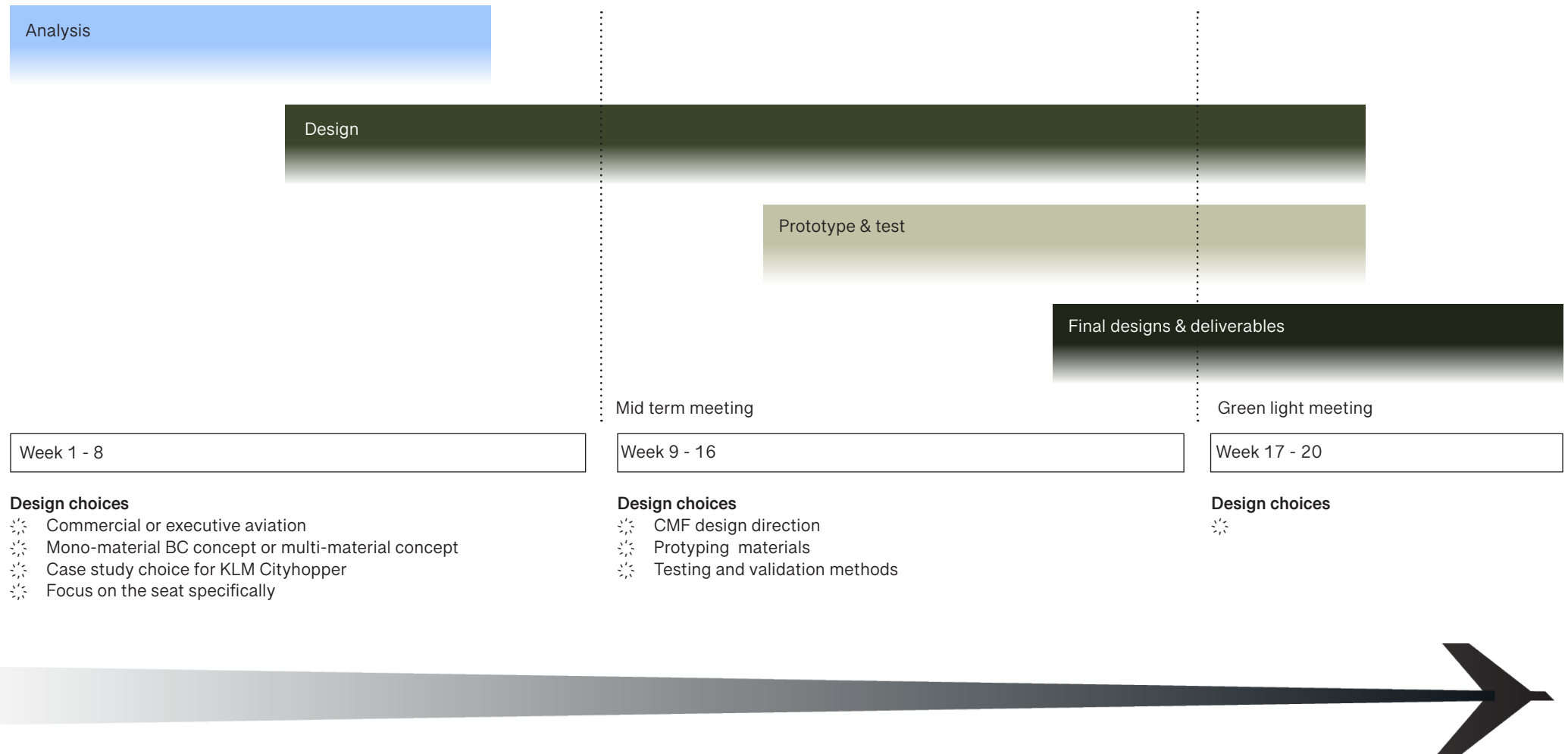


The outcomes of this scope include four BC materials both in physical samples as well as digital materials, which are also integrated into a 1:3 scale model of the seat.

Validation is performed through an operational phase LCA:

- ✧ Demonstrating the reduction in kg CO₂ emissions when implementing the proposed CMF design concept using BC materials.

1.2.2 THE PROCESS



The project followed a structured yet iterative design process consisting of three main phases: analysis, design, and prototyping and testing. This framework was selected to support logically argued and scientifically grounded design decisions, which are articulated within each phase. Although presented sequentially, the phases partially overlapped to allow for continuous iteration, refinement, and feedback integration.

Throughout the process, earlier decisions and outcomes were revisited and adjusted as the project scope evolved and insights emerged. Weekly feedback moments involved supervisors from TU Delft, industry experts from Embraer and Foamlab, IDE alumni with relevant professional experience, former mentors from ArtCenter College of Design, and peers working in related domains. This iterative feedback culture enabled sustained reflection, idea generation, and progressive maturation of the design outcomes.

1.2.3

METHODOLOGY

This page outlines the complete overview of the methodology used throughout the different phases of the process.

1. & 2.

INTRODUCTION & ANALYSIS

- ✧ Literature study (Van Boeijen et al., 2014).
- ✧ Passenger and expert interviews (Van Boeijen et al., 2014).
- ✧ Co-reflection: Engaging with IDE peers, Embraer, Foamlab, and KLM employees (Contextmapping & Co-reflection) (Van Boeijen et al., 2014; Sleeswijk Visser et al., 2005).
- ✧ Stakeholder analysis: Identifying Embraer, Foamlab, KLM, regulators, suppliers, passengers, etc., and their relationships (Van Boeijen et al., 2014).
- ✧ System mapping: Visualizing how materials flow across the aircraft interior life cycle (circular supply chain) (Van Boeijen et al., 2014).
- ✧ Benchmarking: Comparing aviation interiors (Airbus A220, Boeing 737 MAX, Airbus A350) and cross-industry CMF (Benchmarking method) (Van Boeijen et al., 2014).
- ✧ Material-Driven Design Stage 1–2 (Understanding & Experiencing the Material) (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015).
- ✧ Trend analysis / CMF Mapping: Identifying future aesthetics and sustainability trends in mobility and aviation (Van Boeijen et al., 2014).
- ✧ Regulatory scan: Mapping aviation requirements (flammability, toxicity, weight, durability, recyclability) (Van Boeijen et al., 2014; EASA, 2023).

3.

DESIGN

- ✧ Brainstorming & morphological charts (Van Boeijen et al., 2014).
- ✧ Material-Driven Design Stage 3 (Creating the Material Experience Vision) (Karana et al., 2015).
- ✧ Moodboards & collages: Building visual worlds for each class (J, W, Y) (Van Boeijen et al., 2014).
- ✧ CMF palette development: Creating systematic color–material–finish families and hierarchies for the three classes (Van Boeijen et al., 2014).
- ✧ Scenario building: Imagining future airline scenarios to test design fit (Van Boeijen et al., 2014).
- ✧ Analogy & metaphor ideation: Using natural analogies to inspire CMF strategies (Van Boeijen et al., 2014; Karana et al., 2015).
- ✧ Material prototyping: Early mock-ups of foam samples with finishes, testing tactility and aesthetics (Van Boeijen et al., 2014; Rognoli & Karana, 2014).

4.

VALIDATION

- ✧ User testing / Passenger experience evaluation: Testing prototypes with participants using semantic differential scales for comfort and perception (Van Boeijen et al., 2014; Vink, 2020).
- ✧ Material-Driven Design Stage 4 (Material Experience Prototyping) (Karana et al., 2015).
- ✧ Sustainability assessment: Qualitative or semi-quantitative assessment of circularity (e.g., Life Cycle Thinking, recyclability analysis) (Van Boeijen et al., 2014).
- ✧ Expert interviews / Co-reflection: Engaging Embraer designers, Foamlab scientists, KLM designers (Van Boeijen et al., 2014; Sleeswijk Visser et al., 2005).
- ✧ Simulation: Testing cabin experience in simulated interiors (VR / Blender renders or mock-ups) (Van Boeijen et al., 2014).
- ✧ Heuristic evaluation for CMF: Using expert panels to judge color/material/finish coherence, sustainability fit, and aviation compliance (Van Boeijen et al., 2014).

1.2.4

TERMINOLOGY

Color, Material, and Finish (CMF) design

A design discipline concerned with selecting and applying colors, materials, and surface finishes to shape a product's aesthetic and user experience. CMF bridges styling and engineering by defining attributes such as color schemes, textures, patterns, and material types, influencing both visual and tactile qualities. In aircraft cabins, CMF covers elements like seat upholstery, panels, carpets, and trims to create a coherent identity across classes.

Bacterial Cellulose (BC)

A natural cellulose produced by bacteria as an ultra-pure nanofiber network, chemically identical to plant cellulose but without lignin or hemicellulose. Discovered in 1886 during vinegar fermentation, BC has high strength, high water content, and can be grown into custom shapes. In this project, BC is used as the basis for a foam material for aircraft interiors.

Mono-material concept

A design strategy that uses variants of a single base material across multiple components to simplify recycling and reduce waste. In this project, a mono-material seat emphasizes bacterial cellulose for as many seat components as feasible, improving end-of-life disassembly and supporting circularity, while acknowledging practical limits.

Embraer 195-E2

The Embraer 195-E2 is the largest aircraft in the E-Jet E2 family, designed for short- to medium-haul regional routes and seating approximately 120–146 passengers in multi-class configurations. In this project, the 195-E2 serves as the application platform, defining the cabin layout, regulatory framework, and operational constraints for the CMF and BC design.

Embraer

Embraer is a Brazilian aerospace manufacturer specializing in commercial, executive, and defense aircraft, with a strong focus on efficient regional aviation. In this project, Embraer acts as the industrial partner, defining aircraft-specific requirements and evaluating the feasibility of CMF and material concepts for application in the Embraer 195-E2 cabin.

Foamlab

A startup that was founded at Delft University of Technology focused on bacterial cellulose materials, especially foams.

Short-haul flight

Flights of typically under three hours, using single-aisle aircraft and emphasizing efficiency and quick turnaround. Cabin design priorities include fast cleaning, durability, and passenger experience.

Circularity

A design principle aimed at keeping materials in use for as long as possible through reuse, recycling, or biodegradation, minimizing waste. BC foam supports circularity due to its bio-based origin and compostability, while the mono-material approach simplifies material recovery from retired aircraft interiors.

2

ANALYSIS



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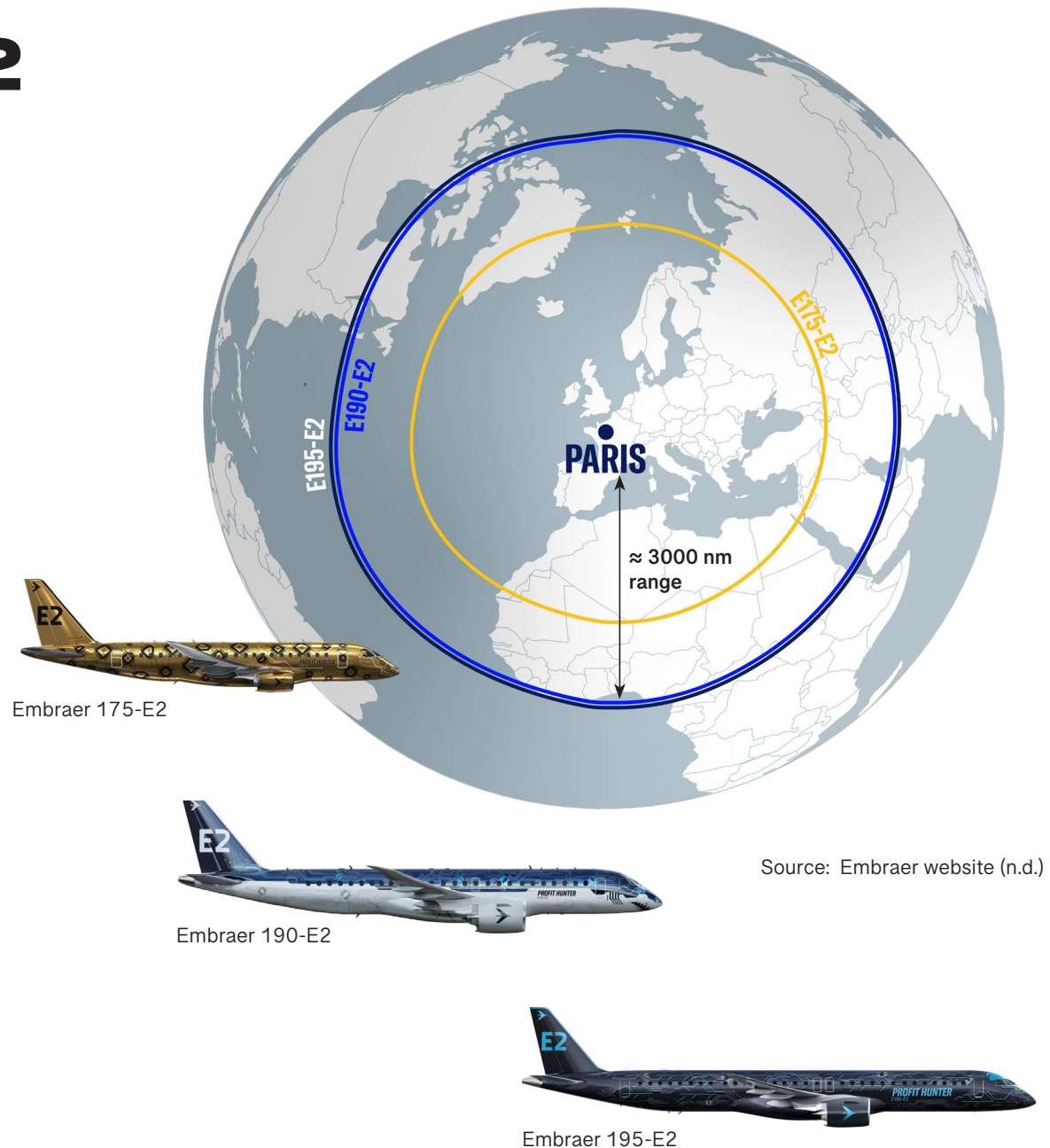
2.1 EMBRAER 195-E2

2.1.1

WHY THE EMBRAER 195-E2

The Embraer 195-E2 was selected as the platform of this thesis because it exemplifies a next-generation regional jet that balances fuel efficiency, sustainability, and passenger comfort. Embraer explicitly notes that manufacturing the E2 cabin now uses “more sustainable processes and products” than previous models (Embraer, 2024a). As the largest member of the E2 family, the 195-E2 offers flexible seating – typically about 120 passengers in a three-class layout or up to 146 in a single-class high-density configuration (E-Jets E2: Airport planning manual, 2024), making it an ideal case study for examining how CMF strategies can be adapted across different cabin classes. Moreover, the E2’s cabin construction emphasizes low weight and durability, aligning with Embraer’s goal of reduced emissions and a carbon-neutral future (Embraer sustainability report, 2024). Internally, this aircraft is designated as the ERJ 190-400, where ERJ refers to Embraer Regional Jet and 190-400 denotes the internal type classification. This designation is used in certification and technical documentation, while E195-E2 functions as the commercial name.

Embraer markets the E2 series under its “Profit Hunter” brand to signal a blend of operational efficiency, environmental performance, and enhanced passenger experience. In line with this, the E195-E2 incorporates major improvements: it achieves roughly 29% lower fuel burn per seat than the prior E-Jet generation (Embraer, 2024b), and engine and airframe refinements yield up to a 68% smaller noise footprint (Embraer, 2023). At the same time, its cabin air quality is greatly improved, because all E-Jet E2s use high-efficiency HEPA filters that capture 99.7% of airborne particles and fully refresh the air at least 20 times per hour (Embraer website, n.d.). While many of the sustainability gains come from aerodynamic and propulsion advances, they underscore the importance of lightweight, efficient interior design.



Source: Embraer website (n.d.)

2.1.2

LAYOUT CONFIGURATIONS

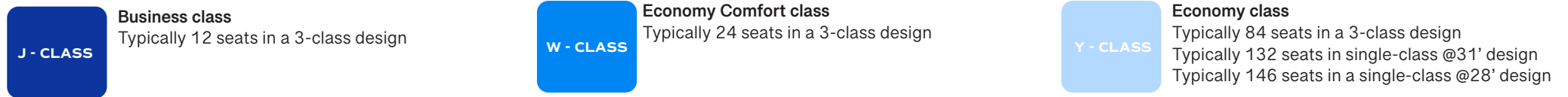
The Embraer 195-E2 can be configured in three seating layouts: a single-class configuration with 146 seats at 28-inch pitch, a single-class layout with 132 seats at 31-inch pitch, or a three-class configuration with 120 seats, including business, premium economy, and economy sections (Embraer, 2023). For this thesis, the three-class configuration was selected because it offers the richest design context for exploring Color, Material, and Finish (CMF). Unlike single-class layouts, which prioritize uniformity and capacity, the tiered configuration enables meaningful differentiation between service levels, challenging the designer to translate hierarchy, comfort, and branding through spatial and sensory transitions (Ashby & Johnson, 2014).

These three classes are typically referred to as J (business), W (economy comfort), and Y (economy), a global airline industry convention derived from fare class codes used in ticketing systems (IATA, 2020). In practice, the boundary between J and W class is often defined by a movable curtain, since the seats are identical, allowing airlines to flexibly adjust class sizes depending on demand and the number of seats sold in each class. This naming system is not just technical, it supports clearer segmentation in design intent, allowing each cabin zone to embody a distinct material identity, emotional tone, and level of service. For CMF strategy, this provides a structured framework to develop tailored designs for each class and their needs.

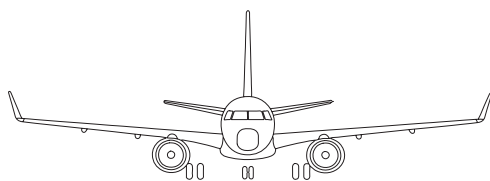


Figure 10: Movable curtain between class J and W. Source: Author.

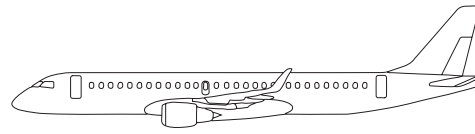
Number of seats in the different class configurations according to Embraer's offering of the 195 E2:



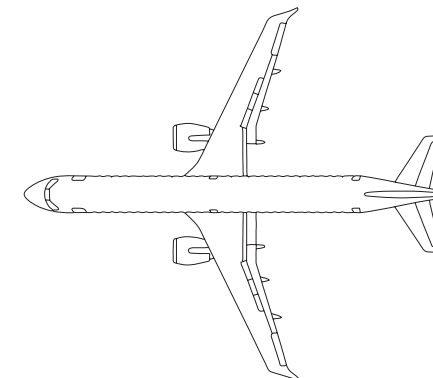
Aircraft dimensions



Height:
10.9 m

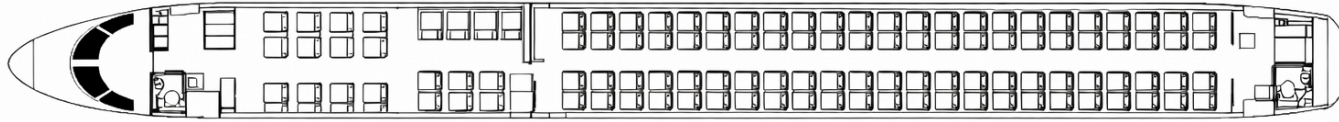


Length: 41.5 m



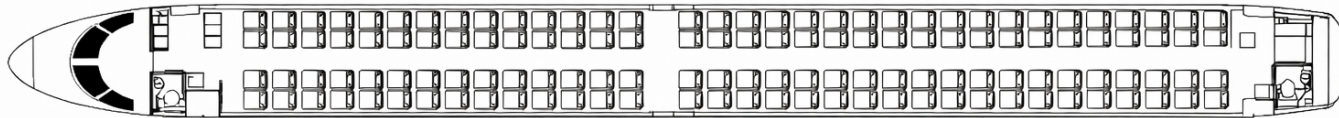
Wingspan :
35.1 m

E195-E2 THREE CLASSES CONFIGURATION



For airlines seeking **segmentation** rather than purely densification.
120 seats total
12 @36" (91 cm)
24 @34" (86 cm)
84 @31" (79 cm)

E195-E2 SINGLE CLASS CONFIGURATION



Moderate density
For a more comfortable version of the single class configuration.
132 seats @31" (79 cm)

E195-E2 SINGLE CLASS CONFIGURATION



High density
For maximum seat count.
146 seats @ 28" (71 cm)

Figure 11: Different class configurations offered by Embraer to airlines. Source: E-Jets E2: Airport planning manual (2024).

2.1.3.

AIRLINE DISTRIBUTION

Embraer does not operate their aircraft, but sells or leases them to different airlines across the globe. KLM Cityhopper owns a fleet of 25 Embraer E195-E2 aircraft, positioning it as a medium-sized yet strategically important customer within the program's global portfolio. As of 2025, Embraer has reported approximately 330 firm orders for the E195-E2, of which around 140 have been delivered and 190 remain in backlog. This places KLM's share of total firm orders at roughly 7.6 percent, a proportion that reflects meaningful engagement without matching the scale of major operators such as Azul Brazilian Airlines or large leasing companies. Consequently, selecting KLM Cityhopper as a case study provides a balanced context: the airline is large enough to influence Embraer's product and interior strategies, yet sufficiently contained to enable close collaboration. Besides this, it is also a positive factor that KLM mainly operates from Amsterdam, from where this thesis is written. (Embraer Commercial Aviation, 2025; Leeham News & Analysis, 2025).



2.1.4.

CASE STUDY: KLM CITYHOPPER

KLM Cityhopper is KLM Royal Dutch Airlines' regional service, operating a fleet of Embraer 175-E2, 190-E2 and 195-E2 aircraft from its hub at Amsterdam Schiphol Airport. It conducts approximately 120 daily departures and arrivals at Schiphol, connecting over 70 European destinations and accounting for nearly one quarter of all KLM aircraft movements at Amsterdam airport (Simple Flying, 2024). Each aircraft typically performs five to six flight round trips per day, requiring exceptionally efficient turnaround and maintenance routines.

A standard turnaround time for KLM Cityhopper's E-Jets is around 35 minutes, reduced from once 50 minutes through process optimization and parallel ground handling activities such as refueling, baggage exchange, catering, and light cabin cleaning (InspireIP, 2022). A cleaning cycle of 10-20 minutes is executed after every flight, while a deep clean is conducted every night. Cabin cleaning and servicing teams operate under a "pit-stop model," where ground and cabin crews work simultaneously above and below the wing to achieve the short turn around time (KLM Careers, 2023). Each flight typically carries four crew members, two pilots and two cabin attendants, while ground handling involves about 12 staff distributed across ramp, gate, and service positions.

As the Dutch flag carrier, KLM positions itself as a hospitable, reliable, and distinctly "blue" brand that emphasizes personal service and a calm, orderly travel experience. Its growing focus on sustainability and fleet renewal strengthens the strategic relevance of KLM Cityhopper as the airline's laboratory for more efficient and lower-impact regional operations.

"We are very proud to be part of such a longstanding, high end airline. If change in the cabin creates a more luxurious experience for the passengers, and does not give us more work, we are all for it."

✧ KLM Flight attendant



Figure 12: KLM Cityhopper cabin crew and KLM Cityhopper Embraer E195-E2 in flight. Source: KLM Royal Dutch Airlines (n.d.).

KLM BRANDING

KLM's branding strategy combines a strong visual identity, Dutch heritage, and sustainability messaging to create a coherent cabin experience. It's even the oldest airline in the world still operating under its original name (KLM Royal Dutch Airline, 2025). The airline consistently applies its signature royal-blue palette, simplified logo forms, and unified typography to ensure recognizability across all physical and digital touchpoints. This visual language reinforces KLM's long historical identity as a trusted "Royal" Dutch carrier, using design elements that signal continuity and national character (KLM Royal Dutch Airlines, 2013). At the same time, sustainability has become a central pillar of the brand, articulated through initiatives such as the Fly Responsibly campaign and the integration of recycled or lower-impact materials in cabin interiors (Travel Professional News, 2021). In its CMF choices, KLM combines its iconic blues with warmer accent colors and recycled textiles, strengthening both brand coherence and passenger comfort. This alignment of color, material, and sustainability narratives creates a cabin atmosphere that embodies KLM's contemporary values while remaining rooted in its brand heritage.

KLM's sustainability statement

We are committed to minimizing the impact of our activities by reducing our environmental footprint and protecting the environment beyond regulatory compliance.



Figure 13: KLM Branding images and corporate color palette and logo. Source: KLM Royal Dutch Airlines (n.d.).

EXAMPLE FLIGHT: KL995 AMS (AMSTERDAM) TO LCY (LONDON CITY)

KLM flight KL995, operating daily between Amsterdam Schiphol (AMS) and London City Airport (LCY), is among the most frequently flown routes in the KLM Cityhopper network, with up to 11 rotations per day. The flight takes approximately 65 minutes and offers five seat options that illustrate how comfort and service scale across KLM Cityhopper flights. Y-class (Economy class) provides standard pitch and includes a complimentary snack and drink, served at no extra cost, typical for KLM, differentiating them from other short haul airline operators. Passengers seated in the front rows of this class benefit from a quieter cabin and faster (dis)embarkation, while extra legroom seats in the exit rows offer up to 61 cm of additional leg room for enhanced comfort. W-class (Economy comfort) combines these benefits with priority boarding and a front-cabin position for a quicker travel flow. At the top tier, J-class (Business class) offers lounge access at Schiphol, priority boarding and a full in-flight meal service featuring freshly prepared dishes and an expanded beverage selection. It also includes flexible rebooking, a free adjacent seat, and a double baggage allowance (permitting two checked bags instead of one).

All fares include a carry on item as well as a personal item, with a double baggage allowance in Business class. Checked baggage can be purchased separately. Despite identical 2–2 seating and limited differences in seats (that will be covered in paragraph 2.1.6. on the Embraer 195-E2, the distinctions across classes emphasize that value on short-haul flights stems from service, comfort, and flexibility rather than physical seat differences (KLM, 2024; Simple Flying, 2024). This underscores the importance of exploring CMF differentiation possibilities between classes.

Class configuration on KL995

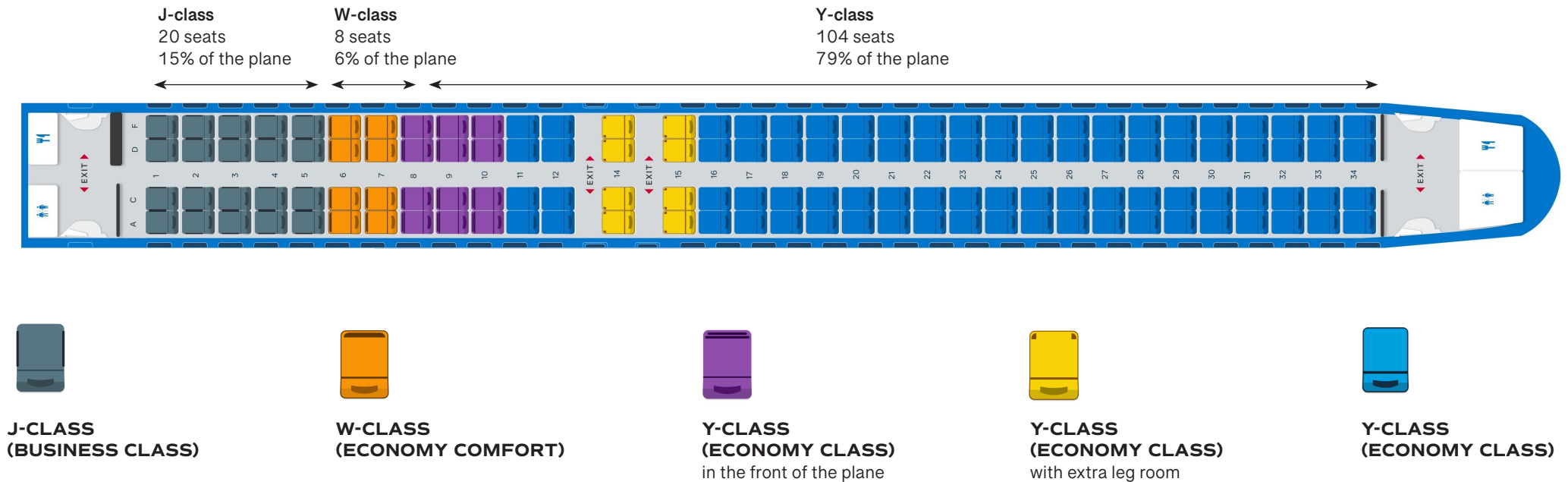


Figure 14: KLM Cityhopper Embraer 195-E2 cabin layout showing J-, W-, and Y-class distribution on flight KL995 (AMS–LCY). Source: KLM Royal Dutch Airlines website (n.d.).






			<u>Service level</u>		
	20 seats	J-CLASS (BUSINESS CLASS) €890 (+€560)	Extra legroom (12 cm), lounge access at Schiphol, extra leg room (upgraded in-flight meal service, flexible rebooking, 2× baggage allowance, priority boarding and disembarkation. Extra flying blue miles, amount depending on passenger's Flying Blue status.	} RECARO R2 seat 28 seats total = 21% of the seats	
	8 seats	W-CLASS (ECONOMY COMFORT) €510 (+€180)	Extra legroom (7 cm), priority boarding, a seat located at front of cabin and faster disembarkation. Extra flying blue miles, amount depending on passenger's Flying Blue status.		
	8 seats	Y-CLASS (ECONOMY CLASS) WITH EXTRA LEG ROOM €440 (+€110)	Exit-row seat with up to 61 cm additional legroom, early boarding, and priority overhead storage space	} RECARO R1 seat 104 seats total = 79% of the seats	
	12 seats	Y-CLASS (ECONOMY CLASS) IN THE FRONT OF THE PLANE €370 (+€40)	Standard seat with front-of-cabin location for quick exit, quieter section of cabin		
	84 seats	Y-CLASS (ECONOMY CLASS) €330 (+0)	Standard legroom, complimentary snacks and drinks, 1× carry-on bag and assigned seat		

Figure 15: Overview of KLM Cityhopper service levels and seat types per cabin class on flight KL995 (AMS–LCY), including indicative ticket price differences.

Source: KLM booking data collected via klm.com on 12/11/2025 for flight KL995 (AMS–LCY).

Disclaimer: Ticket prices are indicative and may vary by booking platform, travel date, demand, fare availability, and time of purchase.

2.1.5. CABIN ARCHITECTURE

The Embraer 195-E2 cabin is structured around a modular architecture that accommodates different service concepts while maintaining a consistent spatial framework. The cross-section measures 3 meters in width, with a central aisle of 0.55 meters and a ceiling height of 2.0 meters (Embraer E-Jets E2: Airport planning manual, 2024). These proportions shape boarding efficiency, and passengers' sense of spaciousness. The seats are mounted onto longitudinal aluminum seat rails integrated into the cabin floor and wall structure, allowing flexible positioning and secure attachment through standardized locking fittings and bolts. The cabin includes one front and one rear galley, two lavatories, and optional hard partitions to delineate service zones. Overhead stowage bins, ceiling panels, and sidewalls form large continuous surfaces that dominate the visual field and are therefore critical carriers of CMF identity. Integrated lighting within these panels enhances atmosphere and can be used to emphasize material qualities or transitions between cabin zones.

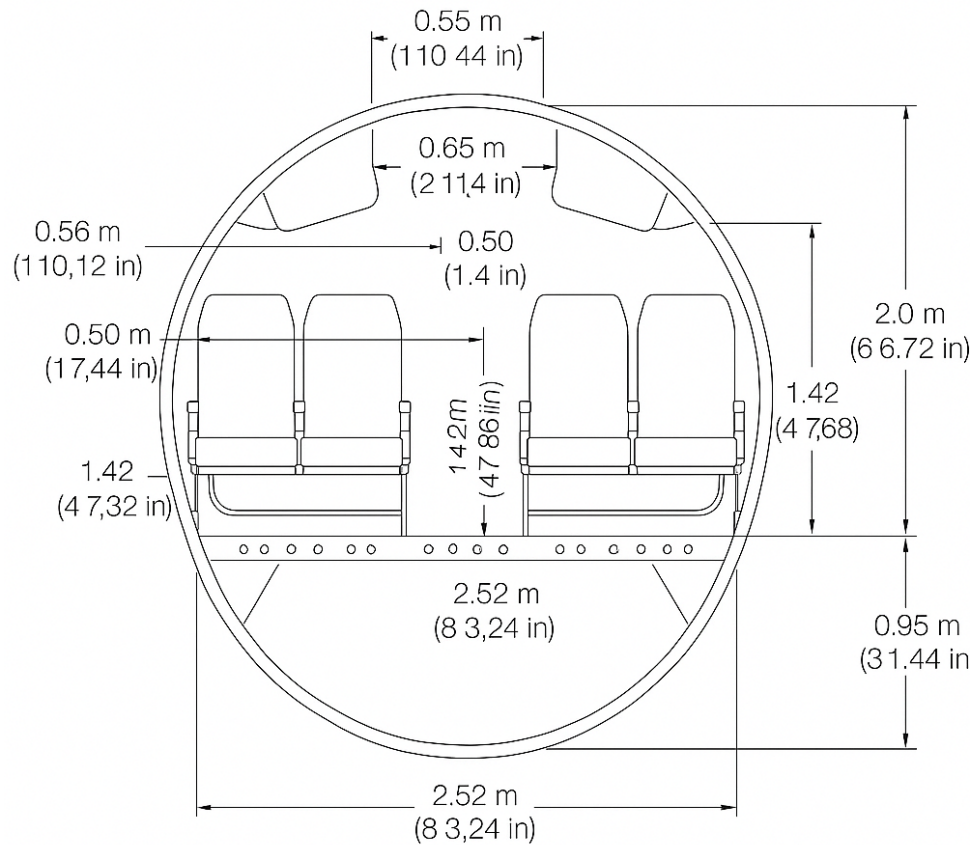


Figure 16: Embraer 195-E2 cabin cross section.
Source: Adapted from E-Jets E2: Airport planning manual (2024).



INTERIOR CABIN PARTS

The Embraer 195-E2 cabin consists of seats, sidewalls, ceiling panels, overhead bins, and flooring, each combining soft touch points and harder surfaces that shape aesthetics and perception. Soft materials such as foams, textiles, and headrests primarily drive comfort and sensory experience through softness, compliance, and texture, while harder elements such as composite panels, laminates, and bin shells communicate durability, safety, and cleanliness (Cavdan et al., 2021; Richaud et al., 2017). For the images showcased in this chapter, I was invited to one of KLM's hangars at Schiphol Airport, where Embraer's 195 E2 models are being maintained, to take these images.

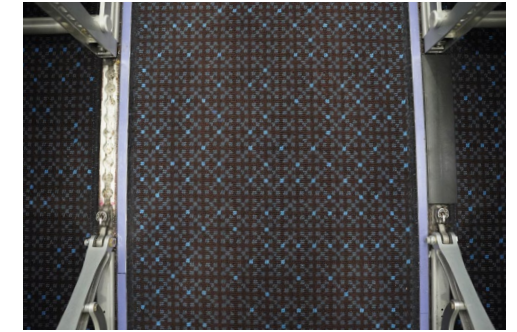
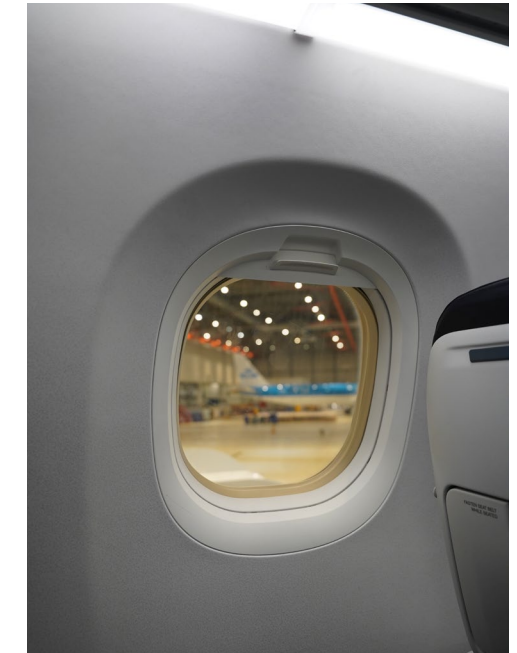
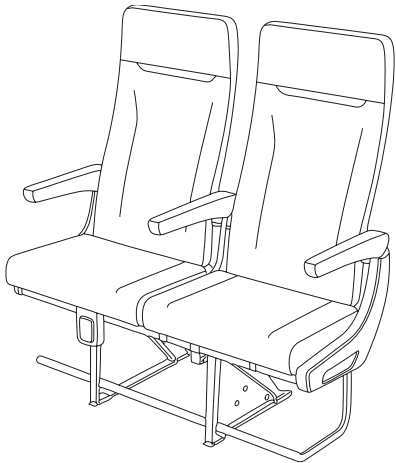


Figure 17: KLM Cityhopper (Embraer 195-E2) cabin parts. Source: Author.



2.1.6. THE SEATS

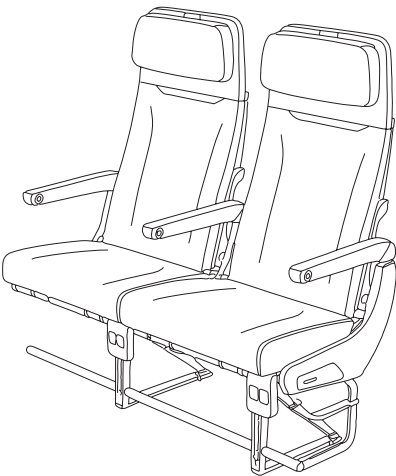
In the KLM Cityhopper, cabin seating is supplied by Recaro Aircraft Seating, with the R1 model in the Y-class and the R2 model in the W- and J-class. The Recaro R2 is a next-generation, slimline fixed-back shell seat designed for short- to medium-haul operations (Recaro Aircraft Seating, 2024). Its structure combines lightweight aluminum and composite framing with optimized load paths to reduce part count and weight. Both seats include one integrated USB power outlet per seat and a fixed back design that does not allow recline. The R1 consist of a lower mesh literature pocket, with a smaller tray table and a separate molded cup holder positioned at the top of the seat. The R2 includes a high rigid literature pocket, with a fold out tray for your phone or beverage, and a full-size sliding tray table (Aviation24, 2023). The premium R2 model also features a headrest adjustable in height and bendable for sideways support. Below you find the parts that differentiate the two seat types from each other and on the next page you will find the shared parts across the two models



RECARO R1
Economy class (79% of the planes' seats)



Source: Author.



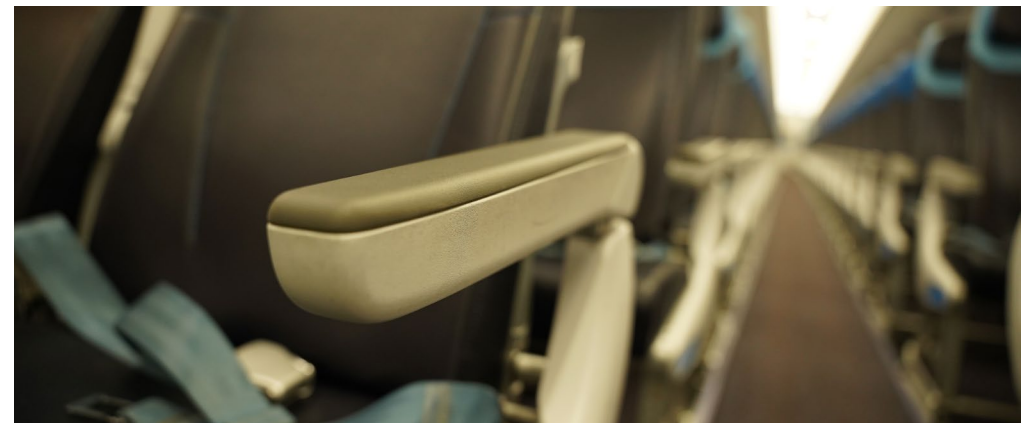
RECARO R2
Business class and Economy comfort (21% of the planes' seats)



Source: Author.

Seat model	RECARO R2	RECARO R2	RECARO R1
Class	J-class (Business class)	W-class (Economy comfor class)	Y-class (Economy class)
Manufacturer	RECARO	RECARO	RECARO
Number of Seats	20	8	104
Seat Pitch	~36" (91 cm)	~34" (86 cm)	~31" (79 cm)
Seat Width	~18 inch (46 cm)	~18 inch (46 cm)	~17 inch (43 cm)
Recline	No	No	No
USB power outlet	Yes	Yes	Yes

Shared parts across the Recaro R1 and R2



Source: Author.

2.2. PASSENGER EXPERIENCE

2.2.1. SCENARIO SKETCH

The following scenario outlines an economy-class passenger's journey on a 2026 (current day) flight from Amsterdam to London with KLM Cityhopper described in 12 stages. Each stage outlines the passenger's activity and the dominant senses engaged in this specific stage after the ✨ symbol.



1. Boarding

The passenger steps into the aircraft and immediately takes in the new cabin environment. A visually pleasing cabin design creates a positive first impression and elevates the passenger's mood, which is known to enhance overall comfort. Research confirms that passengers form their comfort judgment early in the flight (Ahmadpour et al., 2014; Vink et al., 2012).

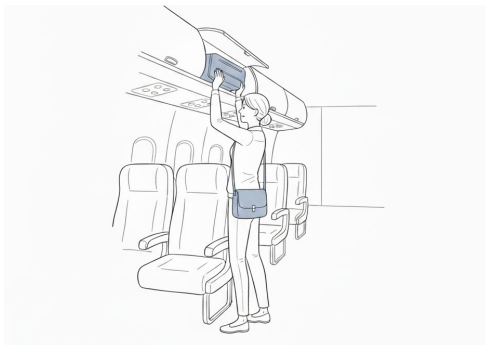
✨ Visual, olfactory and auditory



2. Walking down the aisle

The passenger walks through and waits in the narrow aisle with luggage in hand, navigating around other passengers and seat rows. Close proximity to others and restricted movement make personal space awareness particularly prominent, which is known to affect perceived comfort (Ahmadpour et al., 2014).

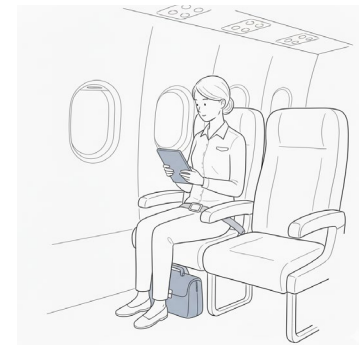
✨ Visual, tactile and auditory



3. Stowing luggage

The passenger lifts their carry-on into the overhead bin, which can be perceived as a physical load, especially for smaller passengers. This tactile experience focuses on weight, reachability and interaction with fellow passengers boarding around them, since some passengers experience it as a rushed and stressful part of their on-board journey. (De Crescenzo et al., 2021).

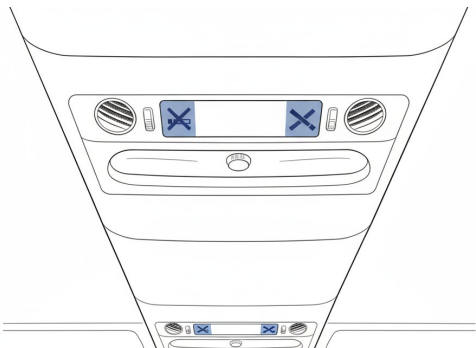
✨ Tactile and visual



4. Seating and settle-in

The passenger sits down in their seat and places their personal item underneath the seat in front of them, possibly taking out personal items that they plan to use during the flight. Seat dimensions and legroom strongly influence physical comfort, although short flight duration can mitigate discomfort (Vink et al., 2012; Vledder et al., 2023).

✨ Tactile and visual



5. Taxi

During taxiing, passengers experience low-frequency vibrations and engine noise while waiting for departure, tray table use is not permitted in this phase until the seatbelt sign turns off after take off. Clear communication from the flight crew might support psychological comfort during this passive and anticipatory phase (Vink et al., 2012).

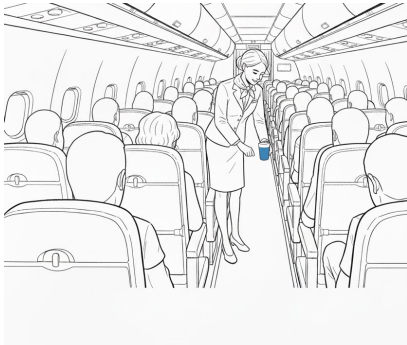
✨ Auditory, tactile and visual



6. Take-off

The passenger feels acceleration forces and increased engine noise as the aircraft lifts off. Some passengers focus on clearing their ears using different techniques. Psychological comfort, including perceived safety and calmness in the cabin, plays a key role alongside physical sensations during this phase (Ahmadpour et al., 2014).

✨ Auditory, tactile and vestibular



7. Food and beverage service

Once take off is completed, the seatbelt sign turns off and usage of the tray table is permitted again. The passenger receives a snack and drink of choice from the cabin crew. Service presentation and attentiveness of the cabin crew can evoke feelings of care and familiarity, which positively influence comfort experience (Ahmadpour et al., 2014).

☼ Gustatory, olfactory and visual



8. Personal entertainment

The passenger engages in solitary activities such as reading, working, or listening to audio. Comfort levels drops in this phase of the flight. Adequate personal space and acceptable noise levels support autonomy and comfort during individual activities (Bouwens et al., 2016; De Crescenzo et al., 2021).

☼ Visual and auditory



9. Trash collection

Cabin crew collects used packaging and cups from their food and beverage service earlier, clearing the passenger's immediate environment. KLM Cabin crew separate waste into different material streams. Cleanliness and the removal of clutter contribute to improved comfort perception (Vink et al., 2012).

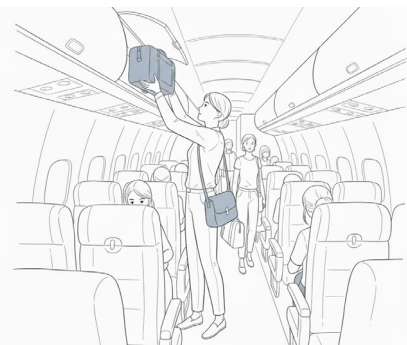
☼ Visual and tactile



10. Landing

The seatbelt sign turns on again, lavatory and tray table use are no longer permitted and passengers experiences deceleration, landing gear noise and touchdown vibrations during arrival. Feelings of relief and satisfaction after a safe landing contribute to overall comfort evaluation (Ahmadpour et al., 2014).

☼ Auditory and tactile



11. Gathering belongings

The passenger unbuckles their seat belt, stands up when there is enough space, stretches and retrieves carry-on luggage from the overhead bin. Regaining freedom of movement and personal space alleviates physical stiffness and supports comfort at the end of the flight (De Crescenzo et al., 2021).

☼ Tactile and visual



12. Disembarkation

The passenger waits for the stairs to attach to the aircraft to disembark the plane and eventually walks toward the front or rear exit, having an overlooking view of the cabin again and leaves the aircraft, often interacting briefly with cabin crew. Cabin cleanliness and social interaction can leave a positive final impression, influencing overall comfort and satisfaction (Ahmadpour et al., 2014).

☼ Visual, tactile and auditory

WHICH CABIN PARTS ARE RELEVANT WHEN?

Cabin focus

- ✧ Curtain
- ✧ Carpet
- ✧ Bins/side walls

Seat focus

- ✧ Seat shell
- ✧ Tray table
- ✧ Literature pocket

- ✧ Seat belt
- ✧ Upholstery
- ✧ Armrests

Cabin focus

- ✧ Curtain
- ✧ Carpet
- ✧ Bins/side walls



Embarking
the plane

In flight experience
in the seat

Disembarking
the plane

2.2.1. INTERVIEWS

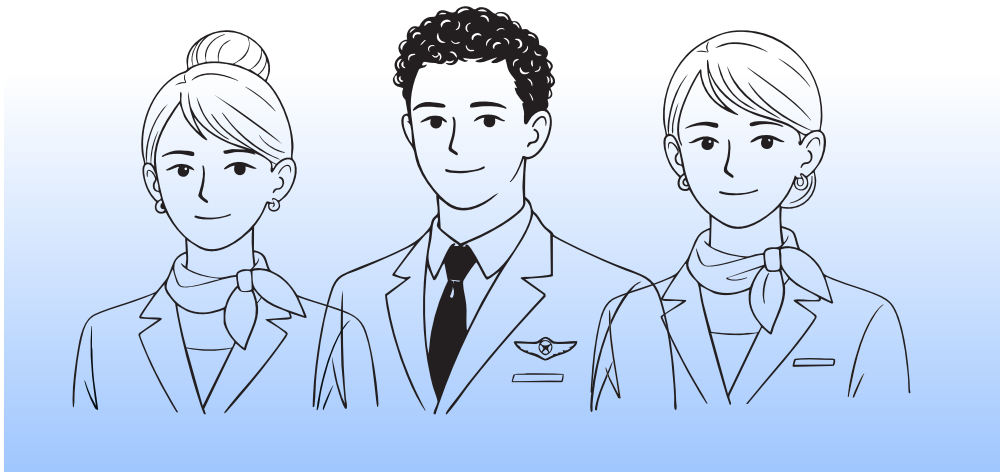
To inform the upcoming design development, semi-structured qualitative interviews were conducted with airline passengers and KLM cabin crew. Five passengers (three traveling most often in Economy class, one in Economy comfort and one in Business class) and three KLM cabin crew members participated. The passengers were selected based on their travel history, having flown at least one short-haul journey with KLM in the past year (regardless of whether they had flown specifically on the 195-E2), and their cabin class. Interviews lasted between 45 and 60 minutes and explored in flight experiences with cabin materials, perceived comfort, cleanliness and sustainability perceptions. Passenger interviews focused on needs, pain points, sensory impressions, and memorable material experiences, while crew interviews addressed passenger archetypes, operational aspects such as cleaning, durability, and recurring passenger feedback. This approach enabled triangulation between end-user and operational perspectives.

Passengers findings

- ✧ Flight choice is driven primarily by price and efficiency, especially on short routes, comfort expectations are low. These factors vary per passenger class and are described in more detail in the design chapters of each cabin class.
- ✧ Social factors strongly affect comfort, noise, crowding, other passengers' behavior and long wait and taxi times at arrival.
- ✧ Food and drink service is a key positive moment for economy class, signaling care and attention even if quality is basic. This is not the case in the more premium classes.
- ✧ Seat comfort is tolerated if legroom is acceptable, but broken, dirty or worn details quickly reduce perceived quality.
- ✧ Cabin interiors are often perceived as outdated, cheap and visually dull, dominated by gray plastics and worn textiles.
- ✧ Desired atmosphere is calm, personal and home-like, allowing passengers to retreat into their own bubble and feel mentally relaxed.
- ✧ Reliability, smooth boarding and fast disembarkation matter more than entertainment or premium features.

Cabin crew findings

- ✧ Clear behavioral differences per class, Business class values privacy, reliability and personal recognition, Economy class is busier and more chaotic, and happy with the included snack and beverage service.
- ✧ Overhead bin capacity and hand luggage are a major operational and passenger stress point.
- ✧ Wear and tear is highly visible and damaging to brand perception, especially carpets, armrests, tray tables and bins.
- ✧ Materials that are easy to clean, durable and robust are strongly preferred for daily operations.
- ✧ Lighting quality significantly influences atmosphere, adjustable and softer lighting increases perceived luxury and calm.
- ✧ Short-haul flights are operationally intense, leaving little margin for recovery or error during service and turn around.
- ✧ Disposable materials in Economy conflict with sustainability ambitions and brand values, while crew desire quieter, less fragile and more consistent material solutions across classes.



2.3. REGULATORY SCAN

The design of aircraft interiors is strongly regulated to ensure passenger safety and long-term reliable operation. At the international level, the International Civil Aviation Organization (ICAO) defines baseline safety standards and harmonization goals across countries. These are then implemented through region-specific certification authorities. For the Embraer 195-E2, the main rules come from the European Union Aviation Safety Agency (EASA) in Europe and the Federal Aviation Administration (FAA) in the United States. These two systems are largely harmonized and describe how cabin materials, seat systems, and emergency features must perform in standardized tests before they can be used in service (ICAO, 2022; EASA, 2013; FAA, 2001). For Color, Material, and Finish (CMF) design this means that choices cannot be based only on aesthetics or sustainability, but must also satisfy requirements on fire behavior, smoke and toxicity, slip resistance, and durability (EASA, 2013).

All materials used inside a commercial aircraft cabin must therefore be tested, among others, for fire safety, slip resistance, and structural integrity under emergency conditions. These requirements are brought together in the FAA Aircraft Materials Fire Test Handbook and EASA certification memorandum on flammability testing, which describe how to apply them in design practice (Horner, 2000; EASA, 2013; EASA, 2011).

2.3.1 FLAMMABILITY TESTING

Fire behavior is a very important restriction in the selection of cabin materials. Almost all non-metallic parts, such as seat foams and upholstery, hard plastic trims, carpets, curtains, sidewall panels, overhead bins, and galley surfaces, must show that they do not spread fire quickly and do not generate excessive smoke or toxic gases (Horner, 2000; EASA, 2013).

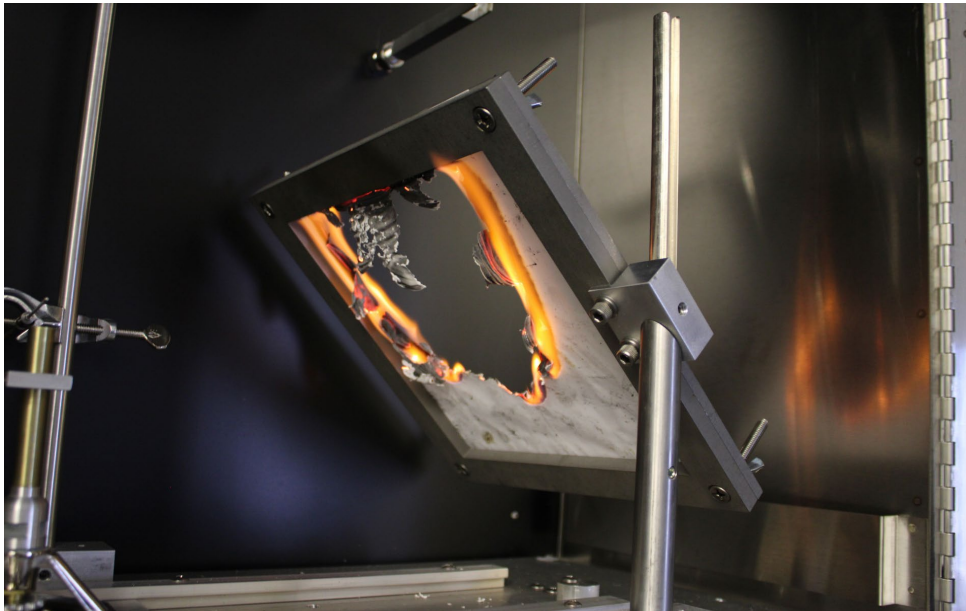


Figure 18: Example of one of the aircraft interior material flammability testings.
Source: Federal Aviation Administration (FAA) (n.d.)



Small-flame tests

In small-flame tests, a Bunsen burner is applied to a small material sample for a short time and the burn length, after-flame time, and any flaming drips are measured. This applies to seat covers, foams as part of cushions, plastic trims, tray tables, carpets, curtains, and many interior panels (Horner, 2000; EASA, 2013).

Seat cushion oil-burner test

For the oil-burner test, complete seat cushions (foam, fire-blocking layer, and cover) are exposed to a strong kerosene flame for about two minutes. The test checks weight loss, flame spread, and burn-through and ensures that the cushion stack provides sufficient fire protection (Horner, 2000).

Heat-release and smoke-density tests

Large interior panels such as sidewalls, ceiling panels, overhead bins, and galley monuments are tested for heat release and smoke density. In these tests, panel specimens are exposed to radiant heat and burned in a smoke chamber to measure how much energy and visible smoke they produce in a fire (Horner, 2000; EASA, 2013).

Smoke-toxicity tests

Smoke-toxicity tests, such as Boeing BSS 7238 and BSS 7239, are used for sidewall laminates, bins, galleys, lavatories, adhesives, coatings, and some seat parts. Materials are burned in a chamber and the concentrations of toxic gases like carbon monoxide, hydrogen cyanide, and hydrogen chloride are measured against internal limits (Master Bond, 2025; VTEC Laboratories, n.d.; Ecosafene, n.d.).

Insulation flame-spread and burn-through tests

Thermal and acoustic insulation blankets behind sidewalls and ceilings are tested to ensure that flames do not travel along the insulation and that external flames cannot quickly burn through into the cabin. Radiant-panel and burner tests are used for this purpose and are recognized as preferred methods by both FAA and EASA (Horner, 2000; EASA, 2011).

2.3.2 SLIP RESISTANCE TESTING

Flooring in areas where liquids or catering items can be spilled, such as galleys, entrances, and lavatories, must provide enough friction so that passengers and crew do not slip. Flooring manufacturers therefore test vinyl or rubber aircraft flooring and, where relevant, carpets, for a defined factor of sliding friction in wet and dry conditions, and explicitly advertise compliance with these slip-resistance criteria (Lonseal, 2018; Lonseal, 2024).

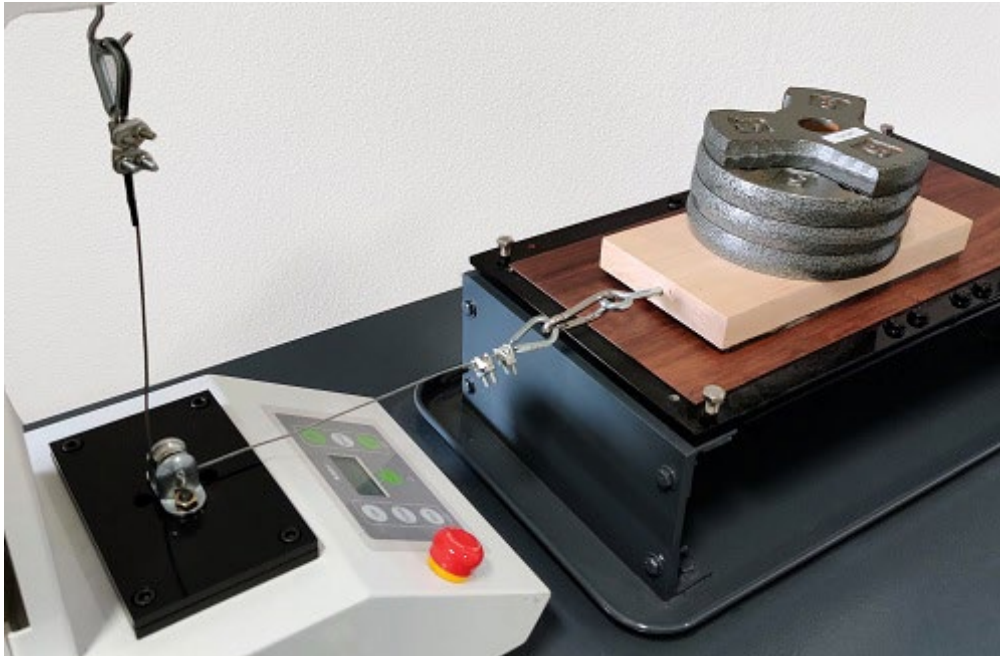


Figure 19: Example of aircraft interior material slip resistance testings.
Source: AeroBlaze Laboratory (n.d.).

2.3.3 STRUCTURAL AND DURABILITY TESTING

Seats and some monuments must also show that they remain intact in an emergency landing. Dynamic tests with crash dummies apply forward and downward impact pulses to complete seats, including foams, upholstery, belts, headrests, armrests, and tray tables. Injury criteria and structural deformation limits are defined by the certification authorities and clarified in dedicated EASA memorandum and FAA guidance (EASA, 2013; EASA, 2018).

Finally, manufacturers and airlines apply additional durability tests that go beyond formal certification. Typical examples include abrasion and wear tests, stain and cleanability tests, and abuse tests on carpets, non-textile flooring, seat covers, armrests, tray tables, and galley floor mats, to make sure that materials keep their appearance and function over many years of service (Horner, 2000; Lonseal, 2018; Lonseal, 2024).



Figure 20: Dynamic 16G forward crashworthiness test of aircraft seats.
Source: Federal Aviation Administration (FAA) (n.d.).

GUIDELINES RELEVANT FOR THIS THESIS

- ☼ **Seats and occupant safety constraints:** Seat foams, covers, and padding interact with dynamic safety tests such as the 16 g crash test. While the seat structure carries most of the load, CMF elements must not compromise safety performance.
- ☼ **Emergency lighting and signage:** Materials must not interfere with floor-path markings and illuminated signage, which must remain visible under all conditions.
- ☼ **Chemical and environmental compliance:** In the European context, the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) regulation restricts hazardous substances such as certain flame retardants or PFAS (per- and polyfluoroalkyl substances). If antimicrobial treatments are used, they must comply with the European Union Biocidal Products Regulation. These rules are important for the acceptance of bio-based foams and coatings.
- ☼ **Cleanability and maintenance:** Aircraft interiors must be cleaned efficiently between flights to meet short turnaround times, which for regional aircraft typically range between 25 and 40 minutes. Materials therefore need to resist stains, moisture, and chemical cleaners while allowing full seat cleaning—vacuuming, wiping, and spot treatment—in less than 90 seconds per seat. Surfaces must also withstand hundreds of cleaning cycles throughout their service life without discoloration, texture loss, or degradation of flame-retardant performance. Design choices such as smooth surfaces, minimal seams, and removable covers help airlines maintain hygiene standards and reduce maintenance costs without interrupting operations.

2.3.4

HYPOTHETICAL MATERIAL TEST PLAN

Although this thesis will not conduct certification tests, it is useful to demonstrate how nanocellulose foam and related CMF components would theoretically be assessed for compliance. This shows awareness of the certification context and ensures that design proposals remain realistic.

Test type	Interior parts	Purpose
Small-flame test	Seat upholstery and leather, foams as part of cushions, hard plastic trims and armrests, tray tables, sidewall and ceiling panels, overhead bins, carpets, galley curtains, galley and lavatory panels	Check how a material reacts to a small flame, so it goes out quickly and does not drip burning material (Horner, 2000; EASA, 2013).
Seat cushion oil-burner test	Complete seat cushions, including foam, fire-blocking layer, and cover	Check whether the full cushion stack can withstand a strong fuel fire without fast burn-through (Horner, 2000).
Heat-release test	Sidewall and ceiling panels, overhead bins, galley and lavatory modules, other large interior panels	Measure how much heat a panel gives off in a fire, to limit how quickly the cabin fire can grow (Horner, 2000; EASA, 2013).
Smoke-density test	Same parts as the heat-release test, sometimes decorative laminates and flooring systems	Measure how much visible smoke a burning material produces, which affects visibility during evacuation (Horner, 2000; EASA, 2013).
Smoke-toxicity test	Sidewalls, ceilings, overhead bins, galleys, lavatories, adhesives, coatings, some seat and monument parts	Measure how much toxic gas is released when a material burns, for example CO, HCN and HCl (Master Bond, 2025; VTEC Laboratories, n.d.; Ecosafene, n.d.).
Slip-resistance test	Galley flooring, lavatories, entrances, door and step areas, sometimes carpets near exits	Show that people can walk safely without slipping in wet and dry conditions (Lonseal, 2018; Lonseal, 2024).
Dynamic seat crash test	Complete passenger and crew seats, including structure, foams, upholstery, belts, headrests, armrests, tray tables	Show that the seat protects passengers during an emergency landing (EASA, 2013; EASA, 2018).
Durability and wear tests	Carpets, non-textile flooring, seat covers, plastic trims, armrests, tray tables, galley mats	Check that materials can handle daily use and cleaning without wearing out too quickly (Horner, 2000; Lonseal, 2018; Lonseal, 2024).

2.4. INTERIOR BENCHMARK

Benchmarking is a comparative design research method that allows designers to identify best practices, innovation gaps, and areas of differentiation by analyzing existing products in the market (Wicher, 2016). In the context of aircraft interiors, benchmarking is essential for positioning new cabin designs against current industry standards, particularly when developing interiors for regional aviation, where comfort, space, branding, and sustainability vary widely by operator and aircraft type. This chapter compares the interiors of four relevant regional aircraft: the Embraer E195-E2 (KLM Cityhopper), Airbus A220-300 (SWISS), ATR 72-600 (Air New Zealand), and COMAC ARJ21-700 (Air China). Each is assessed across three classes where applicable—Business (J), Premium Economy (W), and Economy (Y)—with attention to seat pitch and architecture, color-material-finish (CMF), branding, sustainability, and passenger experience features. This structured benchmark provides a foundation for understanding where the KLM Cityhopper product leads, aligns with, or lags behind competitors (Miller, 2021; ATR, 2025; COMAC, 2021; SWISS, 2024).

AIRBUS A220-300



Figure 21: Swiss cabin interior
Source: Swiss International Air Lines (n.d.), public imagery.

ATR 72-600



Figure 22: Air New Zealand cabin interior
Source: ATR (n.d.), public imagery.

COMAC ARJ21-700



Figure 23: Air China cabin interior
Source: JetPhotos. (n.d.), public imagery.

Airline	Aircraft	Cabin Classes	Materials	Color Palette & Finish	Sustainability	Branding Elements
KLM Cityhopper	Embraer E195-E2	3: Business (J), Economy Comfort (W), Economy (Y)	Synthetic leather upholstery, nylon flooring, polyester seat belt, PVC galley floor mat	Blue/gray tones, matte panels, LED mood lighting	Recycled materials, lightweight seats, LED lighting	Blue headrests, crown logo, minimalist Dutch identity
SWISS	Airbus A220-300	2: Business (J), Economy (Y)	Synthetic leather upholstery, nylon flooring, polyester seat belt, PVC galley floor mat	Warm neutrals, chrome trim, beige accents	Durable materials, slim design, fuel-efficient A220	Swiss cross on headrests, refined luxury styling
Air New Zealand	ATR 72-600	1: Economy (Y)	Synthetic leather upholstery, wool flooring, polyester seat belt, PVC galley floor mat	Monochrome black/white, matte plastics	Light cabin, wool carpets, efficient turboprop	Koru motif, black/white NZ identity
Air China	COMAC ARJ21-700	1: Economy (Y)	Textile upholstery, nylon flooring, polyester seat belt, PVC galley floor mat	Neutral tones (gray/beige), red phoenix logo accents	Carbon/titanium seats, lightweight configuration	Red phoenix logos, bilingual signage, conservative tone

This benchmark shows that KLM's Embraer E195-E2 does not stand out especially among its regional peers for material usage, sustainability, and layout efficiency. Its 2-2 seating avoids middle seats entirely, providing a consistent comfort advantage over its 3-2 layout competitors like the A220-300 and ARJ21. The combination USB power outlets, and most of the time Wi-Fi connection gives KLM a slight technological, especially compared to the analog ARJ21 and the minimalist ATR 72 (Miller, 2021; SWISS, 2024). While SWISS excels in elegant CMF and Air New Zealand in cultural branding, KLM has an opportunity to reinforce its high end identity through improving aesthetics while increasing cabin material circularity. Strategically, KLM's strongest positioning lies in offering a premium regional product that positions KLM Cityhopper as a front runner in the evolving short-haul aviation market, particularly as sustainability and brand identity grow in competitive relevance (ATR, 2025; COMAC, 2021).

2.5. CMF DESIGN

2.5.1 THE EVOLUTION OF CMF DESIGN

1900 - 1950

FOUNDATIONS OF CABIN AESTHETICS

Before CMF was recognized as a formal discipline, aircraft interiors borrowed heavily from ocean liners and trains. Materials like painted metal, wood veneers, and textiles were used to convey progress and luxury, while coordination of colors and surfaces created the first sense of brand identity. Safety regulations for materials were still very minimal.

Aviation example

Pan Am's Boeing 314 flying boat featured coordinated colors and curtained windows to convey luxury and prestige, the Boeing 314 did not have a pressurized cabin, with comfort achieved through spatial layout, materials, and service rather than environmental control. Later aircraft such as the Boeing 377 Stratocruiser introduced pressurized cabins, enabling greater integration of materials and finishes for passenger comfort (Davies, 2016; Jenkins, 2001).



Materials used

Wood veneers, cotton textiles, aluminum panels, bakelite details, and brass trims often handcrafted.

1950 - 2000

BRANDED INTERIORS AND SAFETY COMPLIANCE

CMF principles became more systematic, with bold palettes, standardized surface treatments, and decorative laminates enabling strong airline branding. At the same time, stricter flammability and durability requirements drove material innovation, introducing phenolic-honeycomb panels and decorative films like Tedlar®. CMF matured as a practice balancing aesthetics with regulation.

Aviation example

Braniff's "End of the Plain Plane" campaign, designed by Alexander Girard and Emilio Pucci, used coordinated textiles and colors as a branding tool, while aircraft manufacturers adopted composite panels with fire-resistant decorative films to comply with FAA requirements (Pasztor, 1997; FAA, 2000).



Materials used

Composites, phenolic panels, PU foam, Tedlar films, vinyl fabrics, and anodized aluminum.

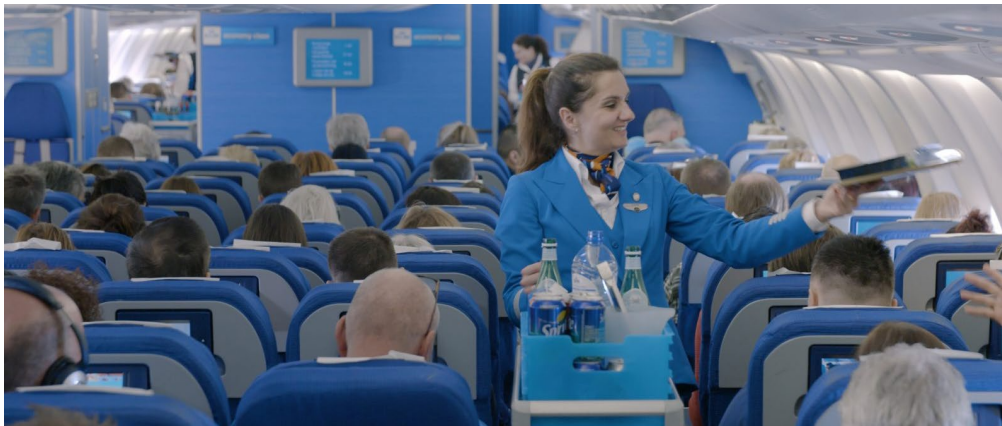
2000 - 2015

EXPERIENCE-LED CMF

CMF expanded beyond surfaces into ambiance, integrating light, gloss, and texture into the passenger experience. Advances in textiles, coatings, and lighting shifted design focus toward sensory atmosphere, cleanliness, and perceived space.

Aviation example

The Airbus A380 and Boeing 787 introduced full-cabin LED mood lighting and electronically dimmable windows, turning light into a tunable “finish” that could be coordinated with trims and textiles for immersive cabin environments (Airbus, 2015; Boeing, 2011).



Materials used

Carbon composites, High Pressure Laminates (HPL), LED lighting, and dimmable glass.

2015 - NOW

CIRCULAR CMF AND SCALABLE RETROFITS

CMF decisions are increasingly judged by life cycle impact, emphasizing recycled, mono-material, and take-back program solutions while maintaining safety compliance. Airlines prioritize finishes that are both sustainable and easy to apply across fleets.

Aviation example

Carpets made from regenerated ECONYL® yarns, recycled/upcycled leather dress covers from Gen Phoenix (ELeather), and lightweight LED retrofit kits illustrate how airlines embed circular materials into existing fleets while still meeting standards for flammability and smoke (Santos et al., 2016)



Materials used

Recycled plastics and fabrics, bio-based plastics, water-based coatings, and modular thermoplastics.

2.5.2 NON-AVIATION CMF FRONTRUNNERS

This chapter examines non-aviation CMF frontrunners to identify transferable strategies that have already proven viable at scale. By studying how adjacent industries integrate circular materials, modularity, and reparability without compromising performance or brand value, aviation CMF development can reduce risk and accelerate the adoption of more sustainable solutions.

AUTOMOTIVE POLESTAR (3 & 4 INTERIORS)

Circular and natural materials

Polestar 3/4 interiors with bio-attributed materials, natural-fiber composites, highly recycled-PET knits (up to 89% recycled).

Why it's relevant

Best-in-class transparent material specs and mono-material logic you can adapt for seat covers, curtains, and soft trims (e.g., knitted PET with low-VOC backings).



WHAT TO BORROW:

Knitted covers with replaceable panels, recycled aluminum visual language for hardware, materials passporting style of documentation.

FURNITURE HERMAN MILLER AERON

Ocean bound plastic program

Aeron/Sayl updates using ocean-bound plastic; brand publishes diversion metrics and performance data.

Why it's relevant

Furniture that hits same touch-points (seat, arm, back) with heavy durability cycles. Their ocean bound plastic integration shows impact without comfort loss, a compelling story for stakeholders.



WHAT TO BORROW:

Colorways that hide scuffs, OBP content in non-critical trims, documentation style for stakeholder buy-in.

FOOTWEAR ADIDAS x ALLBIRDS

Low-carbon shoes

Shoes at ~2.94 kg CO2e per pair, made from bio-based materials, including sugarcane-derived EVA foam mid-soles, eucalyptus fiber uppers, and castor bean oil-based insoles, significantly reducing their carbon footprint.

Why it's relevant

Footwear is a masterclass in designing for lightweight foams, fatigue, sweat/soil. Their carbon accounting and undyed palettes could translate well to the aviation industry.



WHAT TO BORROW:

Undyed/low-dye colorways for maintenance, LCAs as part of CMF specs, bio-EVA learnings for protective toppers.

ELECTRONICS FAIRPHONE 5

Modular, low carbon smartphone with >70% recycled/fair material

At ~30 kg CO2e per device; modular recycled material architecture, recycled Fair trade gold circuitry. Designed-for-repair aesthetics.

Why it's relevant

A blueprint for repairable CMF (fasteners, access paths, finish that tolerates rework). You can apply this logic to seat part replacement (armcap skins, headrest wings) and panel film swaps.



WHAT TO BORROW:

Exposed-but-neat fastener design language, modular sub-covers, visible cues that "repair is normal."

2.6. THE SYSTEM

2.6.1. STAKEHOLDER MAP

This graduation project brings together two central actors, Embraer (aircraft manufacturer) and Foamlab (material innovator and supplier), to explore a circular CMF interior concept for the E195-E2 using nanocellulose foam. Surrounding them are stakeholders with differing values and goals: airline operators (e.g., KLM Cityhopper in the case study) who weigh cost, durability, serviceability, and brand fit; passengers, whose comfort and perceived sustainability shape acceptance; interior suppliers (seat, trim, textile, laminate, and foam-conversion partners) whose specifications, lead times, and certifications determine feasibility; research partners (TU Delft supervision and labs) who ensure academic correctness and translate material research into design criteria; maintenance and cabin cleaning providers who drive life cycle practicality; airports that constrain operational realities; and regulators/governments (EASA/FAA) whose safety requirements gate certification. Aligning these stakeholder interests requires demonstrating material feasibility within the E195-E2 cabin architecture and layouts, while complying with certification constraints and airline operations, and translating Foamlab's bio-based foam into CMF solutions that enhance passenger experience and Embraer's sustainability ambitions (Embraer sustainability report, 2024).

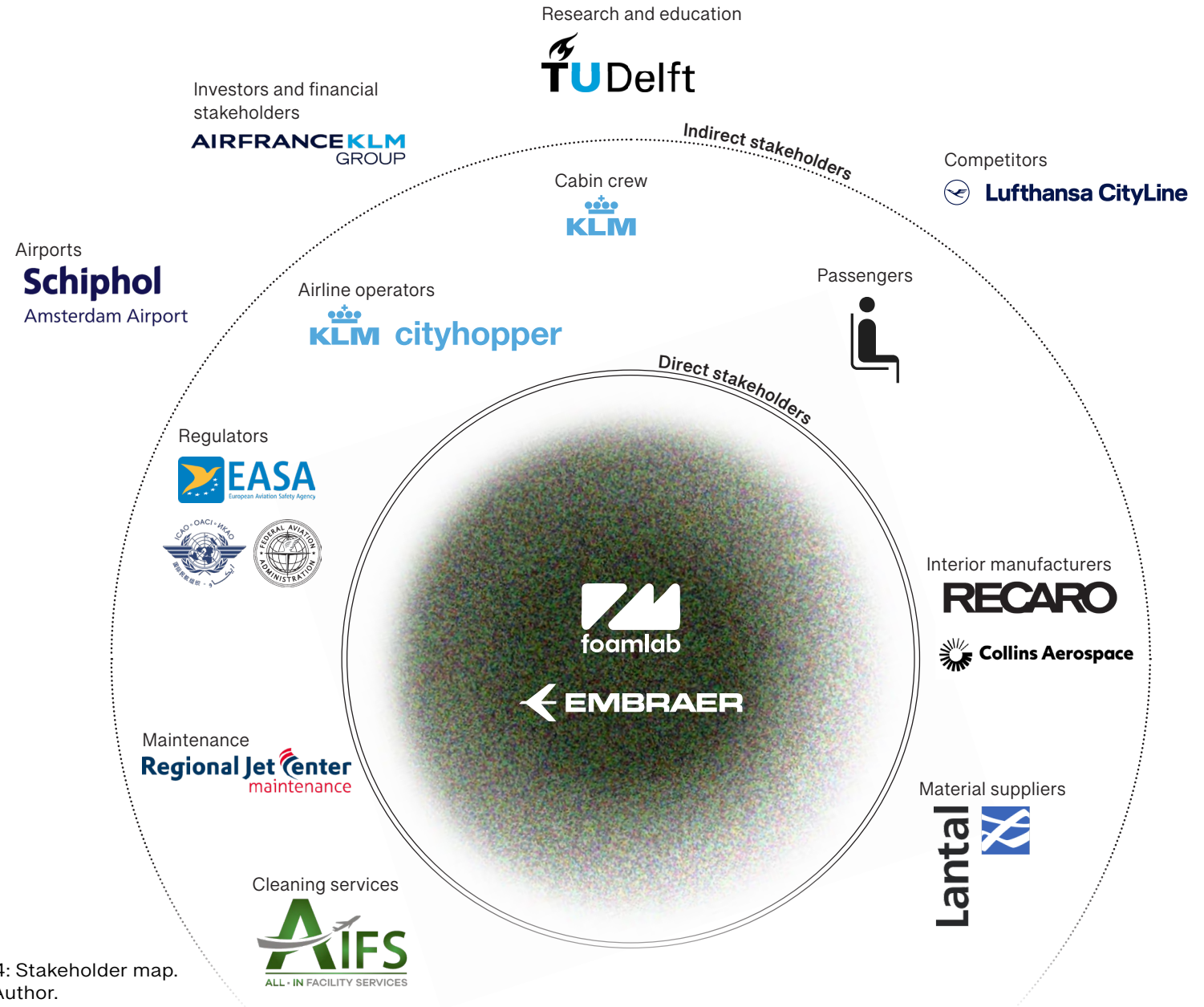


Figure 24: Stakeholder map.
Source: Author.

2.6.2

POWER INTEREST GRID

To manage the diverse actors involved in this project, a Power–Interest Grid (Mendelow, 1991) was developed to categorize stakeholders according to their level of influence over, and interest in, the development of the project. The analysis clarifies which stakeholders require continuous engagement and which can be informed periodically. Embraer, Foamlab, KLM Cityhopper, and the European Union Aviation Safety Agency (EASA) occupy the high-power, high-interest quadrant, indicating the need for close collaboration and iterative feedback. Entities such as Air France–KLM Group, Schiphol Airport, and the Regional Jet Center hold strategic power but lower operational involvement, warranting regular updates rather than active co-creation. Academic and design partners, Recaro, and passengers, exhibit strong interest but limited decision power, making them key sources of insight during testing and evaluation phases. The grid thus supports transparent communication planning and aligns with design management practices that emphasize early stakeholder alignment to mitigate project risk and enhance adoption (Freeman, 1984; Mendelow, 1991).

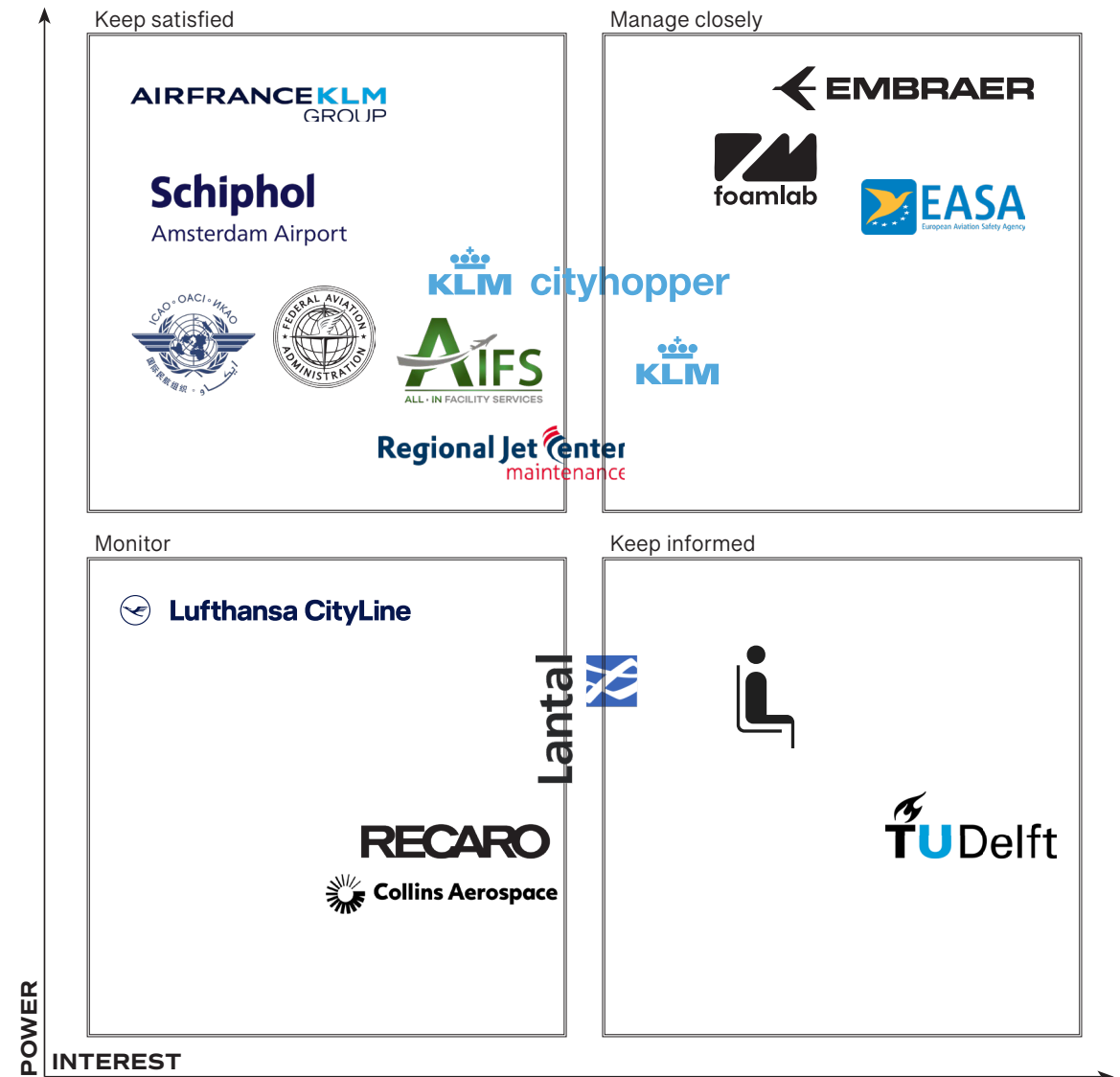


Figure 25: Power interest grid.
Source: Author.

2.6.3 CIRCULAR SUPPLY CHAIN

The circular supply chain for the E195-E2 seat CMF concept includes several stages. It starts with bio-based feedstock cultivation and processing. Then it moves through component manufacturing, aircraft integration, in-service cleaning and repair, and mid-life refurbishment or re-trim. At the end of life, materials can go through certified part harvesting, mechanical or chemical recycling of textiles and plastics, or biological valorisation (Ellen MacArthur Foundation, 2015; AFRA, 2018). To make this work, the system needs design for disassembly at the seat level, material passports for traceability, and reverse-logistics agreements. These must be set up with MROs (Maintenance, Repair and Operations) and seat OEMs (Original Equipment Manufacturers) to connect seat removal to take-back or second-life markets (ISO, 2006; EASA, 2023). There are also less visible, but important, actors. These include cleaning product suppliers, who affect how materials last and recycle; repair teams, who do local re-foaming or re-upholstery; and leasing firms, who influence how often seats are reconfigured. There are also recyclers for complex materials like laminates and coated fabrics, and digital product passport providers that support regulation and track feedstock quality (Bocken et al., 2016; AFRA, 2018; Ellen MacArthur Foundation, 2015). These actors and tools help show where circular value is created, where quality drops, and where better control is needed.

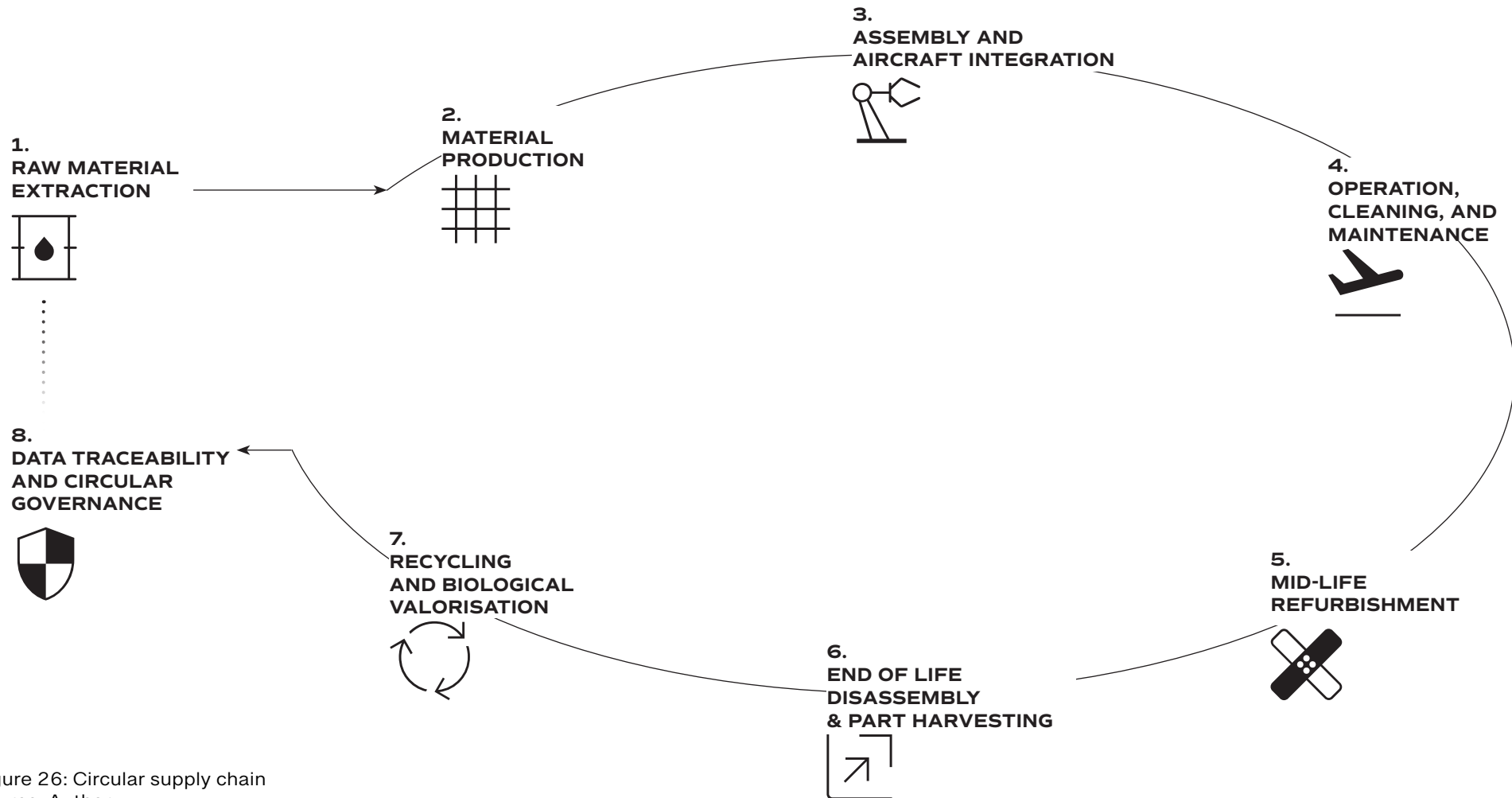


Figure 26: Circular supply chain
Source: Author.

1. RAW MATERIAL EXTRACTION

- ✧ **Actors:** Global petrochemical suppliers (like BASF, Dow and Sabic)
- ✧ **Activities:** Extraction of fossil-based feedstocks (oil, natural gas) and production of PU foams, PVC or PU coatings, polyester textiles, aluminum alloys, and composite resins.
- ✧ **Implications:** High embodied carbon and chemical dependency; most materials are multi-layered and non-recyclable.

2. MATERIAL PRODUCTION

- ✧ **Actors:** Tier-2 material manufacturers (foam formers, textile weavers, coating and adhesive producers).
- ✧ **Activities:** Conversion into interior-ready raw materials: foam seat parts, woven or coated fabrics, and decorative laminates.
- ✧ **Implications:** Materials are engineered primarily for flammability compliance (CS-25.853) and durability, with limited consideration of end-of-life recovery.

3. ASSEMBLY AND AIRCRAFT INTEGRATION

- ✧ **Actors:** Seat manufacturers (e.g., Recaro, Safran), Embraer assembly teams, certification authorities.
- ✧ **Activities:** Assembly of seat structures, foams, and dress covers; installation during final aircraft assembly; verification under CS-25.853 and CS-25.562 crash worthiness standards.
- ✧ **Implications:** Modular attachment and reversible joining methods facilitate future disassembly; however, certification processes remain optimized for linear manufacturing models.

4. OPERATION, CLEANING, AND MAINTENANCE

- ✧ **Actors:** Airlines, MRO (Maintenance, Repair & Overhaul) providers, cleaning-chemical suppliers.
- ✧ **Activities:** Routine operation, cabin cleaning, inspection, and component replacement under airline maintenance programs.
- ✧ **Implications:** Cleaning agents and maintenance practices affect material lifespan and recyclability; partnerships with eco-certified cleaning suppliers extend durability (Bocken et al., 2016).

5. MID-LIFE REFURBISHMENT

- ✧ **Actors:** MRO facilities, cabin refurbishment specialists, leasing companies.
- ✧ **Activities:** Seat re-upholstery, re-foaming, and re-branding during aircraft maintenance; selective replacement of worn materials.
- ✧ **Implications:** Enables life extension of components and reduced waste; however, success depends on standardized or interchangeable components and systems, and accessible design documentation (AFRA, 2018).

6. END OF LIFE DISASSEMBLY & PART HARVESTING

- ✧ **Actors:** Airlines, seat OEMs, logistics providers, part brokers, AFRA-approved recyclers, part resellers, and OEM re-manufacturers.
- ✧ **Activities:** Seats are removed during cabin upgrades or aircraft phase-out. Components are collected, sorted, and either refurbished, recycled, resold, or harvested for reuse.
- ✧ **Implications:** Reverse logistics agreements and digital product passports (DPPs) support traceability and streamline circulation in secondary markets (EASA, 2023). Quality assurance and certification processes are critical to maintain material value and enable the reuse of parts, especially metals (AFRA, 2018).

7. RECYCLING AND BIOLOGICAL VALORISATION

- ✧ **Actors:** Specialized recyclers for polymers, textiles, and composites; bio processing and composting partners.
- ✧ **Activities:** Mechanical and chemical recycling of (mono-material) components such as foams, fabrics, and plastics; recovery of polymer feedstocks; controlled biodegradation or enzymatic conversion of nanocellulose foams into bio-based feedstock or soil conditioners.
- ✧ **Implications:** Combining technical and biological loops maximizes value retention. Effective separation, compatible coatings, and bio-safe flame retardants enable high-quality recycling and safe nutrient return within the bio-economy (Cherrington et al., 2022; Ellen MacArthur Foundation, 2015).

8. DATA TRACEABILITY AND CIRCULAR GOVERNANCE

- ✧ **Actors:** Digital product passport providers, regulatory bodies, OEM sustainability teams.
 - ✧ **Activities:** Tracking of material origin, maintenance history, and end-of-life routes through DPP systems integrated across the aviation supply chain.
 - ✧ **Implications:** Ensures transparency, compliance, and continuous improvement; enables accountability and data-driven circularity at fleet level (EASA, 2023).
-

2.7. MATERIALS

2.7.1. THE MATERIALS DRIVEN DESIGN METHOD (MDD)

The Material Driven Design method is a structured, experience-oriented approach that starts from a specific material and iteratively moves toward applications that elicit targeted material experiences. As depicted in Figure 1 “Material Driven Design (MDD) method,” the process cycles through four action steps, explained below. In this thesis I will mainly focus on steps 2, 3 and 4. MDD purposefully supports co-evolution of materials and artefacts through iterative loops, uses material probes and benchmarking to couple laboratory measurements with user-focused insights, and provides a common language for teams to translate experiential intentions into design decisions with clear traceability from material qualities to application concepts (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015).

Step 1 ☀ Understanding the material, technical and experiential characterization

This step couples data oriented analysis with experiential profile development of the material, see Figure 27 (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015). In this thesis, materials currently used in the KLM Cityhopper, emerging materials and BC foam will be screened for density, stiffness and recovery, compression set, durability, thermal and acoustic behavior, preliminary flammability, and compatibility with upholstery stacks and adhesives, while sensorial probes with passengers elicit perceptual, affective, and action related qualities using the Materials Experience dimensions where relevant (Giaccardi & Karana, 2015).

Step 2 ☀ Creating a materials experience vision

Insights are translated into a concise experiential intention that specifies meanings, emotions, sensorial cues, and action possibilities in context (Karana et al., 2015). For the Embraer 195 E2, a class specific vision will target specific experiences in short haul use, expressed as testable attributes with measurable variables, structured by the Materials Experience framework (Giaccardi & Karana, 2015).

Step 3 ☀ Manifesting materials experience patterns

Concrete patterns are identified and prototyped, that is, repeatable couplings of properties, processing, and form factors that elicit the intended experience, which operationalizes the vision into design action (Karana et al., 2015). Pattern exploration will include foam material color, texture pattern and material pattern like micro embossing, grain and gloss pairings.

Step 4 ☀ Designing material or product concepts

The process culminates in concepts that integrate validated patterns and, where needed, adjust the material itself, enabling co-evolution of the material and the product (Karana et al., 2015). Concepts will be developed for the two aircraft seats that combine bacterial nanocellulose foam with surface CMF design, creating a more sustainable overall interior and CMF design for the Embraer 195 E2.

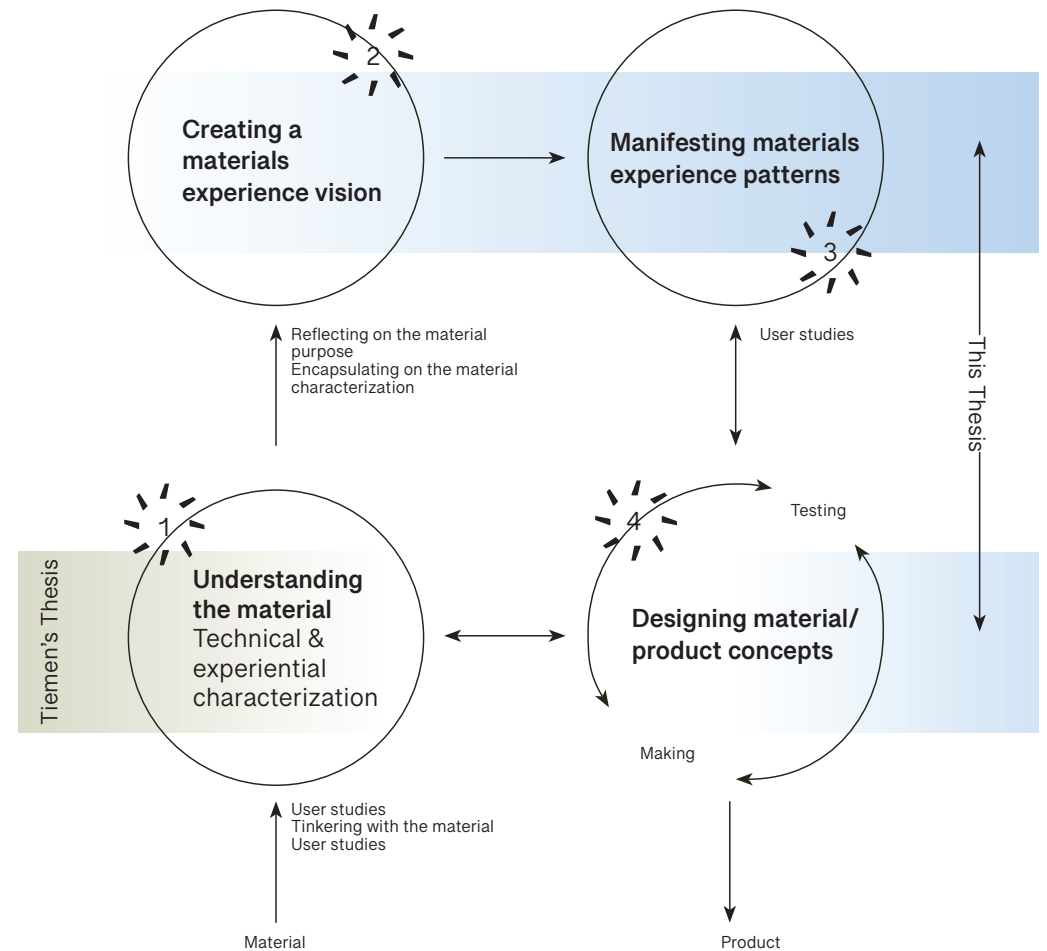


Figure 27: Material Driven Design Method (MDD)
Adapted from Material Driven Design Method (Karana et al., 2015)

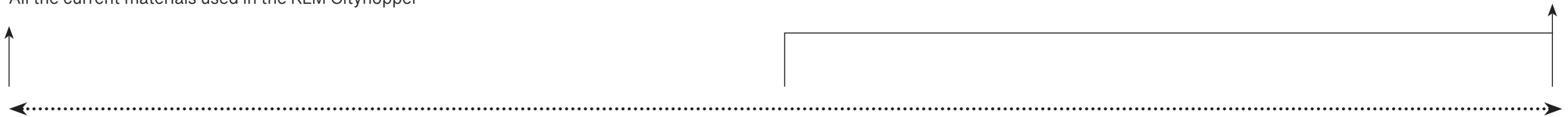
This thesis engages with emerging materials that aligns with MDD's Scenario 2 and 3: relatively unknown materials and material proposals whose properties are further defined through design. MDD is valuable here because it integrates technical and experiential characterization early, guides the formulation of a materials-experience vision for the aircraft cabin context, and structures an iterative design process from exploratory samples to application-ready concepts that, in turn, inform continued material development. In regulated, performance-critical domains such as aviation, this traceable, evidence-based progression helps align experiential goals with strict requirements. (Karana et al., 2015). This is especially helpful in the context and validation of this concept design project.



CURRENT DESIGN

All the current materials used in the KLM Cityhopper

NEW DESIGN
Materials in my new KLM Cityhopper CMF Design.



SCENARIO 1

Well known material

Use a familiar, fully developed material to challenge its settled meanings by placing it in new applications that elicit fresh user experiences.

SCENARIO 2

Relatively unknown material

Use a fully developed but unfamiliar material to define its identity through application choices that introduce new meanings and unique experiences.

SCENARIO 3

Material proposal

Use a semi-developed material whose properties, applications, and meanings co-evolve during design, generating feedback for further materials development.

2.7.2.

MATERIALS EXPERIENCE FRAMEWORK

Figure 28 explains materials experience as a dynamic field bounded by three attractors, people, materials, and practices, with each edge named for the dominant relation at stake. Encounters foreground how people meet and make sense of materials in concrete situations, for example first touch, visual appraisal, and acoustic cues. Performances foreground the passing of practices through products and materials, for example seating, stowing, cleaning, and walking. Collaborations foreground how materials participate in and condition practices through processing routes, maintenance regimes, repair and refurbishment, and life cycle arrangements. The dashed arrows inside the field indicate that experience unfolds along shifting trajectories among these relations rather than in a fixed sequence, meaning a situation can stretch the field toward one relation and then reconfigure toward another as activities progress. The graphic therefore makes two claims explicit, there is no hierarchy among the three entities, and experience is situated and emergent from their mutual shaping over time. In this thesis the figure guides CMF decisions at multiple moments of use. (Giaccardi & Karana, 2015).

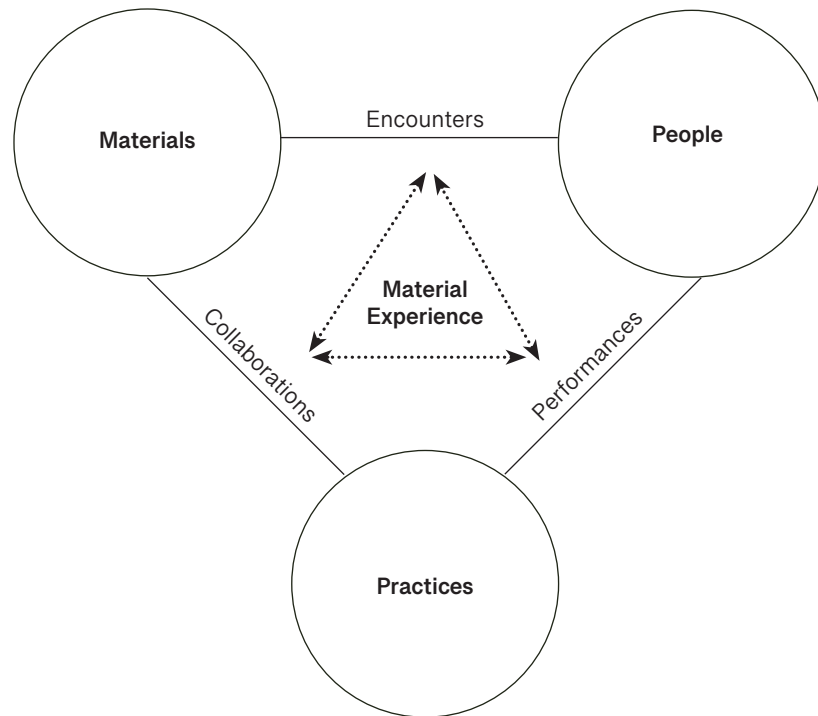


Figure 28: Materials Experience Framework
Source: Adapted from Giaccardi & Karana (2015).

SENSORIAL

Concerns what is perceived through vision, touch, audition, and temperature. In the cabin this includes color under LED lighting, gloss and texture on sidewalls and tray tables, the thermal feel and compliance of foams, and acoustic absorption of carpets and panels. This thesis specifies targets and proxies such as color coordinates, gloss units, roughness ranges, contact temperature and recovery, and compression feel for CMF specifications on the Embraer 195-E2 (Giaccardi & Karana, 2015).

PERFORMATIVE

Concerns what materials allow people to do, for example micro-posture changes, grip and release on handles, rapid cleaning between turns, and refurbishment. Performance requirements include low friction entry into the seat, sufficient grip for headrest adjustment, quick galley wipe-down, and modular replaceability of trim for circularity. Candidate patterns include foam density gradients for gentle yield, micro-grain embosses for dry-soft tactility, and non-textile flooring lay-ups for fast cleanability, evaluated through brief task-based probes with passengers and crew where feasible (Giaccardi & Karana, 2015).

EXPERIENTIAL LAYERS (Giaccardi & Karana, 2015).

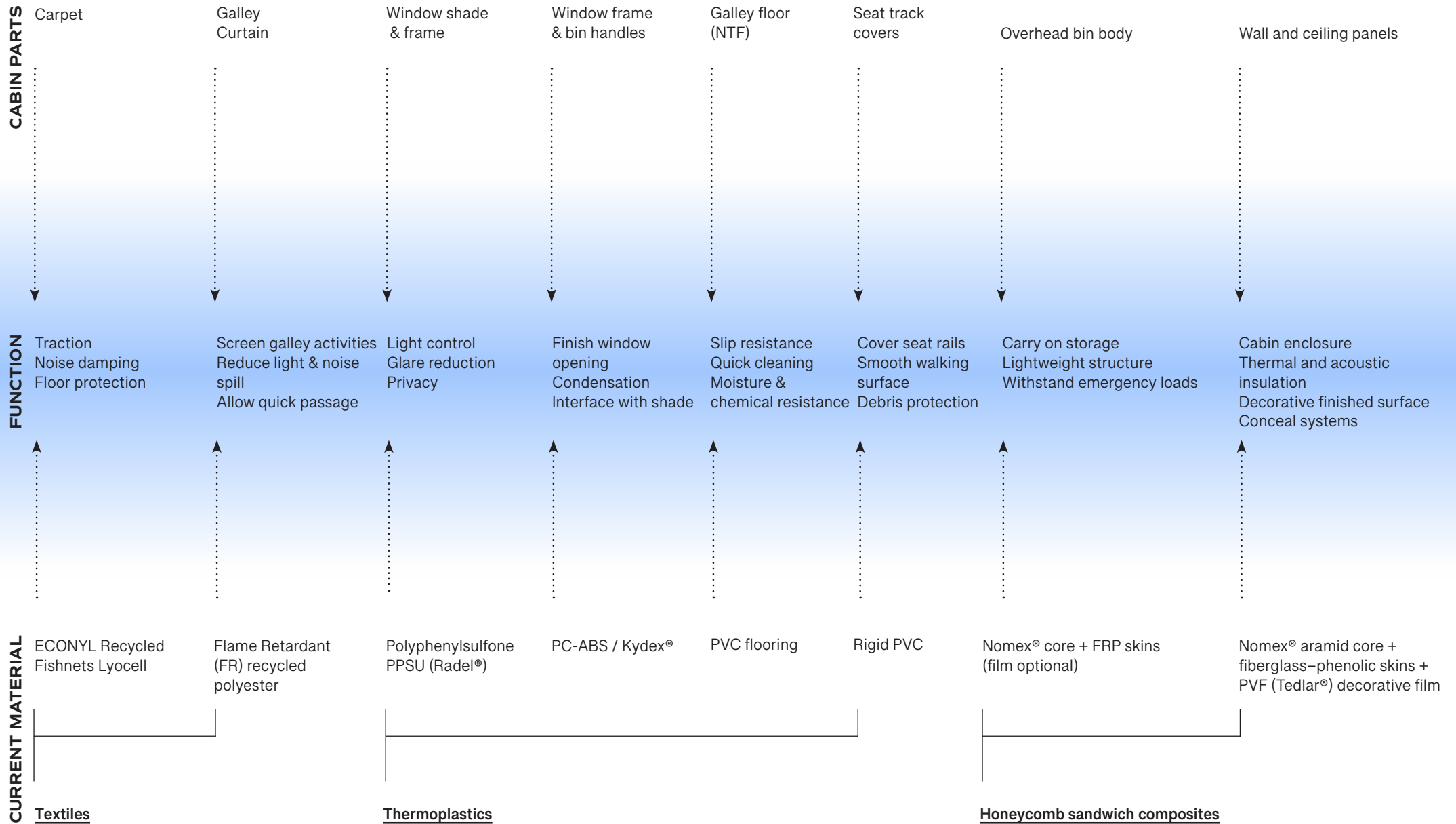
AFFECTIVE

Captures felt responses such as reassurance, calm, or discomfort. These intentions become criteria, for example reducing perceived stickiness on armrests, increasing trust in hygiene with low gloss low soil finishes on high touch parts, and creating a headrest contact that supports a calm settling moment after boarding. Appraisal uses concise valence-arousal reports and brief experience sampling during seat try-outs (Giaccardi & Karana, 2015).

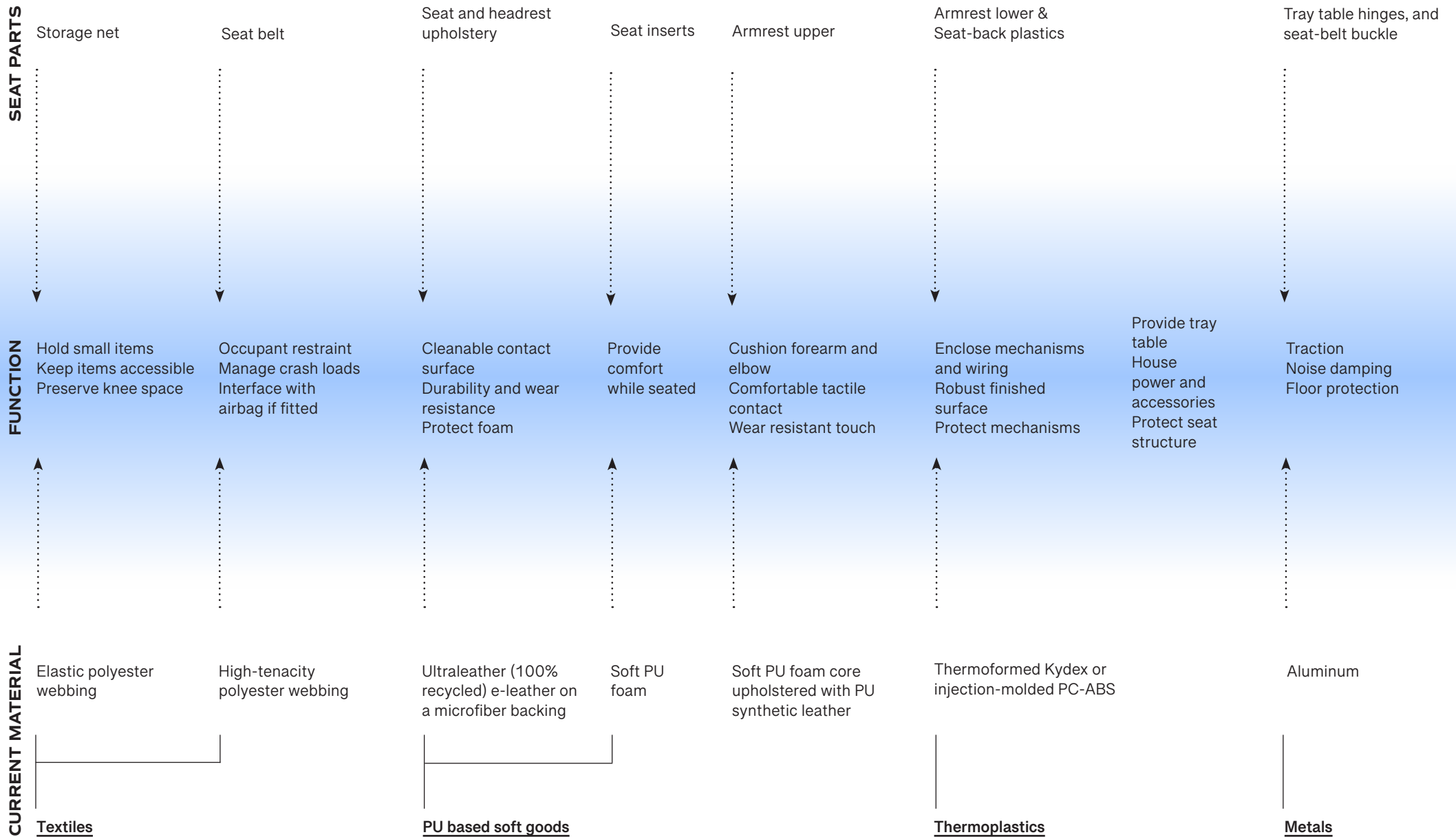
INTERPRETIVE

Addresses meanings attributed to materials, for example modern, clean, trustworthy, natural, or premium. Meanings are context dependent and may vary by class or route. Class specific intentions are linked to CMF choices, for example warm professional tones in Business, restorative uncluttered cues in Economy Comfort, and resilient welcoming cues in Economy, evaluated through wording ladders, semantic differentials, and short elicitation sessions with representative travelers (Giaccardi & Karana, 2015).

2.7.3.A
KLM CITYHOPPER MATERIAL TAXONOMY
CABIN PARTS



2.8.3.B
KLM CITYHOPPER MATERIAL TAXONOMY
SEAT PARTS



2.7.4. REFURBISHMENT FREQUENCY

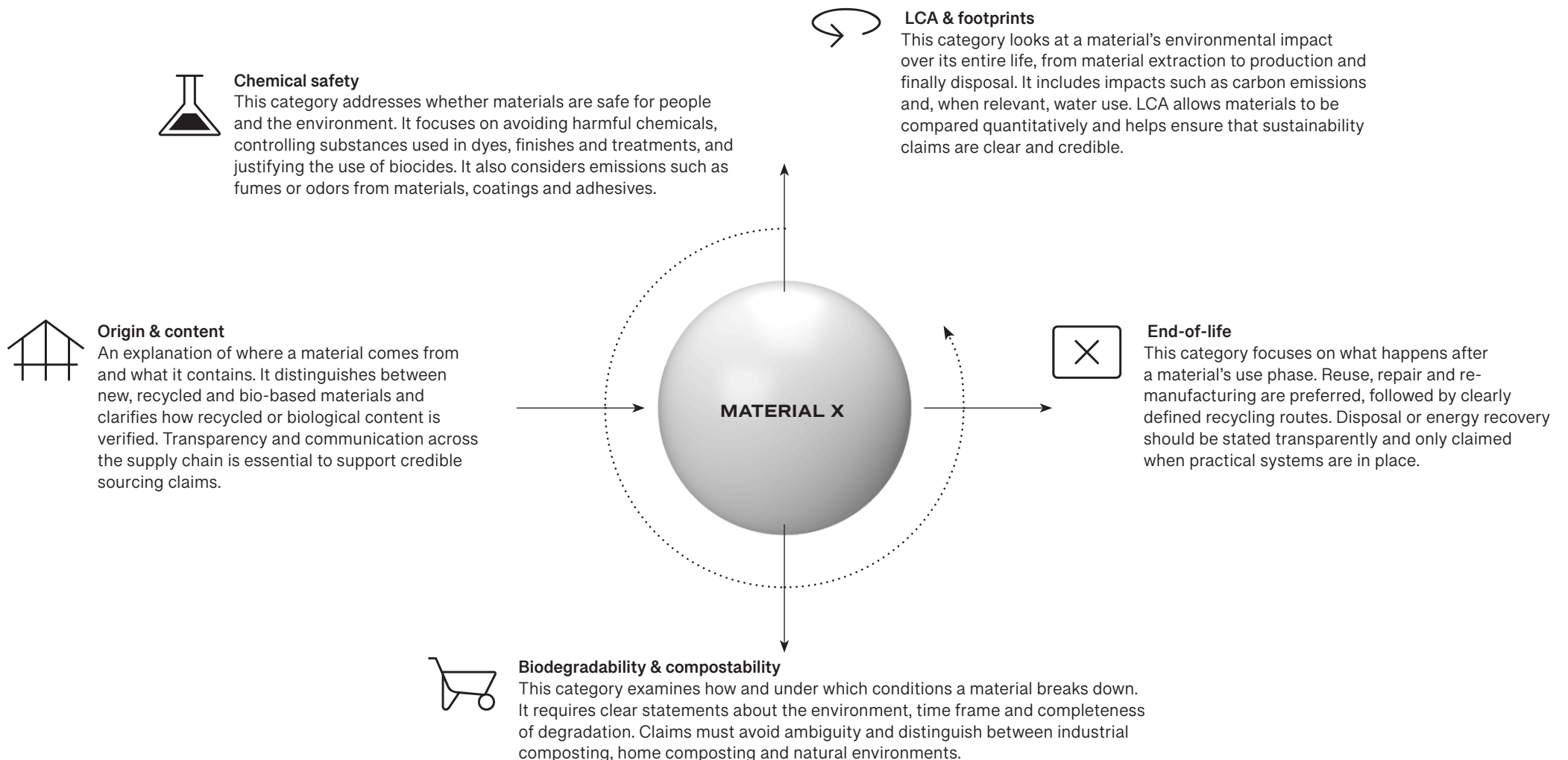
The “Refurbishment Frequency Pyramid” illustrates cabin components in a hierarchy from those needing the most frequent replacement at the top to those rarely replaced at the base. The positioning reflects both how often an item is refurbished and how prone it is to wear or failure, based on industry data and literature (Aircraft Commerce, 2010; Germak & Gabbatore, 2022).



2.7.5 SUSTAINABILITY CLASSIFICATIONS

Sustainability classifications provide a shared, standards-based language that enables sustainability claims to be specific, verifiable and comparable across alternatives. The International Organization for Standardization (ISO) develops internationally agreed standards that structure such classifications across multiple sustainability dimensions. In this thesis, sustainability classifications were analyzed and grouped into five themes, visualized below. (ISO, 2006, 2014, 2016, 2018).

Based on this analysis, the decision was made to focus on the LCA and footprint perspective in this thesis, as this dimension aligns most closely with the project scope, is strongly supported by relevant academic literature (see paragraph 4.2.3.), and allows for quantitative comparison using available and reliable data, that is available at both Embraer and Foamlab. The other sustainability classifications are explicitly acknowledged as relevant and interdependent but fall outside the primary analytical focus of this thesis.



2.7.6. CURRENT MATERIAL INNOVATIONS

This section outlines relevant bio-based, recycled, and circular materials currently entering or forecasted to impact sustainable material innovations, categorized by four different domains:

Foams

- ✧ Algae-based foams: renewable and antimicrobial with low weight and biodegradability, but still under development for mechanical durability and fire, smoke and toxicity compliance, with expected aviation readiness within the next decade (Airbus, 2022; NatureWorks, 2023).
- ✧ Cellulose-based biodegradable foam (Zouch Converters): a fully bio-based, lightweight cushioning foam developed for packaging applications, with potential relevance for aviation seating if durability and fire, smoke and toxicity requirements can be met (Zouch Converters, 2025).
- ✧ Soy-based PU and recycled polyester foams: partially or fully bio-based or recycled foams already used in automotive seating, offering recyclability and significantly reduced life-cycle emissions. (Forvia, 2023; Magna, 2024).
- ✧ Recycled PU foams from post-consumer mattresses: demonstrate circular reuse of existing foam streams and compatibility with aviation standards, enabling integration into next-generation short-haul aircraft seating (Recaro Aircraft Seating, 2024).
- ✧ Cork-based foam layers: lightweight, fully bio-based and naturally antimicrobial and fire-retardant, requiring binders for complex shaping but well aligned with aviation hygiene and tactile requirements (Busquets et al., 2021).

Weight performance: several alternative foam systems achieve 10–20% weight reduction compared to conventional petrochemical PU foams (Airbus, 2022; Forvia, 2023).

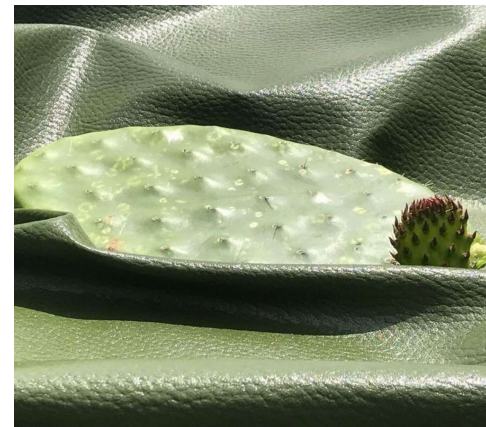
Upholstery & textiles

- ✧ Upcycled leather composites: produced from recycled tannery waste using water-based processes, durable and up to 40% lighter than virgin leather (Gen Phoenix, 2024).
- ✧ Mono-material recyclable seat textiles: fully recyclable seat covers combining recycled content and bio-based coatings, enabling closed-loop re-manufacturing without quality loss (Gen Phoenix, 2024).
- ✧ Plant-based leather alternatives: materials derived from pineapple, cactus, grape skins and mycelium with strong sustainability and aesthetic appeal, but currently lacking aviation-grade abrasion resistance and fire performance, positioning them as mid-term candidates (Montalti, 2023).
- ✧ Wool-based textiles and blends: naturally flame-retardant, tactile and biodegradable, with recycled synthetic blends improving durability while reducing reliance on fossil-based plastics (Cabin Interiors International, 2024).
- ✧ Naturally antimicrobial textiles: cork- and algae-infused fabrics provide microbial resistance without chemical additives, increasingly valued in post-pandemic cabin design (Busquets et al., 2021; NatureWorks, 2023).

Figure 29: Zouch Converters water dissolvable biodegradable foam packaging.
Source: Zouch Converters Ltd. (n.d.).



Figure 30: Cactus-based leather alternative.
Source: Desserto (n.d.).



Panels

- ✧ Flax fiber composites: engineered bio-composites achieving approximately 20% weight reduction while meeting aviation fire safety requirements for interior panels (Bcomp, 2024).
- ✧ Bamboo-based sandwich panels: woven bamboo skins combined with fire-safe resin systems and lightweight cores, achieving up to 50% weight reduction and compliance with aviation flammability standards (VESO, 2023).
- ✧ Multi-fiber bio-composites: composite systems using natural fibers and bio-resins that demonstrate acceptable smoke and heat-release performance when flame-retardant treated, suitable for panels and tray tables (ECO-COMPASS Consortium, 2019).



Figure 31: Flax fiber composite panel
Source: Bcomp (n.d.).



Figure 32: Bamboo-based sandwich panel material. Source: Vescom (n.d.).

EXPERIMENTAL BIODESIGN

- ✧ Mycelium-based composites: grown from agricultural waste and shaped directly in molds, with improved fire performance through mineral and bio-based treatments, but not yet certification-ready, offering long-term potential for panels and acoustic components (TU Delft, 2024).
- ✧ Recycled carbon fiber composites: derived from manufacturing waste and tested for lightweight interior panels, enabling circular use of high-performance composite materials (Boeing, 2023).
- ✧ Recyclable thermoplastics (PEEK, PEI): increasingly adopted in trays and fittings to enable disassembly, reshaping and recycling at end-of-life, supporting circular interior design strategies (Sekisui Kydex, 2024).



Figure 33: Mycelium-based grown sheet material Source: Mogu (n.d.).



Figure 34: Mycelium composite block. Source: Ecovative (n.d.).

2.7.7.

BACTERIAL CELLULOSE (BC)

Bacterial cellulose (BC) is a bio-based polymer produced by specific microorganisms that synthesize cellulose fibers during fermentation. Cellulose itself is a natural carbohydrate polymer that forms the structural backbone of plant cell walls, where many individual chains bundle together into strong microfibrils. In bacterial cellulose, the same polymer is produced without the additional components found in plants, such as lignin and hemicellulose. As a result, BC exhibits a highly pure and uniform three-dimensional fiber network, giving it significant mechanical strength and high water-holding capacity.

During production, bacterial cellulose forms as a hydrated gel that can be shaped, molded, or layered while wet and subsequently dried into lightweight films, mats, or foam-like structures. Its microstructure can be tuned through processing, allowing control over density, stiffness, and surface texture. BC can also be three-dimensionally molded and combined with other bio-based materials through lamination or coating, enabling its use across diverse applications including biomedical products, food packaging and textiles. These characteristics make BC particularly relevant for aircraft interiors, where low weight, material consistency, and design flexibility are of great importance (Girard et al., 2024; Panahi-Sarmad et al., 2024).

From a sustainability perspective, bacterial cellulose is fully bio-based and can be produced from low-value or residual sugar streams, such as sugarcane molasses, which supports a sustainable origin and content profile. In terms of chemical safety, the base material is inherently non-toxic and produced without hazardous solvents, although additional treatments for water resistance or fire performance could potentially introduce chemicals that require careful selection. Bacterial cellulose is inherently biodegradable, but actual biodegradability and compostability depend on the additives and laminations applied to the material variant. At end-of-life, the material offers potential for biological degradation or material recovery when used in mono-material or separable constructions. Finally, its LCA and environmental footprint are primarily driven by feedstock choice and energy consumption during fermentation and drying. Using side streams and renewable energy can substantially reduce impacts, while finishing steps for potential aviation compliance increase the overall footprint and must be considered in a full life-cycle assessment (Zhong, 2020; Forte et al., 2021; Silva et al., 2025).



Figure 35: nanoscale fibrous network of bacterial cellulose
Source: Foamlab (2025).

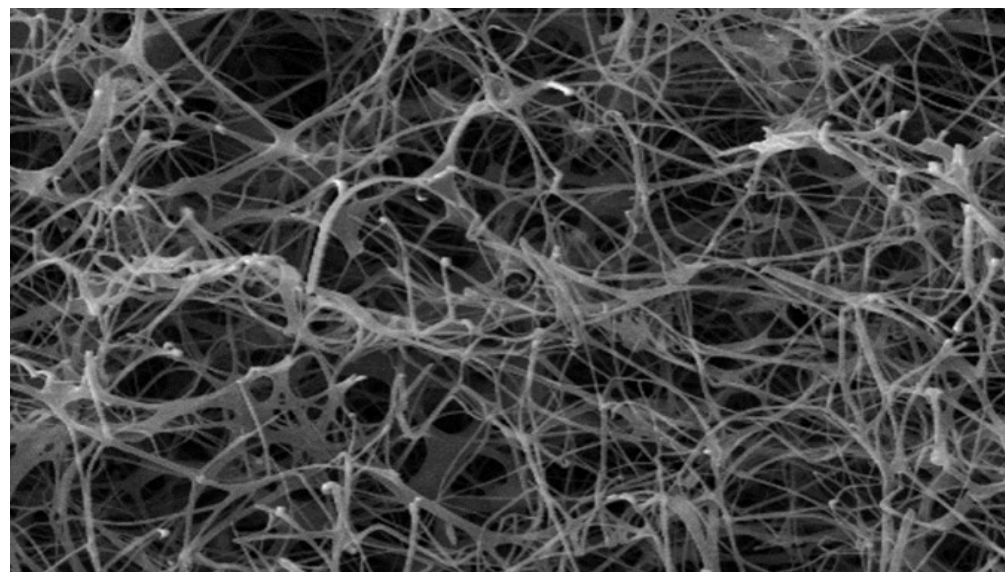


Figure 36: Nanoscale fibrous network of bacterial cellulose.
Source: Jonas et al., (1998)

BC process



1. Mixing

Inoculation
The process starts by mixing the specialized bacteria with the nutrient-rich sugar growth medium.



2. Growth

The mixture is incubated at a controlled temperature to allow the bacteria to synthesize a thick mat of cellulose nanofibers.



3. Harvesting

The resulting wet, gelatinous mat, called the BC pellicle, is harvested and purified by washing to remove the remaining bacteria and media.



4. Processing & finishing

The harvested cellulose is then shaped and processed to achieve the final desired material form.

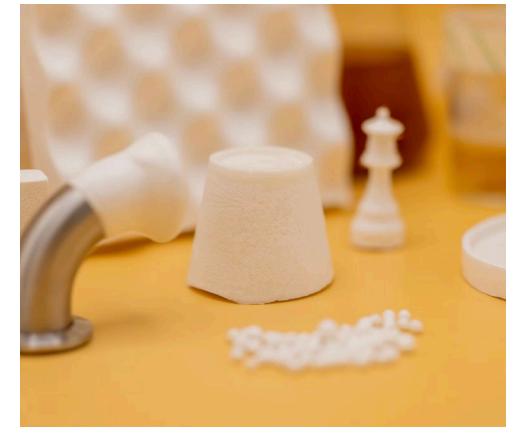


Figure 37: laboratory inoculation and culture preparation, controlled BC growth, pellicle harvesting and shaping into functional material forms.
Source: Nexio Projects (n.d.), BMS (n.d.), University of Exeter (n.d.), Foamlab (2025).

Material

Hard

Soft



Source: Author.

ABS like plastic - Sample 4

- ✦ Rigid
- ✦ Smooth surface
- ✦ Impact- and water resistant
- ✦ Dimensionally stable

Hard structural foam - Sample 1

- ✦ Lightweight
- ✦ Load-bearing
- ✦ Stiff
- ✦ Low compressibility

Leather alternative - Sample 3

- ✦ Soft-touch
- ✦ Flexible
- ✦ Thin
- ✦ Textured surface

Upholstery foam - Sample 2

- ✦ Compressible
- ✦ Resilient
- ✦ Pressure distribution
- ✦ Elastic recovery



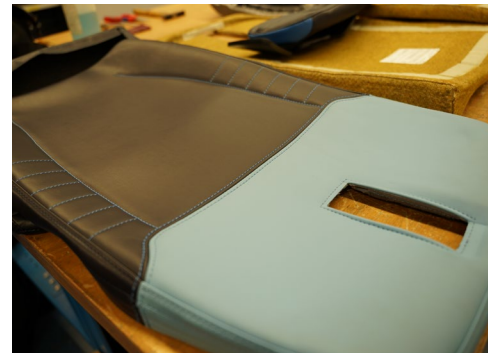
Application



Seat shell and tray table
Source: Author.



Seat pan core



Seat upholstery



Seat cushioning

*Disclaimer
Samples 1 and 4 depict conceptual load-bearing applications and have not been validated. Extensive mechanical, durability, and certification testing would be required prior to implementation.

History and cultural context of Bacterial Cellulose

BC has been known to science for over a century. A.J. Brown first described a gelatinous cellulose film produced by vinegar bacteria in 1886, initially associated with the “mother of vinegar” and later confirmed as bacterial in origin (Bourgeois & Barja, 2009). Research remained limited until the mid-20th century, when Hestrin and Schramm’s defined medium enabled controlled study of BC production (Iguchi et al., 2000). Subsequent work identified practical fermentation challenges, including cellulose-negative mutants in agitated culture conditions (Steel & Walker, 1957). Interest increased substantially in the 1980s–1990s due to emerging medical and industrial applications and improvements in yield and production methods. Overall, BC evolved from a niche observation into a functional biomaterial through advances in cultivation control and growing application demand.

BC in different cultures:

BC has long been featured in food traditions. Nata de coco is produced by fermenting coconut water with cellulose-producing bacteria, forming a cellulose gel widely consumed in Southeast Asia. Kombucha fermentation similarly generates a cellulose pellicle (also known as scoby), which has been maintained and shared across regions as part of traditional brewing practices. Beyond food, BC has appeared in contemporary craft experimentation, for example “BC leather” concepts where microbial cellulose sheets are dried into leather-like films. These examples illustrate that BC has cultural familiarity beyond laboratory contexts, which may support its acceptability as an engineered material.



Source: Sergio Mazzei (n.d.).



Source: Foodandwine.com (n.d.).



Source: British Vogue (n.d.).



Source: Aiaia .audio (n.d.).

Biomedical

BC is widely explored and commercially used in wound dressings because it is conformable, maintains a moist environment, and can act as a protective barrier (Khan et al., 2023).

Food and nutrition

BC is established in foods such as nata de coco and is being investigated as a functional ingredient due to its fiber content and texturing capability, including potential uses as edible films and packaging.

Textiles and wearables

BC can be grown into non-woven sheets that resemble leather-like material when dried and treated. While scaling remains a barrier, these developments position BC as a candidate for animal-free, potentially low-impact textiles.

Electronics, and environmental engineering

BC composites have been explored for acoustic diaphragms due to stiffness-to-weight benefits. In electronics, BC is studied as a porous substrate, separator, or carbon template. In environmental contexts, BC membranes are investigated for filtration and adsorption applications, including wastewater treatment and pollutant capture.

Bacterial cellulose (BC) occupies a distinct position relative to adjacent material classes and innovations, which supports its selection for this research. Compared with plant-derived cellulose, BC is chemically identical but produced in a highly pure form with a nanoscale fiber morphology, resulting in dense networks and superior mechanical performance (Khan et al., 2023). While plant cellulose benefits from lower cost and large-scale availability, these advantages make it more suitable for commodity applications, whereas BC's controlled microstructure and performance justify its exploration in high-value, performance-critical contexts. In comparison with synthetic polymers and polyurethane (PU) foams, BC offers a fully bio-based origin and potential end-of-life advantages, aligning with circular material strategies. However, BC also presents challenges, including moisture sensitivity and limited industrial scale-up so far. Integration rely on controlled growth and post-processing rather than conventional molding routes. Relative to other emerging bio-based materials such as mycelium composites, BC enables finer micro-structural control and higher material purity, although alternative systems may offer faster bulk formation or inherently volumetric growth, suggesting that hybrid or complementary approaches remain an area of ongoing research.

Within this project, BC is therefore positioned as a candidate material for a more circular aircraft interior strategy, with the potential to reduce dependence on fossil-based foams and support a mono-material-oriented CMF narrative (Ferreira et al., 2016). Its tunability, purity, and ability to be produced as sheets or foam-like structures enable both functional cushioning and surface applications. At the same time, aviation deployment requires compliance with stringent requirements related to durability, maintenance, water repellency and fire safety, necessitating careful material development and validation pathways (Ferreira et al., 2016). The collaboration with Foamlab directly supports this process by combining expertise in bacterial cellulose development with design-driven application requirements, enabling iterative translation from laboratory-grown materials to application-informed prototypes. This approach aligns with material-driven design frameworks that emphasize the co-development of material properties, processing constraints, and user experience, rather than treating materials as passive inputs to design (Karana et al., 2015).



Source: Foamlab (2025).

2.8 DESIGN GOAL

Develop a three-class cabin-interior CMF design for the Embraer 195-E2 (KLM Cityhopper), that improves LCA performance by integrating different bacterial cellulose material variants, while maintaining or improving passenger experience relative to the current KLM Cityhopper cabin CMF design.



3

DESIGN



3.1 IDEATION

- 3.1.1. Product & material inspiration boards p. 73
- 3.1.2. Three class design overview p. 80
- 3.1.3. Brainstorm idea p. 82
- 3.1.4. Pattern design p. 83

3.2 THREE CLASS DESIGNS

- 3.2.1. CMF design framework p. 84
- 3.2.2. Economy class (Y-class) p. 88
- 3.2.3. Economy Comfort class (W-class) p. 100
- 3.2.4. Business class (J-class) p. 112

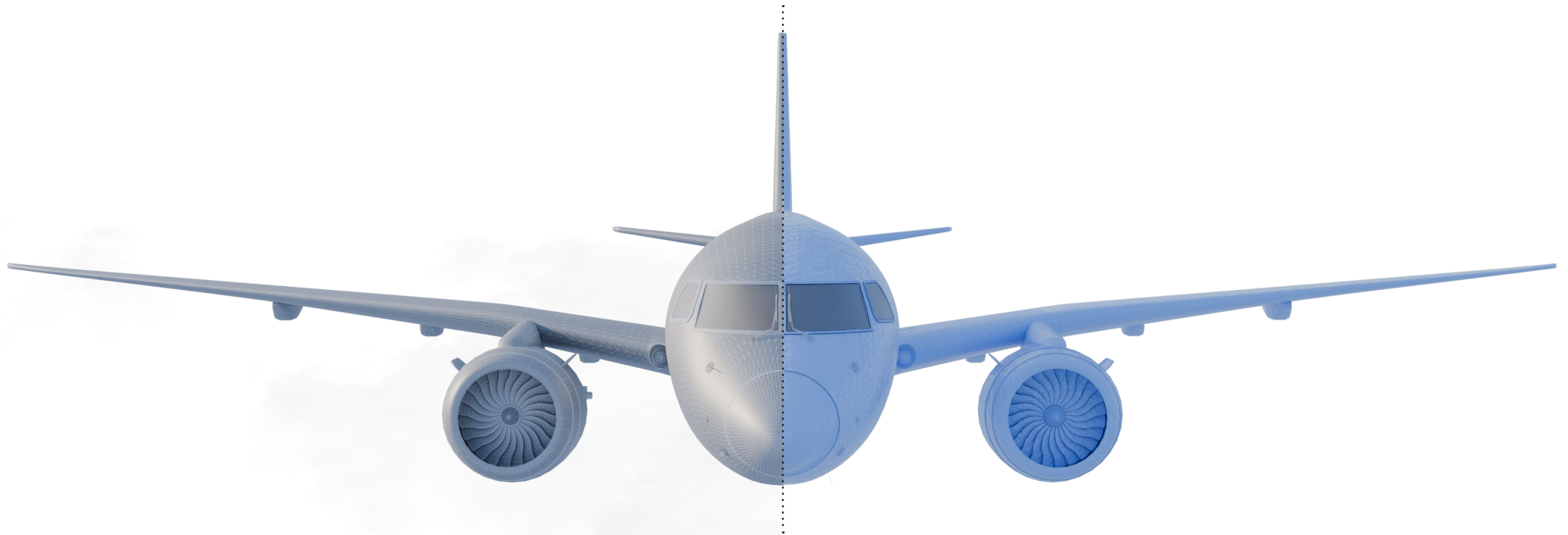
3.1 IDEATION

3.1.1. PRODUCT & MATERIAL INSPIRATION BOARDS

To guide the development of a coherent yet clearly differentiated CMF strategy across the three cabin classes, product and material inspiration boards were created for each class. These boards combine references from all kinds of industries and contexts, like product design, architecture, lifestyle, fashion, and material research to articulate the intended sensory, functional, and tactile qualities of each cabin environment. Rather than serving as aesthetic moodboards alone, they function as analytical CMF tools that translate abstract values such as comfort, cleanliness, premium perception, and calmness into tangible cues in color, material, texture, and finish.

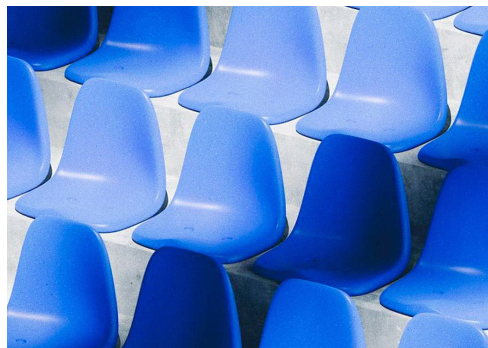
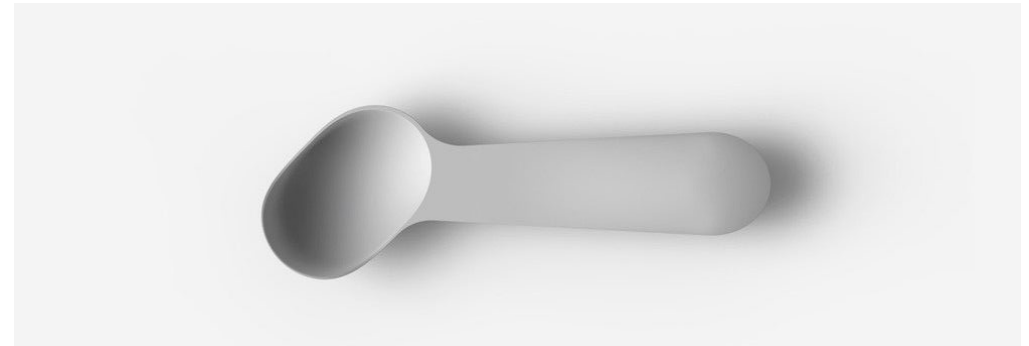
Within this thesis, the inspiration boards provide a visual overview of the intended CMF direction. They articulate the targeted material language and experiential qualities for each cabin class. Separating product inspiration from material inspiration allows for greater design freedom by enabling products and materials to be considered independently, and by opening opportunities to apply materials to products in non-conventional ways, or vice versa.

The use of structured product and material inspiration boards is well established within CMF and material-driven design practice. In both academic research and industrial design processes, such boards are employed to externalise experiential intentions, align multidisciplinary teams, and reduce subjectivity in early-stage decision-making (Ashby & Johnson, 2014; Karana et al., 2015). In aviation and mobility design specifically, CMF inspiration frameworks are commonly used to communicate class hierarchy, brand positioning, and perceived quality (Manzini & Vezzoli, 2003; Vink et al., 2012). As such, the inspiration boards in this project provide a methodologically grounded foundation for the CMF cabin class concepts.



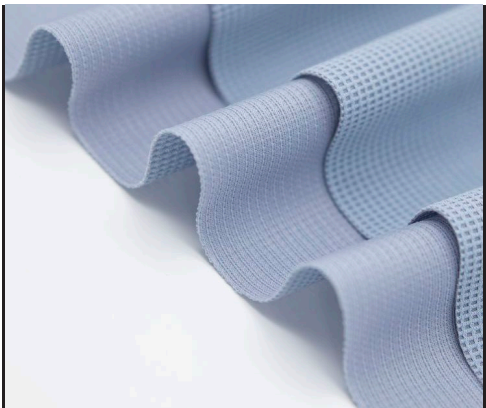
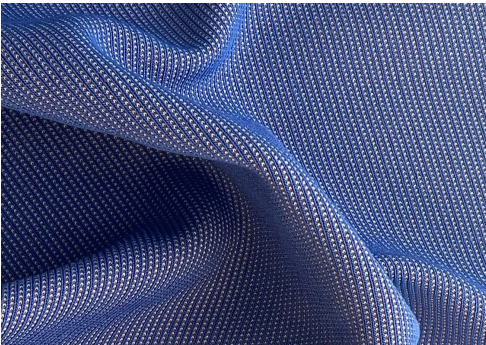
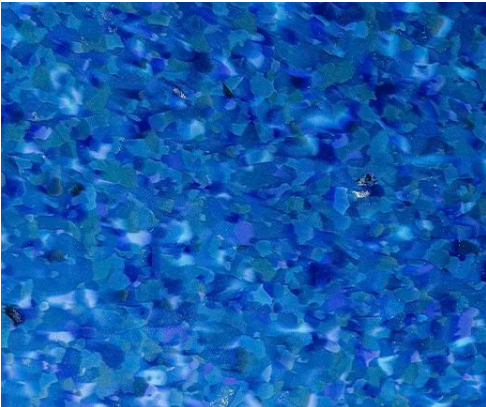
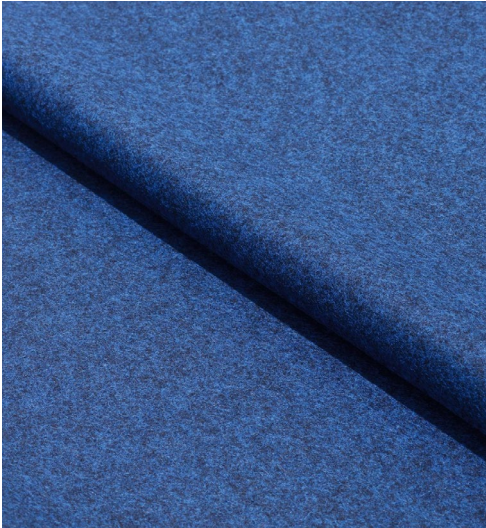
PRODUCT INSPIRATION

DELTA DISCOVERY ✨ Y-CLASS



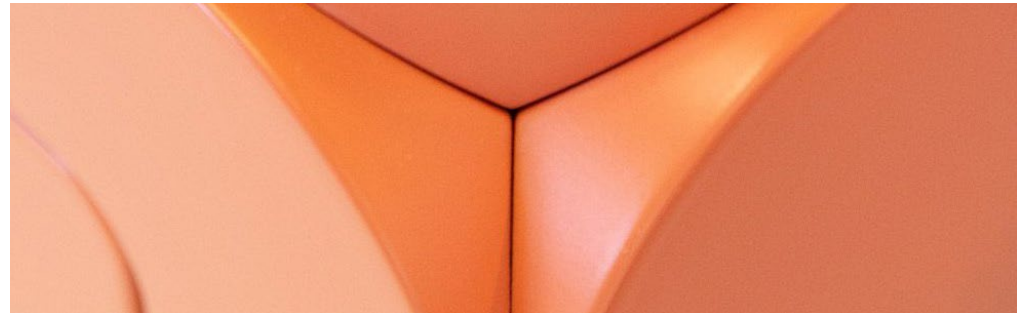
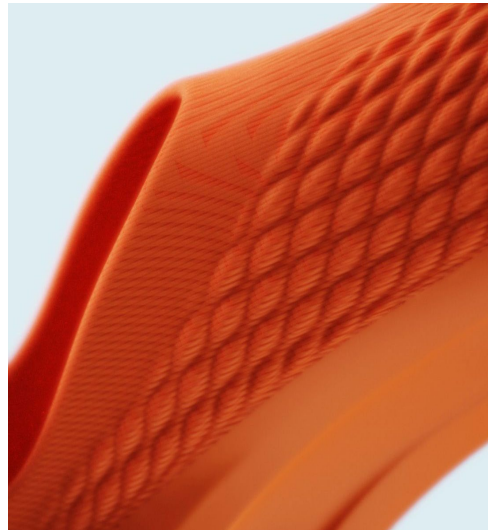
MATERIAL INSPIRATION

DELTA DISCOVERY ✨ Y-CLASS



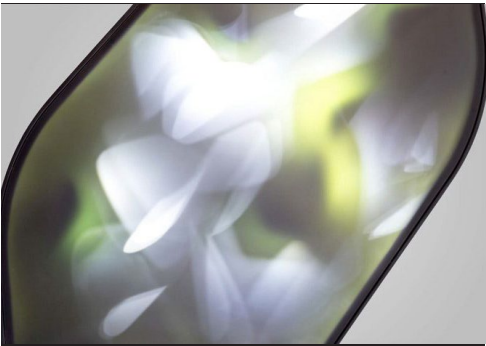
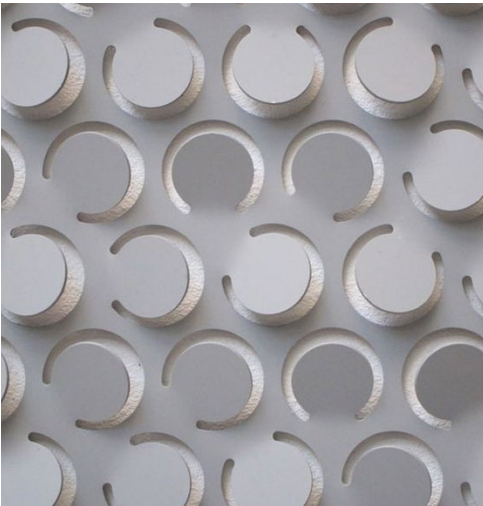
PRODUCT INSPIRATION

CROCUS COMFORT ✨ W-CLASS



MATERIAL INSPIRATION

CROCUS COMFORT ✨ W-CLASS



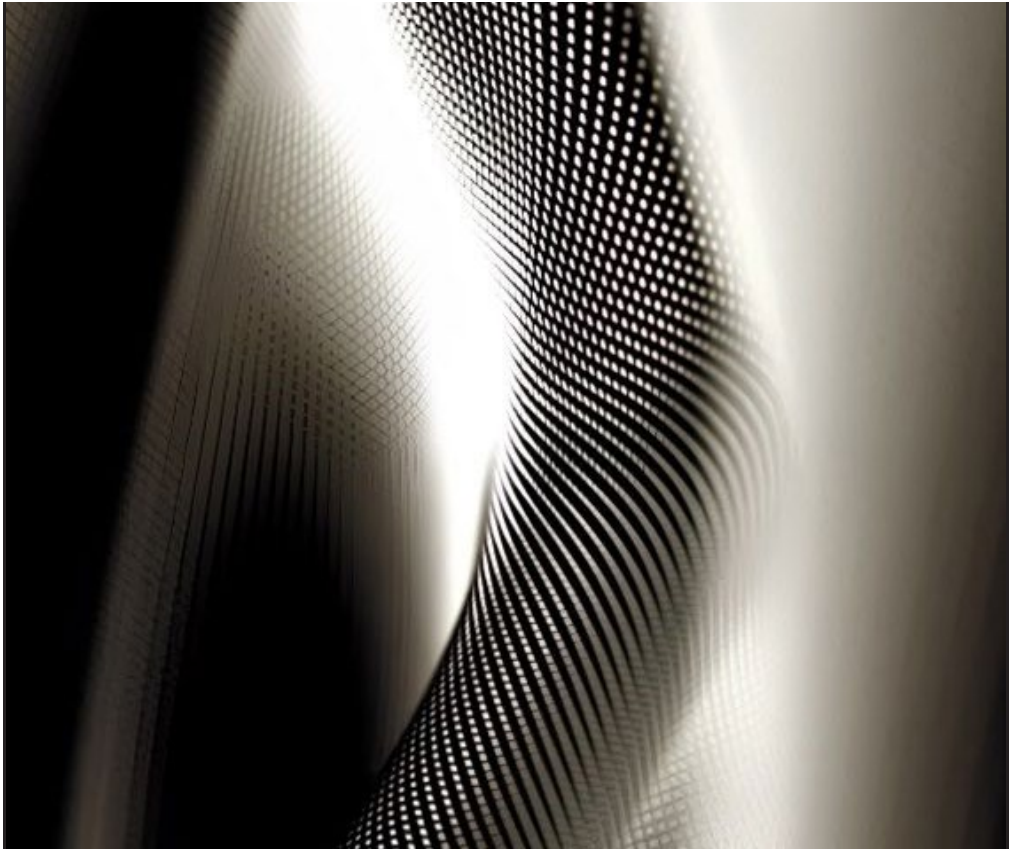
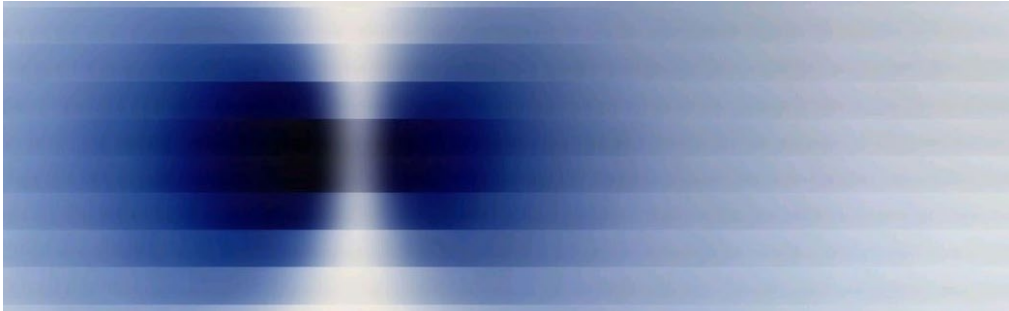
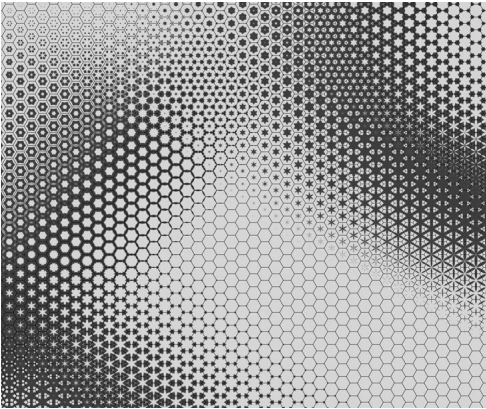
PRODUCT INSPIRATION

VERMEER VESPER ✨ J-CLASS



MATERIAL INSPIRATION

VERMEER VESPER ✨ J-CLASS



3.1.2. THREE CLASS DESIGN OVERVIEW

The class names emerged from an iterative creative process combining brainstorming, semantic clustering, and CMF grade-development practices commonly used in transportation design. Keywords related to cultural references, emotional tone and material character, were mapped and refined into coherent narratives, resulting in class identities that differentiate experiential intent while maintaining a unified CMF design language in line with the KLM brand throughout the cabin.

DELTA DISCOVERY

Y-CLASS ✨ ECONOMY CLASS

The name of this class evokes the energy of shared exploration, rooted in Dutch openness, directness and movement. The name suggests both place and mindset, discovery as a collective journey. The design invites collectivity, clarity, curiosity, and a grounded sense of freedom through universal materials and bold simplicity.



"PLAYFUL MIXING"

CROCUS COMFORT

W-CLASS ✨ ECONOMY COMFORT CLASS

Named after the crocus, one of the Netherlands' earliest spring flowers, this class embodies gentle renewal and tactile warmth. The orange crocus signals optimism, softness, and seasonal transition, mirroring the comfort and brightness this class offers.



"SYMBIOTIC GROWTH"

VERMEER VESPER

J-CLASS ✨ BUSINESS

The name of this class combines the quiet brilliance of Dutch painter Vincent Vermeer with the word vesper, meaning "evening star" or "twilight." The design reflects a moment of flow and focus. Symbolizing a refined, introspective space that supports calmness, privacy, confidence, and presence.

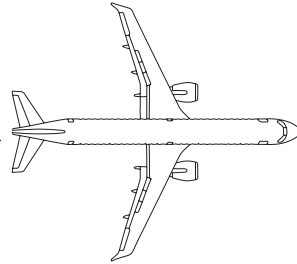


"QUIET HARVESTING"

Y-CLASS
ECONOMY

W-CLASS
ECONOMY COMFORT

J-CLASS
BUSINESS



Not so frequent flyer

Medium frequency flyer

Frequent flyer

Fast paced crew interaction

Medium paced crew interaction

Slow and personal crew interaction

Younger average passenger age

Medium average age

Older average passenger age

Excited, open to surprises

Modest outing

Need for predictability

Leaving home for adventure

In and around the house

Coming home in the plane because they fly so often

Group

Duo

Individual

Chatty

Whisper

Stillness and calm

Fun

Amusing

Serious

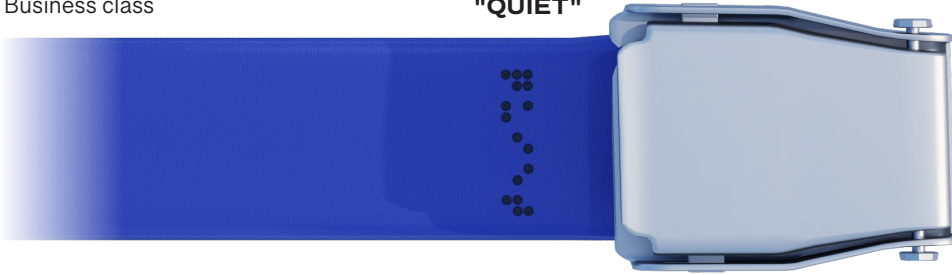
3.1.1. BRAINSTORM IDEA

A subtle design feature was developed to symbolically connect the two words of each class metaphor through the integration of Braille text on the seatbelt. Rather than applying the metaphor keywords explicitly, which was considered overly literal, the words Playful Mixing, Symbiotic Growth, and Quiet Harvesting are encoded in Braille as a tactile “easter egg” embedded within the seatbelt surface. This approach enables metaphorical expression without visual dominance, aligning with the overall CMF intent of understated storytelling.

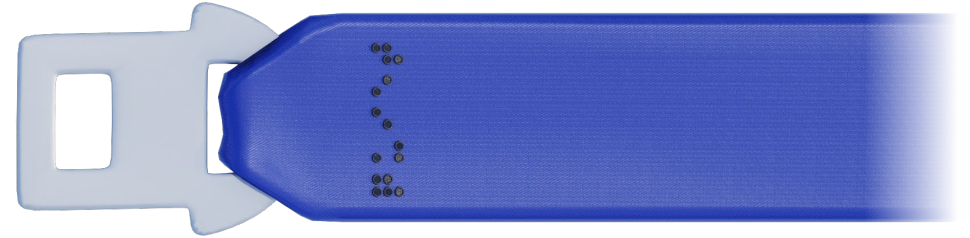
Beyond its symbolic function, the use of Braille reflects KLM’s brand values of inclusivity and accessibility by acknowledging passengers with visual impairments or blindness. The tactile detail invites engagement through touch rather than sight alone and introduces an inclusive layer of meaning that may also draw attention from sighted passengers through curiosity and discovery. As such, the feature operates simultaneously as a narrative connector, a sensory detail, and an inclusive design gesture within the cabin interior.

J-class
Business class

"QUIET"

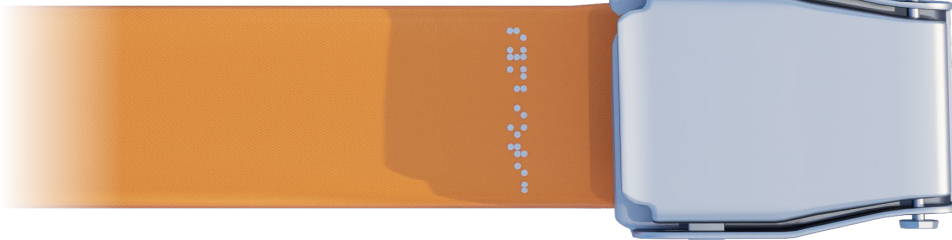


"HARVESTING"

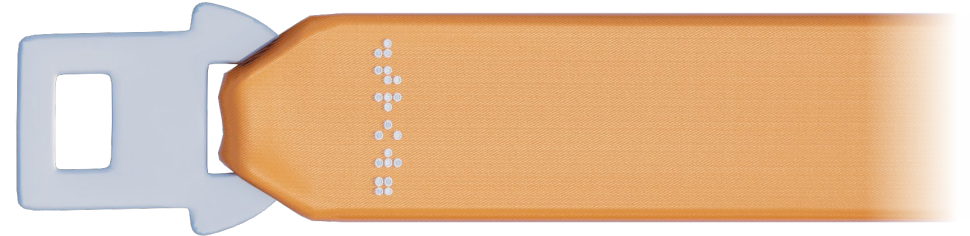


W-class
Economy comfort class

"SYMBIOTIC"



"GROWTH"

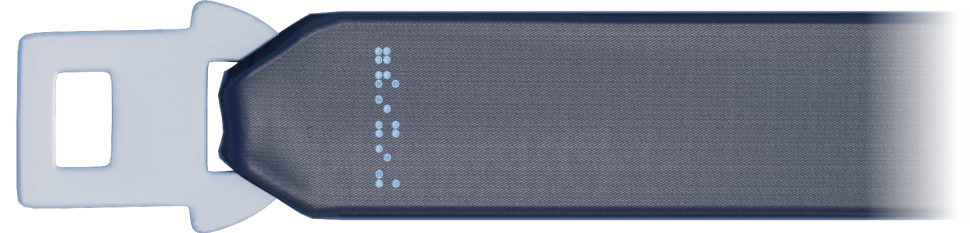


Y-class
Economy class

"PLAYFUL"



"MIXING"



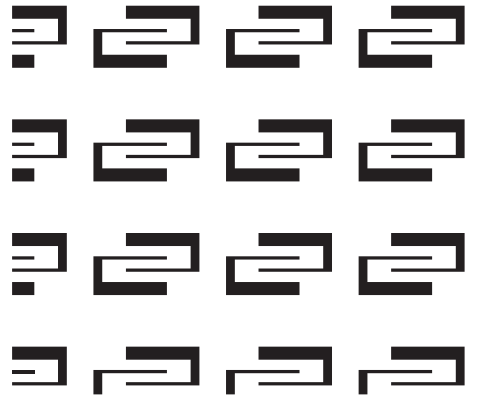


3.1.1. PATTERN DESIGN

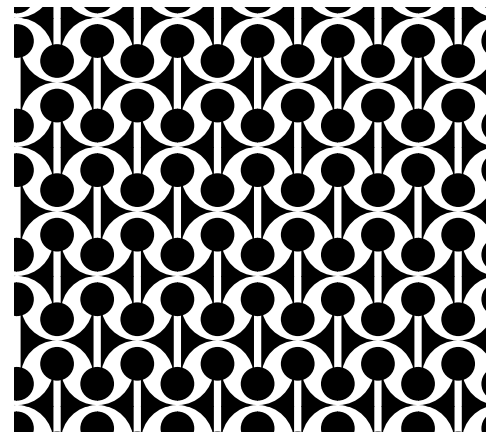
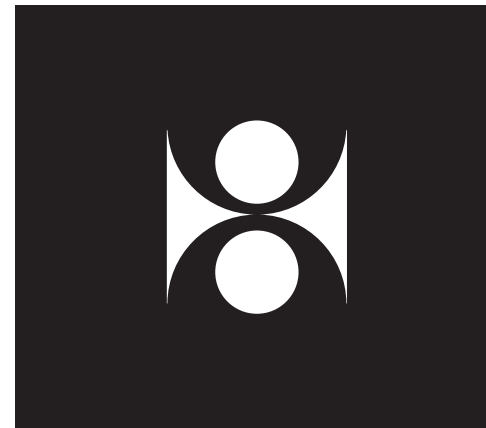
The surface patterns developed for each cabin class translate KLM's brand identity into a layered CMF narrative through abstraction and symbolism. The Economy (Y-class) pattern is constructed exclusively from linear elements, referencing the horizontal base of the KLM crown and expressing efficiency, structure, and repetition and high density layout in this cabin. Economy Comfort (W-class) builds on this foundation by introducing circular forms derived from the second tier of the KLM crown, signaling added softness, personal space, and a two parts coming together, in line with the story of this class (page 99) . The Business (J-class) pattern is based on the cross at the top of the crown, representing the highest level of service and exclusivity; its rounded geometry subtly evokes a windmill, reinforcing Dutch heritage and aligning with the class's moodboard and design vision (page 111). Together, these patterns demonstrate how symbolic form language in CMF design can communicate hierarchy, brand storytelling, and experiential differentiation beyond functional requirements.



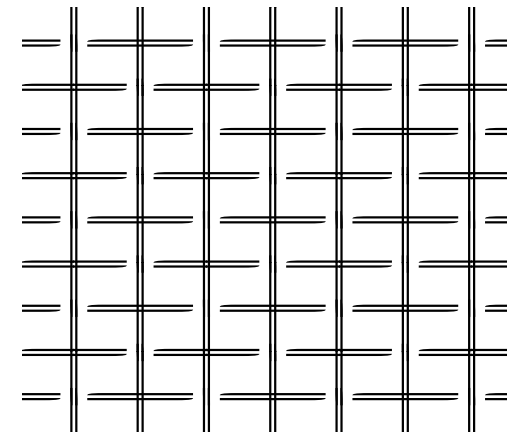
Y-CLASS
ECONOMY



W-CLASS
ECONOMY COMFORT

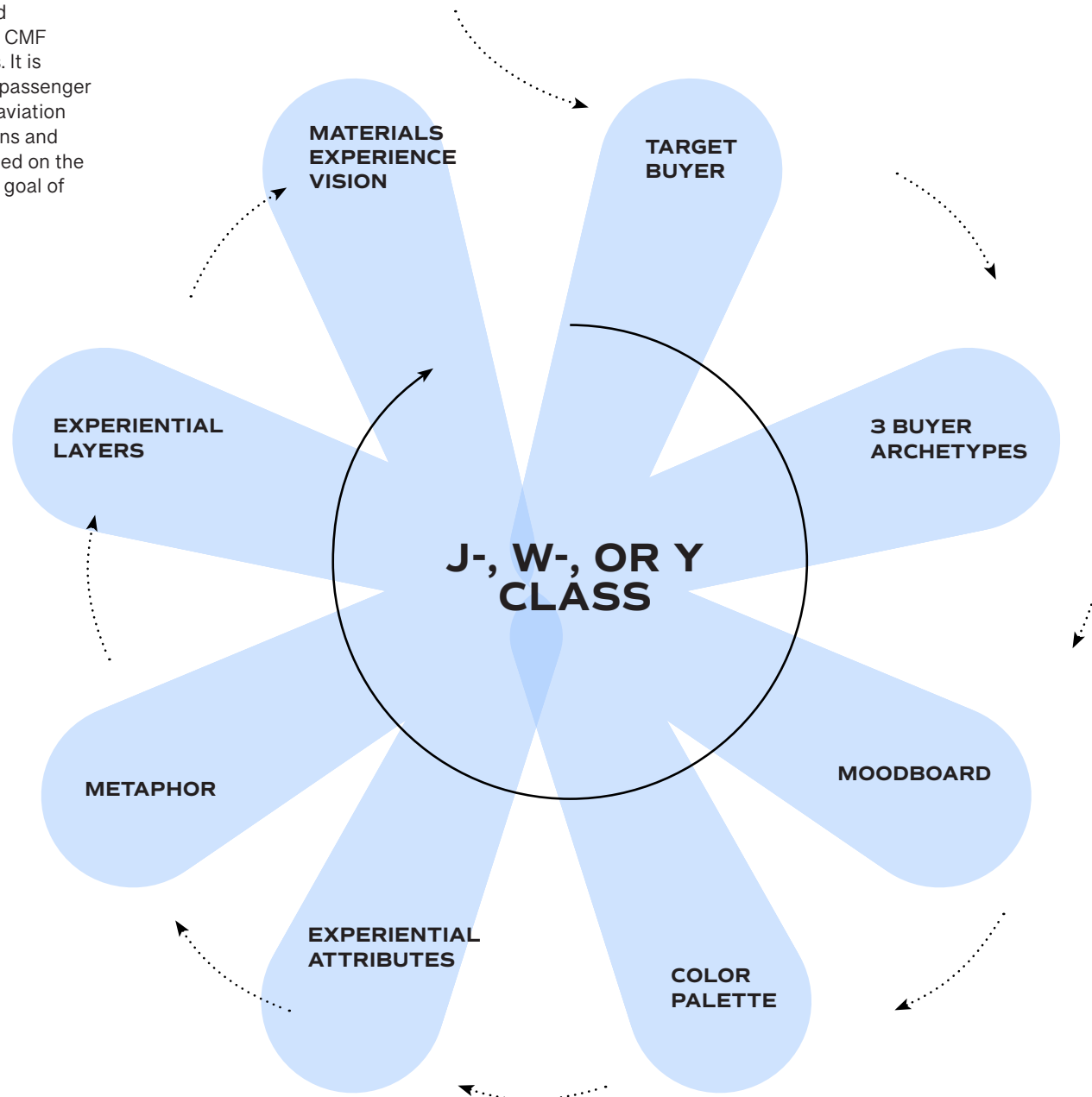


J-CLASS
BUSINESS



3.1.1. CMF DESIGN FRAMEWORK

This design framework was developed specifically for this thesis to structure CMF decision-making across cabin classes. It is informed by established literature on passenger experience, material perception, and aviation comfort, with the academic foundations and references for each component outlined on the following page, alongside the specific goal of each framework element.



Target buyer

Defining the target buyer anchors CMF decisions in real passenger expectations, constraints, and usage patterns. Passenger characteristics such as travel purpose, frequency, price sensitivity, and time pressure directly influence how materials are perceived and evaluated. Studies in aviation comfort indicate that perceived value and appropriateness of materials differ strongly between passenger segments (Vink & Brauer, 2011; Ahmadpour et al., 2014). A clear target buyer definition prevents misalignment between material expression and passenger needs.

Goal: ensure CMF choices match actual passenger contexts and expectations.

Buyer archetypes

The buyer archetypes were developed by synthesizing insights from CMF and passenger experience literature with qualitative findings from cabin crew and passenger interviews conducted in this thesis. Recurring behavioral patterns, expectations, and sensitivities toward comfort, wear, tactility, and perceived luxury were abstracted into three archetypes per cabin class, enabling informed CMF differentiation while maintaining a coherent overall cabin identity.

Goal: guide differentiated yet consistent CMF expression within each class.

Moodboard

Moodboards serve as a visual and emotional translation tool, connecting abstract experience goals to concrete aesthetic references. In CMF design, they help align stakeholders around atmosphere, material character, and emotional tone before detailed specification begins. Visual references are known to support shared interpretation and reduce ambiguity in experiential design processes (Hekkert & van Dijk, 2011). Moodboards therefore act as a bridge between qualitative intent and material selection.

Goal: create a shared experiential reference for CMF development.

Color palette

Color palettes define the emotional baseline of a cabin and strongly influence perceived space, cleanliness, and calmness. In aviation interiors, color is a key driver of visual comfort and orientation, particularly in high-density environments (Gabbatore & Germak, 2022). CMF research shows that coherent, class-specific palettes enhance perceived quality and reduce visual fatigue (Karana & Hekkert, 2010). Color choices must therefore balance brand identity, functional visibility, and long-term wear perception.

Goal: establish a durable, class-specific visual atmosphere.

Experiential attributes

This model captures high-level experiential qualities that describe the intended emotional and social atmosphere of the cabin environment. In design and CMF literature, such attributes are commonly used to articulate affective and interpretive goals that guide material, color, and form decisions beyond functional performance (Desmet & Hekkert, 2007; Karana et al., 2015). By framing these qualities as experiential attributes rather than moods, they function as actionable design criteria that can be consistently translated into CMF choices across the cabin.

Goal: define clear, experience-led attributes that steer consistent CMF decision-making.

Metaphor

Metaphors provide a narrative structure that helps translate abstract values into coherent CMF decisions. By linking materials, colors, and patterns to familiar references, metaphors support intuitive understanding and emotional resonance. Design literature highlights metaphors as powerful tools for meaning-making in product experience, especially in complex systems like interiors (Hekkert, 2006; Desmet & Hekkert, 2007). In CMF design, metaphors ensure that material choices contribute to a readable and memorable story.

Goal: anchor CMF decisions in a clear and emotionally legible narrative.

Four experiential layers

The four experiential layers—sensorial, affective, interpretive, and performative—structure how materials are perceived beyond purely technical performance. This layered approach reflects how passenger simultaneously experience materials through touch, emotion, meaning, and function. Research by Vink et al. (2012) and Karana et al. (2015) demonstrates that comfort and quality perception emerge from the interaction of these layers. Applying this framework ensures that CMF decisions address both functional demands and experiential richness.

Goal: integrate functional performance with multi-layered passenger experience.

Materials experience vision

The material experience vision translates abstract brand and class intentions into tangible sensory qualities such as texture, gloss, softness, and perceived robustness. In CMF design, this vision functions as a guiding filter that aligns material decisions with intended passenger experience rather than isolated performance metrics. Research shows that material perception strongly shapes comfort, cleanliness perception, and overall satisfaction in aircraft cabins (Vink et al., 2012; Karana, Hekkert, & Kandachar, 2009). Establishing this vision early ensures consistency across colors, materials, and finishes.

Goal: align all CMF decisions with a coherent, experience-led intent.

DELTA DISCOVERY

Y-CLASS ✨ ECONOMY CLASS



The name of this class evokes the energy of shared exploration, rooted in Dutch openness, directness and movement. The name suggests both place and mindset, discovery as a collective journey. The design invites collectivity, clarity, curiosity, and a grounded sense of freedom through universal materials and bold simplicity.



TARGET BUYER

DELTA DISCOVERY ✨ Y-CLASS

CLASS DEFINITION

The main cabin, designed for efficiency and social comfort, offering 96 seats at a 31-inch (79 cm) pitch, and 8 at the emergency exits with about 61 cm of extra leg room. This is the most compact layout on board, maximizing passenger capacity while lightweight seats, no recline, contributing to reduced weight and fuel consumption. Targeting cost-conscious travelers and groups, this class emphasizes practicality and approachability.

BOOKING BEHAVIOR

Highly price-sensitive and volume-driven, with bookings split between ultra-early bargain hunters and last-minute convenience seekers. Add-ons like seat selection and extra legroom are selectively purchased, reflecting minimal but targeted spending on comfort. Loyalty is limited unless linked to baggage or punctuality benefits; schedule and fare remain the primary drivers (Vink et al., 2012; Karana et al., 2015).

CMF IMPLICATIONS

Mid-tone patterned textiles to disguise stains and wear, tough molded surfaces with rounded edges for safety and fast maintenance, bright but controlled palette for visual openness, all designed to age visibly well under high use while signaling cleanliness and order (Vink et al., 2012; Karana & Hekkert, 2010).

+

MOTIVATIONS

Lowest available fare for essential travel, access to dependable service and safety at minimal cost, and increasingly, an expectation of basic comfort, cleanliness, and digital convenience (Vink et al., 2012; Karana & Hekkert, 2010).

-

PAIN POINTS

Minimal legroom cause fatigue on longer flights, visible signs of dirt or wear reduce perceived care, and crowding or noise can make the experience feel chaotic and impersonal (Vink et al., 2012;).

“It’s only a short flight, so I usually go for the cheapest option and bring my own entertainment. I don’t expect too much, but if the seat looks dirty, feels warm from the previous passenger, or has broken parts, it really takes away from the experience.”

✨ **KLM Cityhopper Economy class passenger**

BUYER ARCHETYPES

DELTA DISCOVERY ✨ Y-CLASS

Budget-conscious leisure explorer

Short-haul leisure travelers are the largest and most price-sensitive group in many European markets, usually targeted with low fares and simple service concepts (Samunderu & Farrugia, 2022). They fly for city breaks or sun holidays with partners or friends and willingly trade flexibility and seat pitch for a low total trip price. Comfort expectations remain clear: a clean cabin, adequate legroom, pleasant lighting and colors, and friendly crew are decisive for repeat choice, while visual clutter and long boarding times quickly reduce perceived comfort (Vink, Bazley, Kamp, & Blok, 2012; Ahmadpour, Lindgaard, Robert, & Pownall, 2014; De Crescenzo, Bagassi, & Starita, 2021).



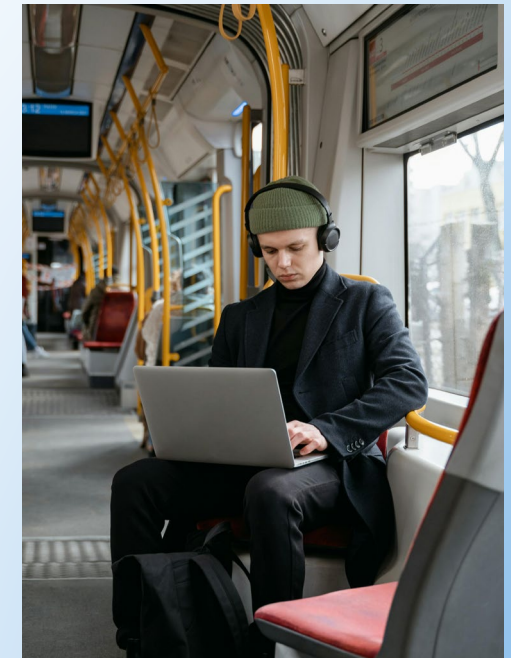
Visiting friends and relatives (VFR) traveler

Short-haul leisure travelers are the largest and most price-sensitive group in many European markets, usually targeted with low fares and simple service concepts (Samunderu & Farrugia, 2022). They fly for holiday or city trips while visiting friend and relatives. Among this target buyer there are also many elderly passengers. Comfort expectations remain clear: a clean cabin, adequate legroom, pleasant lighting and colors, and friendly crew are decisive for repeat choice, while visual clutter and long boarding times quickly reduce perceived comfort (Vink, Bazley, Kamp, & Blok, 2012; Ahmadpour, Lindgaard, Robert, & Pownall, 2014; De Crescenzo, Bagassi, & Starita, 2021).



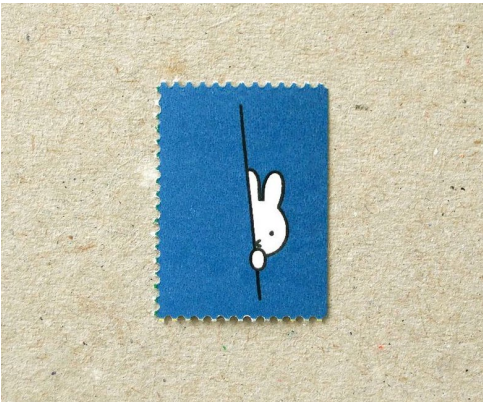
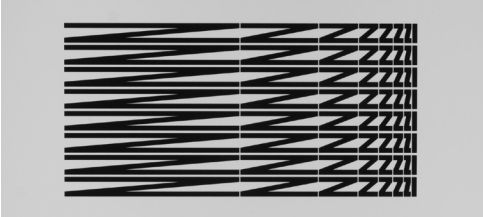
Budget-conscious corporate traveler

Cost-driven consultants, junior managers, and self-employed professionals fly Economy as a rational trade-off between price and reliability. They prioritize punctuality, frequent connections, and predictable on-board basics over premium amenities, often booking late and switching airlines to minimize cost. Comfort is defined pragmatically: adequate seat ergonomics, neutral and clean aesthetics, acceptable noise and lighting, and the ability to work briefly on a laptop or arrive presentable for meetings. Value is perceived when the cabin feels efficient, calm, and non-distracting. (Belobaba, Odoni, & Barnhart, 2016; De Crescenzo, Bagassi, & Asfaux, 2019; Vink, Bazley, Kamp, & Blok, 2012; Gabbatore & Germak, 2023).



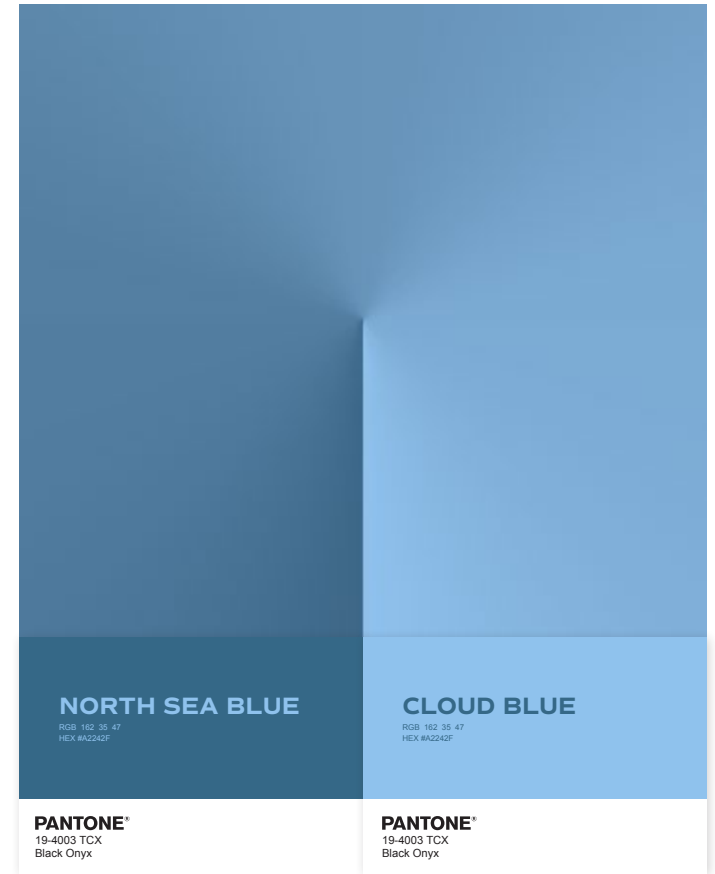
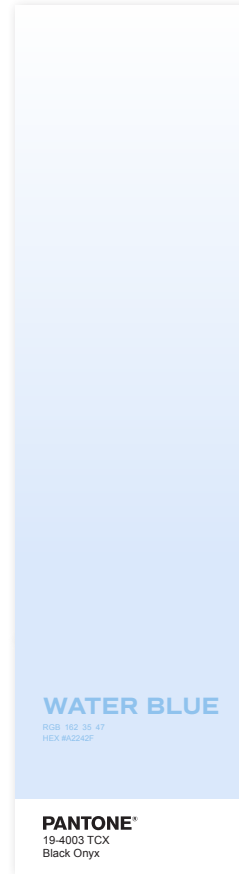
MOODBOARD

DELTA DISCOVERY ✨ Y-CLASS



COLORS

DELTA DISCOVERY ✨ Y-CLASS



EXPERIENTIAL ATTRIBUTES

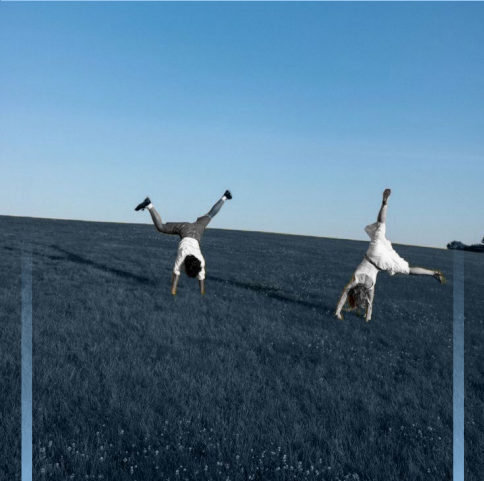
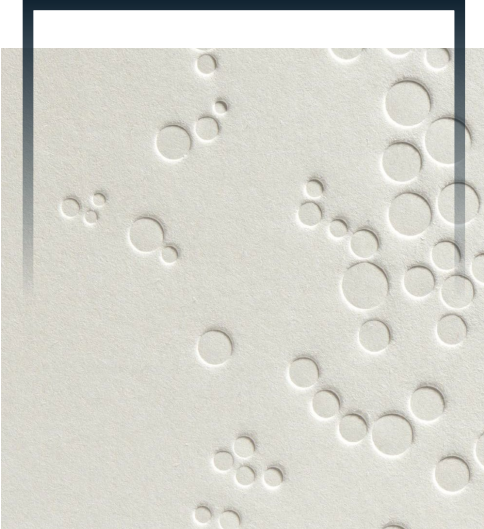
DELTA DISCOVERY ✨ Y-CLASS

EXHILARATION



COLLECTIVE

SIMPLE



FRIVOLOUS

METAPHOR

DELTA DISCOVERY ✨ Y-CLASS

PLAYFUL MIXING

“Your heartbeat racing with excitement as you play hide-and-seek with your friends in kindergarden, searching for the perfect spot, feeling carefree, connected and playful, fully immersed in childhood freedom and joy.”

Similar to the initial stage of bacterial cellulose formation, where multiple ingredients of the growth medium interact and merge, enabling the first emergence of a coherent material structure.

SENSORIAL

Textured
Vibrant
Fresh

Engaging the senses through brighter colors, tactile fabrics, and dynamic lighting that evoke alertness, cleanliness, and energy.

PERFORMATIVE

Resilient
Flexible
Persistent

Supporting fast, collective use, easy wipe-downs, bold contrast, and quick visual scanning in busy aisles.

MATERIAL EXPERIENCE VISION

DELTA DISCOVERY ✨ Y-CLASS

A young, inclusive, and lively setting where robust materials and textures support playful, fast, communal use, welcome chatter, and feel light, durable, and easy to maintain.

AFFECTIVE

Energetic
Casual
Communal

Materials encourage a light, social mood where chatter feels welcome and low-stakes.

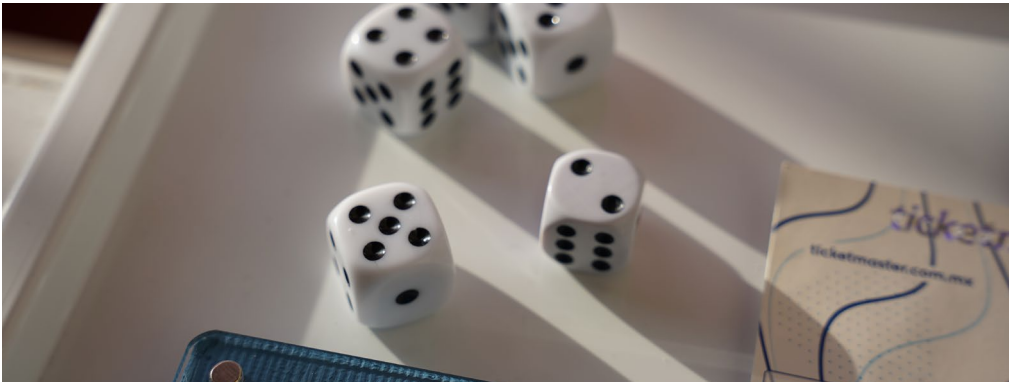
INTERPRETIVE

Universal
Lively
Approachable

The cabin reads as an inclusive, lively environment that prioritizes togetherness and practicality.

MATERIALS BOARD

DELTA DISCOVERY ✨ Y-CLASS



SEAT MATERIALS

DELTA DISCOVERY ✨ Y-CLASS

UPHOLSTERY

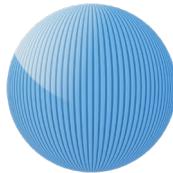
M1.1 ✨ PAN & BACKREST UPHOLSTERY

Color ✨ Night black
Material ✨ BC Leather alternative
Texture ✨ Smooth
Thickness ✨ 0.9 mm
Density ✨ 0.24 g/cm³



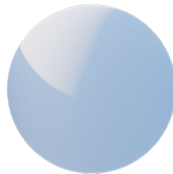
M1.1 ✨ HEADREST UPHOLSTERY

Color ✨ Charcoal gray
Material ✨ BC Leather alternative
Texture ✨ Suede-like
Thickness ✨ 0.7 mm
Density ✨ 0.1 g/cm³



M1.1 ✨ STITCHING

Color ✨ Charcoal gray
Material ✨ BC Leather alternative
Texture ✨ Suede-like
Thickness ✨ 0.7 mm
Density ✨ 0.1 g/cm³



SEATBELT

M1.1 ✨ SEATBELT WEBBING

Color ✨ Delft blue
Material ✨ 100% Recycled high-tenacity polyester
Texture ✨ Tightly woven slightly ribbed
Thickness ✨ 1.5 mm
Density ✨ 1.38 g/cm³



M1.1 ✨ SEATBELT BUCKLE & LATCH

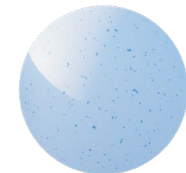
Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



SEAT SHELL

M1.1 ✨ SEAT SHELL & TRAY TABLE

Color ✨ Delft blue
Material ✨ 100% Recycled high-tenacity polyester
Texture ✨ Tightly woven slightly ribbed
Thickness ✨ 1.5 mm
Density ✨ 1.38 g/cm³



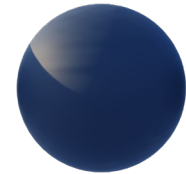
M1.1 ✨ SEAT SHELL LITERATURE NET

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



M1.1 ✨ SEAT SHELL LITERATURE FRAME

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



FRAME

M1.1 ✨ SEAT FRAME

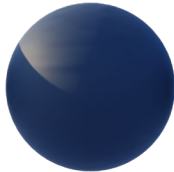
Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



ARMREST

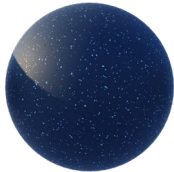
M1.1 ✨ ARMREST UPPER

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



M1.1 ✨ ARMREST LOWER

Color	✨ Delft blue
Material	✨ 85% Recycled aluminum
Texture	✨ Brushed satin metal
Thickness	✨ 4 mm
Density	✨ 2.7 g/cm ³



CABIN MATERIALS

DELTA DISCOVERY ✨ Y-CLASS

M1.1 ✨ CARPET

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



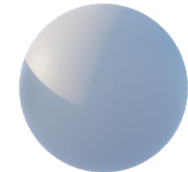
M1.1 ✨ SEATRAILCOVERS

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



M1.1 ✨ WALL PANEL

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



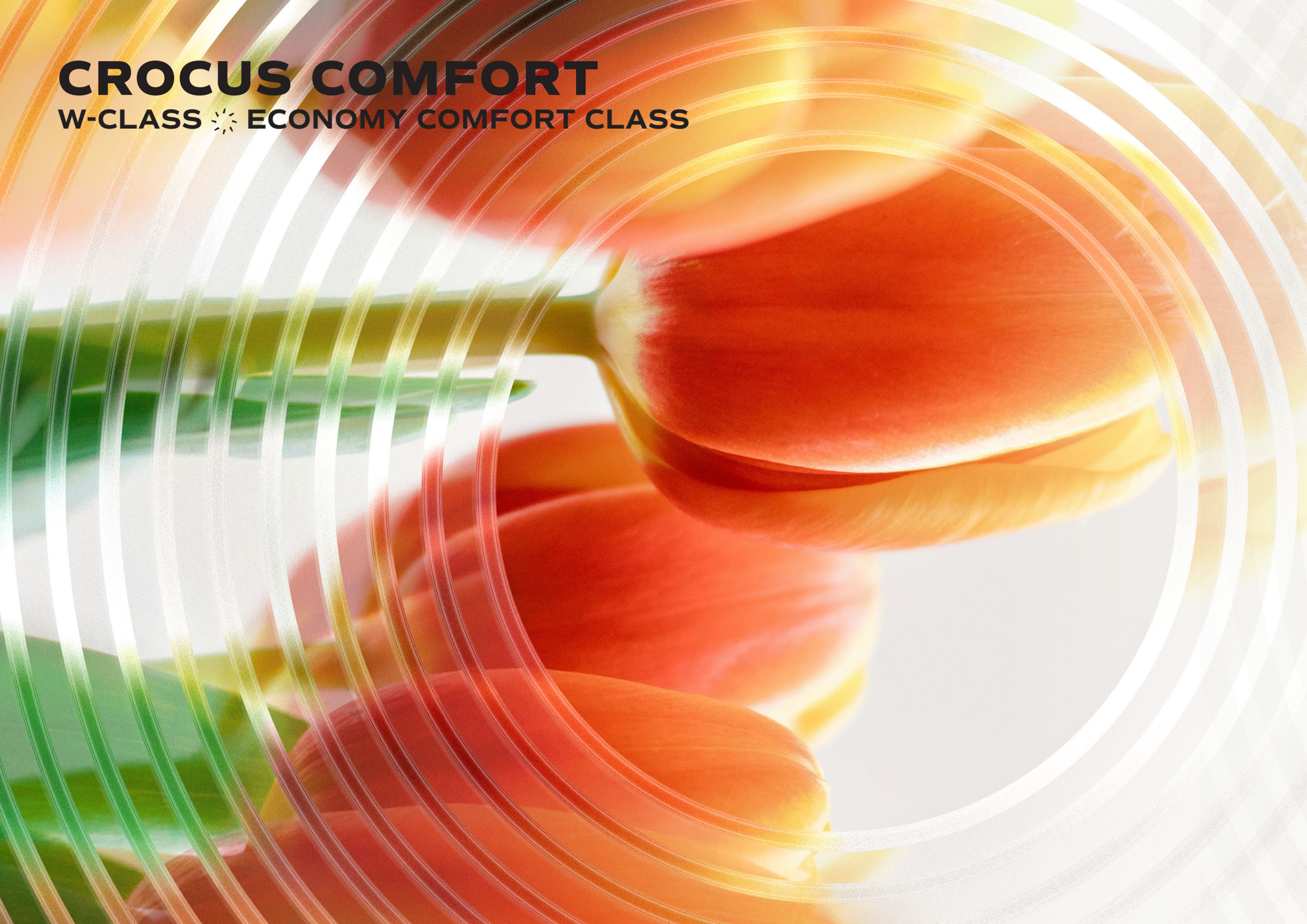
M1.1 ✨ CURTAIN

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



CROCUS COMFORT

W-CLASS ✨ ECONOMY COMFORT CLASS



Named after the crocus, one of the Netherlands' earliest spring flowers, this class embodies gentle renewal and tactile warmth. The orange crocus signals optimism, softness, and seasonal transition, mirroring the comfort and brightness this class offers.



TARGET BUYER

CROCUS COMFORT ✨ W-CLASS

CLASS DEFINITION

The intermediate cabin offering, 8 seats arranged at a 34 inch (86 cm) pitch. It provides about 8 cm of extra legroom over economy, using the same Recaro R2 seat model as business class but in a denser configuration (2 inches/5 cm less than business class). Targeting travelers who seek enhanced comfort and service on regional flights without the full price of business class. Affordable luxury, bridging the gap between economy efficiency and business-class comfort.

BOOKING BEHAVIOR

Often booked as a comfort upgrade by business travelers restricted from flying Business, or by leisure travelers seeking a calmer, more spacious flight; typically purchased mid-window or as an upsell close to departure. Dynamic pricing and loyalty incentives drive uptake, with flexible fares still common due to uncertain schedules. Comfort is weighed against cost, so booking behavior reflects a calculated investment in wellbeing over status (Vink et al., 2012; Karana & Hekkert, 2010).

CMF IMPLICATIONS

Matte warm neutrals and tonal contrasts to suggest gentle separation from economy, subtly textured soft-touch armrests and low-gloss seat backs for quiet tactility, refined woven or recycled upholstery that balances cleanability with elevated hand-feel and consistent wear over higher loads (Vink et al., 2012; Karana et al., 2015).

+

MOTIVATIONS

Extra legroom and recline for reduced fatigue, a quieter cabin zone with quicker boarding and exit, and perceptibly better comfort and care without the full price of Business (Vink et al., 2012; Karana et al., 2015).

-

PAIN POINTS

Passengers might feel the “in-between” nature: it’s not as spacious or exclusive as business class, yet significantly priced higher than economy. (Vink et al., 2012)

“I used some Flying Blue miles to upgrade to Economy Comfort. On a short flight like this, extra baggage besides my trolley or better food isn’t important to me, I mainly value extra legroom and priority boarding. I think this class is the best value for money on a short flight like this.”

✨ *KLM Cityhopper Economy comfort class passenger*

BUYER ARCHETYPES

CROCUS COMFORT ✨ W-CLASS

The sensible business traveler

Regional sales manager or consultant who flies frequently but whose company policy rarely covers business class. They choose W-Class to arrive less worn-out, valuing the extra legroom and quiet to prepare for meetings. They often work during the flight, so they notice details like a stable tray table and good lighting. For them, Premium Economy is a professional tool – a productive bubble where a comfortable seat and premium touches (like a hot towel or quality coffee) help maintain their work routine in the air. They appreciate the subtle luxury, knowing it's a smart investment in their alertness and well-being without breaking the travel budget.



The treat-seeking leisure couple

A middle-aged or retired couple on a short European break who normally fly economy but upgraded to W-class to “make this trip special.” They notice and appreciate every added touch, from early boarding and quieter rows to softer headrests and warmer cabin colors, and spend most of the flight reading, talking, and looking out of the window. For them, tangible material cues such as cleanliness, softness, and a pleasant color and lighting palette confirm that the extra money created a more memorable, comfortable journey (Vink, Bazley, Kamp, & Blok, 2012; Santos, Leiva, Costa, & Gregolin, 2016; Ahmadpour et al., 2014).



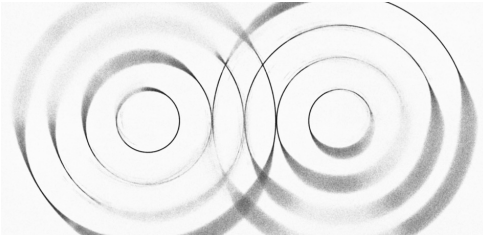
The Flying Blue upgrader

A frequent KLM or SkyTeam traveler who usually books economy but uses Flying Blue miles or credits to move up to Economy Comfort on selected flights. The upgrade is a strategic, rational choice: more legroom, faster boarding, and a quieter cabin in exchange for loyalty currency rather than cash. At the same time, being seated in W-class gives a subtle feeling of recognition and status, which strengthens their emotional bond with the airline beyond the purely functional benefit of extra space (Şahin, Kuşakçı, & Mbowe, 2021; Wever, 2022; Ahmadpour et al., 2014; De Crescenzo et al., 2021).



MOODBOARD

CROCUS COMFORT ✨ W-CLASS



COLORS

CROCUS COMFORT W-CLASS



CANVAS BEIGE RGB 162 35 47 HEX #A2242F	SPRING ORANGE RGB 162 35 47 HEX #A2242F
PANTONE® 19-4003 TCX Black Onyx	PANTONE® 19-4003 TCX Black Onyx

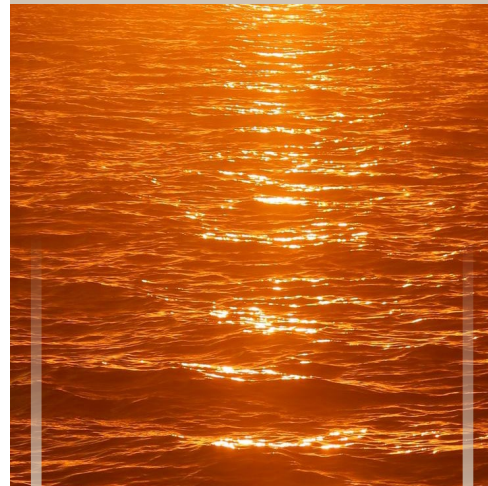
SUN ORANGE RGB 162 35 47 HEX #A2242F
PANTONE® 19-4003 TCX Black Onyx

SOIL BROWN RGB 162 35 47 HEX #A2242F	PORCELAIN WHITE RGB 162 35 47 HEX #A2242F
PANTONE® 19-4003 TCX Black Onyx	PANTONE® 19-4003 TCX Black Onyx

EXPERIENTIAL ATTRIBUTES

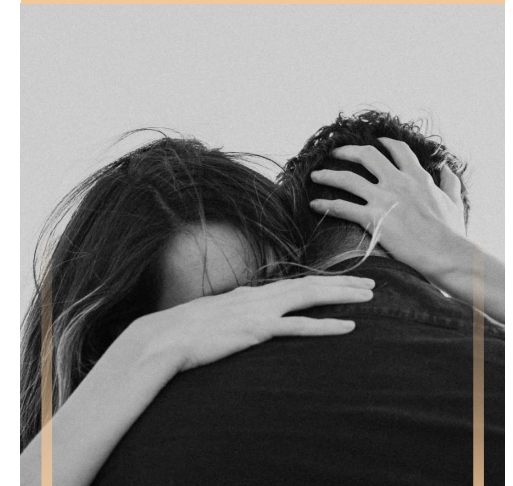
CROCUS COMFORT ✨ W-CLASS

BLOOM



SUNSHINE

CRISP



CONNECTED

METAPHOR

CROCUS COMFORT ✨ W-CLASS

SYMBIOTIC GROWTH

“A warm early-spring day in your late twenties, stepping out in the first light clothes of the year. What begins as an ordinary weekend day unfolds into one of your most treasured memories, promising yourself to the love that has effortlessly been there all along.”

Mirroring the central phase of bacterial cellulose formation, when bacteria and medium act in harmony, enabling the cellulose network to expand naturally and without external intervention.



SENSORIAL

Soft
Contrast
Warm

Tactile softness and warm hues support close conversation and a “whisper-friendly” ambiance between seatmates.

PERFORMATIVE

Sharing
Intuitive
Durable

Details invite small shared actions—passing items, co-viewing screens, through obvious grips, rests, and hinge lines.

MATERIAL EXPERIENCE VISION

CROCUS COMFORT ✨ W-CLASS

A bright, warm cocoon where soft textures and subtle floral details invite close conversation, small shared gestures, and a gentle sense of happiness.

AFFECTIVE

Playful
Delighted
Exciting

Gentle pops of interest spark lightheartedness without raising arousal beyond a comfortable, intimate zone.

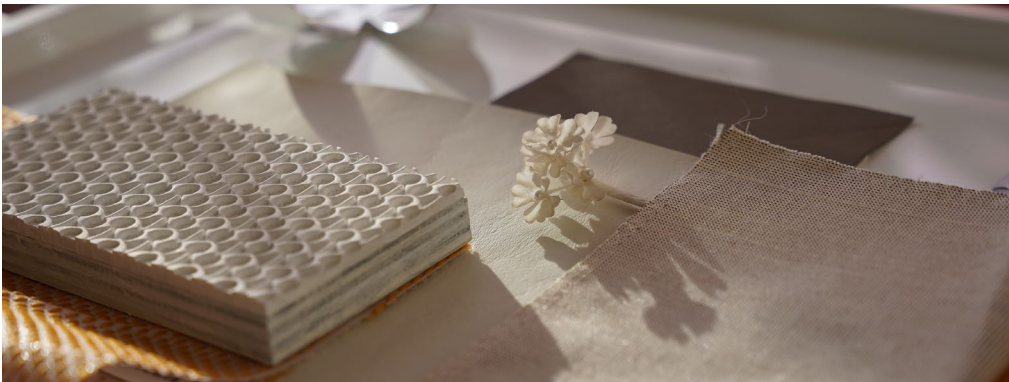
INTERPRETIVE

Sociable
Smart-upgrade
Different

The setting communicates a modern, sociable “together” space that feels like a considered step up from economy.

MATERIALS BOARD

CROCUS COMFORT ✨ W-CLASS



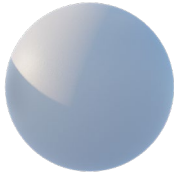
SEAT MATERIALS

CROCUS COMFORT ✨ W-CLASS

UPHOLSTERY

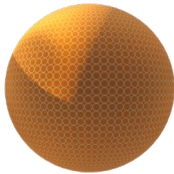
M1.1 ✨ PAN & BACKREST UPHOLSTERY

Color ✨ Night black
Material ✨ BC Leather alternative
Texture ✨ Smooth
Thickness ✨ 0.9 mm
Density ✨ 0.24 g/cm³



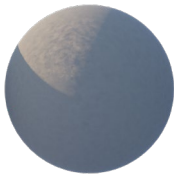
M1.1 ✨ HEADREST UPHOLSTERY

Color ✨ Charcoal gray
Material ✨ BC Leather alternative
Texture ✨ Suede-like
Thickness ✨ 0.7 mm
Density ✨ 0.1 g/cm³



M1.1 ✨ STITCHING

Color ✨ Charcoal gray
Material ✨ BC Leather alternative
Texture ✨ Suede-like
Thickness ✨ 0.7 mm
Density ✨ 0.1 g/cm³



SEATBELT

M1.1 ✨ SEATBELT WEBBING

Color ✨ Delft blue
Material ✨ 100% Recycled high-tenacity polyester
Texture ✨ Tightly woven slightly ribbed
Thickness ✨ 1.5 mm
Density ✨ 1.38 g/cm³



M1.1 ✨ SEATBELT BUCKLE & LATCH

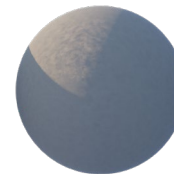
Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



SEAT SHELL

M1.1 ✨ SEAT SHELL & TRAY TABLE

Color ✨ Delft blue
Material ✨ 100% Recycled high-tenacity polyester
Texture ✨ Tightly woven slightly ribbed
Thickness ✨ 1.5 mm
Density ✨ 1.38 g/cm³



M1.1 ✨ SEAT SHELL LITERATURE NET

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



M1.1 ✨ SEAT SHELL LITERATURE FRAME

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



FRAME

M1.1 ✨ SEAT FRAME

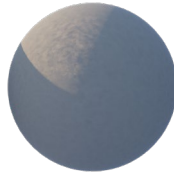
Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



ARMREST

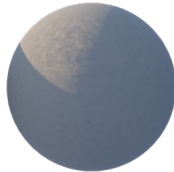
M1.1 ✨ ARMREST UPPER

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



M1.1 ✨ ARMREST LOWER

Color	✨ Delft blue
Material	✨ 85% Recycled aluminum
Texture	✨ Brushed satin metal
Thickness	✨ 4 mm
Density	✨ 2.7 g/cm ³



CABIN MATERIALS

CROCUS COMFORT ✨ W-CLASS

M1.1 ✨ CARPET

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



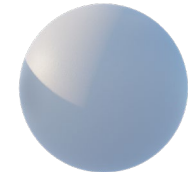
M1.1 ✨ SEAT-RAIL COVERS

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



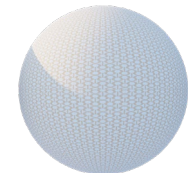
M1.1 ✨ WALL PANEL

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



M1.1 ✨ CURTAIN

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



VERMEER VESPER

J-CLASS ✨ BUSINESS CLASS

The name of this class combines the quiet brilliance of Dutch painter Vermeer with the word vesper, meaning “evening star” or “twilight.” The design reflects a moment of flow and focus. Symbolizing a refined, introspective space that supports calmness, privacy, confidence, and presence.



TARGET BUYER

VERMEER VESPER ✨ J-CLASS

CLASS DEFINITION

Front cabin with priority ground services and an upgraded meal and drinks service, two by two layout, pitch 33 in (84 cm), special perks include priority check-in and boarding, quieter zone at the front.

BOOKING BEHAVIOR

More late and changeable than leisure, often tied to meetings and premium long-haul connections, higher use of flexible fares when European delays make priority more valuable.

CMF IMPLICATIONS

Darker value blocking around headrest and side trims for perceived privacy, low-sheen fine-grain hard parts and soft-touch contact areas that resist scuffs in fast turns, tightly woven easy-clean textiles with neat stitching to read as quiet premium in the same shell.

+

MOTIVATIONS

Priority at the airport for time savings and smoother connections, a calmer and more private atmosphere, better food and drink than Economy Comfort.

PAIN POINTS

Same basic seat shell as the rest of the cabin so premium must be signaled by service and finishes, no “blocked middle seat” in a two by two layout.

“Short flights like this feel almost like a car ride to me because I take them so often. I want the experience to be as seamless and calm as possible, so I can either get some work done or rest before arriving. Since I’m paying a premium, I expect extra personal attention and a clear distinction from other classes in both seat quality and service.”

✨ *KLM Cityhopper Business class passenger*

BUYER ARCHETYPES

VERMEER VESPER ✨ J-CLASS

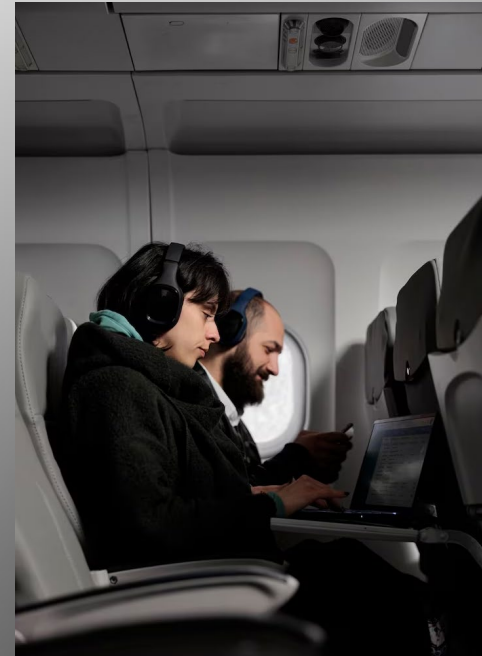
Time constrained corporate traveler

A salaried employee traveling under a corporate travel policy, where the employer pays and the goal is to protect schedule and reduce operational risk. They choose this cabin to guarantee priority at every touch point, to minimize queue time, and to safeguard tight connections; on disruptive days they willingly pay change fees or upgrade to preserve punctuality because the cost is borne by the company and the business impact of delay is high. Bookings skew late and are frequently modified, flexible fares are common, and the preferred seats are the very front rows for speed, control, and reliable deplaning.



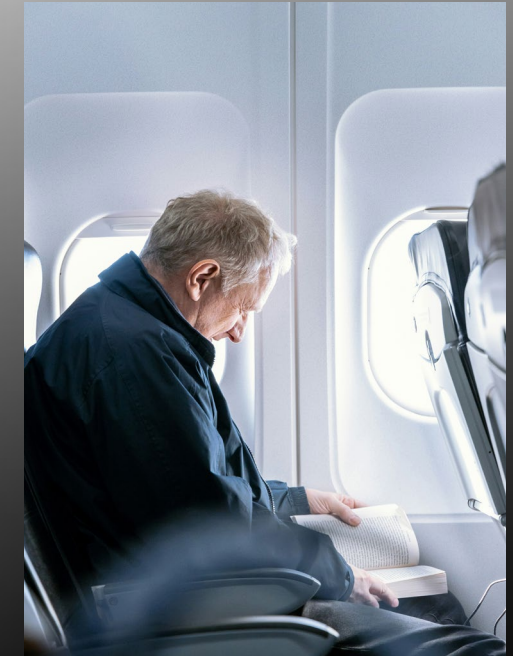
Self employed professional

An owner, consultant, or freelancer who pays personally and applies a return-on-time calculation to every trip. They select this cabin only when the expected productivity gain outweighs the fare premium, prioritizing a quiet, orderly workspace, refined finishes, and attentive service that support focused work; aisle congestion and visual clutter are the main irritants. Bookings are mid to late window but changes are selective to avoid extra cost, and seat preference focuses on rows that feel calm and functionally supportive rather than strictly the first row, since value is measured against personal profit and loss.



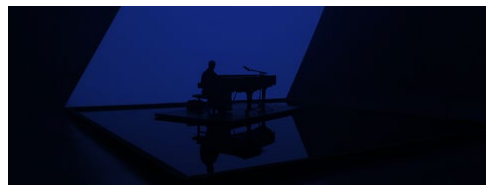
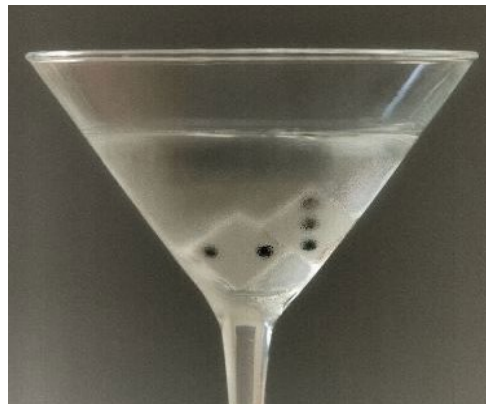
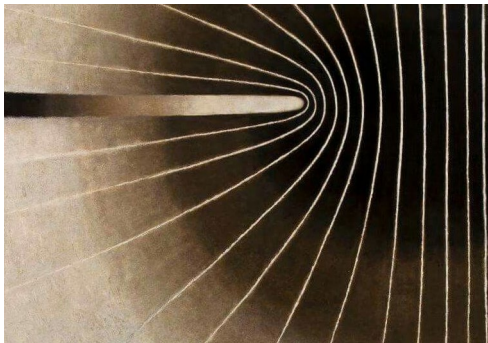
Passenger with reduced mobility (PRM)

An elderly traveler or passenger with reduced mobility who prefers early boarding, short walking distances, and extra space near the door. Assistance is available in any cabin under European Union rules and through Schiphol and KLM, yet many still choose the front for comfort and control. They tend to book earlier, flag assistance in the record, and follow KLM guidance to allow extra connection time at Amsterdam.



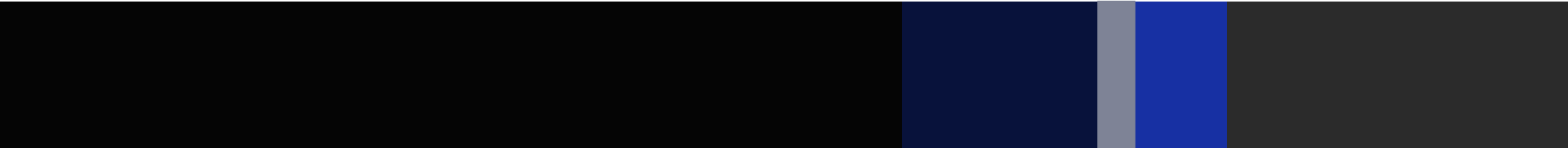
MOODBOARD

VERMEER VESPER ✨ J-CLASS



COLORS

VERMEER VESPER ✨ J-CLASS



NIGHT BLACK RGB 162 35 47 HEX #A2242F	ADMIRAL BLUE RGB 162 35 47 HEX #A2242F
PANTONE® 19-4003 TCX Black Onyx	PANTONE® 19-4003 TCX Black Onyx

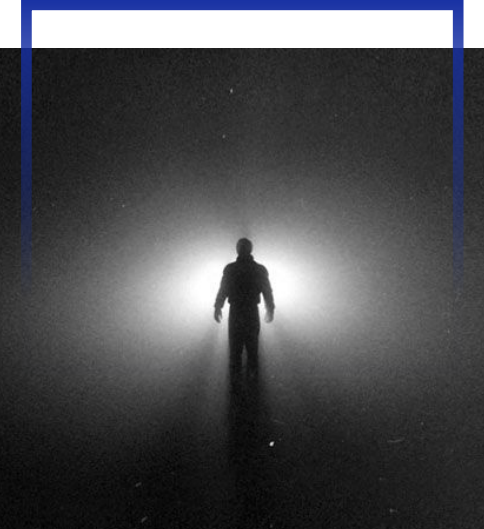
SILVER GREY RGB 162 35 47 HEX #A2242F
PANTONE® 19-4003 TCX Black Onyx

DELFT BLUE RGB 162 35 47 HEX #A2242F	CHARCOAL GRAY RGB 162 35 47 HEX #A2242F
PANTONE® 19-4003 TCX Black Onyx	PANTONE® 19-4003 TCX Black Onyx

EXPERIENTIAL ATTRIBUTES

VERMEER VESPER ✨ J-CLASS

CONFIDENCE



OPULENCE

FOCUS



HERITAGE

QUIET HARVESTING

“A warm early-spring day in your late twenties, stepping out in the first light clothes of the year. What begins as an ordinary weekend day unfolds into one of your most treasured memories, promising yourself to the love that has effortlessly been there all along.”

Reflecting the harvesting stage of bacterial cellulose production, in which biological activity has ceased and the material exists as a stable, non-living structure with defined properties.



SENSORIAL

Smooth
Matte
Quiet

The palette dampens visual and acoustic noise so the body settles and attention narrows to the task at hand.

PERFORMATIVE

Frictionless
Shielding
Quality

Surfaces smoothly guide micro-actions, from stowing to working, using tactility and form to carve a personal bubble.

MATERIAL EXPERIENCE VISION

VERMEER VESPER ✨ J-CLASS

A composed, dark, private sanctuary where matte and cool, acoustically soft materials lower arousal and create a focused, experienced, and chic atmosphere that encourages deliberate movement and professional order.

AFFECTIVE

Composed
Confident
Private/exclusive

Materials should elicit a sense of control and privacy that reduces arousal and supports sustained concentration.

INTERPRETIVE

Professional
Orderly
Proud

The cabin reads as a disciplined workspace that signals competence and reliability through restrained finishes.

MATERIALS BOARD

VERMEER VESPER ✨ J-CLASS



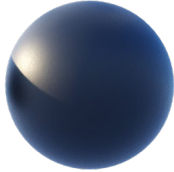
SEAT MATERIALS

VERMEER VESPER ✨ J-CLASS

UPHOLSTERY

M1.1 ✨ PAN & BACKREST UPHOLSTERY

Color ✨ Night black
Material ✨ BC Leather alternative
Texture ✨ Smooth
Thickness ✨ 0.9 mm
Density ✨ 0.24 g/cm³



M1.1 ✨ HEADREST UPHOLSTERY

Color ✨ Charcoal gray
Material ✨ BC Leather alternative
Texture ✨ Suede-like
Thickness ✨ 0.7 mm
Density ✨ 0.1 g/cm³



M1.1 ✨ STITCHING

Color ✨ Charcoal gray
Material ✨ BC Leather alternative
Texture ✨ Suede-like
Thickness ✨ 0.7 mm
Density ✨ 0.1 g/cm³



SEATBELT

M1.1 ✨ SEATBELT WEBBING

Color ✨ Delft blue
Material ✨ 100% Recycled high-tenacity polyester
Texture ✨ Tightly woven slightly ribbed
Thickness ✨ 1.5 mm
Density ✨ 1.38 g/cm³



M1.1 ✨ SEATBELT BUCKLE & LATCH

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



SEAT SHELL

M1.1 ✨ SEAT SHELL & TRAY TABLE

Color ✨ Delft blue
Material ✨ 100% Recycled high-tenacity polyester
Texture ✨ Tightly woven slightly ribbed
Thickness ✨ 1.5 mm
Density ✨ 1.38 g/cm³



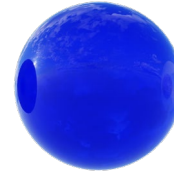
M1.1 ✨ SEAT SHELL LITERATURE NET

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



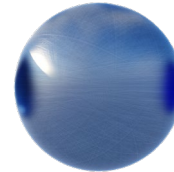
M1.1 ✨ SEAT SHELL LITERATURE FRAME

Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



M1.1 ✨ SEAT SHELL COAT HANGER

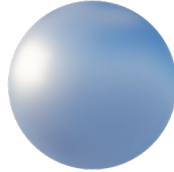
Color ✨ Delft blue
Material ✨ 85% Recycled aluminum
Texture ✨ Brushed satin metal
Thickness ✨ 4 mm
Density ✨ 2.7 g/cm³



FRAME

M1.1 ✨ SEAT FRAME & LUGGAGE RACK

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



ARMREST

M1.1 ✨ ARMREST UPPER

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



M1.1 ✨ ARMREST LOWER

Color	✨ Delft blue
Material	✨ 85% Recycled aluminum
Texture	✨ Brushed satin metal
Thickness	✨ 4 mm
Density	✨ 2.7 g/cm ³

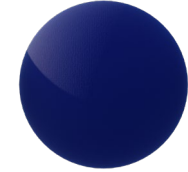


CABIN MATERIALS

VERMEER VESPER ✨ J-CLASS

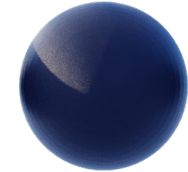
M1.1 ✨ CARPET

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



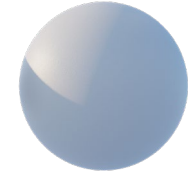
M1.1 ✨ SEAT RAIL COVERS

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



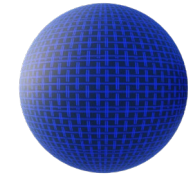
M1.1 ✨ WALL PANEL

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



M1.1 ✨ CURTAIN

Color	✨ Delft blue
Material	✨ 100% Recycled high-tenacity polyester
Texture	✨ Tightly woven slightly ribbed
Thickness	✨ 1.5 mm
Density	✨ 1.38 g/cm ³



4

**PROTOTYPE
& VALIDATE**



4.1 ☀ CMF PROTOTYPING & TESTING

- 4.1.1. CMF physical prototyping p. 124
- 4.1.2. Classification test (1) p. 125
- 4.1.3. CMF digital prototyping p. 131
- 4.1.4. Passenger experience test (2) p. 150

4.2 ☀ BC PROTOTYPING & TESTING

- 4.2.1. BC physical prototyping p. 156
- 4.2.2. BC digital prototyping p. 158
- 4.2.3. Life cycle Assessment p. 162

4.3 ☀ EVALUATION

- 4.3.1. Discussion p. 168
- 4.3.2. Limitations p. 168
- 4.3.3. Conclusion p. 171
- 4.3.4. Recommendations p. 171
- 4.3.5. Personal reflection p. 172

4.1 CMF PROTOTYPING PHYSICAL

During prototyping, a CMF (Color, Material, Finish) design approach encompassed both physical and digital methods to refine the aircraft interior. Physical prototyping involved assembling CMF material boards featuring the new bio-based foam samples alongside complementary leather-alternative textiles. A laser cutter was employed to etch custom patterns into these foam and leather-alternative samples. This approach effectively simulated detailed upholstery stitching, perforations, and trim panel motifs, providing a realistic preview of these finishes. In parallel, a full 3D cabin interior model was developed in Blender to enable digital prototyping. Custom procedural material shaders were created in Blender to represent the bio-based foams and finishes. This process involved scanning textures from physical samples, performing UV mapping, and applying a PBR (physically based rendering) workflow to calibrate color, roughness, and normal maps. Finally, the scene was configured with appropriate lighting and rendering settings to produce photorealistic visualizations of the cabin, allowing evaluation of the new materials and patterns in context under realistic aircraft lighting conditions.

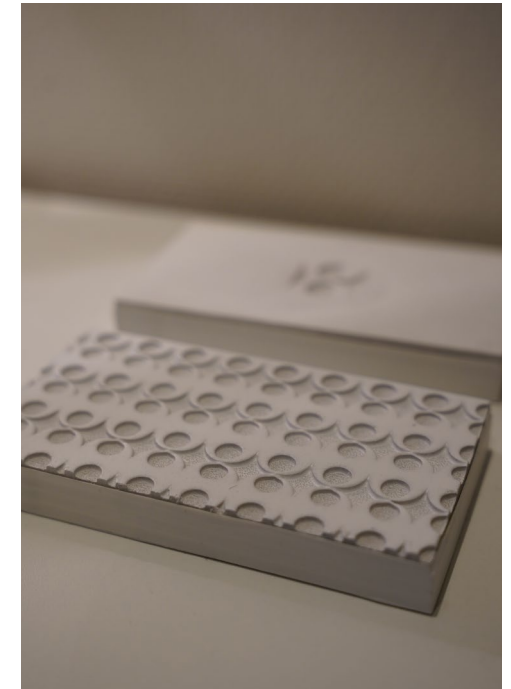
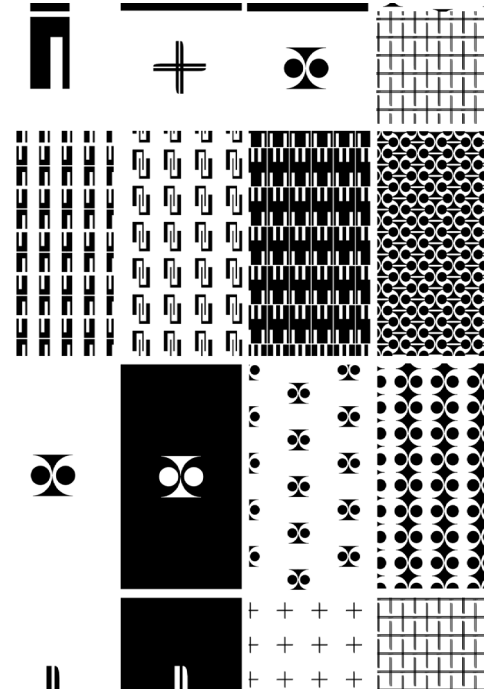


Figure 38: Material trays
Source: Author.

Figure 39: Pattern design and laser-cut samples
Source: Author.

○ 4.2.1. IN-PERSON CMF DESIGN CLASSIFICATION FOR AIRCRAFT CABIN CLASSES

A FORCED-CHOICE PERCEPTUAL CLASSIFICATION MATCH TASK TEST 1

OBJECTIVE

The objective of this test is to evaluate whether three physical CMF designs, each consisting of a material tray, a mood board, and an associated color and metaphor concept, are perceived by participants as representing the intended airline cabin classes: Economy, Economy Comfort, and Business.

TEST AIMS

The test aims to:

1. Determine whether participant classifications deviate significantly from random assignment.
2. Assess the degree of alignment between the designer's intended cabin class and participants' perceptual interpretation of each CMF design.

METHOD

Study design:

A forced-choice perceptual classification task was conducted in person.

Stimuli

Participants were presented with three unlabeled CMF design sets, each comprising:

✧ A physical CMF material tray, mood board, color palette and a metaphor.

In parallel, three cabin class descriptions were provided, each consisting of:

✧ A price range, buyer archetype including needs and pain points, representative passenger quote, material experience vision.

The order of presentation of both the CMF designs and the cabin class descriptions was systematically varied to reduce order effects.

TASK

Participants were asked to match each CMF design set to the cabin class description they felt belonged together. Each cabin class description was briefly explained verbally prior to the task, while the CMF designs themselves were not explained and relied solely on visual and material cues. Participants were permitted to view the designs in silence as a group but were instructed to return individually to the room to make their choice, in order to avoid influencing one another.

After completing the classification task, participants were asked which element of the CMF design (material tray, mood board, colors, or metaphor) had been most influential in informing their decision.



Figure 40: Participants looking at CMF designs.
Source: Author.

PARTICIPANTS

Target sample size: 30–40 participants.

Inclusion criterion: participants must have flown as passengers within the past 12 months.

ANALYSIS

- ✧ Classification results will be summarized using a confusion (classification) matrix.
- ✧ A chi-square goodness-of-fit test will be performed to assess whether the observed classification frequencies deviate significantly from random chance (33.3% in a three-choice task).
- ✧ Statistical analysis will be conducted using Microsoft Excel and its built-in chi-square test function.
- ✧ Written reasoning provided by participants will not be coded or analyzed qualitatively, as this falls outside the scope of the test. However, this feedback will be used to inform subsequent design refinement.

Example result of a participant

Economy class - B
Economy comfort class - C
Business class - A



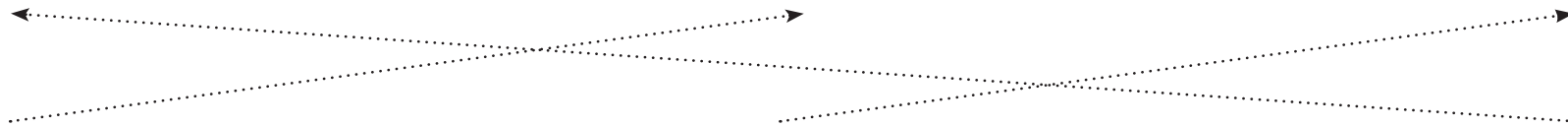
Design A
(Material tray, mood board, colors & metaphor)



Design B
(Material tray, mood board, colors & metaphor)



Design C
(Material tray, mood board, colors & metaphor)



Economy class
(Price range \$, buyer archetypes, passenger quote, & material experience vision)

Economy comfort class
(Price range \$, buyer archetypes, passenger quote, & material experience vision)

Business class
(Price range \$, buyer archetypes, passenger quote, & material experience vision)

OUTCOME CRITERIA

- ✧ A statistically significant chi-square result indicates that participants are not assigning CMF designs randomly.
- ✧ A CMF design is considered successfully perceived if at least 70% of participants assign it to its intended cabin class.
- ✧ This threshold substantially exceeds the 33.3% chance level and aligns with common practice in perception and design classification research (Ulrich & Miller, 2004; Ahmadi et al., 2021; Wang & Lin, 2021).
- ✧ The test also yields insight into which CMF component (material tray, mood board, colors, or metaphor) most strongly influences cabin class perception.

HYPOTHESES

It is expected that the Economy class will be most consistently identified as the lowest-priced cabin. Some confusion is anticipated between Economy Comfort and Business, as the more expressive visual language of Economy Comfort may lead it to be perceived as a higher class, while the Business class may be interpreted as more understated. This effect is expected to arise primarily from visual first impressions rather than from a deeper understanding of passenger needs associated with each class.



Figure 41: Participant matching cabin class to a design.
Source: Author.

COMPARABLE STUDIES

- ✧ Tutzauer et al. (2016): This study used a forced-choice classification task and confusion matrix analysis to measure how accurately participants could recognize different 3D building types (with 96 participants and no majority consensus threshold). It is referenced in our work because its methodology for evaluating visual recognition accuracy closely aligns with our approach.
- ✧ Wang & Lin (2021): They employed a forced-choice semantic matching task and reported percentage accuracy for interpreting figurative product designs (similes, metaphors, and analogies). We cite this work as it provides insight into measuring how users perceive and understand design semantics, which parallels the semantic evaluation aspect of our study.
- ✧ Ugale et al. (2020): This research applied chi-square goodness-of-fit tests to determine whether observed product color preferences (in an Indian consumer context) were significantly different from random chance. It is included as a reference because it exemplifies the use of statistical tests to evaluate categorical preferences, informing our own analysis of preference data.



Figure 42: Participant engaging in tactile evaluation of materials in the material tray.
Source: Author.

QUANTITATIVE CLASSIFICATION RESULTS

Participants largely identified the intended cabin classes correctly, although recognition varied by class.

- ✧ Economy class design: Correctly classified by 89% of participants; 11% selected Economy Comfort and 0% Business.
- ✧ Economy Comfort design: Correctly classified by 83%; 11% selected Economy and 6% Business.
- ✧ Business class design: Correctly classified by 95%; 6% selected Economy Comfort and 0% selected Economy.

The Economy and Business designs showed strong perceptual clarity, while the Economy Comfort design exhibited greater ambiguity, primarily being confused with Economy class. This is in line with usual CMF design practices, since the middle class is often the hardest to position.

STATISTICAL ANALYSIS

Test aim 1:

Chi-square goodness-of-fit tests showed that classification distributions for all three designs deviated significantly from random chance (33.3%), confirming non-random, design-driven perception (Economy and Business: $p < 0.001$; Economy Comfort: $p < 0.01$).

Test aim 2:

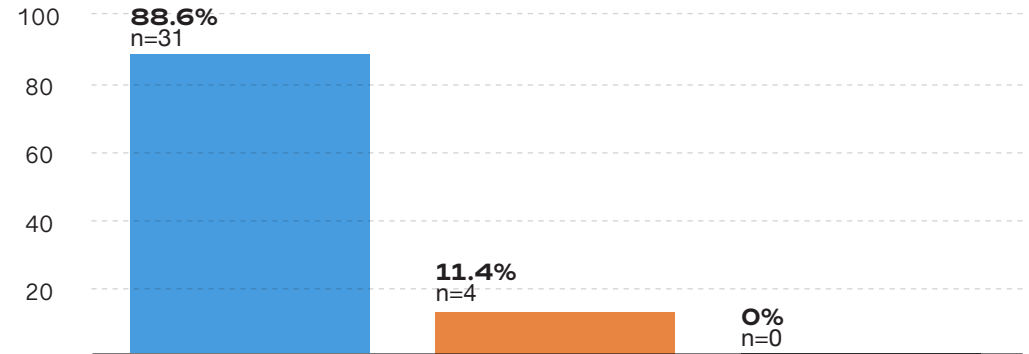
Analysis of the data indicates a significant difference in correct classification rates across the three designs ($p < 0.05$). Post-hoc comparisons showed that the Economy Comfort design was identified significantly less accurately than the Business class design ($p < 0.05$). No significant difference was found between Economy and Business recognition rates.

INTERPRETATION

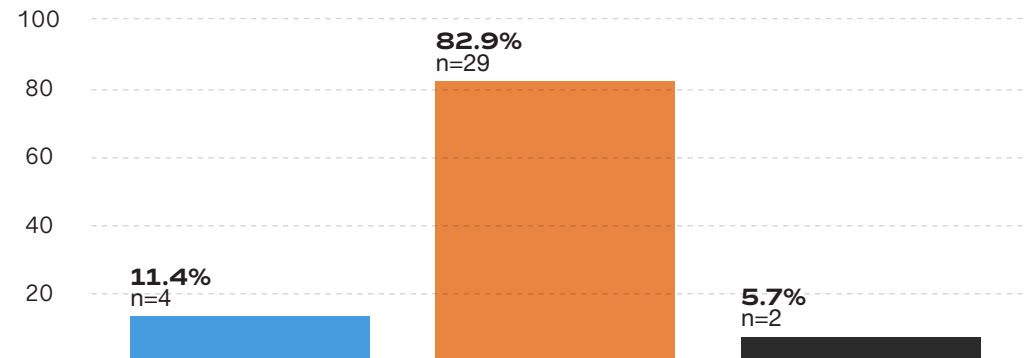
The high recognition rates for the Economy and Business designs indicate that their CMF cues clearly aligned with established passenger expectations. The Business design, in particular, effectively communicated premium quality through material richness and visual coherence, while the Economy design was readily associated with functional, low-complexity aesthetics.

The lower recognition rate for the Economy Comfort design suggests insufficient perceptual differentiation. Participants appeared to lack a strong mental model for this intermediate class, resulting in overlap with both Economy and Business. In many cases, the Economy Comfort design was interpreted as standard Economy, indicating that its premium cues were not salient enough. This highlights the challenge of balancing brand coherence with class differentiation and suggests a need to strengthen mid-tier visual and material signals.

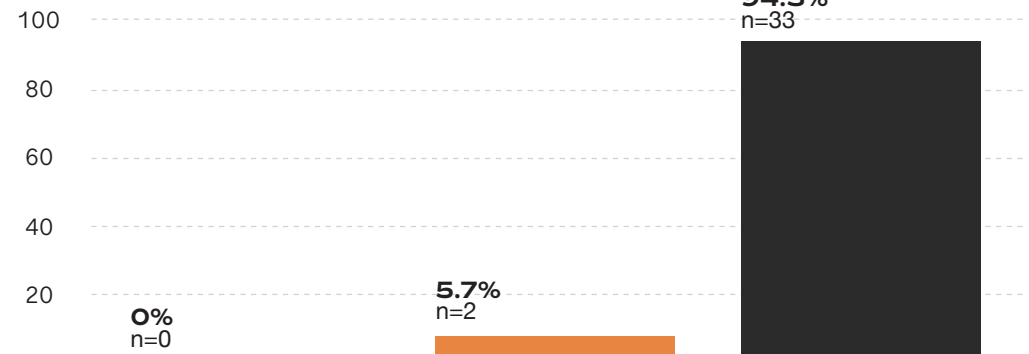
Classification of Economy design (blue)



Classification of Economy comfort design (orange)



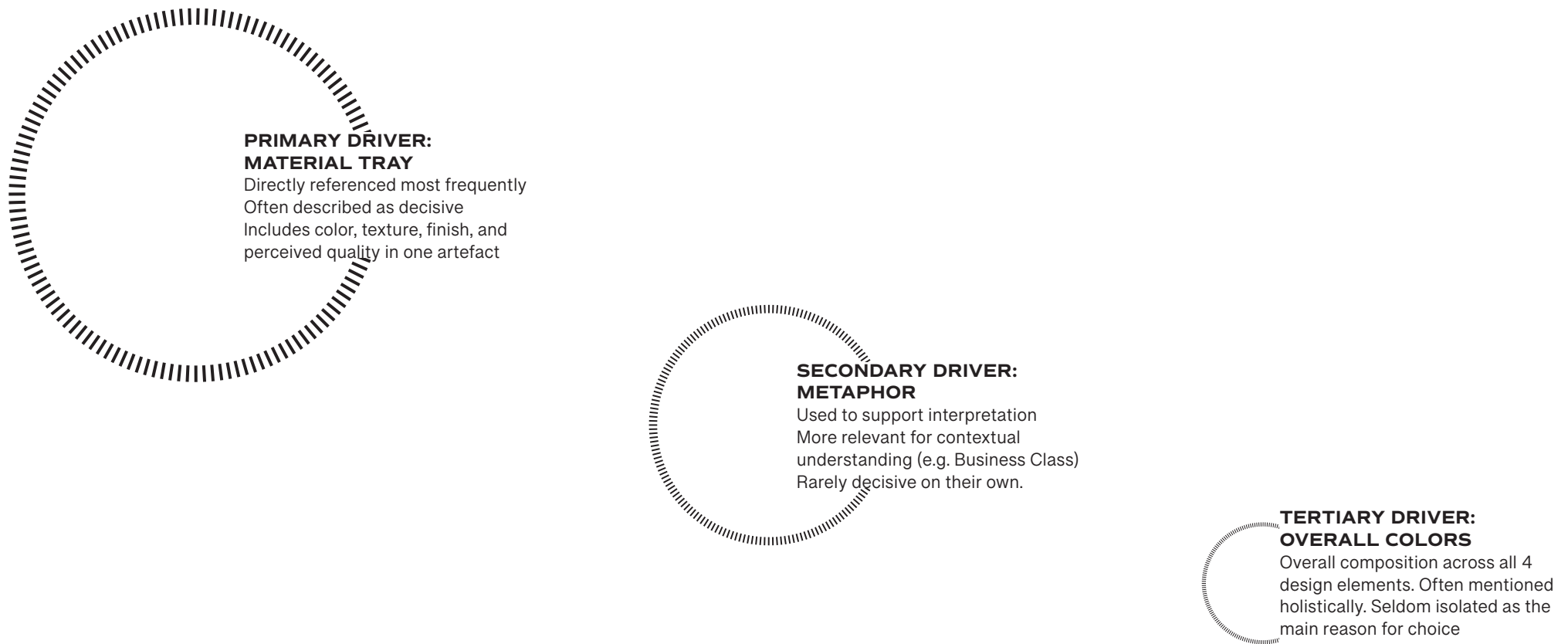
Classification of Business design (black)



QUALITATIVE DRIVER RESULTS

Open-ended responses to the question “Which part of the design was most influential when making your choice?” were analyzed using a qualitative frequency-based method. This method supports rapid identification of dominant perceptual drivers in an early-stage CMF evaluation like this case.

The analysis of the qualitative data gathered shows that the material tray was the most influential design element in participants’ decision-making. Mentions of the material tray substantially exceeded references to the moodboard, metaphor, or color palette. Several respondents explicitly indicated that color was already perceived as embedded within the total glance of the whole design, reducing its role as a standalone design factor. The metaphor and moodboard functioned primarily as interpretative or contextual aids rather than as primary drivers. Overall, the results indicate that tangible material representation dominates early CMF perception and selection, outweighing abstract narrative or purely visual 2D design elements.



LIMITATIONS

Several limitations should be considered. The participant sample was relatively small and may not fully represent the broader passenger population. The forced-choice format required a classification even in cases of uncertainty and did not capture confidence levels. Additionally, evaluations were based on static visuals rather than immersive or real-world cabin experiences, potentially limiting contextual understanding.

CONCLUSION

Test 1 demonstrates that CMF design can effectively communicate cabin class hierarchy, with strong perceptual alignment for Economy and Business interiors. The Economy Comfort design, while performing above the set "successfully perceived percentage" of 70% to its intended cabin class, showed reduced clarity and requires further refinement to establish a distinct middle class identity. These findings validate the overall CMF approach and provide clear direction for targeted design iteration prior to subsequent passenger experience testing in test 2.



Figure 43: Participant matching cabin class to a design.
Source: Author.

4.1 CMF PROTOTYPING DIGITAL

For the digital prototyping phase of this thesis, the aircraft seats and cabin interior were modeled using multiple 3D CAD environments. Based on the developed geometries, digital material definitions were created in accordance with the proposed CMF concepts, employing Adobe Substance software to generate physically based rendering (PBR) materials. These materials were subsequently applied to the models and integrated into the complete cabin environment, enabling the production of high-fidelity contextual visualizations of the proposed interior designs.

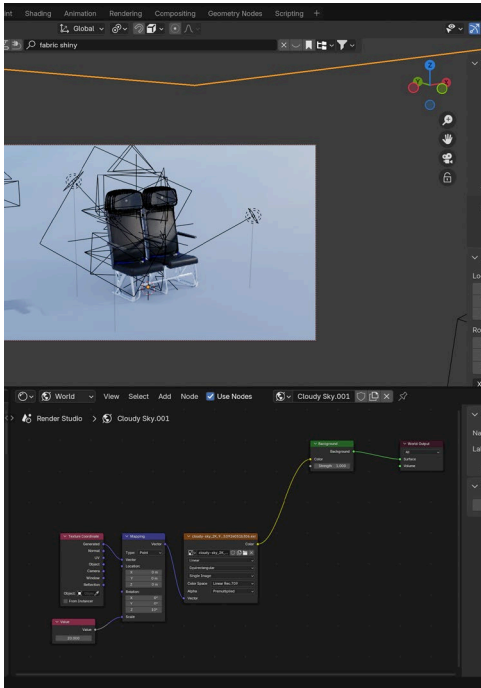


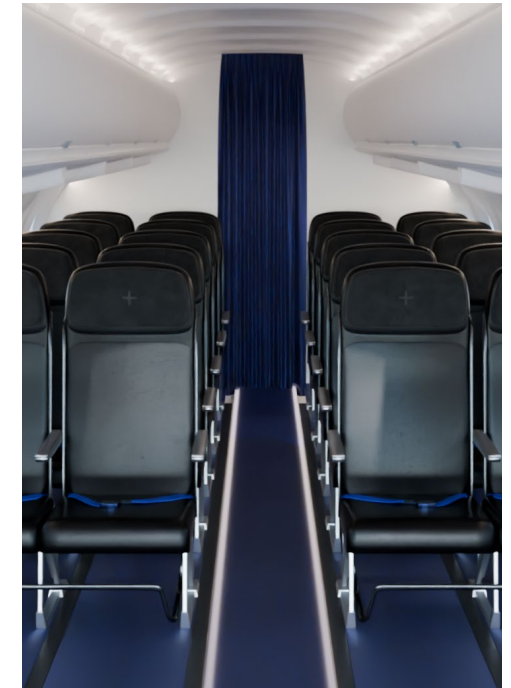
Figure 44: 3D CAD modeling
Source: Author.



Figure 45: Parametric digital material design. Source: Author.



Figure 46: Design renderings.
Source: Author.

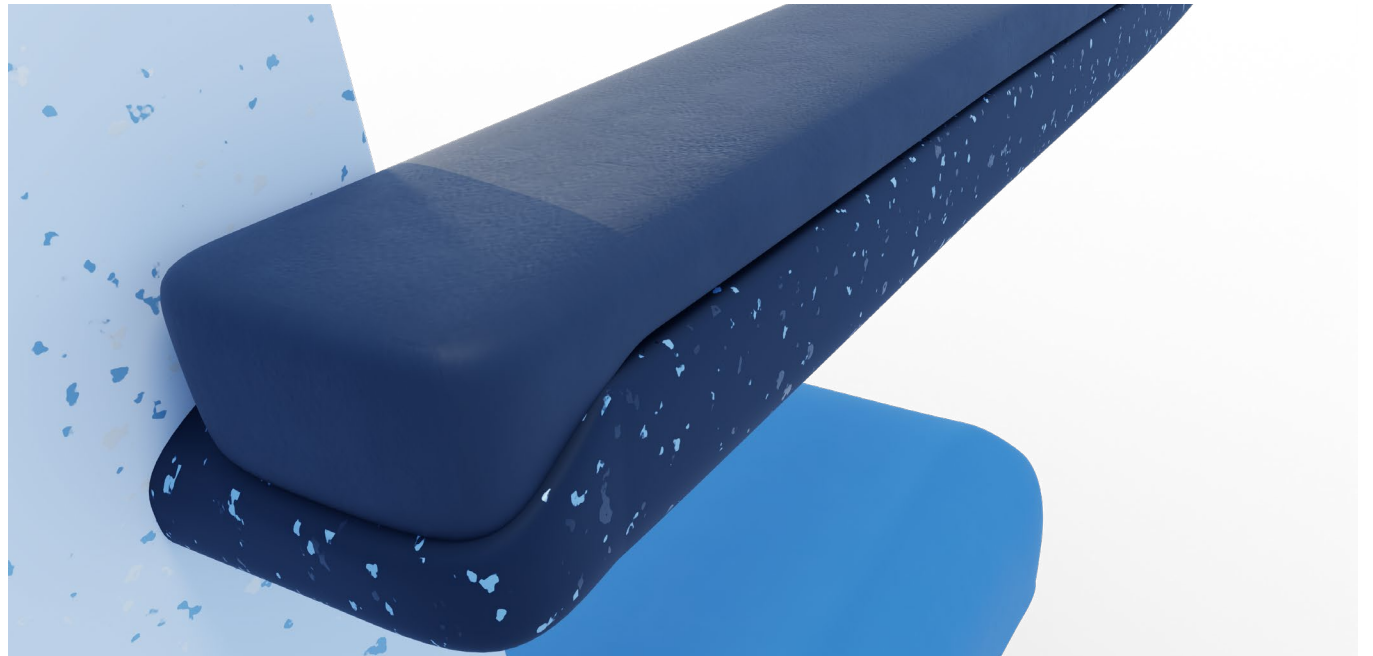
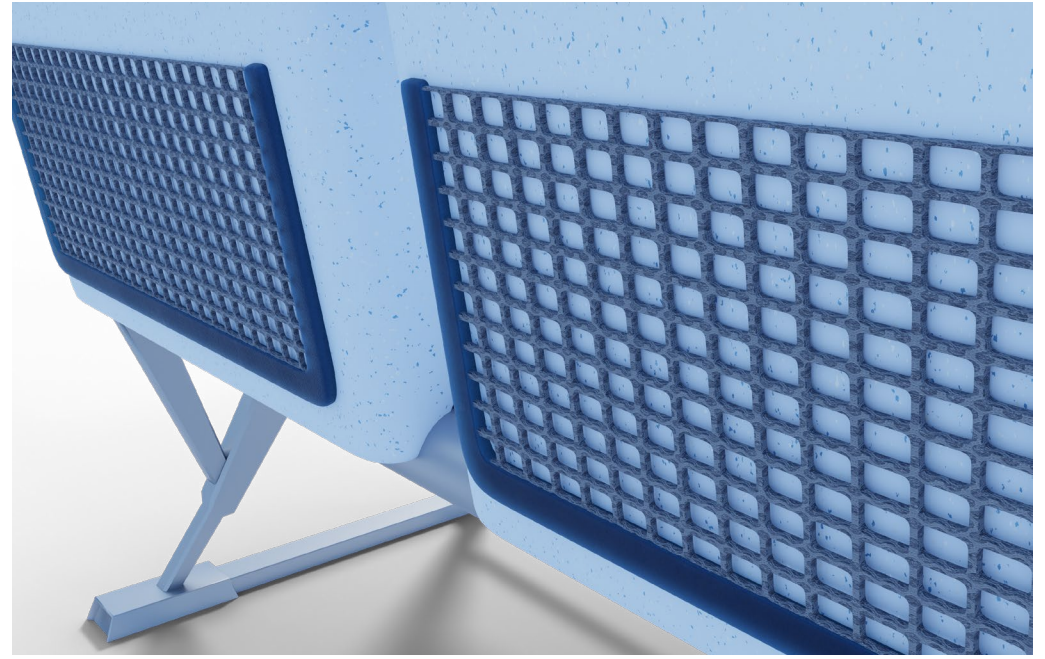




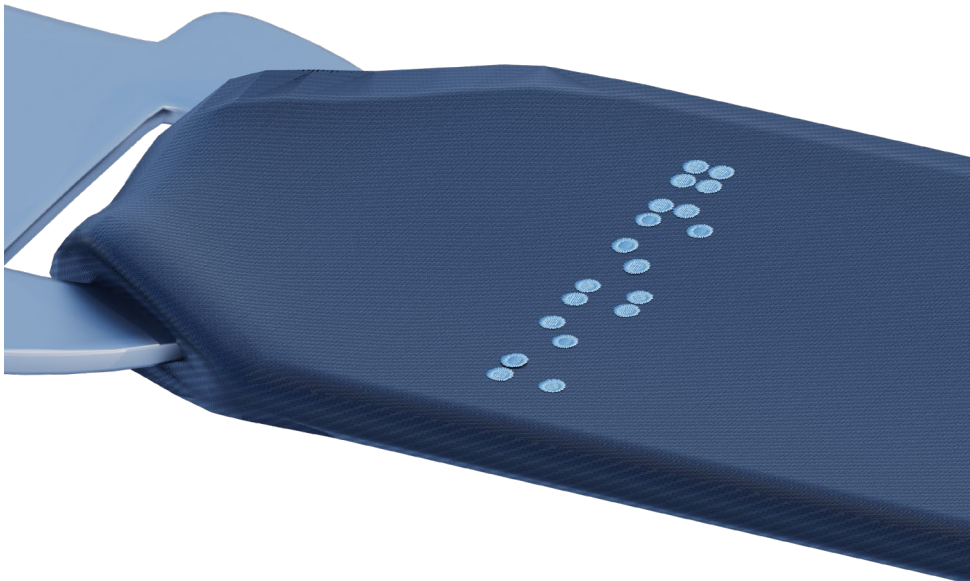
DELTA DISCOVERY

Y-CLASS ✨ ECONOMY CLASS









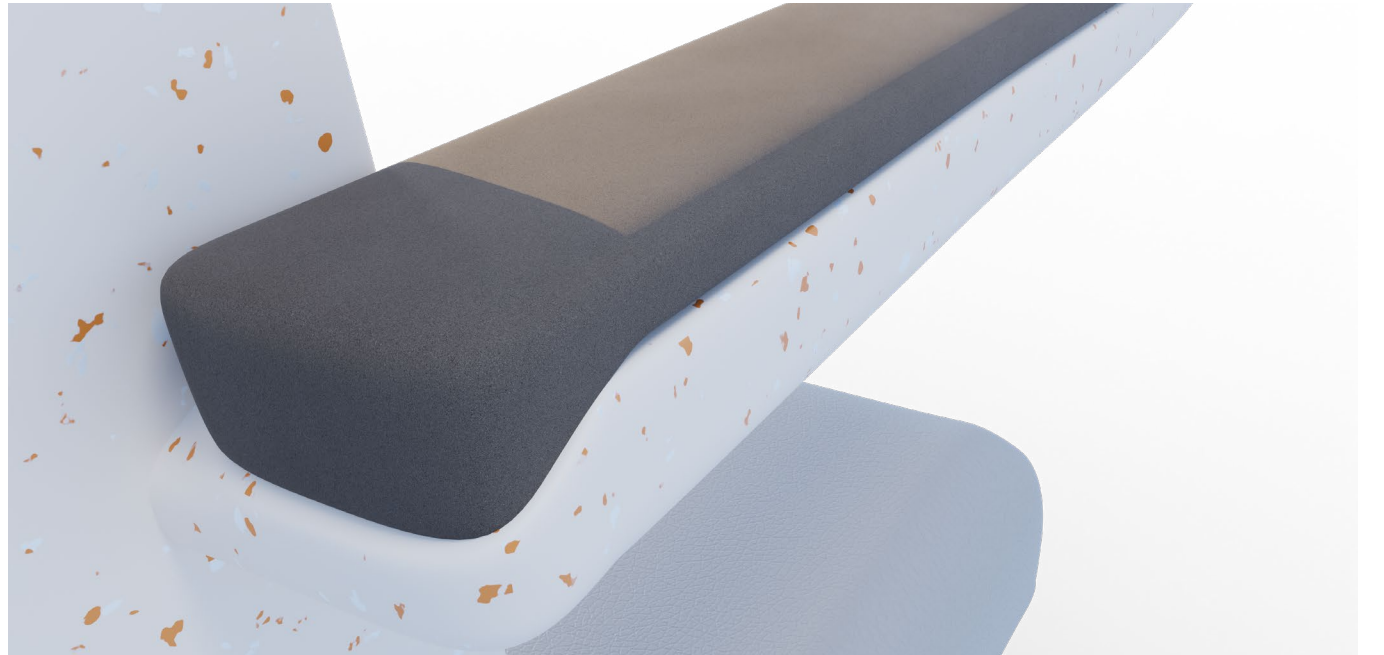
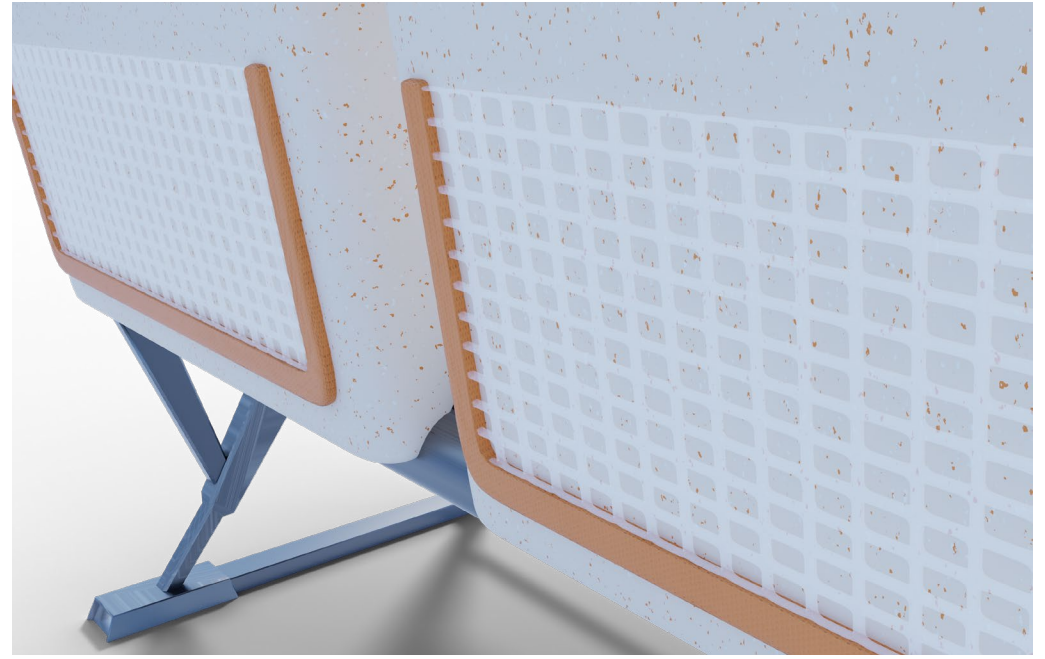


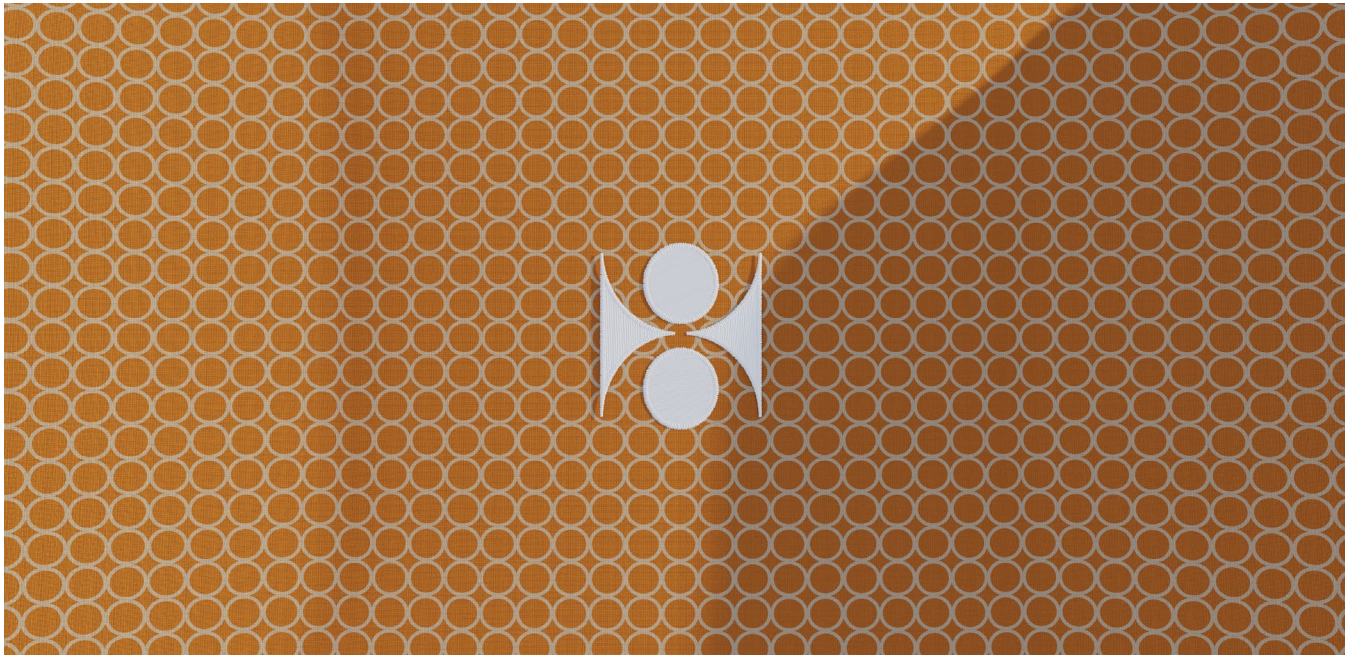


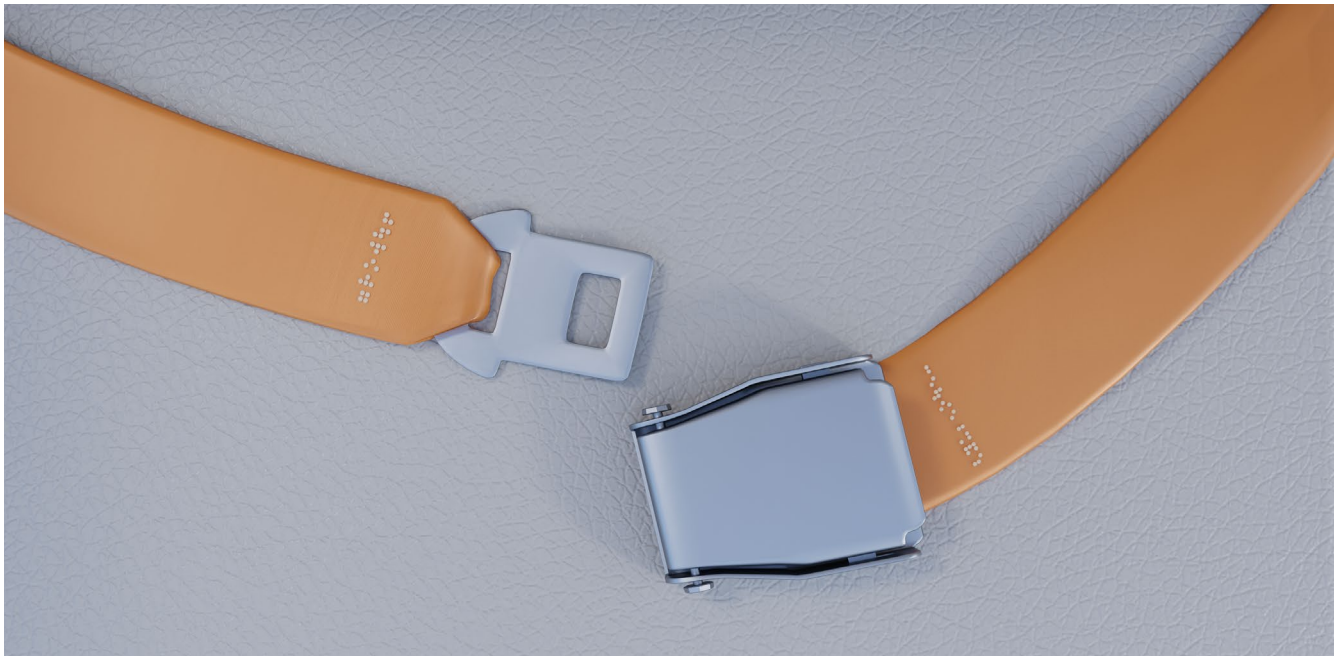
CROCUS COMFORT

W-CLASS ✨ ECONOMY COMFORT CLASS









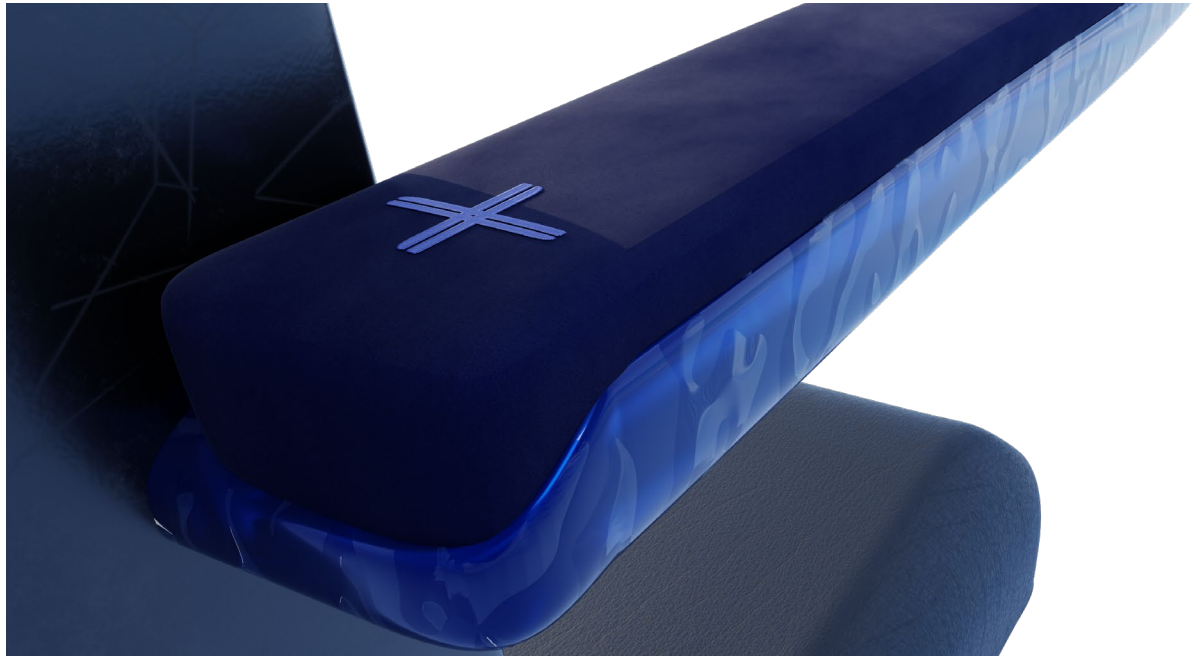
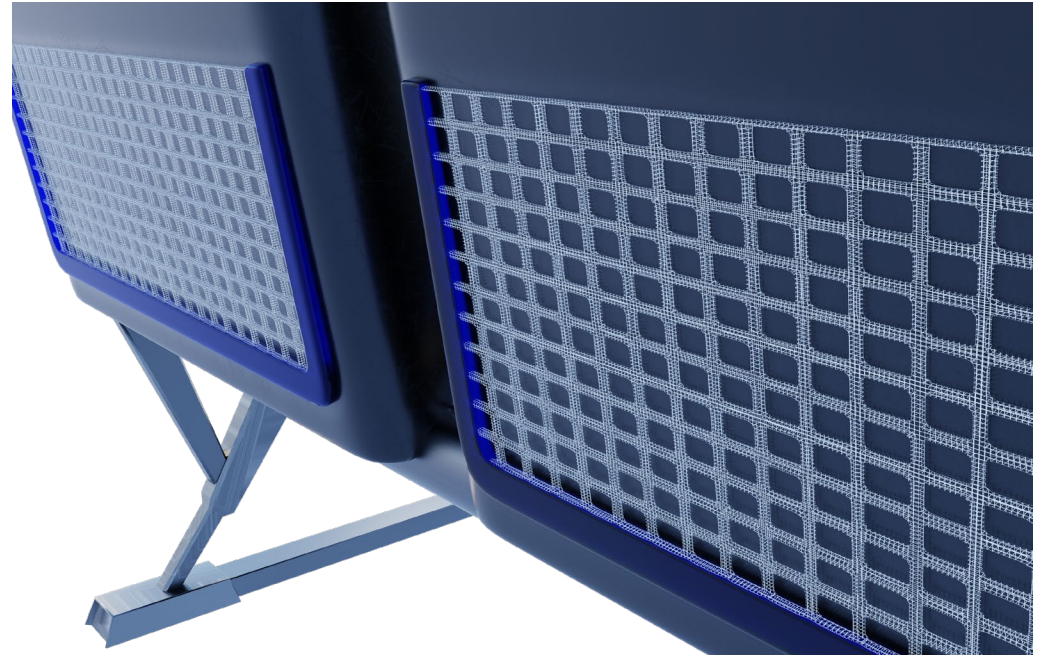


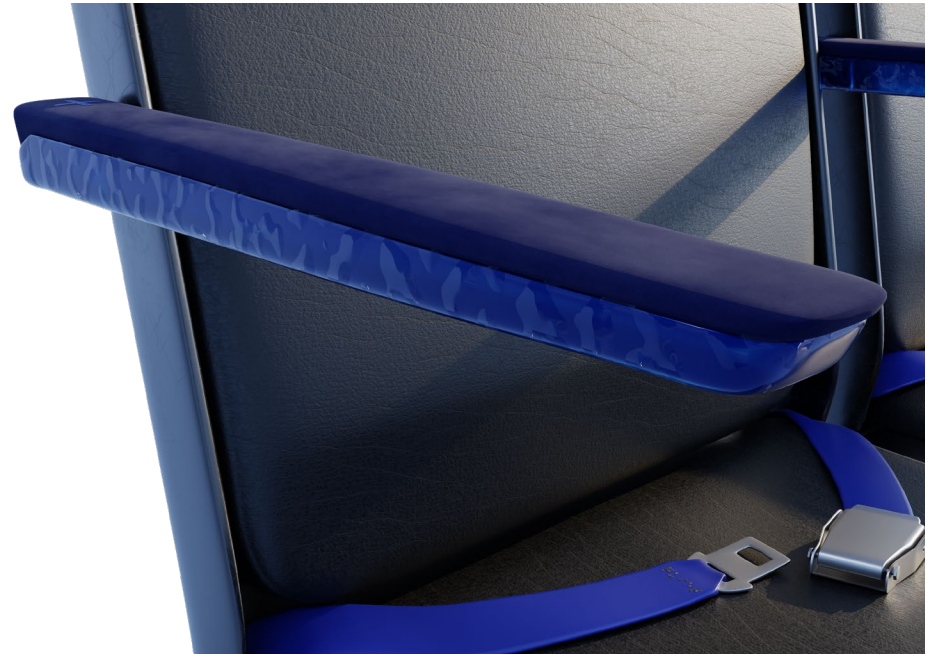


VERMEER VESPER

J-CLASS ✦ BUSINESS CLASS











○ 4.2.2.

PASSENGER EXPERIENCE EVALUATION OF NEW AIRCRAFT CABIN CMF DESIGNS

A WITHIN-SUBJECT LIKERT-SCALE COMPARATIVE PERCEPTION TEST USING RENDERINGS

TEST 2 ✨ ONLINE

OBJECTIVE

The objective of this test is to evaluate whether the newly developed three-class CMF cabin designs are perceived as more comfortable, premium, sustainable, modern, clean, and aesthetically appealing than KLM's current cabin interiors. In addition, the study aims to generate insight into the relative importance of each parameter and the underlying reasoning behind passengers' preferences.

TEST AIMS

- ✨ Determine whether perceived passenger experience differs significantly between the new CMF designs and the current KLM CMF.
- ✨ Establish overall passenger preference between the two design directions per cabin class.
- ✨ Identify the relative importance of individual perceptual parameters in forming overall judgments.
- ✨ Collect explanatory qualitative feedback to support final design decisions.

METHOD

A within-subject comparative evaluation was conducted using Likert-scale ratings. Each participant evaluated both the current and the new CMF design, enabling direct comparison while controlling for individual response bias and reducing required sample size. The order of presentation was not varied. All designs were shown in Y-, W-, and J-class sequence, consistent with common CMF design practices.

STIMULI

Participants were shown side-by-side high-quality renderings of KLM's current cabin CMF design and the newly proposed CMF design. This comparison was repeated for Y-, W-, and J-class, in this particular order.

TASK

For each cabin class, participants rated both designs separately on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) for the following parameters:

- ✨ Visual comfort
- ✨ Aesthetic appeal
- ✨ Premium feel
- ✨ Perceived sustainability
- ✨ Modernity
- ✨ Perceived cleanliness

Participants subsequently ranked the six parameters according to their importance in forming a judgment. Finally, participants indicated overall preference between the two designs and provided a short written explanation.



Figure 47: Design renderings. Source: Author.

RATIONALE FOR RENDER-BASED EVALUATION

High-resolution static renderings were used instead of VR to ensure consistency, minimize distraction, and avoid technical barriers. Prior research validates the use of 2D visual stimuli for early-stage cabin and seat perception studies, where first impressions are primarily visually driven (Gabbatore & Germak, 2019; Lee & Choi, 2020). Given the project scope and timeline, VR was deemed unnecessary and inefficient at this stage.

SCREEN VARIATION CONSIDERATIONS

Although participants completed the study on different devices, the within-subject comparative setup ensures that screen-related variation affects both designs equally per participant. Such variation introduces random noise rather than systematic bias, which is acceptable in early-stage comparative perception research (Palmer et al., 2013; Sonderegger & Sauer, 2015).

PARTICIPANTS

- ✧ Target sample size: 40–60 participants.
- ✧ Inclusion criterion: participants must have flown as airline passengers within the past 12 months.

ANALYSIS

- ✧ Mean Likert scores are calculated per parameter, per class, and per design.
- ✧ Paired-sample t-tests ($\alpha = 0.05$) are used to assess whether differences between designs are statistically significant.
- ✧ Overall preference is analyzed using a chi-square goodness-of-fit test against a 50/50 distribution.
- ✧ Results are visualized using bar charts, tables and circle diagrams.
- ✧ Written explanations will be reviewed to identify recurring themes but will not be formally coded. Each theme should be supported by qualitative data of at least 10% of participants.

OUTCOME CRITERIA

- ✧ Statistically significant positive differences indicate improved perception of the new CMF design.
- ✧ A significant deviation from a 50/50 split indicates an overall design preference.
- ✧ Parameter rankings reveal which experiential dimensions most strongly influence passenger judgment.
- ✧ Qualitative input informs final refinement prior to prototyping.

EXAMPLE QUESTION



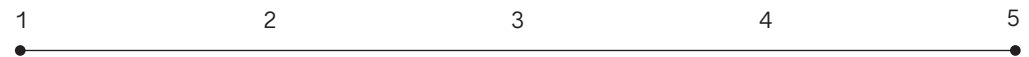
Design A
(Unbranded current KLM Design in a wide angle view and close up view render)



Design B
(New CMF Design from this thesis in a wide angle view and close up view render)

Please indicate to what extent you agree with the following statement for each of the two CMF designs:

"This CMF design looks comfortable."



1 = Strongly disagree

5 = Strongly agree

HYPOTHESES

- H1:** The new CMF design is rated significantly higher than the current KLM CMF across all six parameters in all three cabin classes.
- H2:** Parameters are ranked in descending importance as premium feel, comfort, cleanliness, aesthetic appeal, modernity, and sustainability perception.
- H3:** A majority of participants (>50%) prefer the new CMF design across all cabin classes.
- H4:** Screen-related variation introduces random noise but does not bias within-subject comparisons.

COMPARABLE STUDIES

- ☀ Gabbatore & Germak (2019): Evaluated aircraft cabin CMF schemes using full-cabin static visual projections combined with 5-point Likert ratings for comfort, elegance, and stress. It is referenced because it demonstrates that static visual stimuli can reliably capture perceived comfort and atmosphere in early-stage aircraft cabin CMF evaluation, directly aligning with the visual-comparative approach used in this test.
- ☀ Lee & Choi (2020) Validated the use of printed 2D renderings to assess passenger comfort perceptions of seat designs through Likert-scale ratings. It is included as it provides methodological justification for using image-based renderings instead of immersive environments when evaluating visual comfort and design impressions.
- ☀ Vledder et al. (2023): Applied a within-subject experimental design with Likert scales and open-ended questions to compare passenger comfort perception across transport modes (N = 130). It is cited because its within-subject structure and combination of quantitative and qualitative measures closely parallel the comparative evaluation framework adopted in this test.
- ☀ Ahmadvpour et al. (2014): Investigated aircraft passenger comfort by distinguishing comfort from discomfort and emphasized the importance of qualitative explanations alongside quantitative ratings. It is referenced as it supports the inclusion of short written explanations to interpret perceptual dimensions such as aesthetics, calmness, and overall experience beyond numerical scores.



.....

2. PARAMETER IMPORTANCE

“Rank the six parameters according to their importance in forming your judgment.”



.....

3. OVERALL PREFERENCE

“Overall I prefer design design X in Economy class.”

Design A Design B

“Overall I prefer design design X in Economy Comfort class.”

Design A Design B

“Overall I prefer design design X in Business class.”

Design A Design B

RESULTS 1: PASSENGER EXPERIENCE

Across all three cabin classes, the proposed CMF concepts (Design B) received higher mean Likert ratings than the current reference interior (Design A) on all six passenger-experience dimensions, based on responses from 57 participants. All participants traveled by plane in the last 12 months and are of equally varied ages and genders. In Economy class, paired-sample t-tests revealed statistically significant improvements for comfort, aesthetic appeal, sustainability perception, modernity, and cleanliness ($p < .05$), whereas the increase in perceived premium feel did not reach significance ($p = .130$), despite a visible difference in mean scores. This indicates greater inter-participant variability for the premium feel construct in Economy, reducing statistical power despite a comparable effect magnitude. In Economy Comfort and Business Class, all six parameters showed statistically significant positive differences in favor of Design B ($p \leq .001$). The largest and most robust effects were observed for premium feel and aesthetic appeal in Business Class, accompanied by relatively low standard deviations, indicating both strong and consistent perceptual shifts. Sustainability perception showed smaller absolute mean differences but remained significant, particularly in the higher classes, suggesting that material cues were interpreted more coherently when aligned with premium contextual expectations.

Overall, the results demonstrate that the new CMF direction systematically enhances perceived cabin quality across experiential dimensions, with increasing effect strength and perceptual agreement from Economy to Business Class. While visual and material updates already improve most attributes in Economy, the non-significant change in premium feel suggests that this construct is more context-dependent and less reliably conveyed through CMF alone in lower service classes, requiring either stronger sensory cues or complementary spatial and service-related design interventions.

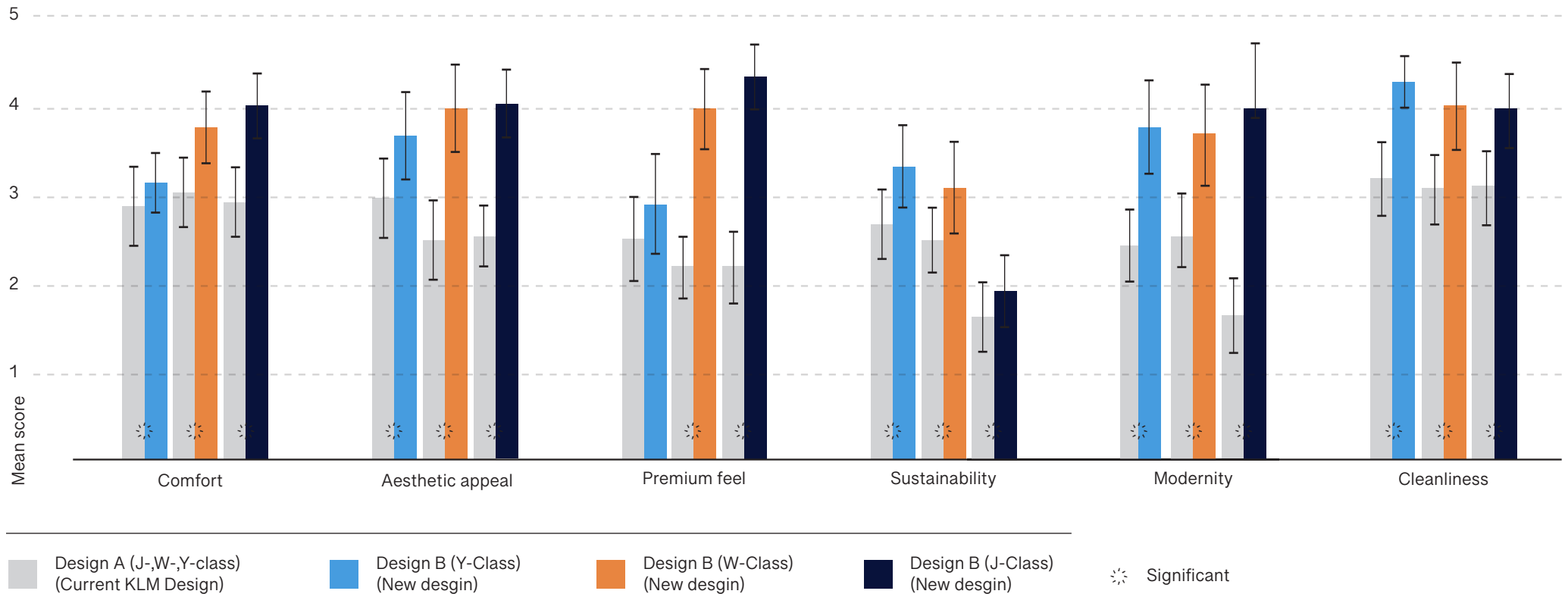


Figure 48: Mean Likert ratings (1 = strongly disagree, 5 = strongly agree) for perceived comfort, aesthetic appeal, premium feel, sustainability, modernity, and cleanliness of the current KLM cabin CMF (Design A) and the proposed CMF concepts (Design B) across Y-, W-, and J- class.

RESULTS 2: PARAMETER IMPORTANCE HIERARCHY ANALYSIS

Analysis of the importance ranking task revealed a significant difference in importance across the six parameters ($p < .001$). Comfort emerged as by far the most important attribute ($M = 5.52$), followed by cleanliness ($M = 4.74$). Premium feel occupied an intermediate position ($M = 3.07$), while aesthetic appeal ($M = 2.74$), sustainability perception ($M = 2.69$), and modernity ($M = 2.26$) were ranked as less influential in overall passenger judgment. This hierarchy suggests that functional and hygiene-related qualities dominate passenger priorities, whereas symbolic and future-oriented impressions, although relevant, play a secondary role in shaping overall passenger experience.

Parameter	Mean	Median	SD	% "Most Important" (6)
Comfort	5.52	6	0.94	69.1%
Cleanliness	4.74	5	1.09	20.0%
Premium feel	3.07	3	1.27	0%
Aesthetic appeal	2.74	2	1.47	5.5%
Sustainability	2.69	3	1.39	3.6%
Modernity	2.26	2	1.08	0%



Hierarchy results (from most important to least important):

1. Comfort
2. Cleanliness
3. Premium feel
4. Aesthetic appeal
5. Sustainability
6. Modernity

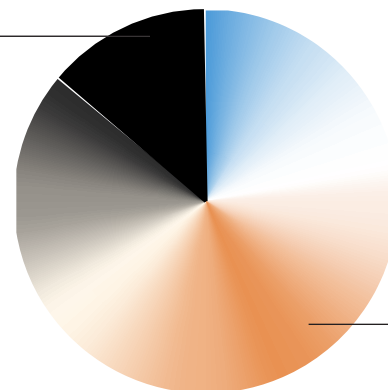
Figure 4.2.2.2.

Mean importance rankings (1 = least important, 6 = most important) of six experiential parameters (comfort, aesthetic appeal, premium feel, sustainability, modernity, cleanliness) aggregated across all participants, illustrating the relative hierarchy of attributes contributing to overall cabin evaluation.

RESULTS 3: OVERALL PREFERENCE

When participants were asked to indicate their overall design preference, a clear majority selected the new CMF concept. Of the valid responses ($n = 57$), 49 favoured Design B and only 8 preferred Design A. A chi-square goodness-of-fit test against an equal 50/50 distribution confirmed that this deviation was highly significant ($p < .001$), indicating a large effect. This strong preference corroborates the parameter-level findings and demonstrates that, when considered holistically, the new CMF design direction is perceived as substantially more appealing than the current cabin reference across the evaluated passenger classes.

DESIGN A
14%
n=8



DESIGN B
86%
n=49

Figure 49: Overall design preference distribution for the current CMF (Design A) and the proposed CMF (Design B) across all cabin classes, expressed as percentage of respondents. A chi-square goodness-of-fit test confirmed a statistically significant deviation from a 50/50 distribution in favor of the new CMF design.

QUALITATIVE THEMES

1. Perceived cleanliness and maintenance

Perceived cleanliness emerged as a dominant evaluation criterion, extending beyond hygiene to include visual cues of maintenance and durability. Darker upholstery and finishes were consistently preferred, as they were associated with improved stain concealment and a more enduring clean appearance. Light colors were occasionally perceived as fresh, but were predominantly regarded as impractical in an aviation context due to concerns about visible wear and long-term cleanliness. These findings indicate that visual signals of maintainability play a critical role in passenger experience.

2. Visual appeal and premium feel

Participants strongly associated perceived premium quality with material contrast, color depth, and compositional coherence. The proposed CMF direction, particularly in Economy Comfort and Business Class, was described as visually richer and more refined, while the current reference design was frequently perceived as outdated or generic. Subtle detailing, such as accent textiles and coordinated flooring, contributed significantly to perceptions of comfort and luxury, suggesting that premium perception is driven by nuanced material and color interactions rather than by single elements in isolation.

3. Spatial and emotional experience

The new CMF designs were generally perceived as more spacious, calming, and emotionally balanced, particularly in Economy and Business Class. Lighter tonal compositions and reduced visual clutter contributed to impressions of openness, modernity, and higher quality. In contrast, the uniformity of the current design was often described as visually dense or emotionally flat. Participant responses revealed a tension between familiarity and novelty, with some favouring established visual conventions associated with trust and comfort, while others preferred a more contemporary and differentiated cabin atmosphere.

DISCUSSION

This study set out to evaluate whether a new three-class CMF direction would improve perceived passenger experience, to identify which parameters most influence passenger judgment, to identify the overall preference for design A or B and to gather insight in the passengers reasoning. Findings show that the new designs (Design B) outperformed the current KLM reference (Design A) across all six parameters, comfort, aesthetic appeal, premium feel, sustainability, modernity, and cleanliness, with particularly strong effects in higher service classes. Economy showed more variability, especially for premium feel.

The attribute ranking revealed that comfort and cleanliness are perceived as most important, confirming that sensory and functional factors remain central to passenger experience. Qualitative feedback reinforced these results and provided deeper insight into how material contrast, cleanliness cues, and perceived class separation shape emotional responses and expectations. A key strength of the study lies in its within-subject design, which controls for individual variation and enables more robust conclusions from a modest sample.

LIMITATIONS

Several limitations should be acknowledged when interpreting these findings. First, the study relied on visual stimuli rather than in-situ or full-scale mock-ups, which may have constrained participants' ability to accurately judge tactility and spatial qualities. Second, Likert-scale data were treated as interval-level for the purpose of calculating mean scores and conducting parametric tests, an assumption that is common in design research but nonetheless introduces a degree of methodological approximation. Third, the sample size, while sufficient to detect medium to large effects, limits the generalisability of the results to the broader flying population and does not allow for detailed subgroup analyses (e.g., by age, gender, travel frequency, or cultural background). Finally, the importance ranking task captured relative priorities but did not measure trade-offs in real choice situations, which may differ under actual booking or in-flight conditions.

CONCLUSION

The evaluation demonstrates that the proposed CMF designs significantly enhance perceived cabin quality across Economy, Economy Comfort, and Business class, with the strongest and most consistent gains observed in the higher service classes. Improvements were particularly evident for comfort, aesthetic appeal, premium feel, modernity, and cleanliness, and were supported by a pronounced overall preference for the new concept. The importance hierarchy further indicates that comfort and cleanliness dominate passenger judgment, suggesting that CMF interventions should primarily reinforce these parameters. All together, the results provide quantitative evidence that the new CMF direction constitutes a meaningful improvement over the current reference and offers a robust basis for further design refinement and prototyping.



4.2 BC PROTOTYPING

Bacterial cellulose (BC) foam prototyping focused on leveraging the material's tunable properties to create multiple interior material analogues. Four distinct BC foam variants were developed, each intended to replicate a different conventional aircraft interior material.

All four variants were fabricated as 3D block samples to serve as tactile demonstrators of their properties. In addition, a 3D-printed scale model (approximately 1:3 scale) was constructed to showcase the BC foam applications in context. One seat model features a removable cushion assembly to expose its layered construction, while the other is cross-sectioned to reveal the BC foam integrated within the seat structure. The largest seat cushion in this model measures 15 cm across (versus ~46 cm full size), representing an approximate one-third scale. This combination of sample blocks and the scaled seat model clearly illustrates the material–system integration of the BC foam, providing a tangible demonstration for reviewers and stakeholders.



Figure 50: Making samples.
Source: Author.



Figure 51: 3D printed scale model (~1:3).
Source: Author.



Figure 52: Four digital materials.
Source: Author.

4.2.1

BC PHYSICAL PROTOTYPING

BC foam prototyping focused on exploring the material's tunable mechanical and surface properties through the fabrication of four distinct material samples, each intended to possibly replace a conventional aircraft interior material in the future. The samples were produced as physical demonstrators to support evaluation and material understanding. Due to intellectual property considerations, details regarding recipes, processing parameters, and production methods remain confidential and are therefore not disclosed in this thesis.

Sample 1: Hard BC foam

This sample represents a high-density, rigid foam configuration intended to approximate the mechanical behavior of polyurethane foam cores used in structural seat components. The material is characterised by high stiffness, low elastic recovery, and dimensional stability, making it suitable for load-bearing or form-stable applications such as seat pan cores or internal structural elements.



Sample 2: Soft BC foam

This sample represents a low-density, flexible BC foam intended for cushioning applications. It is characterised by high compressibility, elastic recovery, and soft tactile response, reflecting functional requirements associated with seat pan cushions, backrest cushions, and headrest padding.



Sample 3: BC leather alternative

This sample represents a thin BC foam combined with a protective surface coating to emulate the appearance and performance of coated textiles or synthetic leather upholstery. The material is characterised by flexibility, surface smoothness, and enhanced abrasion resistance, and is intended to approximate upholstery materials used in visible seat surfaces while retaining a bio-based substrate.



Sample 4: Rigid BC material

This sample represents a rigid BC foam configuration intended to approximate the mechanical characteristics of ABS plastic used in hard interior components. It is characterised by high rigidity, dimensional stability, and dense morphology, making it suitable as a conceptual substitute for components such as tray tables, armrest structures, and seat shell elements.



Combining sample 1 and 2 into one volume

A key objective is to integrate the functional roles of Samples 1 and 2 into a single, graded BC foam volume. Such an approach would among others, simplify end-of-life processing, and strengthen the monomaterial design strategy of the seat. Ongoing research exploring this concept is conducted by Tiemen Kos as part of his MSc thesis.



4.2.1

BC DIGITAL PROTOTYPING

Four bacterial cellulose (BC) material variants were digitally reconstructed in Adobe Substance 3D using image-based capture and physically based rendering (PBR) workflows. High-resolution surface photographs were converted into seamless texture maps (base color, normal, roughness, and height), capturing key micro-structural features such as porosity, fiber distribution, and surface reflectance. The resulting materials were applied to 3D geometry in Blender, enabling physically plausible lighting interaction and scale-consistent comparison, and supporting digital prototyping of BC components within this thesis.

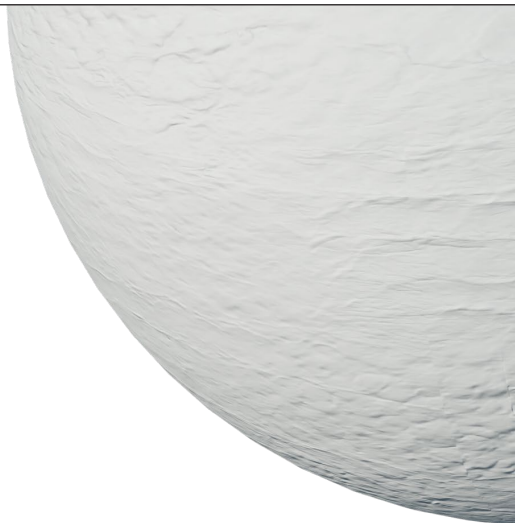
Sample 1: Rigid BC foam



Sample 2: Soft BC foam



Sample 3: BC Leather alternative



Sample 4: ABS Like BC



1: HARD BC FOAM

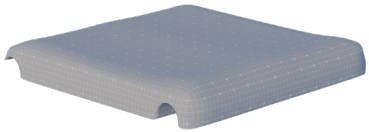


Material properties

- ⚙ High stiffness
- ⚙ Low recovery
- ⚙ Structural stability

Refurbishment frequency: 10+ years

Parts with this material:



Seat pan core

2: SOFT BC FOAM

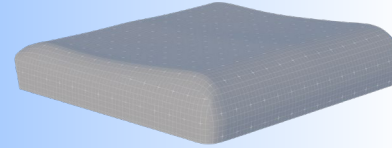


Material properties

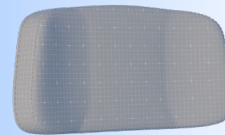
- ⚙ High compressibility
- ⚙ Elastic recovery
- ⚙ Soft tactility

Refurbishment frequency: 5-10 years

Parts with this material:



Seat pan cushion

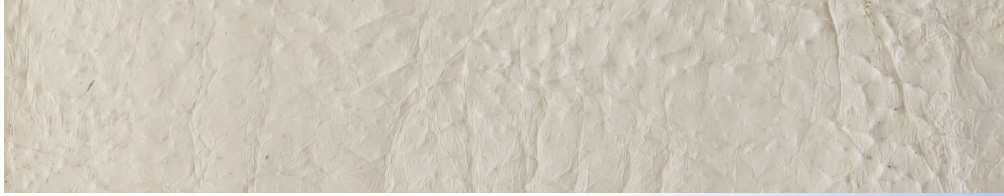


Headrest cushion



Backrest cushion

3: BC LEATHER ALTERNATIVE

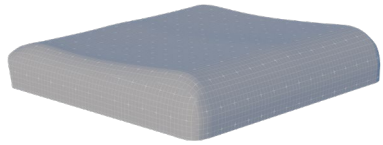


Material properties

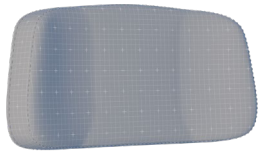
- ✦ Flexible
- ✦ Smooth surface
- ✦ High tensile strength

Refurbishment frequency: 5-10 years

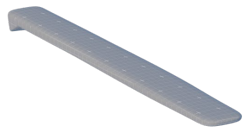
Parts with this material:



Seat pan upholstery

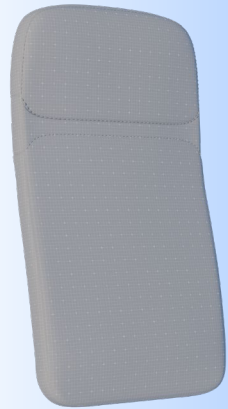


Headrest upholstery



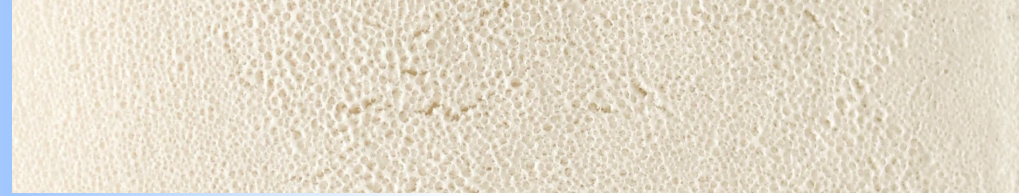
Armrest upholstery

Ditail material



Backrest upholstery

4: RIGID ABS LIKE BC

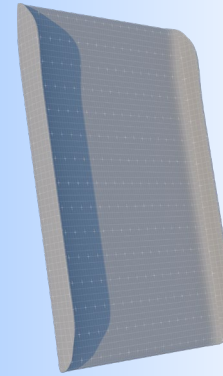


Material properties

- ✦ High rigidity
- ✦ Dimensional stability
- ✦ Dense morphology

Refurbishment frequency: 5-7 years for movable parts and 10+ years for static parts

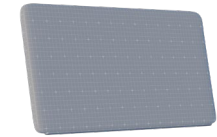
Parts with this material:



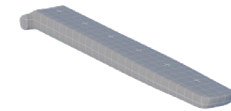
Seat shell



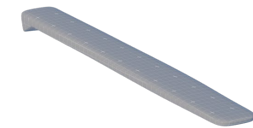
Seat pocket net frame



Tray table



Armrest lower



Armrest upper

SAMPLE 4: ABS LIKE BC

Total weight per seat: 2.69 kg
Percentage of total seat weight: 65%

SAMPLE 3: BC LEATHER

Total weight per seat: 1.21 kg
Percentage of total seat weight: 29%

SAMPLE 1: RIGID FOAM

Total weight per seat: 0.01 kg
Percentage of total seat weight: 2%

SAMPLE 2: FLUFFY FOAM

Total weight per seat: 0.16 kg
Percentage of total seat weight: 4%

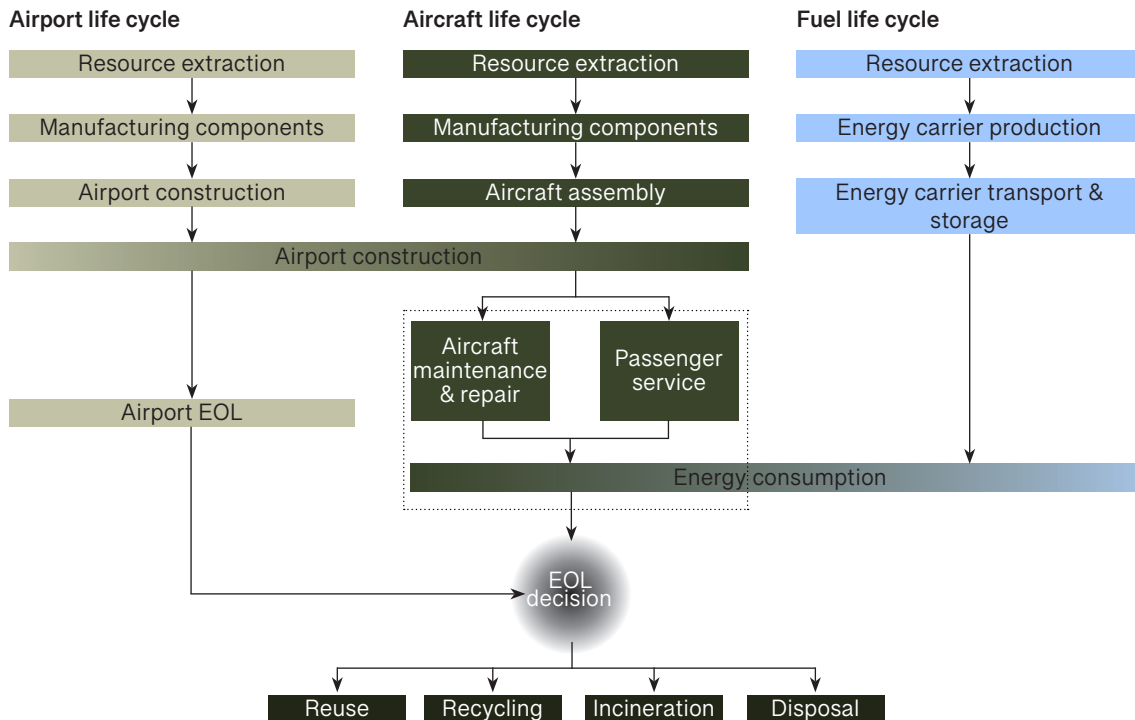


● 4.2.3. LIFE CYCLE ASSESSMENT (LCA)

Assessment (LCA) is applied to quantify potential CO² savings from material-driven cabin weight reduction. By translating CMF and material choices into operational emission values, the LCA provides evidence-based validation of the concept's sustainability claims. To quantify this effect in the operational-phase LCA, fuel consumption per trip is required, as CO² emissions are directly proportional to mission fuel burn. Typical take-off weight is additionally needed because aircraft mass strongly determines fuel consumption for a given mission, enabling weight reductions to be translated into operational emission savings (Scholz, 2013).

Research question: What is the difference in life-cycle CO²-equivalent emissions between aircraft seat components manufactured using polyurethane-based materials and those manufactured using bacterial cellulose-based materials, and what is the magnitude of this difference expressed in kg CO² per year per plane?

Figure 53: Aviation life-cycle system boundaries highlighting the operational phase. Data redrawn from Melo et al. (2020)



In aviation, the operational phase dominates environmental impact, with in-service fuel use accounting for approximately 70–80% of total life-cycle CO² emissions for commercial aircraft (Logan & Tunkel, 2024), far exceeding manufacturing and end-of-life contributions. Accordingly, this thesis focuses the LCA on the operations stage, where fuel burn and CO² output are primarily influenced by component weight, a parameter readily available at this stage of the project and at Foamlab. Heavier aircraft require more fuel and thus produce higher emissions, a relationship well recognized by airlines: Lufthansa reported that removing 1 kg across its fleet saved approximately 30 tons of fuel per year (Aircraft Monitor, 2018). Reducing weight is therefore a direct and effective means of lowering operational fuel burn and emissions.

Research question: What is the difference in life-cycle CO²-equivalent emissions between aircraft seat components manufactured using polyurethane-based materials and those manufactured using bacterial cellulose-based materials, and what is the magnitude of this difference expressed in kg CO² per year per plane?

FUEL CONSUMPTION PER TRIP

To quantify operational emissions, we first need to find a way to accurately estimate the fuel consumption per trip, since this is sensitive data which is not available to the public. In order to do so we employ a method based on the aircraft's payload–range diagram, found in Embraer's public Airport Planning Manual of the three E-Jets. A payload–rang diagram illustrates the trade-off between the distance an aircraft can fly and the amount of payload (passengers and cargo) it can carry. It typically has two “kinks” or breakpoints that define three regions of operation (Aerostudents, n.d.). The three phases will now be explained to understand the diagram better.

Phase A

Up to the first kink, the aircraft can carry its maximum payload and still add fuel for additional range (payload stays constant while range increases). At this point, the aircraft reaches its maximum take-off weight (MTOW) condition with full payload.

Phase B

Beyond this, any further increase in range requires trading payload for more fuel, this is shown by a linear descending section of the diagram where payload is gradually reduced as range increases. This linear relationship holds until the second kink, where the aircraft's fuel tanks are full (fuel capacity reached) and no additional fuel can be loaded (Aerostudents, n.d.). At the second kink, the aircraft is typically at maximum fuel and a greatly reduced payload. In fact, the difference in payload between the first and second kink is essentially replaced by an equal weight of fuel. This means any payload offloaded in phase B directly translates to extra fuel on board, enabling longer range (Aircraft Monitor, 2018).

Phase C

Beyond the second kink (the ferry range region), no further fuel can be added, so only by removing all payload can range be slightly extended (which is usually uneconomical).

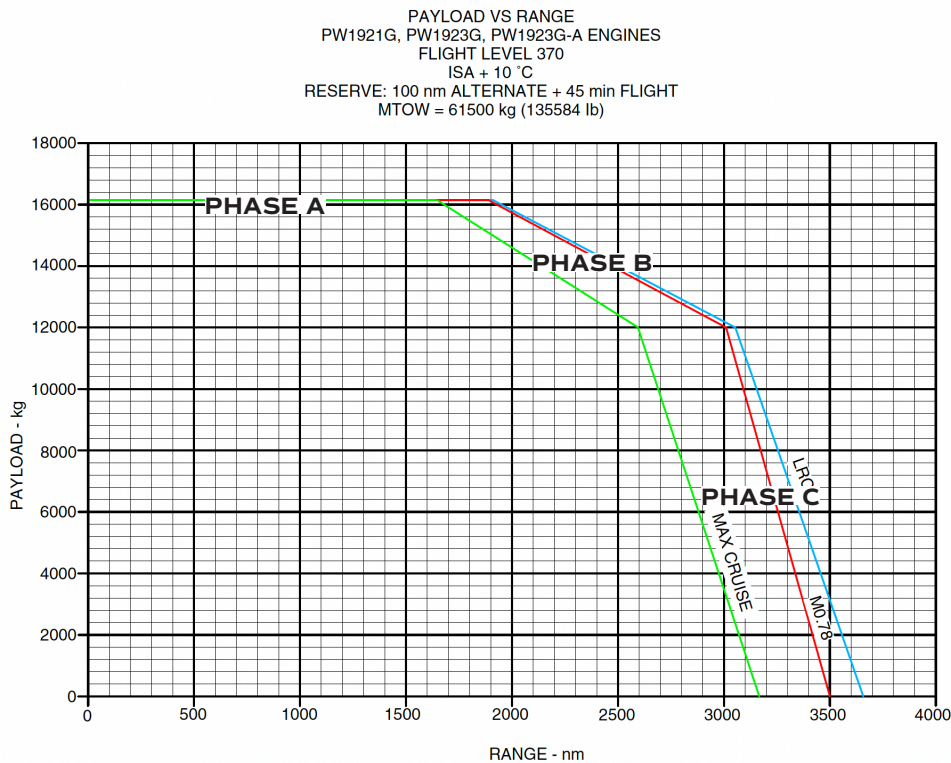


Figure 54: Payload x Range - ISA Conditions. Source: Embraer 195 E2 (Airport Planning Manual, 2024)

Using this diagram, I derive a fuel-to-distance ratio for the Embraer 195 E2 aircraft. In the approximately linear regime between the first and second kink, fuel burn increases almost in proportion to the distance. For example, trading 1 kg of payload for 1 kg of fuel allows the aircraft to fly a bit farther, effectively a constant marginal fuel per distance. (This is supported by empirical data: roughly 0.2 kg of fuel is needed to carry 1 kg of weight over 1000 km (Steinegger, 2018), indicating near-constant fuel requirements per unit weight-distance over a range of operation.) I therefore assume a constant fuel burn per kilometer in this range (see page for further assumptions). From the payload–range chart, I obtain a specific value for this fuel-to-range fraction (in kg fuel per nm) based on the aircraft's performance. Multiplying this fraction by a representative average trip range gives the fuel consumed per average trip. For this average trip range, I use a trip distance of 800 nm (nautical miles), which is the advertised distance for the 195-E2. (Embraer, 2025) With these parameters, it is possible to make an accurate estimation of the fuel per trip. The calculation is as follows:

$$\text{Fuel per trip (kg)} = \left(\frac{\Delta \text{Fuel}}{\Delta \text{Range}} \right) \times (\text{Average trip range}).$$

In words, I use the slope of the payload–range trade-off (fuel per unit distance) between kink one and two, and multiply it by the chosen average trip distance. This yields an approximate fuel burn for one trip of this design. I obtain delta fuel (kg) and delta range (nm) from two points on the linear portion of the payload–range curve, for example, between the point of maximum payload range and the point of maximum fuel. I acknowledge that this method simplifies reality, however, it is the only viable approach in the absence of operational data and it captures the dominant effect of range on fuel consumption based on the available information.

TYPICAL TAKE-OFF WEIGHT (TOW) VS MAXIMUM TAKE-OFF WEIGHT (MTOW)

It is important to note that for an average mission, the aircraft will not always depart at MTOW. On shorter routes, the plane may be payload-limited (full of passengers) but does not need to fill the tanks with fuel, due to trip range, resulting in a lower take-off weight. Using the payload–range analysis, I can estimate a more realistic take-off weight for the average trip (800 nm), compared to the MTOW, which is publicly available data. This is aimed to increase accuracy of my calculations and therefore LCA correctness.

Essentially, I start from the MTOW scenario and subtract the unused fuel weight (since shorter trips require less fuel). As discussed, the first kink of the payload–range diagram corresponds to the scenario where the aircraft is at MTOW with maximum payload loaded and just enough fuel for that maximum-payload range. I denote the fuel weight in this scenario as F_{MTOW} (this is the fuel weight at the point where adding more fuel would force a payload reduction). For an average range trip, the required fuel will be less, call this F_{AVG} . The difference $F_{MTOW} - F_{AVG}$ is the fuel weight we do not need to carry on the average trip. Therefore, the average take-off weight can be approximated by:

$$TOW_{avg} \approx MTOW - (F_{MTOW} - F_{avg}).$$

In other words, I subtract the excess fuel (beyond what the average mission requires) from the max take-off weight. This yields a lower estimated TOW for the representative trip. Taking the Embraer 195-E2, with a MTOW of 62,000 kg, and at the MTOW point, it would carry 12,000 kg of fuel, but an average 800 km trip needs only, say, 6,000 kg of fuel, then roughly 6,000 kg of weight is saved on that trip. The take-off weight in that case would be about 56,000 kg instead of the full 62,000 kg. In practice, airlines often operate below MTOW for most trips, carrying full payload but not topping off the fuel tanks if the distance is short. The earlier Lufthansa example is illustrative: they physically removed extra fuel tanks from some long-range aircraft because those tanks were unnecessary for the shorter routes they actually flew (Aircraft Monitor, 2018). By doing so, the operating empty weight dropped, and the planes could carry more payload or burn less fuel, demonstrating that typical missions rarely use an aircraft's full range (and weight) capability. This TOW estimate aligns with this real-world behavior by reflecting a more realistic weight in the operational phase of the LCA, compared to using the MTOW.

Because the TOW_{avg} is lower than the MTOW, the fuel burn per kilogram of aircraft mass becomes relatively higher, meaning that weight savings achieved by replacing PU-based materials with lighter bacterial cellulose components result in a proportionally larger CO_2 -equivalent reduction in the operational-phase LCA.

FUEL COMBUSTION AND CO_2 EMISSION CALCULATION

With fuel burn per trip known, CO_2 emissions can be estimated assuming complete combustion of conventional Jet-A fuel. Each kilogram of jet fuel produces approximately 3.15–3.16 kg of CO_2 (ICAO, 2016), based on its hydrocarbon composition and stoichiometric oxidation. Carbon (≈ 85 –86% of jet fuel by mass) oxidizes to CO_2 , with 1 kg of carbon yielding 3.67 kg of CO_2 (molecular weight ratio 44/12). Multiplying this by the carbon fraction results in about 3.1–3.2 kg CO_2 per kg of fuel, consistent with the standard emission index of 3.16 used in aviation (ICAO, 2016, 2022).

Accordingly, CO_2 emissions per trip are calculated by multiplying fuel mass by 3.16 kg CO_2 /kg fuel. In life-cycle assessments, this value is typically scaled by annual flight activity and aircraft lifetime; regional jets operate approximately 2,500–3,500 flights per year, with $\sim 3,000$ flights commonly adopted as a representative average (Scholz, 2013; Eurocontrol, 2021).

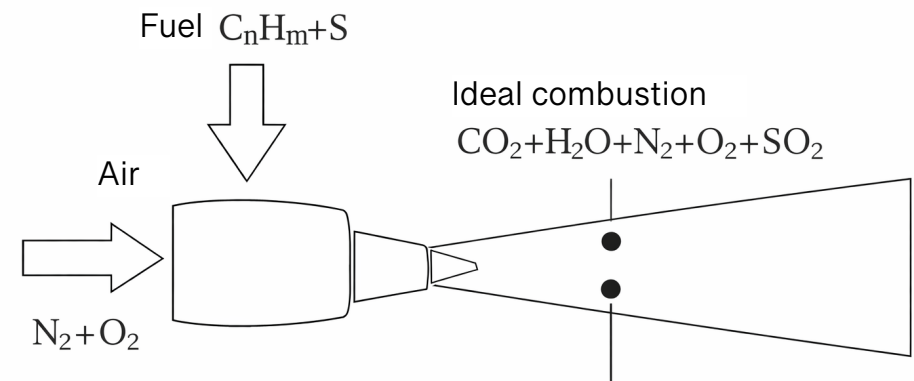


Figure 55: Schematic of ideal aircraft engine combustion process

ASSUMPTIONS

Several assumptions underlie this analysis and estimation approach:

- ✧ Representative flight profile: A single average mission distance of approximately 800 nautical miles is used to estimate fuel burn. Although operational ranges vary, this value reflects typical utilization of the Embraer 195-E2 and provides a consistent baseline for LCA purposes (Embraer, 2025).
- ✧ Aircraft weight usage: MTOW and associated structural limits are used as reference points, assuming high load factors and near-full payload. As average missions do not require full fuel tanks, MTOW-based fuel estimates are adjusted downward to a representative average take-off weight.
- ✧ Linear fuel–range scaling: Fuel consumption is assumed to scale linearly with range within the relevant operational envelope, supported by the near-linear segment of the payload–range diagram between maximum-payload and maximum-fuel conditions. Non-linear effects related to in-flight fuel burn are neglected, which is acceptable for high-level LCA estimates over moderate ranges (Aerostudents, n.d.; Aircraft Monitor, 2018).
- ✧ Complete combustion to CO₂: All burned fuel is assumed to be fully converted to CO₂ using a constant emission factor of 3.16 kg CO₂ per kg of fuel. Non-CO₂ effects such as NO_x emissions and contrail formation are excluded, as are upstream emissions from fuel production.
- ✧ Constant fuel properties: The analysis assumes conventional Jet-A/A1 fuel with constant carbon content and energy density. Alternative fuels or blends are not considered, as these would alter the fuel-to-CO₂ conversion factor and life-cycle emissions.
- ✧ Seat mass distribution assumption: The analysis assumes the primary structural base frame accounts for 35% of total seat mass, which is not redesigned in this thesis. This assumption is consistent with published data on next-generation economy seats from Expliseat and comparative industry benchmarks reported by Collins Aerospace (Expliseat, 2020; Collins Aerospace, 2019).

These assumptions enable an operational-phase LCA within the conceptual scope of this thesis. While they simplify real-world variability, they are grounded in authoritative sources and considered appropriate for a comparative assessment.

GOAL & SCOPE

This Life Cycle Assessment (LCA) was conducted to quantify the operational-phase CO₂ emission difference between aircraft seats manufactured using conventional polyurethane-based materials and seats manufactured using bacterial cellulose-based alternatives. The LCA serves as an evidence-based validation of the sustainability potential of material-driven CMF decisions at aircraft interior component level.

The functional unit is defined as one Embraer 195-E2 aircraft operated for one year under representative short-haul conditions. The system boundary is limited to the operational phase, as in-service fuel consumption dominates the life-cycle greenhouse gas emissions of commercial aircraft, accounting for approximately 70–80% of total life-cycle CO₂-equivalent emissions (Scholz, 2013; Logan & Tunkel, 2024). Manufacturing and end-of-life phases are excluded, consistent with early-stage comparative aviation LCAs.

Aircraft operational parameters were obtained from publicly available Embraer documentation and aviation literature, while seat geometries were derived from a detailed Blender model with identical volumes for baseline and redesigned seats. Material density data for conventional components were sourced from established databases (Ashby, 2017), and bacterial cellulose properties were measured from physical samples produced and characterized at Foamlab. The impact category considered is Global Warming Potential (GWP₁₀₀), expressed in kg CO₂-equivalent.

HYPOTHESIS

Replacing conventional polyurethane-based aircraft seat materials with bacterial cellulose-based alternatives results in a measurable reduction in operational-phase CO₂ emissions for the Embraer 195-E2, due to material-driven seat mass reduction that lowers aircraft fuel consumption under representative short-haul operating conditions.



LIFE CYCLE INVENTORY (LCI)

The Life Cycle Inventory defines operational fuel use and mass parameters for a representative short-haul Embraer 195-E2 mission (Figure X). Fuel consumption is derived from the linear portion of the payload–range diagram, assuming proportional scaling with range and carried mass under typical operating conditions. Operational CO₂ emissions are calculated from mission fuel burn using a standard Jet-A emission factor and scaled to annual utilization. Seat-level mass differences are quantified using identical geometries to isolate material effects, with conventional material densities taken from established databases and bacterial cellulose densities measured from Foamlab samples. The resulting seat mass reduction is aggregated at aircraft level and forms the basis for the impact assessment.

Embraer 195-E2 for a typical short haul 800nm mission

MOTW (maximum take-off weight)	61,500 kg
TOW (take-off weight)(for an 800 nm mission)	56,508 kg
Payload (for an 800 nm mission)	16,000 kg
Fuel per trip	4,698 kg
Seats	120
Flights per year	3,000

Figure X. Operational parameters for the Embraer 195-E2 representative short-haul mission

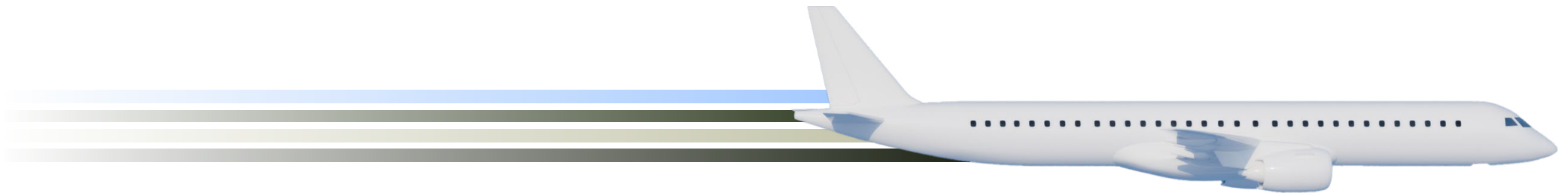
LIFE CYCLE IMPACT ASSESSMENT (LCIA)

For the Embraer 195-E2, the aircraft-level mass reduction of 672 kg results in a fuel burn reduction of approximately 56.5 tonnes of fuel per year, which corresponds to approximately 535,000 kg CO₂ per aircraft per year. Normalized per seat, this equals approximately 4,460 kg CO₂ saved per seat per year. At component level, the relative contributions to total seat mass reduction and the current design are listed in the table below.

	Sample 1 (Soft foam)	Sample 2 (Hard foam)	Sample 3 (BC upholstery)	Sample 4(Hard BC)	Total
Weight old part [gr]	490	913	2,042	3,055	6,500
Weight new part [gr]	58	103	804	1,782	2,748
Weight saving/seat/trip [gr]	-432	-810	-1,238	-1,273	-3,752
Fuel saving/plane/trip [kg]	-4.31	-8.08	-12.35	-12.70	-37.44
CO ₂ saving/plane/year [kg]	-40,868.51	-76,584.54	-117,066.99	-120,379.76	-354,899.81
CO ₂ saving/5 years [kg]	-204,342.55	-382,922.69	-585,334.97	-601,898.82	-1,774,499.04
CO ₂ saving/10 years [kg]	-408,685.11	-765,845.39	-1,170,669.94	-1,203,797.65	-3,548,998.08

Figure 57: LCA results table.

*LCA disclaimer. Results are based on a simulation model and assumed parameters, not on measured data from a real aircraft seat or in-service operation. Values are indicative and comparative only.



By lowering the total plane weight with 450 kg we save:

**355.000
KG CO₂**

**PER YEAR
PER PLANE**

*based on 120 seats per plane

**8.9 MILLION
KG CO₂**

**FOR THE TOTAL KLM FLEET
PER YEAR**

*based on 25 Embraer 195-E2's in the KLM fleet in 2025

**58.6 MILLION
KG CO₂**

**FOR ALL EMBRAER 195-E2
IN OPERATION PER YEAR**

*based on 165 Embraer 195-E2's in operation in 2025

**292.8 MILLION
KG CO₂**

**FOR ALL EMBRAER 195-E2
IN OPERATION PER 5 YEARS**

*based on 165 Embraer 195-E2's in operation in each of those years

Which is equal to about:



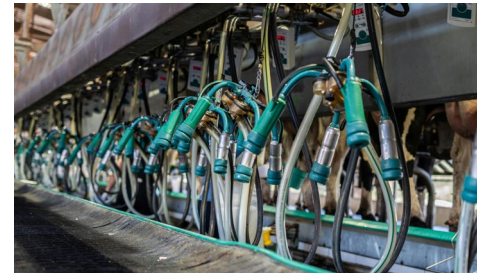
22 laps around the Earth in a petrol car (European Environment Agency, 2023)

Which is equal to about:



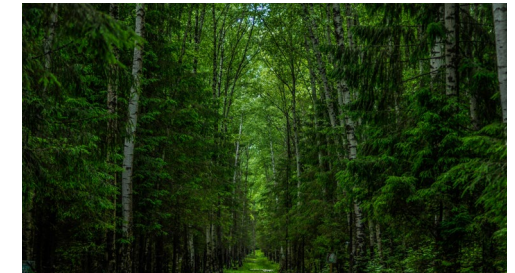
750 European homes heated for one year (Ivanova et al., 2020)

Which is equal to about:



Producing milk for the entire population of the Netherlands for one year. (Poore & Nemecek, 2018; FAO dairy footprint data)

Which is equal to about:



14 million mature trees absorbing CO₂ for one year (U.S. Forest Service, 2022)



1.8 million hot showers (IEA; DEFRA emission factors)



150,000 people eating beef burgers for one year (Poore & Nemecek, 2018)



30 million pairs of jeans manufactured (Levi Strauss LCA; WRAP textiles data)



Producing smartphones for the entire EU population once. (Apple Environmental Reports; European Commission population data)

*LCA disclaimer. Results are based on a simulation model and assumed parameters, not on measured data from a real aircraft seat or in-service operation. Values are indicative and comparative only.

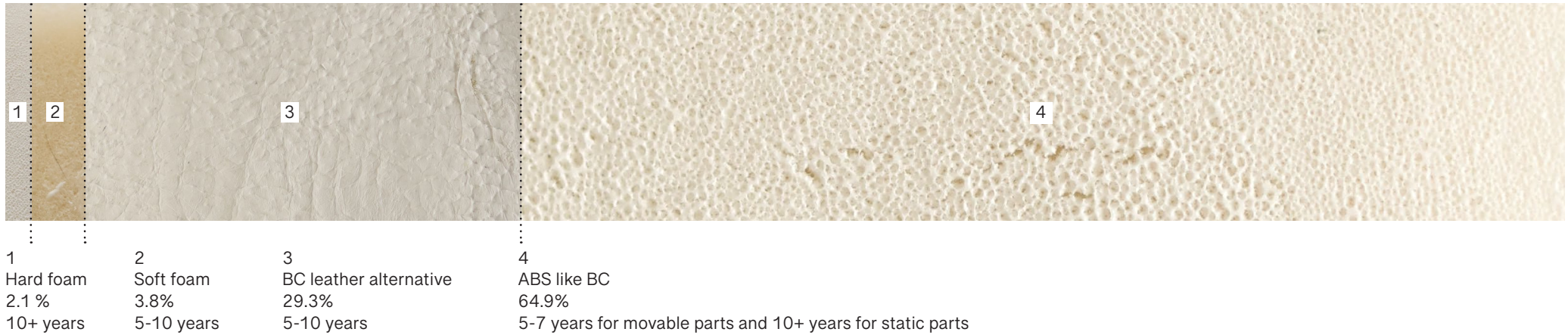


Figure 57: LCA results percentage of total weight and estimated refurbishment frequency, based on paragraph 2.7.4.. Source: Author.

INTERPRETATION AND DISCUSSION

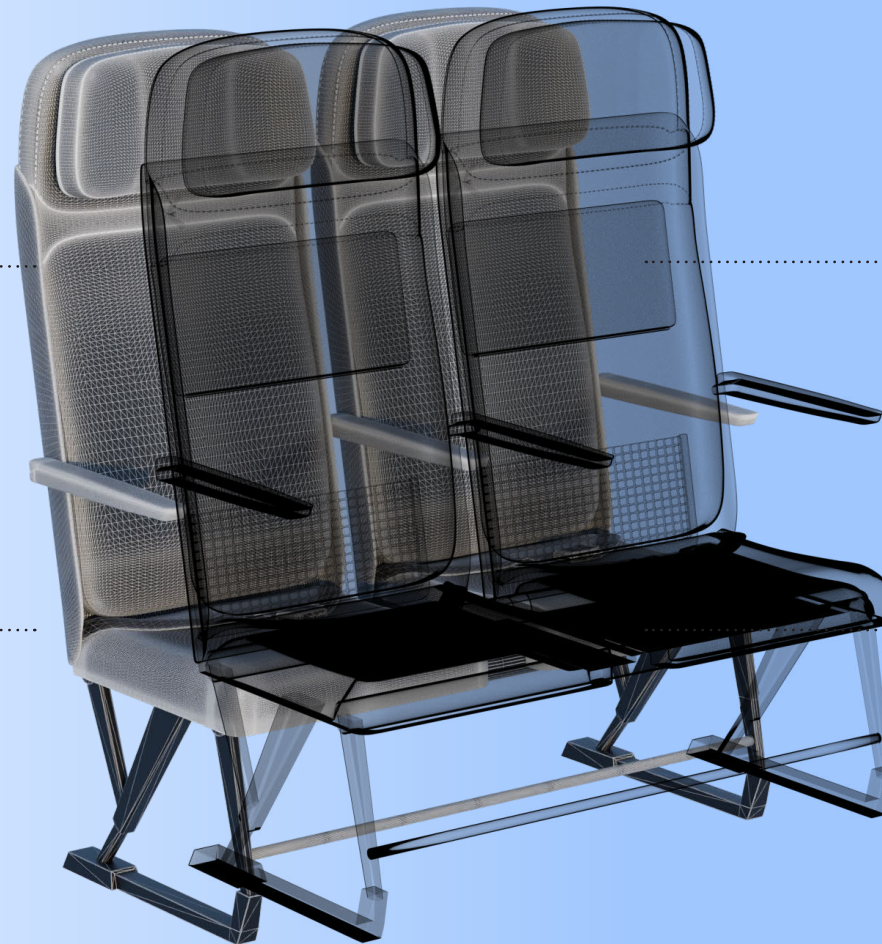
The results demonstrate that material-driven weight reduction at seat level yields substantial operational CO₂ savings at aircraft scale. The magnitude of the reduction is primarily driven by the dominance of fuel combustion in the aviation life cycle and the strong coupling between aircraft mass and fuel consumption.

The analysis confirms that mass-intensive components, particularly seat pan, cushioning, and structural shells, offer the greatest environmental leverage. Smaller components such as armrests and headrests contribute less individually but remain relevant when aggregated across the cabin. Several assumptions underlie this analysis, including linear scaling between weight and fuel burn, a representative mission profile, and exclusion of non-CO₂ effects such as NO_x emissions and contrail formation. These simplifications are consistent with early-stage aviation LCAs and do not alter the comparative conclusion. While production and end-of-life impacts were excluded, existing literature indicates that these phases are secondary relative to operational emissions for aircraft interior

CONCLUSION

This LCA shows that replacing conventional polyurethane-based seat materials with bacterial cellulose-based alternatives can reduce operational emissions by approximately 535 tonnes of CO₂ per aircraft per year for an Embraer 195-E2. The findings confirm that lightweight, bio-based CMF strategies constitute a highly effective intervention point for reducing aviation climate impact at the component level, particularly when applied across full cabin configurations.

TOTAL WEIGHT SAVINGS OF 3.8 KG PER SEAT WHICH IS 58% OF THE ORIGINAL WEIGHT



SAMPLE 4: ABS LIKE BC

Total weight saving per seat: 1.3 kg
% of weight/CO2 saved for this material: 41%

SAMPLE 3: BC LEATHER
Total weight saving per seat: 1.2 kg
% of weight/CO2 saved for this material: 61%

SAMPLE 1: RIGID FOAM

Total weight saving per seat: 0.4 kg
% of weight/CO2 saved for this material: 88%

SAMPLE 2: FLUFFY FOAM
Total weight saving per seat: 0.8 kg
% of weight/CO2 saved for this material: 89%

*LCA disclaimer. Results are based on a simulation model and assumed parameters, not on measured data from a real aircraft seat or in-service operation. Values are indicative and comparative only.

4.3.1 DISCUSSION

This thesis demonstrates that CMF design can function as both an experiential and environmental intervention point in short-haul aviation when material choices are treated as system-level decisions rather than primarily surface styling.

The forced-choice classification study confirmed that all three cabin class concepts were perceptually legible. Economy and Business classes were recognized with the highest accuracy, while Economy Comfort exhibited overlap with adjacent classes, predominantly with Economy. This indicates that the mid-tier class requires more explicit class-specific cues to reduce perceptual uncertainty. Qualitative driver analysis further revealed that the physical material tray was the dominant factor in participants' decision-making, outweighing the influence of moodboards, metaphors, and color palettes. This finding reinforces the value of tangible material prototyping in early-stage CMF development, as it integrates color, texture, finish, and perceived quality into a single evaluative artefact that closely reflects how passengers form their judgments.

During the second perceptual study, participants consistently prioritized the passenger experience parameters comfort and cleanliness, indicating that CMF cues are primarily interpreted through functional and hygiene-related meanings, after which aesthetic appeal, premium feel, modernity, and sustainability act as reinforcing attributes. This hierarchy suggests that regional aircraft cabins mostly improve through the use of materials and finishes that visually communicate ease of maintenance, durability, and tactility, besides decorative complexity.

The combined use of physical CMF prototypes and high-fidelity digital renderings strengthened the internal validity of the evaluation framework. Material trays, laser-cut pattern samples, and BC foam demonstrators enabled holistic engagement with material qualities, while digitally rendered cabin environments ensured geometric consistency and controlled lighting across comparisons. The physically based rendering workflow allowed perceptual differences to be attributed primarily to CMF decisions rather than visualization artefacts.

From a sustainability perspective, the operational-phase LCA demonstrates that seat mass reduction through the implementation of bacterial cellulose materials, replacing conventional polyurethane-based components, can translate into substantial CO₂ savings due to the dominance of fuel burn in the aviation life cycle. The analysis shows that the largest leverage lies in mass-intensive seat elements such as the seat shell, tray table, and armrests, which together accounted for the majority of the total weight reduction.

4.3.2. LIMITATIONS

Perceptual evaluation methods

Both CMF studies relied on static representations, consisting of physical CMF design elements or rendered visuals, rather than immersive or in-cabin evaluations. While consistent with comparable early-stage CMF research, this likely constrained assessment of full spatial experience, lighting interaction, and prolonged tactile experience and comfort. The forced-choice classification required assignment of a class to a design even in cases of uncertainty, potentially inflating classification rates for less clear designs. Likert-scale ratings were treated as interval-level data for parametric testing, a common but approximate practice in design research.

Sample size and representativeness

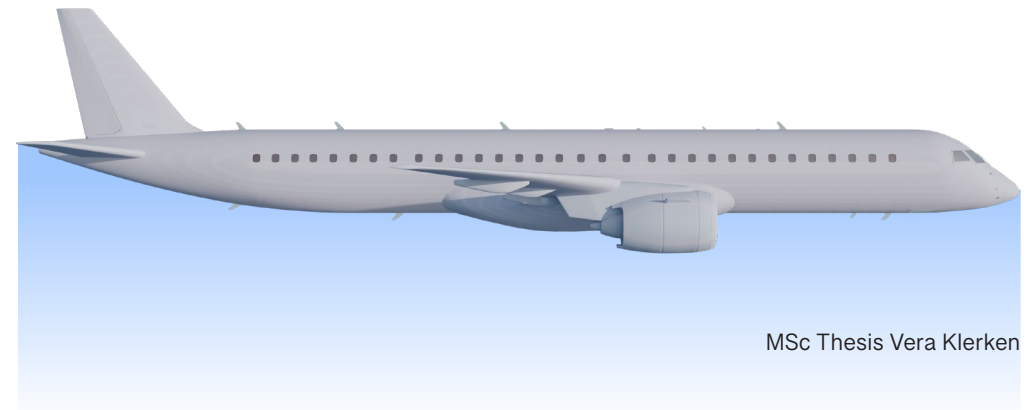
Sample sizes were sufficient to detect medium to large effects but limit generalisability and prevent subgroup analysis by demographics, travel frequency, or cultural background, which may influence CMF perception in real world airline contexts.

Representation of bacterial cellulose

The tactile and visual qualities of bacterial cellulose as a fully aviation-ready upholstery and foam system were not directly tested. At the time of the study, BC samples suitable for realistic surface finishing, color stability, and durability were not yet available, and further material processing fell outside the scope of this project. Bacterial cellulose was therefore represented in the report through self-developed digital twin materials and was not explicitly accounted for in the renderings. As a result, passenger experience specifically related to potential differences in texture and tactility of the BC material has not yet been evaluated.

LCA scope and modeling assumptions

The LCA was limited to the operational phase and excludes manufacturing, refurbishment, and end-of-life impacts, as well as non-CO₂ climate effects. Although refurbishment frequency of seat components is discussed in the report, it was not incorporated into the LCA, which focuses exclusively on mass-driven fuel burn. Fuel consumption was estimated using publicly available data and assumptions within a representative mission profile. Seat mass differences were derived from identical design geometries combined with material density inputs, resulting in design-stage estimates rather than certified data.



4.3.3. CONCLUSION

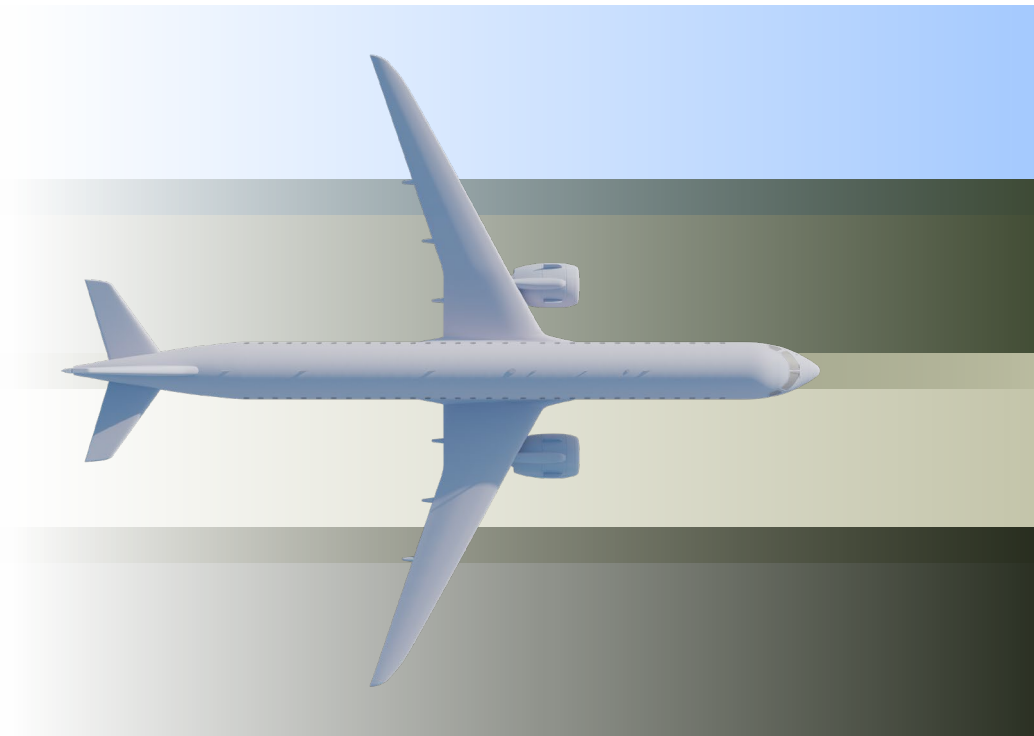
This thesis developed and validated a three-class cabin CMF concept for the Embraer 195-E2 that integrates bacterial cellulose material variants to improve circular potential while maintaining or improving passenger experience relative to the current KLM Cityhopper interior. The perceptual evaluations demonstrate that the proposed CMF direction is consistently preferred and significantly enhances perceived passenger experience across classes, with comfort and cleanliness emerging as dominant experiential drivers. CMF was shown to effectively communicate cabin hierarchy, while also revealing that the Economy Comfort tier requires strengthened differentiation cues to reduce overlap with adjacent classes.

The operational-phase LCA indicates that substituting conventional polyurethane-based seat materials with bacterial cellulose-based alternatives can reduce operational emissions by approximately 355,000 kg CO₂ per aircraft per year under representative short-haul conditions. This reduction is driven by a 3.8 kg mass reduction per seat and a 450 kg aircraft-level reduction in a 120-seat configuration. Together, these findings confirm that lightweight, bio-based CMF strategies constitute a high-impact intervention point for reducing aviation climate impact at component level when applied across full cabin configurations and airline fleets.

4.3.4. RECOMMENDATIONS

Future work should prioritize the development and testing of aviation-ready bacterial cellulose materials that accurately represent final surface quality, durability, color stability, and aging behavior. Immersive evaluation methods, such as full-scale mock-ups or in-situ cabin testing, would enable assessment of real world passenger experience.

From a sustainability perspective, extending the LCA to include manufacturing, refurbishment cycles, and end-of-life scenarios, supported by certified seat bill-of-materials and supplier process data, would strengthen industrial relevance and support certification-oriented decision-making. Finally, expanding the CMF strategy beyond seating to additional cabin components offers potential for cumulative mass reduction and deeper system-level circular design integration.



4.3.5. PERSONAL REFLECTION

To structure the personal reflection in a clear and academically grounded manner, Gibbs' Reflective Cycle is applied. This framework is widely used in design and engineering education to support systematic reflection on professional practice by guiding the author through a sequence of description, evaluation, analysis, and forward-looking action.

1. Description

This thesis was conducted within an industry-collaborative context, positioning me at the intersection of CMF design, material innovation, and sustainability research. My role involved developing and evaluating a three-class cabin CMF concept for the Embraer 195-E2, while balancing creative design exploration with academic rigor and navigating practical constraints related to material readiness, data availability, and company requirements and expectations. Throughout the project, I was responsible for managing the planning, scope, deliverables, and stakeholder relationships through regular meetings with all parties involved.

2. Feelings

Throughout the project, I became increasingly aware of the responsibility associated with working on a novel design concept within a relatively conservative industry, as well as with formulating sustainability-related design claims. This awareness reinforced the importance of careful methodological framing, transparent communication of assumptions, and critical reflection on the scope and validity of the project. As a result, I feel proud of the outcomes achieved.

Due to the absence of a dedicated workspace at the partner companies, I primarily worked from home. While this offered flexibility, it was at times challenging and a bit isolating, as informal idea exchange and communication with colleagues or peers was less readily available. At certain moments, I felt overwhelmed, partly due to my own enthusiasm and ambition. I managed this by maintaining close contact with peers and by keeping a clear overview of the project planning. Overall, however, I felt motivated and engaged throughout the process and am satisfied with the final results.

3. Evaluation

Reflecting on the project, I encountered several moments where my ambitions exceeded the realistic scope of the available timeframe. Driven by my passion for CMF design and sustainability, I occasionally overestimated what could be achieved within the project constraints. At the same time, communication regarding the evolving scope of the project with all stakeholders was effective. In my view there was consistent room for honest feedback through multiple channels, and I am satisfied with the level of involvement and contribution from the various company partners, which positively influenced the quality of the project.





4. Analysis

The three-step design process established during the early stages of the project proved effective in providing a solid foundation project and planning. This structure ensured that sufficient background knowledge was developed before progressing into detailed design, reducing the need for rework. However, I underestimated the extent to which each phase would evolve through additional iterations and refinements as the project progressed.

Working predominantly from home also highlighted the importance of in-person interaction for creative development. In future projects, I would prefer a more balanced distribution between office-based and remote work, as regular discussions with peers and professionals both within and outside the project scope are highly beneficial to the design process. Although much of this interaction took place online with fellow graduating students, which proved valuable, physical collaboration remains an important aspect of creative work in my opinion.

5. Conclusion

This thesis provided substantial learning opportunities across multiple domains. I gained experience in project management, stakeholder coordination, and leading a novel design project within a conservative industry context. From a CMF perspective, I developed an understanding of designing for an aviation environment, including the specific constraints and requirements distinct from automotive design, which I was familiar with. I also successfully achieved my learning goals related to further developing my 3D CAD and rendering skills, as well as gaining proficiency in Adobe Substance 3D software. In addition, the project significantly expanded my knowledge of bio-based materials and bacterial cellulose, including their production processes, limitations, and potential applications within CMF design.

6. Action plan

For future projects, I intend to maintain a better balance between working from home and working in an office environment. I will continue to apply a structured approach that involves gathering feedback from stakeholders at each stage of the design process to support continuous learning and improvement.

Furthermore, I aim to actively safeguard my personal learning objectives and professional interests, with the goal of developing as a CMF designer specialising in sustainable and bio-based materials, and contributing to innovative projects in fields that are often perceived as challenging or resistant to change.

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6

APPENDIX

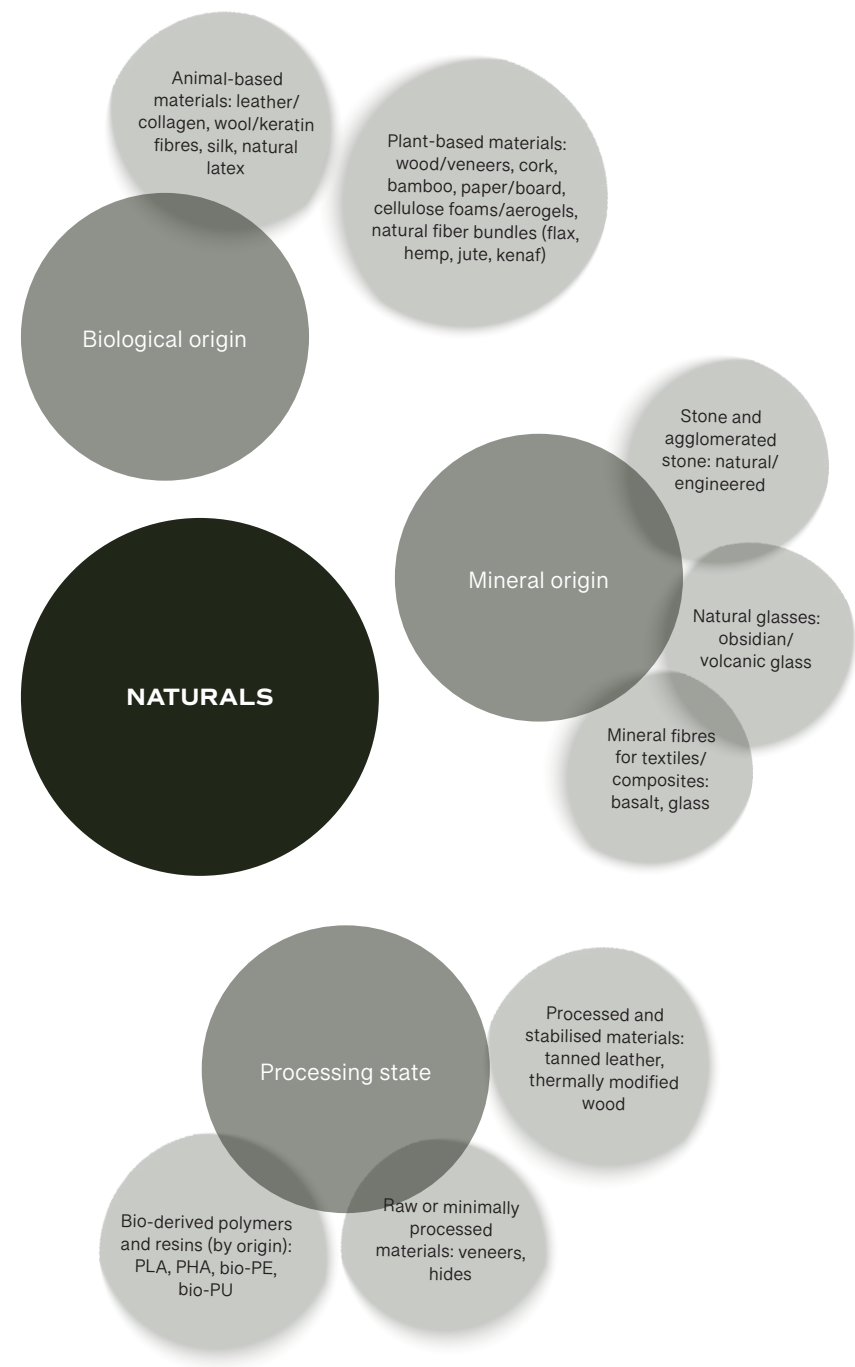
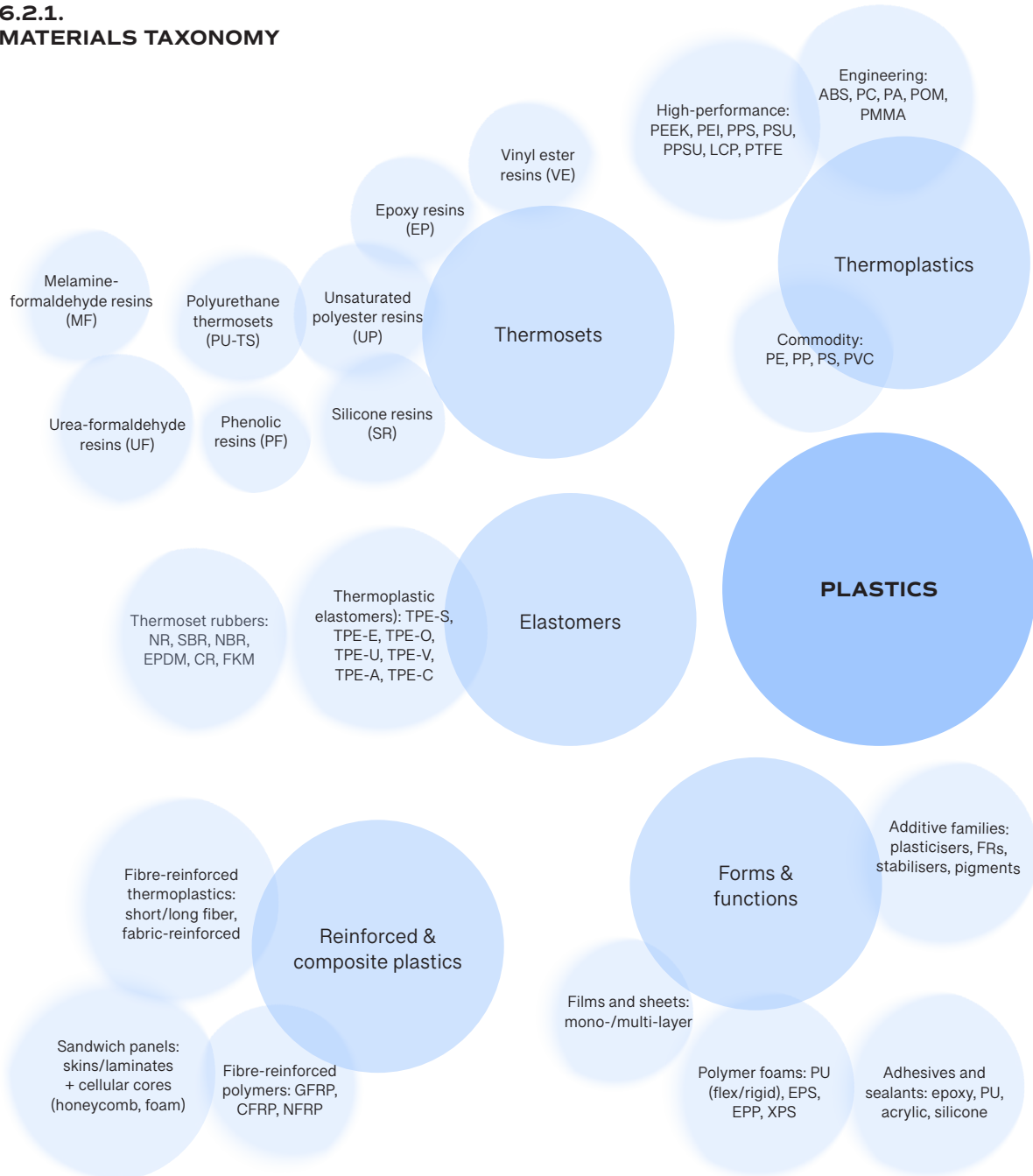
6.1.1. INTERVIEWS PASSENGERS

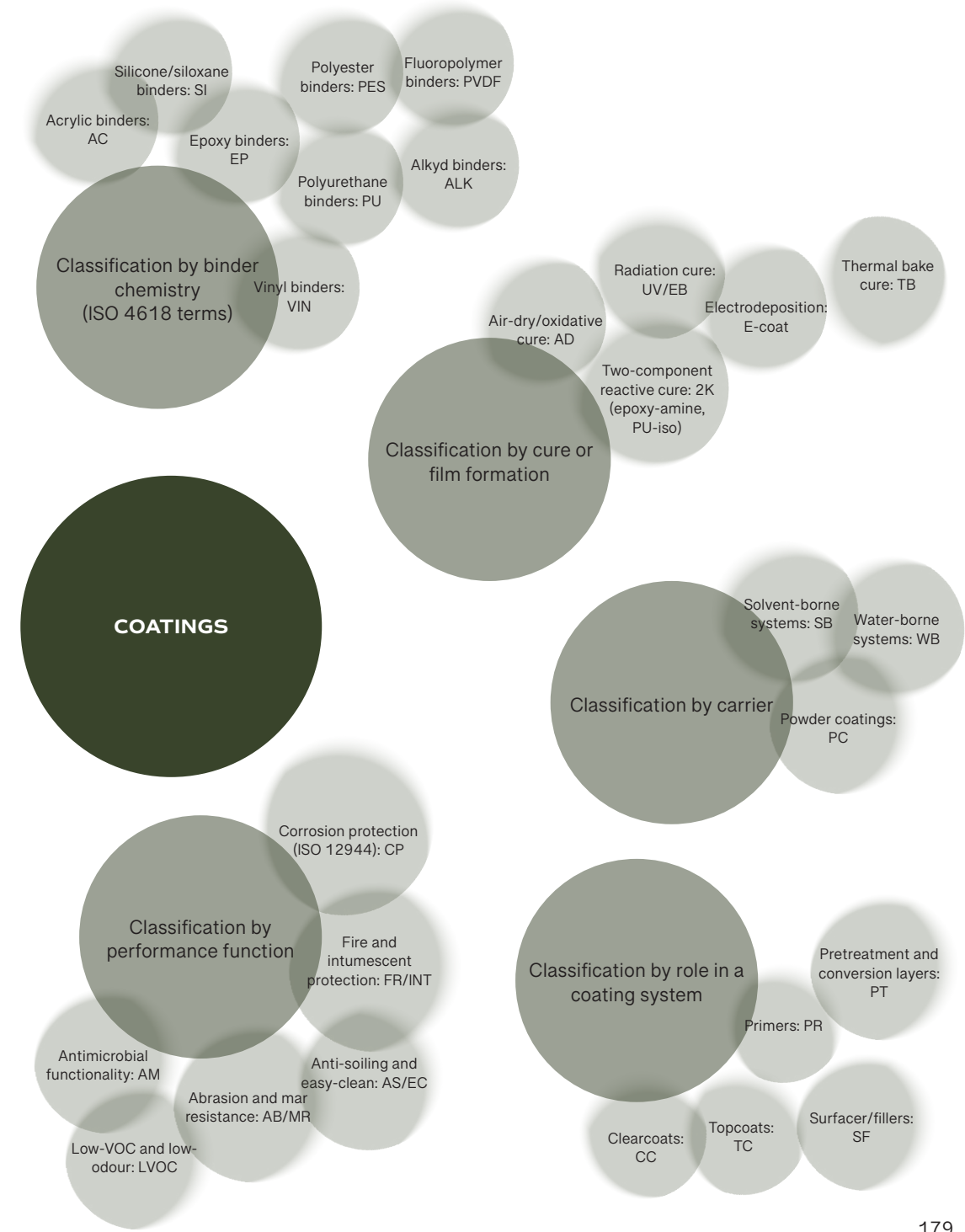
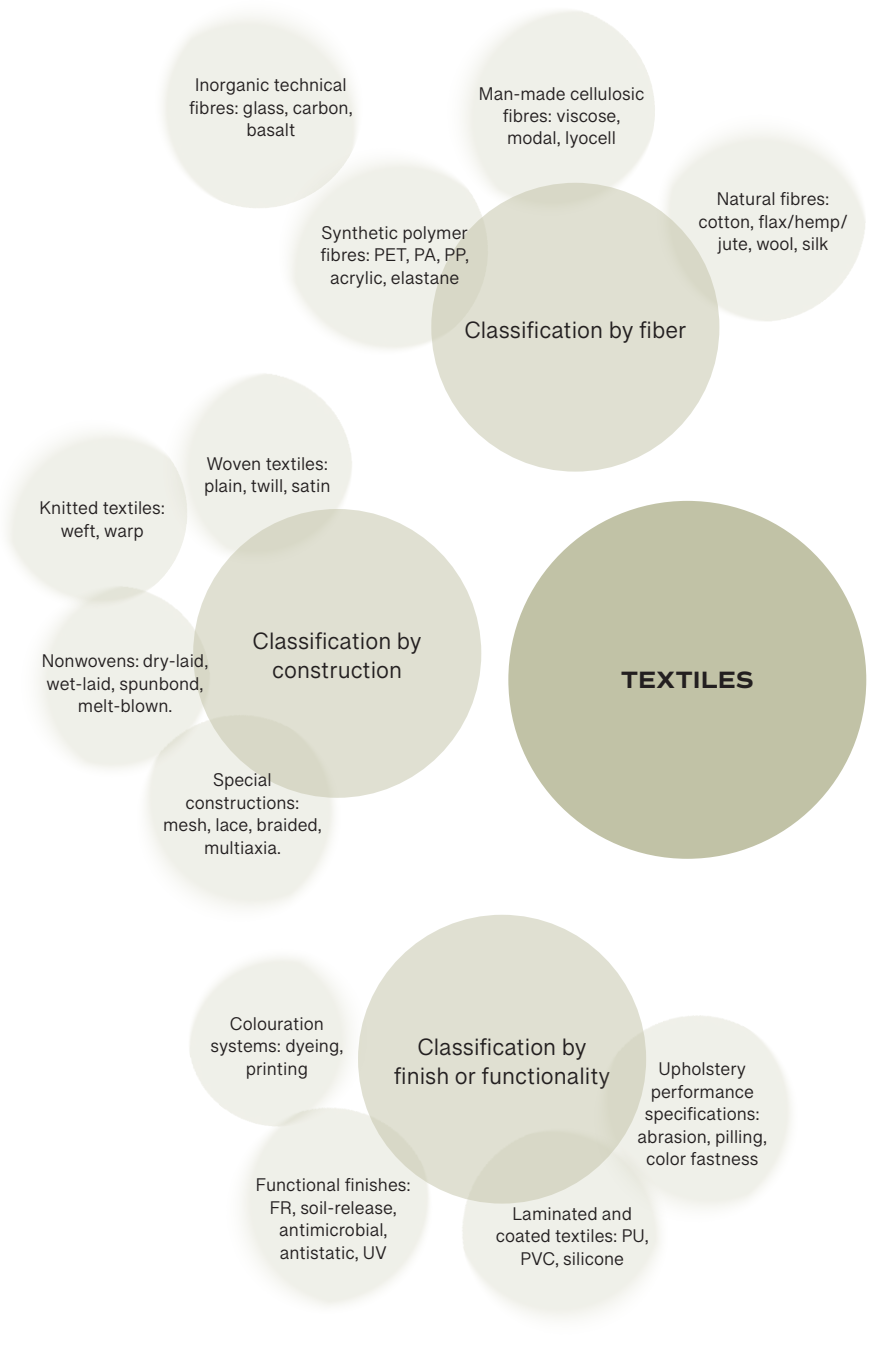
1. Introduction
Can you briefly describe how often you fly and whether you have recently traveled on a regional flight?
2. Travel context
Which airline and travel class did you use on your most recent flight?
What was the purpose of this trip (e.g. work, visiting family, leisure)?
What did you expect beforehand from this flight and the cabin experience?
How do you usually prepare for this type of short flight?
3. Motivations and expectations
What do you pay most attention to when choosing your seat or travel class?
What does comfort mean to you during a short-haul flight?
Which factors make a flight comfortable or uncomfortable for you?
Are there specific moments during the flight that you experience as positive?
How would you describe the ideal on-board atmosphere? Can you compare it to another environment or experience?
4. On-board experience and sensory impressions
Which materials or surfaces in the cabin do you remember most clearly?
How would you describe the seat in terms of texture, softness, temperature, and cleanliness?
Are there colors, details, or lighting conditions that stood out to you (positively or negatively)?
Were there sounds, smells, or visual elements that influenced your comfort?
How did the cabin environment make you feel (e.g. calm, stressed, comfortable, indifferent)?
5. Improvements and preferences
If you could change one aspect of the cabin interior, what would that be?
What would make the seating area feel more personal or comfortable to you?
Which colors, materials, or finishes do you associate with comfort, quality, or relaxation?
To what extent does sustainability or material choice influence how you value the interior?
6. Closing
Is there anything about the cabin experience that you consider important but that has not yet been discussed?

6.1.2. INTERVIEWS CABIN CREW

1. Introduction
Can you briefly describe your role and how long you have worked as cabin crew on the Embraer 195-E2?
2. Work context
Can you recall a recent flight where you operated all three cabin classes? What type of flight was this (e.g., business travelers, leisure, mixed)?
3. Passenger profiles and expectations by class
How would you describe the typical passenger profile in Business (J), Economy Comfort (W), and Economy (Y)?
What do passengers in each class seem to value most about their on-board experience?
What are the most common complaints you hear in each class, and what do passengers seem most satisfied with?
From your perspective, what makes a flight comfortable or uncomfortable to work on as cabin crew?
4. Operational experience and service
How do loyalty programs and passenger status (e.g., Flying Blue levels) influence passenger expectations and on-board interactions?
How do hand luggage volume and overhead bin capacity affect service and stress levels during boarding?
How much time is typically available for cabin cleaning and turnaround on these flights?
5. Cabin experience and sensory impressions
Looking at the current Embraer 195-E2 cabin, which materials or surfaces stand out most to you in J, W, and Y?
Are there specific areas you frequently touch or clean where material quality really matters (e.g., armrests, tray tables, curtains, galley surfaces)?
How do you experience the seats across the different classes in terms of texture, temperature, softness, cleanliness, and wear?
Do you notice that certain colors, finishes, or lighting conditions influence cabin atmosphere or passenger behavior?
Are there sounds, smells, or visual details in the cabin that you find particularly pleasant or disruptive during service?
6. Atmosphere and emotional experience
Which moments during a flight (boarding, service, cruise, landing) do you experience as the most pleasant or the most stressful, and does this differ by class?
How would you describe the ideal atmosphere in Business, Economy Comfort, and Economy for both passengers and crew?
Is there a place, object, or situation that you would use as a metaphor for the ideal atmosphere in each class?
7. Improvements and wishes
If you could change one aspect of the Embraer 195-E2 interior, what would it be, and would this differ between J, W, and Y?
What material improvements would make your work easier or more pleasant, for example in terms of cleaning, durability, glare, or noise?
What could make the seating area feel more personal or comfortable for passengers?
Which materials, colors, or finishes do you personally associate with comfort, quality, or calmness as cabin crew?

6.2.1. MATERIALS TAXONOMY





6.2.2.

DEFINITIONS FROM MATERIAL TAXONOMY

A-C

Abrasion resistance: Ability of a surface or fabric to resist wear from rubbing.

ABS: Acrylonitrile–butadiene–styrene; strong, tough engineering plastic for casings and interior parts.

Acetal (POM): Stiff, low-friction engineering plastic used in precise mechanical components.

Acrylic (PMMA): Transparent “acrylic glass” with high clarity and surface hardness.

Additives: Compounds added in small amounts to plastics or coatings to modify color, UV resistance, or flame behavior.

Agglomerated stone: Composite of crushed rock bound with resin or cement for decorative panels.

Air-dry/oxidative cure: Coating that hardens through reaction with air oxygen at room temperature.

Alkyd: Oil-based polyester resin that provides gloss and good flow in coatings.

Antimicrobial: Surface treatment that prevents growth of bacteria or fungi.

Appendix F (aviation): FAA flammability and smoke emission test standard for aircraft interiors.

Bamboo: Renewable, lightweight, high-strength material suitable for interior veneers.

Basalt fiber: Fiber spun from volcanic rock; high heat and chemical resistance.

BC (Bacterial cellulose): Naturally produced cellulose with very pure fine fiber network; forms aerogels, foams, or films.

Bio-based content: Proportion of renewable carbon in a product as defined by ISO/ASTM standards.

Bio-derived polymers: Plastics synthesized from biological feedstocks such as PLA or PHA.

Bio-PU: Polyurethane produced partially from bio-based polyols for reduced carbon footprint.

Braided textile: Yarn structure interlaced diagonally for strength and flexibility.

Carbon fiber: Very stiff, lightweight fiber made from carbon filaments used in composites.

Cellular core: Lightweight foam or honeycomb layer used in sandwich structures.

Cellulose foam/aerogel: Ultralight cellulose-based materials for insulation or cushioning.

Chloroprene rubber (CR): Weather-resistant rubber known commercially as neoprene.

Clearcoat: Transparent protective paint layer adding gloss and surface durability.

Closed-cell foam: Foam with sealed air pockets, providing thermal insulation and water resistance.

Closed-loop recycling: Recycling process where materials return to the same product type.

Coated textile: Fabric covered with polymer coating (PU, PVC, or silicone) for durability or barrier properties.

Color fastness: Resistance of dyed fabric to fading or bleeding during use.

Composite: Combination of fibres and matrix giving high strength and low weight.

Conversion coating (pretreatment): Chemical surface layer improving corrosion resistance and paint adhesion.

Cork: Lightweight, renewable bark material used for damping and insulation.

Cotton: Natural cellulose fiber, soft, breathable, and biodegradable.

Cure (thermal bake): Heat-activated hardening step for coatings or resins.

CFRP: Carbon-fibre reinforced polymer with high stiffness-to-weight ratio.

CS-25.853 (EASA): European flammability rule for aircraft interior materials.

D-J

Dry-laid nonwoven: Fiber web formed and bonded without weaving, used in composites and insulation.

E-coat (electrodeposition): Electrically applied, uniform corrosion-resistant coating.

EASA: European Union Aviation Safety Agency, setting certification standards.

Elastic recovery: Ability of a material to return to original shape after stretching.

Elastomer: Rubber-like polymer with flexibility and resilience.

EP (epoxy resin): High-strength, chemical-resistant thermoset resin for coatings or composites.

EPDM: Synthetic rubber with excellent weather, ozone, and UV resistance.

Engineering thermoplastics: Durable, higher-heat plastics such as ABS, PC, PA, and POM.

EPP: Expanded polypropylene foam, flexible and impact-absorbing.

Fabric-reinforced thermoplastics: Thermoplastics reinforced with woven or knitted fabrics for stiffness.

Fiber bundle (natural): Groups of flax, hemp, or jute fibres used as biocomposite reinforcement.

Films and sheets: Thin, flexible plastics used as laminates, facings, or barriers.

Fire retardant (FR): Chemicals or finishes that slow ignition and reduce flame spread.

Flax: Plant fiber offering low weight and high stiffness for composites.

Foam (polymer): Lightweight material with air-filled cells for cushioning or insulation.

Foamcore/sandwich panel: Structure with strong outer layers bonded to lightweight core.

FRP: Fibre-reinforced polymer, combining strength of fibres with polymer matrix.

GFRP: Glass-fibre reinforced polymer; cost-efficient, widely used composite.

Glass fiber: Inorganic fiber from molten glass, strong and non-flammable.

Heat release rate: Rate of heat emission in combustion, key metric in aviation fire safety.

Hemp: Natural fiber used for sustainable textiles and composites.

Honeycomb core: Hexagonal cell structure providing stiffness with minimal weight.

Hydrophobisation: Process that makes material surfaces repel water.

Intumescent coating: Fire-resistant paint that swells into insulating char under heat.

ISO 1043: Defines plastic material abbreviations and symbols.

ISO 12944: Specifies standards for corrosion protection in coatings.

ISO 18064: Classification of thermoplastic elastomers (TPEs).

ISO 2076: Generic naming system for man-made fibres.

ISO 4618: Defines paint and varnish terminology.

Jute: Coarse plant fiber used in packaging, insulation, and natural composites.

K-P

Kenaf: Fast-growing bast fiber similar to jute, used for reinforcement. Knitted textiles: Loop-based fabrics; weft knits are elastic, warp knits more stable.

Laminated textile: Fabric bonded to films or layers for improved durability or barrier.

LCP: Liquid-crystal polymer; high-strength, high-temperature engineering plastic.

Leather: Processed animal hide known for durability and flexibility.

Low-VOC: Low volatile organic compound coatings with reduced emissions.

Lyocell: Regenerated cellulose fiber made through closed-loop solvent spinning.

Mar resistance: Ability to resist fine scratches and surface dulling.

Melt-blown nonwoven: Fine fiber web produced by high-speed blowing of molten polymer.

MF (melamine-formaldehyde): Heat-resistant thermoset used in laminates and coatings.

Modal: Smooth, soft regenerated cellulose fiber with high strength.

Multiaxial textile: Layers of fibres oriented in different directions for composites.

NBR: Nitrile rubber with oil and fuel resistance.

Natural latex: Renewable rubber tapped from trees with high elasticity.

NFRP: Natural-fibre reinforced polymer using flax or hemp fibres in resin matrix.

Nonwoven: Fabric made by bonding fibres rather than weaving or knitting.

Open-cell foam: Foam with connected pores for breathability and cushioning.

PA (polyamide, nylon): Tough, abrasion-resistant engineering plastic for durable parts.

PEEK: High-performance plastic with exceptional temperature and chemical resistance.

PEI: Tough, heat-resistant plastic used for interior and structural parts.

PET: Polyester used as both fiber and plastic with high recyclability.

PF (phenolic resin): Thermoset with superior fire, smoke, and toxicity performance.

PLA: Biodegradable bioplastic derived from renewable sources.

Polyester (binder): Flexible coating resin providing weather and chemical resistance.

Polyester fiber: Strong, wrinkle-resistant synthetic textile fiber.

Polypropylene (PP): Light, durable thermoplastic for panels or housings.

Polyurethane (PU): Versatile polymer for foams, coatings, and adhesives.

Powder coating: Solvent-free coating cured by heat to a smooth, durable finish.

Primers: Base coating layer promoting adhesion and corrosion resistance.

PSU/PPSU: Transparent, high-temperature plastics for aviation interiors.

PTFE: Fluoropolymer with extreme chemical and heat resistance.

PVC: Versatile plastic used in flexible and rigid forms.

PVDF: High-end fluoropolymer binder offering long-term weather stability.

R-Z

Reactive 2K: Two-component coating or adhesive system mixed before application.

Resin (UP): Unsaturated polyester thermoset for composites and coatings.

Rigid foam: Lightweight foam with stable structure used for cores or insulation.

Rubber (thermoset): Crosslinked elastomer that retains elasticity at high temperatures.

Seat-cushion test: Fire-safety test for complete aircraft seat assemblies (Appendix F).

Silicone (binder/resin): Flexible, heat-resistant polymer with siloxane backbone.

Silicone rubber (SR): Elastic, high-temperature-resistant silicone used for seals.

Siloxane: Base structure of silicone polymers giving flexibility and heat stability.

Silk: Natural protein fiber with smooth texture and tensile strength.

Smoke density: Measurement of smoke generated during material combustion.

Solvent-borne: Coating type dissolved in organic solvents for high durability.

Spunbond nonwoven: Durable web made of thermally bonded continuous filaments.

Stabilisers: Additives that prevent degradation from heat or UV.

Styrenic TPE (TPE-S): Rubber-like plastic with good grip and flexibility.

Thermally modified wood: Heat-treated wood with improved stability and resistance.

Thermoplastic elastomer (TPE): Elastic polymer processed as a thermoplastic.

Thermoplastics: Plastics that can be softened and reshaped multiple times.

Thermosets: Plastics that cure permanently and cannot be remelted.

Topcoat: Final protective and decorative coating layer.

TPE-U: Thermoplastic polyurethane elastomer with excellent abrasion resistance.

TPE-V: Dynamically vulcanised TPE combining rubber and plastic phases.

Twill weave: Fabric weave with diagonal ribs and smooth drape.

UV/EB cure: Fast-curing coating process using ultraviolet or electron beam energy.

Vinyl (binder): Coating resin based on vinyl polymers like PVC or VAE.

Viscose: Regenerated cellulose fiber with good absorbency and comfort.

VOC: Volatile organic compounds; solvent vapours that contribute to air emissions.

Water-borne: Coating dispersed in water for lower VOC impact.

Wood: Natural composite of cellulose, hemicellulose, and lignin used for veneers.

Wool: Natural protein fiber that is warm and inherently flame-resistant.

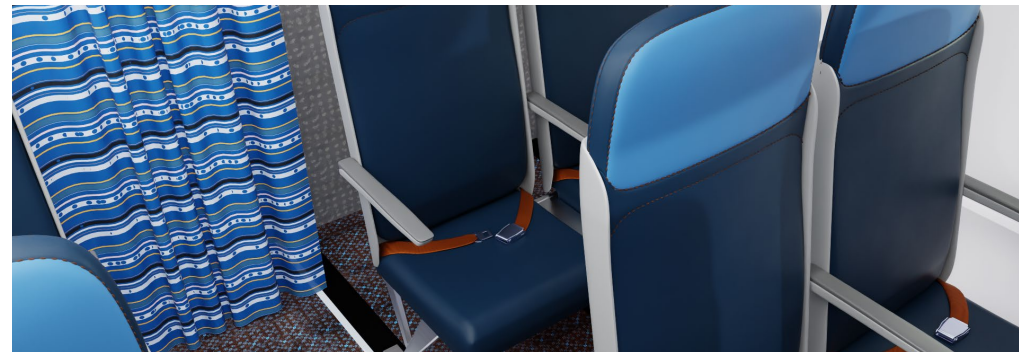
Woven (plain weave): Basic fabric construction interlacing warp and weft at right angles.

XPS: Closed-cell extruded polystyrene foam for insulation.

Zinc phosphate (pretreatment): Corrosion-protective coating that enhances paint adhesion.

6.3 TEST 2 RENDERS

KLM Y-class



KLM J-and W-class



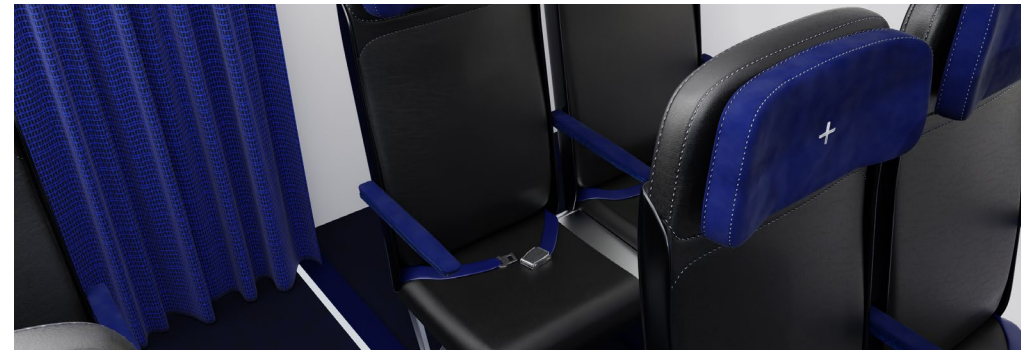
New Y-class



New W-class



New J-class



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