



Seated in Uncertainty:

Dealing with substances of concern in office chair design.

A Safe & Circular by Design approach to office chairs.

Dealing with substances of concern in office chair design.

A Safe & Circular by Design approach to office chairs.

MSc. Graduation Thesis
May, 2026

Fabian Hoogendijk
Integrated Product Design
Faculty of Industrial design Engineering
Delft University of Technology

Chair
Prof.dr. A.R. (Ruud) Balkenende
Design for Sustainability
Sustainable Design engineering

Mentor
Maaïke Weber
Design for Sustainability
Sustainable design engineering

Company Mentor
Martin Steffner
Senior Designer
NPK Design

 **TU Delft**

 **npk** strategic
product
innovation

Abstract

This thesis applies the Safe and Circular by Design (SCbD) methodology and the MAPSSS (Mapping Assessment for Product Substance Safety and Sustainability) tool to B2B office task chairs, demonstrating how material safety can be integrated into the design process from early stages. The research was motivated by a gap in current practice: substances of concern in products are addressed almost exclusively through regulatory compliance, while the product design perspective remains largely absent.

The study follows the four steps of the MAPSSS tool.

Step 0 mapped the full lifecycle of a median office task chair, constructed from physical teardown evidence and material composition data from the Declare Living Future database.

Step 1 identified TCPP (tris(1-chloro-2-propyl) phosphate) in polyurethane foam as the priority substance of concern, with the use phase carrying the highest concern scores across both human health and environmental pathways, and end of life carrying the second highest.

Step 2 developed three design concepts, each corresponding to one of the SCbD strategies:

The Avoid concept removes TCPP and foam entirely through an SLS-printed nylon construction,

The Reduce concept retains the standard foam architecture but intercepts TCPP migration through an integrated active carbon filter system

The Control concept removes foam from components where it is not functionally necessary, substitutes aramid textile, and combines this with controlled off-gassing during manufacture and biophilic-supported filtration during use.

Step 3 assessed the three concepts against the reference chair, showing that the Control and Reduce strategy shift the hazard profile across the lifecycle rather than removing it, and that each depends on conditions outside the product itself to deliver its intended reduction. And the Avoid strategy creates a new scenario to be studied which can be better or worse than previous scenario.

The research draws on twenty expert interviews conducted across the full office chair value chain, a physical teardown of two second-hand chairs, and a feedback session with NPK Design. The findings show that chemical safety and circularity are structurally deprioritised across the industry, that the MAPSSS methodology adds a complementary substance-of-concern lens to existing sustainability practice, and that the methodology's principal barriers to adoption are the absence of accessible component-level material data, the chemistry knowledge required in Step 1, and the lack of built-in validation mechanisms across the steps.

The thesis contributes a real-industry application of the SCbD methodology and MAPSSS tool, a set of concrete recommendations for the further development of both, and three resolved design concepts that illustrate the range of design responses available when applying the SCbD framework to a product containing a substance of concern.

Table of Content

Introduction

1.1 Introduction	12
1.2 Problem statement	12
1.3 Project scope	12
1.4 Research questions	13
1.5 Approach	14

Background

2.1 Circular economy	18
2.2 The Safe and Circular by Design research project	18
2.3 Research design motivation	19
2.4 Substances of concern, Safe and Circular by Design, and the MAPSSS tool	19

The Office Task Chair

3.1 The office task chair as a product category	26
3.2 Norms, certifications, and regulatory context	27
3.3 The median chair	28
3.4 Industry insights	32
3.5 Conclusion	37

SCbD Step 0: Identify

4.1 Introduction and approach	40
4.2 Results	40
4.3 Conclusion	43

SCbD Step 1: Analyse

5.1 Introduction and approach	46
5.2 Selection of the priority substance of concern	46
5.3 Physical teardown observations relevant to TCPP	48
5.4 Results: Hotspot assessment of TCPP across the lifecycle	50
5.5 Conclusion	53
5.6 Scope for the design solution	54

Scbd Step 2: Select and Design

6.1 Introduction	58
6.2 Approach	58
6.3 Key insights	59
6.4 List of requirements	59
6.5 Design approach	61
6.6 Final Designs	62
6.7 Reflection on strategy per application	65
6.8 Conclusion	65

SCbD Step 3: Asses

7.1 Introduction	68
7.2 Approach	68
7.3 Assesment per concept	68
7.4 Comparative results	69
7.5 Reflection on trade-offs	70
7.6 Conclusion	71

Discussion

8.1 Introduction	74
8.2 Answering Research questions	74
8.3 The SCbD methodology from a designer's perspective	75
8.4 Uncertainty and validation	76
8.5 What the three concepts together reveal	77
8.6 Industry implications and recommendations	78
8.7 Recommendations for the SCbD methodology and MAPSSS tool	79

Conclusion

9.1 Conclusion	84
9.2 Limitations	84
9.3 Future work	85
9.4 Personal reflection	85

References

Appendix

List of abbreviations

- **ABS** - Acrylonitrile Butadiene Styrene
- **ANSI** - American National Standards Institute
- **B2B** - Business to Business
- **B2C** - Business to Consumer
- **BCIPHIPP** - Bis(1-chloro-2-propyl) 1-(1-hydroxypropan-2-yl) Phosphate
- **BIFMA** - Business and Institutional Furniture Manufacturers Association
- **CAS** - Chemical Abstracts Service
- **CO₂** - Carbon Dioxide
- **DPP** - Digital Product Passport
- **ECHA** - European Chemicals Agency
- **ESPR** - EU Ecodesign for Sustainable Products Regulation
- **FR** - Flame Retardant
- **GS** - Geprüfte Sicherheit
- **LCA** - Life Cycle Assessment
- **MAPSSS** - Mapping Assessment for Product Substance Safety and Sustainability
- **NEN** - Nederlands Normalisatie-instituut
- **NIAS** - Non-Intentionally Added Substances
- **OEM** - Original Equipment Manufacturer
- **PA** - Polyamide (Nylon)
- **PBT** - Persistent, Bioaccumulative and Toxic
- **POPs** - Persistent Organic Pollutants
- **PPE** - Personal Protective Equipment
- **PSS** - Product Service System
- **PU** - Polyurethane
- **PVC** - Polyvinyl Chloride
- **RA** - Risk Assessment
- **REACH** - Registration, Evaluation, Authorisation and Restriction of Chemicals
- **RQ** - Research Question
- **SCbD** - Safe and Circular by Design
- **SLS** - Selective Laser Sintering
- **SoC** - Substance of Concern
- **SQ** - Sub-question
- **SVHC** - Substance of Very High Concern
- **SVOC** - Semi-Volatile Organic Compound
- **TCEP** - Tris(2-Chloroethyl) Phosphate
- **TCPP** - Tris(1-Chloro-2-Propyl) Phosphate
- **TPU** - Thermoplastic Polyurethane
- **VOC** - Volatile Organic Compound
- **vPvB** - Very Persistent and Very Bioaccumulative



1

Chapter 1

Introduction

1.1 Introduction	12
1.2 Problem statement	12
1.3 Project scope	12
1.4 Research questions	13
1.5 Approach	14

1.1 Introduction

This thesis applies the **Safe and Circular by Design (SCbD)** methodology and the **MAPSSS (Mapping Assessment for Product Substance Safety and Sustainability)** tool to B2B office task chairs, demonstrating how material safety can be integrated into the design process from early stages. The research was motivated by a gap in current practice: substances of concern in products are addressed almost exclusively through regulatory compliance, while the product design perspective remains largely absent.

The study follows the four steps of the MAPSSS tool.

Step 0 Analyze, which maps the full lifecycle of a median office task chair, constructed from physical teardown evidence and material composition data from the Declare Living Future database.

Step 1 Identify, which identifies TCPP (tris(1-chloro-2-propyl) phosphate) in polyurethane foam as the priority substance of concern, with the use phase carrying the highest concern scores across both human health and environmental pathways, and end of life carrying the second highest.

Step 2 Select and Design, where three design concepts were developed, each corresponding to one of the SCbD strategies: the **Avoid** concept removes TCPP and foam entirely through an SLS-printed nylon construction; the **Reduce** concept retains the standard foam architecture but intercepts TCPP migration through an integrated active carbon filter system; and the **Control** concept removes foam from components where it is not functionally necessary, substitutes aramid textile, and combines this with controlled off-gassing during manufacture and biophilic-supported filtration during use.

Step 3 Assess, which assesses the three concepts against the reference chair, showing that each strategy shifts the hazard profile across the lifecycle rather than removing it, and that each depends on conditions outside the product itself to deliver its intended reduction.

The research draws on twenty expert interviews conducted across the full office chair value chain, a physical teardown of two second-hand chairs, and a feedback session with NPK Design. The findings show that chemical safety and circularity are structurally deprioritised across the industry, that the MAPSSS methodology adds a complementary substance-of-concern lens to existing sustainability practice, and that the methodology's principal barriers to adoption are the absence of accessible component-level material data, the chemistry knowledge required in Step 1, and the lack of built-in validation mechanisms across the steps.

The thesis contributes a first real-industry application of the SCbD methodology and MAPSSS tool, a set of concrete recommendations for the further development of both, and three resolved design concepts that illustrate the range of design responses available when applying the SCbD framework to a product containing a substance of concern.

1.2 Problem statement

Hazardous chemicals in furniture products are also an information transparency problem. Data on the chemical composition of materials is lacking across the value chain, and without this transparency, circular economy practices such as recycling and reuse cannot be carried out safely (Government of the Netherlands, 2024).

Current design practice offers limited guidance for addressing substances of concern at the product level. Identifying and mitigating material hazards is uncommon among designers, and existing tools are oriented towards chemical and material developers rather than the designers who specify materials in products (Bolaños Arriola et al., 2024). Safety decisions are typically deferred to later design phases, where material choices are already largely fixed.

This research applies the SCbD methodology and the MAPSSS (Mapping Assessment for Product Substance Safety and Sustainability) tool to B2B office task chairs to demonstrate how material safety can be integrated into the design process from early stages, improving both health outcomes and circularity.

1.3 Project scope

This graduation project examines B2B office task chairs as a case study. The B2B market offers a more controlled research environment than B2C: it operates under strict regulatory frameworks such as ANSI/BIFMA standards, maintains established take-back and refurbishment programmes, and provides greater oversight of product lifecycles (BIFMA, 2024). This focus enables clearer industry contextualisation and more targeted analysis of relevant design factors.

1.4 Research questions

The research is structured around four primary research questions, each supported by sub-questions.

RQ1. How are substances of concern currently identified and managed in desk chair design and production?

This question maps current industry practice across the value chain: the tools and methods used to assess material safety, how designers and manufacturers address substances of concern in their workflows, and where the main knowledge gaps lie.

- SQ1.1 What methods or tools are currently used to assess material safety in furniture design, and what gaps exist?
- SQ1.2 How do designers and manufacturers currently identify and address substances of concern in their workflows?
- SQ1.3 What are the main knowledge gaps among industry actors regarding substances of concern and safe design practices?
- SQ1.4 Who makes key material and design choices within the value chain, and at what stage?
- SQ1.5 How is communication managed between the different decision-makers in the chair value chain, from design to manufacturing?

RQ2. How can the Safe and Circular by Design methodology be applied effectively to support safer desk chair design?

This question evaluates the SCbD framework as a practical design tool: how it improves material decision-making, how it relates to existing certifications and standards, and what barriers limit its implementation in industrial practice.

- SQ2.1 How can the SCbD framework improve designers' workflow and decision-making regarding safe materials?
- SQ2.2 How can the SCbD framework complement or be integrated with existing certifications, standards, and labels?
- SQ2.3 What are the limitations and implementation barriers of applying the framework in current industrial practice?
- SQ2.4 What benefits could safe and circular design bring to manufacturers and users?

RQ3. What are the main substances of concern in desk chairs, and what risks do they pose to human and environmental health?

This question identifies which chair components contain substances of concern, the hazards and exposure risks they present across the lifecycle, and why these substances remain in use despite the availability of alternatives.

- SQ3.1 What desk chair components contain substances of concern, and what hazards and emissions do they pose across the product lifecycle?
- SQ3.2 What are the most impactful substances of concern in terms of exposure risk and hazard severity?
- SQ3.3 Why are these substances present despite the existence of alternatives?

RQ4. What challenges arise when substituting or managing substances of concern in desk chairs?

This question addresses the practical and organisational barriers to safer material selection: trade-offs between performance, cost, and recyclability, supply chain constraints, and the economic and regulatory pressures shaping material decisions in the furniture industry.

- SQ4.1 What are the main trade-offs when substituting substances of concern, for example in terms of performance, cost, durability, and recyclability?
- SQ4.2 What organisational or supply chain challenges hinder the avoidance of substances of concern?
- SQ4.3 What incentives or pressures (economic, regulatory, or consumer-driven) shape material decisions in the furniture industry?

1.5 Approach

This research follows a qualitative, practice-based case study strategy, applying the SCbD methodology to B2B office task chairs to translate the theoretical framework into a practical design process.

Domain knowledge was built through primary and secondary research. An exploratory literature review covering peer-reviewed articles, industry reports, and grey literature established the theoretical and regulatory background. Expert interviews across the full value chain, from product design and manufacturing through to end of life, provided industry knowledge unavailable through published sources. Product teardowns and investigation of material databases and safety datasheets supplemented this.

The MAPSSS tool was then applied across its four steps. In Step 0 (Identify), the material composition of a median desk chair was mapped using bill of materials databases, material datasheets, and expert consultation. In Step 1 (Analyse), the most impactful materials and substances were identified through hazard and exposure analysis of safety datasheets, validated through expert interviews. In Step 2 (Select and Design), the data informed three design concepts, each corresponding to one of the SCbD strategies: Avoid, Reduce, and Control. The concepts were compared against conventional desk chair design to illustrate how SCbD-informed design leads to different outcomes. In Step 3 (Assess), the concepts were evaluated against the median chair established in Steps 0 and 1.

Finally, the method itself was assessed through feedback sessions with designers and industry experts on whether the SCbD methodology and MAPSSS tool are viable and useful within current industrial design practice, and how they might be improved.

Reading guide

This thesis is structured around the four steps of the MAPSSS tool, preceded by introductory and background chapters and followed by a discussion and conclusion.

Chapter 1 introduces the project, outlining the problem statement, project scope, research questions, and approach.

Chapter 2 establishes the theoretical background. It opens with the circular economy as the overarching framework, introduces the tension between circularity and material safety that motivates the project, covers substances of concern and the regulatory frameworks governing them, and presents the Safe and Circular by Design research project and the MAPSSS tool in detail.

Chapter 3 introduces B2B office task chairs as the product category studied in this research. It covers the product architecture and material composition of task chairs, the relevant regulatory context, the construction of the median chair through physical teardown and the Declare database, and findings from twenty expert interviews conducted across the office chair value chain.

Chapters 4 through 7 present the stepwise application of the SCbD methodology to the case study. Each chapter follows the same structure: a brief introduction, the approach taken, the results obtained, and a conclusion.

Chapter 4 covers Step 0 (Identify), in which the material composition of the median desk chair is mapped through physical teardown and material analysis, producing a complete lifecycle map.

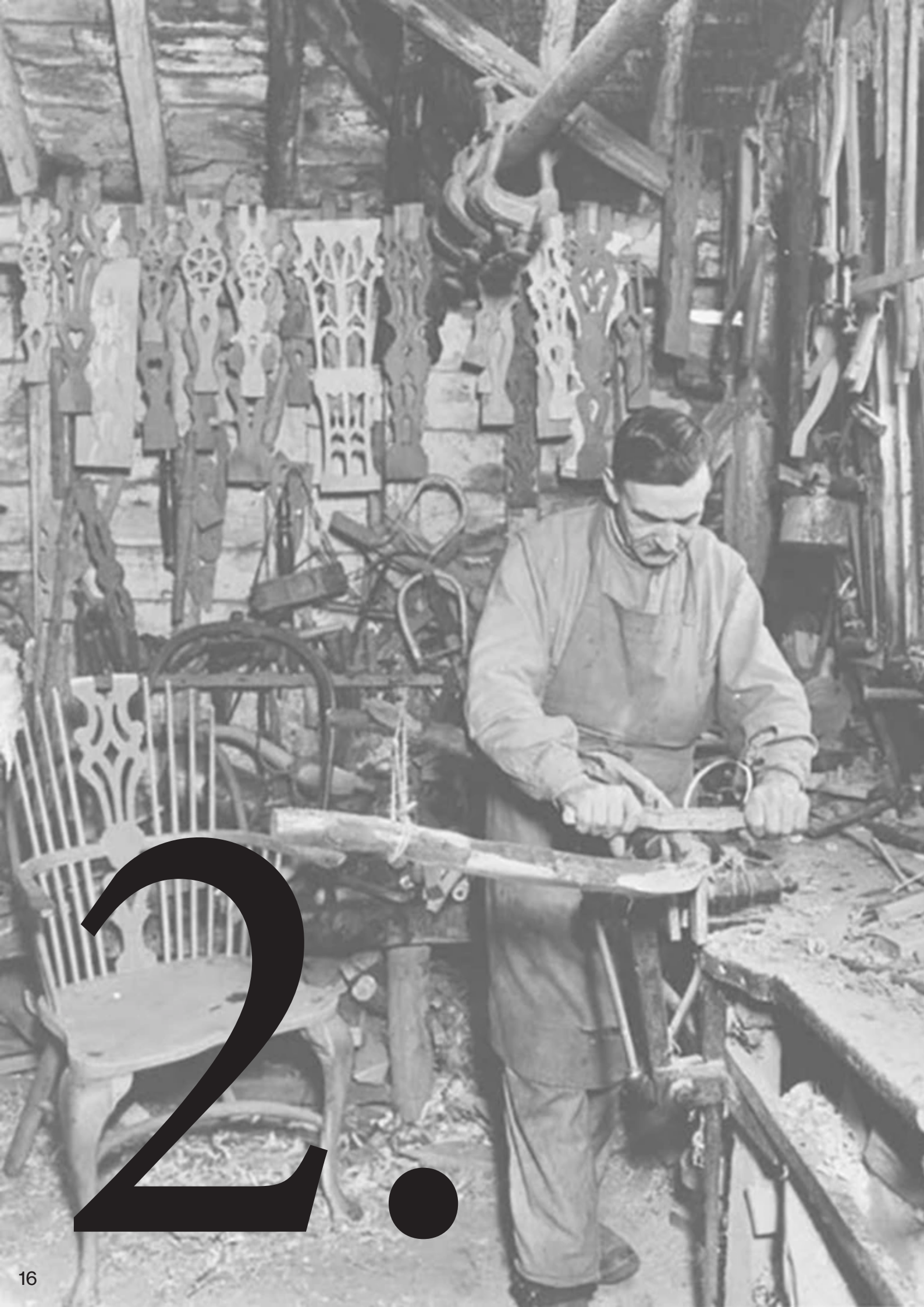
Chapter 5 presents Step 1 (Analyse), in which a hotspot assessment is conducted to identify TCPP in polyurethane foam as the priority substance of concern and to establish the use phase and end-of-life phase as the stages requiring design intervention.

Chapter 6 covers Step 2 (Select and Design), detailing the selection of SCbD strategies and the development of three design concepts, one per strategy, addressing the identified substance of concern.

Chapter 7 presents Step 3 (Assess), in which the three design concepts are evaluated against the reference chair to compare their effects on the identified concern scenarios, their negative consequences, and their tradeoffs.

Chapter 8 discusses the findings across two angles. The first is methodological: how the SCbD framework and MAPSSS tool performed when applied to a real industry context, and what limitations and recommendations emerge from the case study. The second is industry-facing: what the findings reveal about current practice in the office task chair industry and what conditions would support a transition toward safer and more circular design.

Chapter 9 closes the thesis with a conclusion synthesising the main findings, a discussion of the limitations of the work, directions for future research, and a personal reflection on the project.



2.

Chapter 2

Background

2.1 Circular Economy.....	18
2.2 The Safe and Circular by Design research project.....	18
2.3 Research design motivation	19
2.4 Substances of concern, Safe and circular design by design	19
2.5 Detailed explanation of the SCbD method and MAPSSS tool.....	20
2.6 Conclusion	22

This chapter establishes the theoretical background for this graduation project. It begins with the principles of the **circular economy** and the ambition of keeping materials in use for as long as possible. It then introduces a tension that complicates this ambition: the presence of substances of concern in products, and the risks these substances pose when materials are reused, recycled, or kept in circulation. This tension defines the problem this project addresses.

The chapter then introduces the Safe and Circular by Design (SCbD) research project, established to respond to this tension, and explains how this graduation project originates from it. It covers the regulatory frameworks governing substances of concern, the principles underpinning the SCbD approach, and the MAPSSS tool developed within the project, which serves as the methodological foundation for this research.

2.1 Circular economy

The **circular economy** is a systemic framework developed in response to interlinked environmental challenges, including climate change, biodiversity loss, and the accumulation of waste and pollution. It departs from the linear model of take, make, and dispose, proposing an economy that decouples value creation from the consumption of finite resources. The framework rests on three principles: eliminating waste and pollution by design, keeping products and materials in use at their highest value, and regenerating natural systems (Ellen MacArthur Foundation, 2013).

These principles are represented through the butterfly diagram (Figure 2.1), which distinguishes between the technical cycle, where products and materials are kept in circulation through reuse, repair, refurbishment, and recycling, and the biological cycle, where biodegradable materials are returned safely to the environment (Ellen MacArthur Foundation, 2021). The diagram prioritises smaller loops: reuse and repair are favoured over recycling, as tighter loops consume less energy and fewer materials and retain more of a product's embedded value (Ellen MacArthur Foundation, 2013).

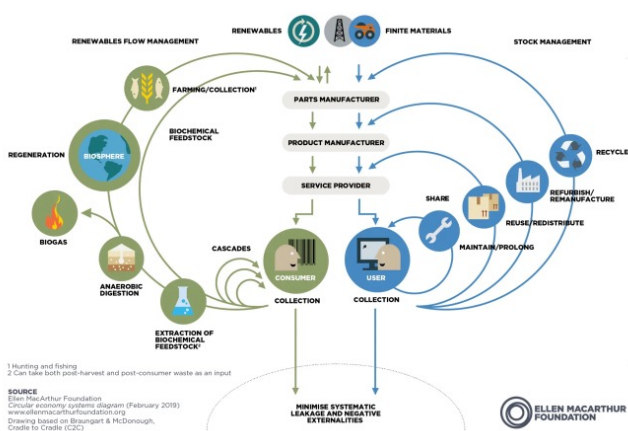


Figure 2.1. Butterfly diagram of the circular economy, showing the biological and technical cycles (Ellen MacArthur Foundation, 2021).

The extent to which these principles can be realised is largely determined at the design stage, where decisions about material composition, product architecture, and component connections shape whether a product can later be reused, repaired, or

recycled (Ellen MacArthur Foundation, n.d.). A range of methods has been developed to support circular design, frequently structured as R-strategies that order interventions by the value they retain, from Rethink and Reduce through to Reuse, Repair, and Recycle (Potting et al., 2017), or as Design for X strategies such as Design for Disassembly and Design for Recycling. Both produce design guidelines that can be applied throughout a project.

While circular strategies aim to keep products and materials in use for as long as possible, this ambition carries a complication. Extending a product's life, or recovering its materials for reuse or recycling, also extends the time over which any hazardous substances within it remain in circulation. As Figure 2.2 illustrates, most chemicals currently in use have insufficiently characterised effects on human health and the environment (European Environment Agency, 2020), meaning that many materials kept in circulation under circular economy strategies may carry risks that are not yet fully understood.

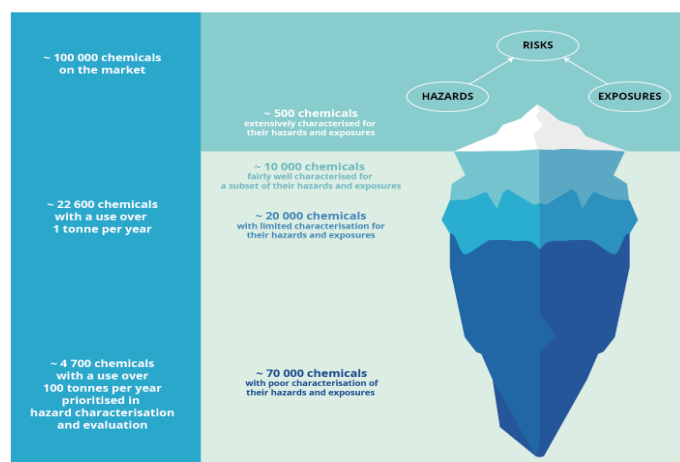


Figure 2.2. Butterfly diagram of the circular economy, showing the biological and technical cycles (Ellen MacArthur Foundation, 2021).

Circularity and material safety can therefore come into tension, and a product cannot be considered genuinely circular if keeping it in use prolongs exposure to harmful substances. This tension defines the problem this thesis addresses, beginning with an understanding of what substances of concern are.

2.2 The Safe and Circular by Design research project

Certain chemicals are now widely recognised as posing significant hazards to people and the environment, and this recognition has generated considerable regulatory attention. Within the European Union, this attention has focused on evaluating and registering the risks of substances produced or imported, most prominently through the **REACH** regulation (European Union, 2006). This approach operates largely at the level of the individual substance: a chemical is assessed, and where its effects are found to be unacceptable, its use is restricted.

A recurring limitation of this approach in practice is that companies often replace a restricted substance with a structurally similar but less studied alternative, which may later prove to carry comparable hazards (Slunge et al., 2022). Because restriction follows evidence of harm, a substitute can remain in use for an extended period before its risks are fully characterised. Addressing chemical hazards at the level of the substance alone is therefore insufficient, and the question of which substances are used must also be addressed at the level of the product.

That decision, however, is made by designers and design engineers, whereas existing databases and assessment frameworks are oriented towards material and chemical developers (Bolaños Arriola et al., 2024). The information and practical methods available to designers on material safety remain limited, and such methods are not widely used.

The Safe and Circular by Design research project was initiated to address this gap. Conducted with academic and industry partners, its objective is “to develop, test and implement a method that enables the design of safe products that fit into a circular economy, based on an assessment of risks of exposure, environmental and social impacts, and a conscious evaluation of ethical consequences” (TU Delft, 2023). The project combines safe-by-design principles with circular product design, with particular emphasis on material safety, and relies on real design projects as practical test cases. This graduation project is one such case, applying the method to B2B office task chairs.

2.3 Research design motivation

This graduation project was selected as a case study because the SCbD method and MAPSSS tool had not previously been applied within a real design process; existing examples in the literature are based on fictional or theoretical cases (Bolaños Arriola et al., 2023). Applying the tool in a real industry context required a level of product and supply chain knowledge that is not available through literature alone.

The office chair industry presents particular challenges in this regard. Material safety data is rarely disclosed publicly, as suppliers and manufacturers typically limit chemical transparency to compliance with restricted substance lists rather than providing full material declarations (Monclús et al., 2025). Understanding which substances are present in specific chair components, and at which stages of the lifecycle they pose risks, required direct access to industry knowledge beyond what published sources can provide. This made the office chair a demanding but relevant test case for the SCbD method.

2.4 Substances of concern, Safe and Circular by Design, and the MAPSSS tool

Introduction

This chapter establishes the theoretical background for the research. It first introduces substances of concern and the regulatory frameworks that govern them, then presents the Safe and Circular by Design (SCbD) approach and its methodological foundations.

It continues with an introduction to office task chairs as the product studied in this research, and concludes with the exploratory literature that situates the case study within the furniture industry and its material context.

Exploratory literature research

The exploratory literature research drew on three databases: Google Scholar, ScienceDirect, and Scopus. Search terms included substances of concern, VOC in furniture, substances of concern in furniture, non-intentionally added substances, and challenges of recycled plastic use. The search returned peer-reviewed articles, industry reports, and grey literature. The findings inform the sections that follow, covering substances of concern, the SCbD methodology, and the regulatory and industry context of office task chairs.

2.4.1 Substances of Concern and regulatory frameworks

Substances of concern (SoC) are hazardous substances present in products that may pose risks to human health and the environment throughout a product’s lifecycle, and throughout any subsequent lifecycles created by circular strategies such as reuse and recycling (Bolaños Arriola et al., 2025). The presence of SoC in products is a central obstacle to a circular economy, because materials and components intended for reuse or recycling may carry hazardous substances that impede their reintroduction or generate new risks in later applications (Bolaños Arriola et al., 2025).

Substances are conventionally classified as hazardous on the basis of known hazard types and severity, following the globally harmonised system of classification and labelling of chemicals (Bolaños Arriola et al., 2025). This classification rests on known and reported effects and therefore does not account for substances in use but not yet identified as hazardous, nor for pollutants generated by products during their lifecycle, such as microplastics (Bolaños Arriola et al., 2025).

Within this category, several groups are of particular regulatory relevance, including **persistent organic pollutants (POPs)** and substances classified as persistent, **bioaccumulative and toxic (PBT)** or **very persistent and very bioaccumulative (vPvB)**.

In the European Union, these substances are addressed through distinct regulatory instruments. **The Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)** regulation is the principal framework for chemical safety, under which substances meeting PBT, vPvB, or comparable criteria can be identified as substances of very high concern and placed on the Candidate List (European Parliament and Council of the European Union, 2006).

Persistent organic pollutants are governed separately under the EU regulation on persistent organic pollutants, which restricts or eliminates their production and use (Bolaños Arriola et al., 2025).

2.4.2 Principles of Safe and Circular by Design

The Safe and Circular by Design (SCbD) approach responds to a tension within the circular economy. Products containing substances of concern cannot be safely reused, recycled, or recovered, which places the management of these substances in direct conflict with circularity (Bolaños Arriola et al., 2025). Addressing substances of concern only at the chemical or material level, for example through substitution, is often insufficient, because it can introduce new risks, new forms of environmental impact, or trade-offs in performance and cost (Bolaños Arriola et al., 2025).

SCbD reframes this as a design problem rather than a purely chemical one. It integrates safety and circularity considerations early in the development process, before material and substance choices become fixed, and treats the designer as an active participant in mitigating the risks posed by substances of concern (Bolaños Arriola et al., 2025). Rather than limiting designers to material selection, the approach extends their scope to the product architecture, the use context, and the surrounding systems across the full lifecycle (Bolaños Arriola et al., 2025).

The approach is operationalised as a structured, stepwise method comprising four steps, shown in Figure 2.3. It guides designers through the analysis of a product-substance combination, the mapping of emission and exposure scenarios across its lifecycle, and the selection and assessment of design strategies to mitigate the associated risks (Bolaños Arriola et al., 2023).

These strategies are organised into three groups.

Avoid strategies eliminate the substance from the product, for instance through substitution or redesign.

Reduce strategies lower the quantity of the substance or its emissions where elimination is not possible.

Control strategies prevent or limit emissions and exposure by containing the substance within the product or managing it across the lifecycle (Bolaños Arriola et al., 2025). The method prioritises Avoid over Reduce and Control, reflecting the principle that removing a hazard is preferable to managing the risks it presents (Bolaños Arriola et al., 2025).

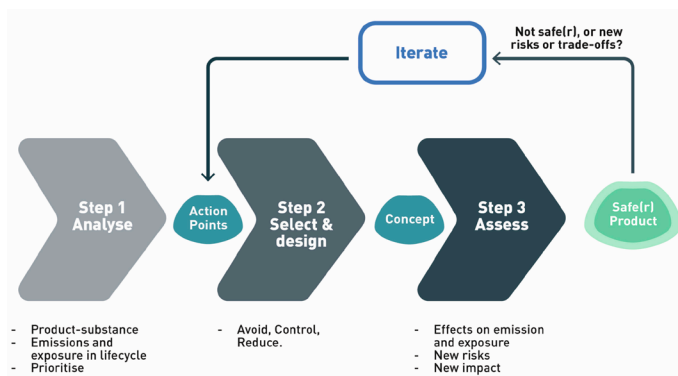


Figure 2.3. Overview of the Safe and Circular by Design method.

2.5 The applied Safe and Circular by Design method and the Mapping Assessment for Product Substance Safety and Sustainability tool

This section describes in detail how the **Safe and Circular by Design** methodology and the **Mapping Assessment for Product Substance Safety and Sustainability (MAPSSS)** tool should be applied.

Where Section 2.4.2 introduced the SCbD approach conceptually, this section explains the method as it should be used in practice, step by step, and describes the tool developed to support its application to products containing substances of concern.

2.5.1 Overview of the methodology

This section describes the application of the Safe and Circular by Design (SCbD) methodology in this research.

As introduced in Section 2.4.2, the methodology provides a structured approach to identifying and mitigating substances of concern through design.

The methodological basis for this approach was developed by Bolaños Arriola et al. (2023), whose four-step method is shown in Figure 2.4.

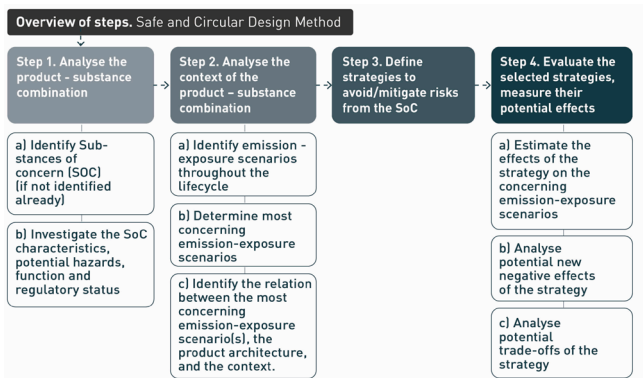


Figure 2.4. Overview of steps of the Safe and Circular Design Method, showing the four analytical and design steps and their sub-tasks. Source: Bolaños Arriola et al. (2023).

The method is organised into four steps: Step 0 **Identify**, Step 1 **Analyse**, Step 2 **Select and Design**, and Step 3 **Assess**.

Each step is addressed in its corresponding chapter. Within each step, different research and design methods were applied. The identification and analysis phases drew on literature review, expert consultation, and physical product analysis.

The selection and assessment phases employed industrial design methods to develop and evaluate concepts.

2.5.2 The MAPSSS tool

The **Mapping Assessment for Product Substance Safety and Sustainability (MAPSSS)** tool was developed within the SCbD methodology to support the lifecycle mapping and hotspot analysis conducted in Steps 0 and 1.

It consists of two components: a visual lifecycle mapping framework built in Miro and an Excel-based hotspot calculator.

The Miro framework supports designers in mapping the full lifecycle of a product by working through each process it undergoes, from **raw material extraction through manufacturing, use, and end-of-life**.

For each process, the designer records the relevant **inputs and outputs**, for example a raw material entering a manufacturing process and a component leaving it. This makes it possible to trace where substances of concern are present, how they move through the lifecycle, and what emission and exposure scenarios may arise at each stage, for both human health and the environment. The lifecycle mapping template as implemented in Miro is shown in Figure 2.5.

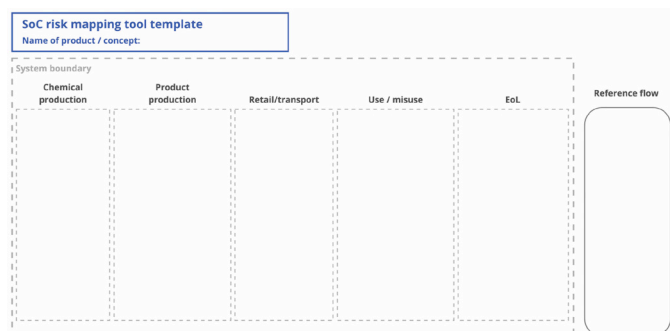


Figure 2.5. The MAPSSS lifecycle mapping template as implemented in Miro, showing lifecycle stages across columns and space for recording process inputs, outputs, and associated substances of concern.

The **Excel-based hotspot calculator** is then used to analyse the scenarios identified in the lifecycle map. Each scenario is assigned a **concern score** and an **uncertainty rating**, producing a structured, qualitative overview of which lifecycle stages and substances represent the greatest risk.

This allows the designer to **identify hotspots**, the stages that require priority attention, and to concentrate subsequent design interventions accordingly. The hotspot calculator is shown in Figure 2.6.

Figure 2.6. The MAPSSS hotspot calculator as implemented in Excel, showing concern scores and uncertainty ratings assigned to emission and exposure scenarios across the product lifecycle.

The **output** of the tool is **qualitative** rather than **quantitative**. It does not produce precise exposure measurements, but provides a structured and comparable overview that supports decision-making in the early stages of the design process.

2.5.3 Step 0. Identify

Step 0 maps the full lifecycle of the product under investigation. This means identifying and describing all processes the product undergoes, from raw material extraction through manufacturing, use, and end-of-life treatment. For each process, the relevant inputs and outputs are recorded, including the materials and substances involved, making it possible to trace where substances of concern are present and what emission and exposure scenarios may arise.

For the office task chair, the product architecture is structured around its main functional components: the seat, backrest, base, and adjustment mechanism, each consisting of subcomponents with their own material compositions and associated processes. This component structure organises the lifecycle map developed in this thesis, with components mapped individually to keep the analysis readable before being assessed as a whole product.

Three approaches were used to gather the data needed to build the map. The Declare Living Future database served as the primary source for material composition data. An exploratory grey literature review covered relevant manufacturing and end-of-life processes. A physical product teardown provided direct material evidence and component-level detail. The bill of materials developed from this teardown provided the starting point for mapping the production phase, from which the mapping was extended upstream to raw material extraction. CAS numbers were added for most materials to enable traceability and support the subsequent analysis in Step 1.

To populate the lifecycle map, the MAPSSS tool provides a set of standardised mapping elements to represent processes, inputs and outputs, and to indicate whether a substance carries a known hazard or a safety uncertainty. These elements are shown in Figure 2.7.

Elements for system mapping

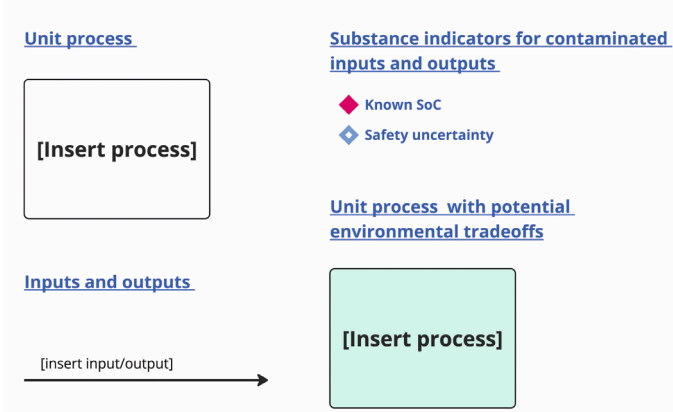


Figure 2.7. Standardised system mapping elements used in the MAPSSS lifecycle mapping framework.

2.5.4 Step 1. Analyse

Step 1 moves from lifecycle mapping to evaluation, determining which substances and lifecycle stages represent the greatest risk to human health and the environment. Where Step 0 established what is present and where across the lifecycle, Step 1 assesses how concerning each identified scenario is.

The analysis is structured around the exposure and emission scenarios identified in the lifecycle map. For each scenario, the MAPSSS tool distinguishes between two categories of impact: human health and ecosystem health. Within human health, scenarios are differentiated by the population exposed, including bystanders, vulnerable groups such as children and pregnant women, and occupational users. Within ecosystem health, scenarios consider the vulnerability of the receiving environment. The exposure points through which contact may occur, including air, surface water, wastewater, soil, dust, and direct contact, are recorded for each scenario. The mapping elements used to express these scenarios are shown in Figure 2.8.

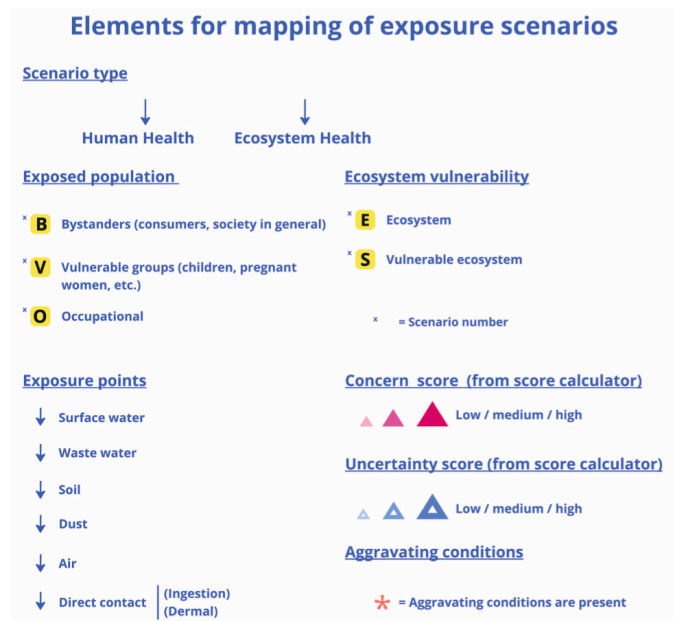


Figure 2.8 Elements for mapping exposure scenarios in the MAPSSS framework.

Each scenario is then evaluated using the MAPSSS hotspot calculator. A concern score is assigned reflecting the severity and likelihood of exposure at a given lifecycle stage, and an

uncertainty rating is assigned reflecting the reliability and completeness of the available data. The analysis also considers whether emission reduction measures or safety controls are already in place, and whether aggravating conditions are present that could increase exposure or risk. Together, these inputs produce a structured qualitative overview from which hotspots can be identified: the stages and substances requiring the most attention in the design phase that follows.

Figure 2.9 illustrates how these elements are applied to a unit process in practice.

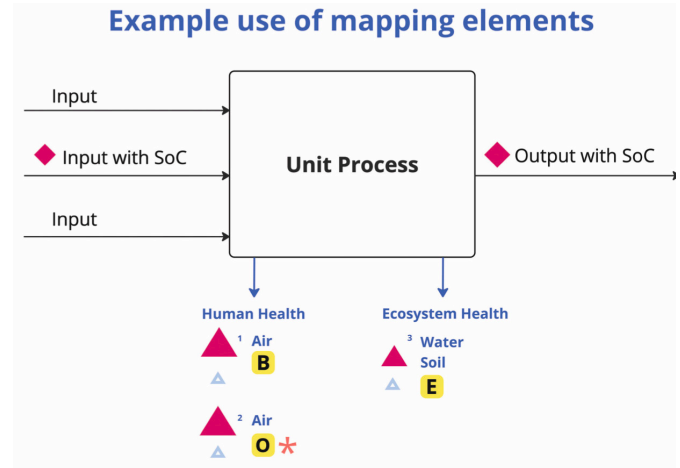


Figure 2.9 Example application of mapping elements to a unit process.

The results of the hotspot calculator are translated back into the lifecycle map in Miro, giving a visual overview of where concern is concentrated across the full lifecycle. This output forms the basis for Step 2, in which design strategies are selected and developed to address the identified hotspots.

2.5.5 Step 0. Select and Design

With the hotspots identified in Step 1, the methodology moves into Step 2: selecting and developing design strategies to mitigate the risks associated with the substance of concern. This step guides the designer in generating interventions across three strategy categories, arranged in order of priority: Avoid, Reduce, and Control (Bolaños Arriola et al., 2023). The formal definitions of each strategy group are given in Figure 2.10.

Strategy groups	Definition and characteristics
Avoid	Any action or modification to the product that eliminates the SoC. Including any form of chemical/material substitution.
Control	Any action or modification to the product or the systems surrounding it that results in: <ul style="list-style-type: none"> a) The prevention of emissions of the SoC in any stage of the lifecycle b) The prevention of exposure to the SoC in any stage of the lifecycle.
Reduce	Any action or modification to the product or the systems surrounding it that results in: <ul style="list-style-type: none"> a) A significant reduction of the volume of the SoC in the product. b) A reduction of emissions of the SoC in any stage of the lifecycle. c) A reduction of exposure of the SoC in any stage of the lifecycle.

Figure 2.10 Definitions and characteristics of the three strategy groups used in Step 2 of the SCbD method. Source: Bolaños Arriola et al. (2025).

Avoid strategies encompass any action or modification to the product that eliminates the substance of concern, including chemical or material substitution, delivering the product function through alternative means, or phasing out non-essential applications (Bolaños Arriola et al., 2025).

Control strategies include any modification to the product or its surrounding systems that prevents emissions or exposure to the substance at any stage of the lifecycle, for instance through hermetic containment or controlled end-of-life recovery (Bolaños Arriola et al., 2025).

Reduce strategies cover any modification that significantly reduces the volume of the substance in the product, its emissions, or exposure at any stage of the lifecycle (Bolaños Arriola et al., 2025). Figure 2.11 gives an overview of the strategy categories and example interventions under each.

Avoid		
Avoid	Alternative value proposition or function	Waterproofing weaving techniques
Substitute	With substances or materials known to be safe	Natural rubber for flooring
	With less harmful substances or materials	Non ozone depleting refrigerants
Phase out	Re-evaluate essentiality	No PFAS in non essential uses

Reduce		Control	
Reduce content (lower volumes = lower exposure)	Reduce content of the SoC in the product or limit use to certain components	Reduced amount of refrigerant	Contain / isolate
Increase useful life / Keep in use longer (to avoid accumulation at end of life)	Durability	Increase quality	Prevent emissions or exposure by isolating the SoC in the product.
	Maintenance and repair	Reinforcing cable sleeves	
Inform / customize	To protect vulnerable groups	Risk information	Redefine production/ manufacturing processes
	To avoid mechanisms that aggravate emissions	Washing information on label	
			Control collection / recovery
			Separate collection
			Monitor materials to avoid SoC
			SoC can be easily separated
			Maintain influence in case unforeseen negative effects arise.

Figure 2.11 Overview of the Avoid, Reduce, and Control strategy categories in Step 2 of the SCbD method, showing example interventions under each category.

The hierarchy reflects a principle: **Avoid** is prioritised over **Reduce** and **Control** because removing a hazard is preferable to managing the risks it presents.

However, the three categories are not mutually exclusive. In practice, strategies are frequently combined, particularly where a safer substitute is available, but its safety profile remains uncertain, in which case Control or Reduce strategies can provide additional safety barriers in the interim (Bolaños Arriola et al., 2025).

Each strategy may also carry drawbacks, including new environmental impacts, performance losses, or increased costs, and these trade-offs must be considered as part of the selection process.

The hotspots and the relationships between the substance, the product architecture, and the exposure pathways identified in Step 1 form the starting point for strategy development. These are used to generate and develop design concepts targeted at the lifecycle stages and scenarios of greatest concern. The concepts are subsequently carried forward to Step 3, where they are assessed against the baseline situation established in Step 1 to evaluate their effects on the identified concern scenarios, their potential negative consequences, and their trade-offs (Bolaños Arriola et al., 2023).

2.5.6 Step 3. Asses

Step 3 evaluates the design concepts developed in Step 2 against the baseline situation established in Step 1. Rather than selecting further strategies, this step determines whether the strategies already developed are effective, whether they introduce new problems, and whether the process needs to iterate. The assessment is structured around three questions (Bolaños Arriola et al., 2023).

First, the designer estimates whether the selected strategy reduces, maintains, or increases the level of concern for each of the emission and exposure scenarios identified as hotspots in Step 1. This makes the effect of the intervention on the original concern scenarios visible and comparable against the baseline.

Second, the designer examines the potential negative consequences of the strategy across the full lifecycle. A strategy that reduces concern at one stage may introduce new risks or new forms of environmental impact at another, for instance a containment approach that complicates end-of-life recovery, or a substitute material that carries its own hazard profile (Bolaños Arriola et al., 2023).

Third, the designer analyses the potential trade-offs of the strategy, which may include reduced product performance, increased manufacturing costs, changes in material availability, or organisational implications (Bolaños Arriola et al., 2023).

Together, these three assessments produce a structured, evidence-based picture of each concept's strengths and limitations. Where a concept does not sufficiently reduce concern, or introduces unacceptable new risks or trade-offs, the methodology iterates back to Step 2 to refine or replace the strategy, as shown in Figure 2.3. The goal is not the elimination of all risk, but an informed and defensible reduction of it, grounded in the evidence gathered across the preceding steps.

2.6 Conclusion

This chapter has established the theoretical foundation for this research across four interconnected areas.

The circular economy provides the ambition: keeping products and materials in use at their highest value for as long as possible. Substances of concern introduce the complication: hazardous substances present in products do not disappear when materials are reused or recycled, and may generate new risks across subsequent lifecycles. Regulatory frameworks address this problem at the level of individual substances, but this approach is insufficient on its own, because restriction follows evidence of harm and substitutes may carry comparable risks that take time to characterise.

The Safe and Circular by Design approach responds to this gap by repositioning the problem as a design problem. Rather than relying solely on chemical substitution, SCbD equips designers to address substances of concern at the level of the product architecture, the use context, and the surrounding systems, across the full lifecycle and including circular strategies. The MAPSSS tool operationalises this approach through lifecycle mapping and structured hotspot analysis, giving designers a practical method to identify where concern is concentrated and where design intervention is most needed.

Together, these theoretical foundations provide the basis for applying the SCbD method and MAPSSS tool to a real product context, with the aim of developing design concepts that reduce the risks posed by substances of concern while maintaining or improving circularity.

3



Chapter 3

The Office Task Chair

3.1 The office task chair as a product category	26
3.2 Norms, certifications, and regulatory context.....	27
3.3 The median chair	28
3.4 Industry insights.....	32
3.5 Conclusion	37

This chapter introduces the office task chair as the product context for this research. It establishes what task chairs are, how they are constructed, and why they present a relevant case for applying the Safe and Circular by Design methodology.

The chapter then situates the product within its industry, examining the norms and certifications that govern it, the structure of the value chain, and how chemical safety and circularity are currently handled in practice. The product teardown and the construction of the median chair are described next, establishing the research object used throughout this thesis.

The chapter concludes with findings from twenty expert interviews conducted across the office chair value chain, covering industry structure and decision-making, current chemical safety practices, and the challenges that hinder circularity.

3.1 The office task chair as a product category

3.1.1 Definition and product context

Office seating encompasses a broad range of chair types designed for use in professional environments, including executive chairs, ergonomic chairs, drafting stools, and speciality options such as kneeling chairs (National Business Furniture, n.d.). Within this category, the **task chair** is the most prevalent type in professional offices. Task chairs are designed for intensive daily use over extended periods of seated work, typically featuring height adjustment, lumbar support, and a swivel base as standard, with varying degrees of ergonomic adjustability depending on the market segment (Office Furniture Direct, n.d.).

This thesis focuses on task chairs in the **business-to-business (B2B) market**.

In this context, chairs are purchased in volume by organisations rather than individual consumers, and procurement decisions are typically made by purchasing departments rather than the end users.

This separation between user and customer has direct implications for product requirements: comfort and ergonomics are priorities for the user, while price tends to dominate purchasing decisions.

Material safety and chemical composition rarely feature in the procurement conversation, even though users may spend several hours per day in direct contact with their chair over the product's full-service life. Cumulative exposure over this period is a relevant health consideration that is rarely addressed at either the purchasing or the design stage.

The prolonged and repeated nature of task chair use makes material safety particularly relevant. Foams, adhesives, and surface treatments can emit volatile organic compounds (VOCs) that contribute to indoor air pollution, while flame retardants and plasticizers present in upholstery and plastic components are classified as substances of concern due to their persistence, bioaccumulation potential, and toxicological properties (Wiesinger et al., 2021; Ulker et al., 2021).

The use of recycled plastics introduces a further challenge: post-consumer recycled materials frequently contain **non-intentionally added substances (NIAS)**, including polymer degradation products, additive residues, and contaminants from prior applications, which are difficult to trace or control (Horodytska et al., 2020).

These characteristics make the office task chair a relevant and demanding product context for applying a safe and circular design approach.

3.1.2 Product architecture

A typical office task chair is composed of several functional component groups, each serving a distinct structural or ergonomic purpose.

These can be organised into five groups: the seating system, the backrest system, the armrest system, the support and adjustment system, and the base system. Figure 3.1 shows an exploded view of a representative task chair identifying the main components within each group.



Figure 3.1 Exploded view of a typical office task chair, showing its main components.

Table 3.1 gives an overview of each component group, its constituent components, and the primary materials typically used in their construction.

Table 3.1 Component groups, components, and typical materials of an office task chair.

Component group	Components	Typical materials
Seating system	Seat cushion, seat pan, seat mesh	Polyurethane foam, glass-fibre reinforced nylon, polypropylene, polyester or nylon mesh, textile or leather
Backrest system	Backrest frame, backrest cushion or mesh, headrest	Glass-fibre reinforced nylon, polypropylene, polyurethane foam, polyester or nylon mesh, textile or leather
Support and adjustment system	Armrest frame, armrest pad, mounting brackets	Nylon, polypropylene, polyurethane foam, steel
Support and adjustment system	Armrest system	Steel, plastic housing, internal lubricants, chrome or powder-coated steel
Base system	Star base, castors	Die-cast aluminium or glass-fibre reinforced nylon, nylon, polypropylene, rubber or polyurethane tread, steel

Each component group carries its own material profile and associated substance of concern implications. Together, these material combinations give the task chair a complex and layered substance profile that extends across multiple components and lifecycle stages, which is examined in detail in the hotspot analysis in Chapter 5.

3.2 Norms, certifications, and regulatory context

The design, market entry, and procurement of office task chairs is shaped by a range of standards and certifications. These fall into two categories: **ergonomic and physical safety standards**, which define the baseline performance requirements every chair must meet, and **sustainability and chemical safety certifications**, which address material composition, environmental impact, and chemical emissions beyond the physical baseline. The latter are voluntary, but their adoption is growing as regulatory pressure and client sustainability requirements increase.

3.2.1 Ergonomic and physical safety standards

Office task chairs sold in the Dutch and broader European market must comply with the NEN-EN 1335 standard series, which sets the baseline requirements for office seating. NEN-EN 1335-1 (2020) establishes dimensional requirements, defining minimum and recommended ranges for seat height, seat depth, backrest height, and armrest dimensions relative to the seated user.

NEN-EN 1335-2 (2018) covers physical safety requirements, specifying test methods and performance criteria for structural integrity, stability, and mechanical durability under repeated loading conditions. Together these two standards define the physical envelope within which every task chair on the European market must perform.

These standards are relevant to this research as baseline design constraints that any concept developed through the SCbD methodology must continue to meet. They are otherwise considered out of scope, as they address physical performance and dimensional compliance rather than material composition, chemical emissions, or end-of-life considerations.

3.2.2 Sustainability and chemical safety certifications

Beyond the baseline physical standards, a growing number of sustainability and chemical safety certifications address the material composition, environmental impact, and chemical emissions of office furniture. The main schemes relevant to the office chair industry are summarised in Table 3.2.

Table 3.2 Overview of sustainability and chemical safety certifications relevant to the office chair industry, including their scope and focus.

Certification	Issuing body	Primary focus
BIFMA e3	Business and Institutional Furniture Manufacturers Association	Sustainability performance across materials, energy, human and ecosystem health
GREENGUARD	UL LLC	VOC emissions limits for indoor air quality
GS	GS-LCIE	Physical safety and VOC emissions
FEMB Level	Furniture EPD Management Group	Environmental performance and lifecycle assessment
Cradle to Cradle	Cradle to Cradle Products Innovation Institute	Material health, recyclability, and circular economy principles

The **GS certification** is a German product safety mark that, beyond physical safety requirements, evaluates exposure to volatile organic compounds, making it one of the few widely adopted schemes to address chemical emissions directly.

GREENGUARD similarly sets strict limits on VOC emissions from furniture products, establishing maximum allowable concentrations for a range of individual compounds (UL LLC, 2013). Both certifications address chemical safety at the level of emissions testing, measuring what leaves the product rather than examining what is in it.

This research focuses primarily on **BIFMA e3** and the associated **Declare material transparency label**, administered by the International Living Future Institute.

BIFMA e3 is a multi-attribute sustainability standard that addresses material health, human and ecosystem health, energy use, and social considerations across the full product lifecycle (Business and Institutional Furniture Manufacturers Association, 2024).

Unlike VOC-based certifications, it requires manufacturers to disclose the chemical ingredients of their products, making it possible to identify substances of concern at the composition level rather than only at the point of emission.

The Declare label operationalises this requirement by providing a standardised ingredient disclosure format for building and interior products, drawing on the Living Product Challenge materials database to flag substances against known hazard lists (International Living Future Institute, n.d.).

This level of chemical transparency makes BIFMA e3 and Declare more directly useful for this research than the other schemes listed, which either focus on physical performance or address chemical safety only at the emissions stage.

The other certifications were excluded from detailed analysis because publicly accessible documentation at higher certification levels is limited or requires paid access.

3.3 The median chair

To apply the SCbD methodology to a representative product rather than a single proprietary model, a median chair was constructed as the research object for this thesis.

This approach combines material composition data from ten reference chairs with physical component evidence from a product teardown, producing a composite that represents the typical material profile of a B2B office task chair.

3.3.1 Product teardown

Approach

Two second-hand office task chairs were purchased and physically disassembled to establish an evidence-based component inventory.

The teardown aimed to identify the main components of a typical task chair, understand how they are manufactured and assembled, assess how easily they can be separated at end of life, and identify where users and end-of-life workers may be exposed to the materials.

The two chairs were selected to represent different common construction approaches: the first features a metal backrest frame with mesh and textile upholstery, and the second is constructed predominantly from plastic and foam components. Both chairs had either reached end of life or transitioned from a B2B to a consumer market context.

The chairs selected for disassembly are shown in Figure 3.2.



Figure 3.2 Office task chairs selected for physical disassembly and material analysis, showing front and rear views of both models.

Findings

The teardown revealed the component structure of both chairs and highlighted differences in how well each was designed for disassembly. Basic components such as the backrest, armrests, and seat were straightforward to remove on both models.

The first chair demonstrated a relatively modular construction. The backrest consisted of a textile cover stretched over a metal frame with a lumbar support element mounted internally, an assembly that could be taken apart without damage and would allow for component replacement. The star base was fully modular and could be disassembled including the castors.

However, the seat and mechanism presented greater difficulty. Once the mechanism was separated from the star base, it could not be disassembled further without damage. The seat cushion was similarly problematic, as the polyurethane foam was bonded directly to a wooden seat pan, making material separation effectively impossible without destroying one or both components.

The larger structural components were manufactured from engineering-grade materials, including glass-fibre reinforced nylon for the star base and ABS for the covers. The disassembled components of the first chair are shown in Figure 3.3.



Figure 3.3 . Physical disassembly and component breakdown of the first office chair.

The second chair presented similar disassembly challenges but with a less modular construction overall.

The star base was a single-piece unit made from steel or aluminium with a surface coating, offering no possibility for component-level disassembly.

The mechanism was more complex than that of the first chair, providing movement in both the vertical axis and the front-to-back direction of the seat pan, and was left intact during disassembly as separating it would have required destructive tools.

The backrest was covered by a large plastic shell, with textile and foam stapled directly onto it, making separation highly time-consuming and difficult to achieve without material damage.

The disassembled components of the second chair are shown in Figure 3.4.



Figure 3.4 . Physical disassembly and component breakdown of the second office chair.

Based on the teardown, the following main components were identified as representative of a typical office task chair: star base, castors, gas lift, mechanism, seat pan, seat cushion, backrest structure, backrest cushion or mesh, armrests, hardware, and packaging.

This component inventory provided the structural framework for the lifecycle map developed in Step 0 and informed the construction of the median chair described in Section 3.3.3.

3.3.2 The Declare database and case study selection

To complement the physical teardown with material composition data, the Declare database administered by the International Living Future Institute was used as the primary data source.

Declare is a publicly accessible material transparency platform that provides standardised ingredient disclosures for building and interior products, requiring manufacturers to declare the chemical composition of their products against known hazard lists (International Living Future Institute, n.d.).

An example of a Declare material declaration for an office chair is shown in Figure 3.5.

Ingredients:

A380 Aluminum; Polypropylene; Nylon 6; ASTM A1008 Steel; Polyurethane; Polystyrene; JIS STKM12B Carbon Steel; 11L41 CRS / #45 Carbon Steel; Glass/Mineral Fiber; Talc; JIS SPCC Carbon Steel; Propylene/ethylene copolymer; Polycarbonate; AISI 1008 Carbon Steel; Thermoplastic Polyurethane; TPU; AISI 12L14 Carbon Steel; Polyamide PA6; AISI 1215 Carbon Steel; Aluminum Powder; Zinc; Carbon black; 1215MS Steel; Acrylonitrile-Butadiene-Styrene Copolymer; 1,4-Butanediol, polymer with α -hydro- ω -hydroxypoly(oxy-1,4-butanediyl) and 1,1'-methylenebis[4-isocyanatobenzene]; POM; 1-Butene, polymer with ethene; JIS G3509 SCM435 Steel; Carbon Black; JIS G3141 SPCC Carbon Steel; AISI 1018 Carbon Steel; Chromium hydroxide (Cr(OH)₃); Chromium, metallic; GB/T 700 Q235 Steel; Chromium oxide (Cr₂O₃); Styrene-Butadiene polymer; Polyethylene; SAE 1022 Steel; Trivalent Chromium Compound; Chromium; Poly[imino(1,6-dioxo-1,6-hexanedyl)imino-1,6-hexanedyl]; AISI 1065 Carbon Steel; Octadecanamide, N,N'-1,2-ethanedylbis-; **Petroleum distillates, hydrotreated heavy naphthenic[†]**; Undisclosed (0.03-0.07%); Benzenepropanoic acid, 3,5-bis(1,1-dimethylethyl)-4-hydroxy-, 2,2-bis[[3-[3,5-bis(1,1-dimethylethyl)-4-hydroxyphenyl]-1-oxopropoxy]methyl]-1,3-propanediyl ester; DGEBPA-b; Octadecanoic acid, calcium salt; Phenol, 2,4-bis(1,1-dimethylethyl)-, phosphite (3:1); Silicon; Zinc hydroxide (Zn(OH)₂); 10B21 Steel; Butanedioic acid, dimethyl ester, polymer with 4-hydroxy-2,2,6,6-tetramethyl-1-piperidineethanol; Calcium Carbonate; **Distillates (petroleum), hydrotreated heavy paraffinic[†]**; Ethylene; JIS G3522 SWP-B Carbon Steel; Nylon 66; Poly[oxy(methyl-1,2-ethanedyl)], α -butyl- ω -hydroxy-; POM; 1,3-Propanediamine, N'-[3-(dimethylamino)propyl]-N,N-dimethyl-; 1,4-Benzenedicarboxylic acid, polymer with 1,3-dihydro-1,3-dioxo-5-isobenzofuranicarboxylic acid, 2,2-dimethyl-1,3-propanediol and hexanedioic acid; buta-1,3-diene; prop-2-enenitrile; styrene; Caprolactam; JIS G3507 Carbon Steel; Poly(oxyethylene); SAE 841 Oilite Bronze; SAE 841 Oilite Bronze; Titanium dioxide; Copper; Sodium Sulfate; 13-Docosanamide, (Z)-; **Cobalt metal powder[†]**; Glycerol mono- and di-stearate; Iron; JIS G4053 SCM435 Steel; Phosphorus; Poly(oxyethylene), α -acetyl- ω -(acetyloxy)-; Poly[oxy(methyl-1,2-ethanedyl)], α -hydro- ω -(2-aminomethylethoxy)-, ether with 2-ethyl-2-(hydroxymethyl)-1,3-propanediol (3:1); Styrene-acrylonitrile copolymers; Undisclosed (< 0.01%); White mineral oil (petroleum)

[†]LBC Temp Exception RL-004b - Proprietary Ingredients in Declare
[†]SIN List present > 100ppm

Living Building Challenge Criteria: Compliant

I-13 Red List:

- LBC Red List Free
- LBC Red List Approved
- Declared

% Disclosed: 99.92% at 100ppm
 VOC Content: Not Applicable

I-10 Interior Performance: CDPH Standard Method v1.2-2017
I-14 Responsible Sourcing: Not Applicable

Figure 3.5. Example of a Declare material declaration for an office chair

Material information available on manufacturer websites is typically limited and inconsistent, making it difficult to establish a reliable baseline for material composition across the product category.

The Declare database provides a standardised alternative, with detailed ingredient disclosures that make it possible to identify which materials and substances are present in a given product.

One limitation is that materials are listed at the product level without being linked to specific components. This was addressed by cross-referencing the Declare material lists with the component inventory established through the teardown, using additional research to connect each material to its corresponding component and subcomponent.

Ten office task chair models from different brands within the Declare database were selected as reference chairs. These ten models are described in Appendix A.

The main limitation of this selection is that the Declare database includes only chairs that have undergone rigorous transparency reporting, meaning the reference set reflects better practice rather than the industry average. The actual median chair on the market likely contains a more concerning material composition than the one developed here.

3.3.3 Construction of the median chair

Using the ten reference chairs from the Declare database together with the component inventory from the teardown, a median chair was constructed to represent the typical material composition of a B2B office task chair.

The component structure identified through the teardown provided the framework, and the material data from the Declare declarations was used to populate each component with its typical material composition. CAS numbers were added for most materials to enable traceability and support the hotspot analysis in Step 1. Risk ratings were assigned on the basis of ECHA classification data, IARC carcinogen classifications, and REACH candidate list status at the time of writing, and reflect the concern level associated with each material during production and handling rather than in the finished article.

Table 3.3 provides an overview of the median chair's material composition by component and subcomponent, organised by component group. The full material declarations for each of the ten reference chairs are provided in Appendix A.

Table 3.3. Material composition overview of the median office task chair by component and subcomponent, including CAS numbers and production-phase risk ratings. Risk ratings: H = high, M = medium, L = low. Sources: Declare Living Future database, ECHA classification and labelling inventory, IARC monographs; REACH candidate list.

Component	Subcomponent	Material	CAS	Material Category	Risk
Base & Casters	5-star base	Nylon 6 (glass-filled)	25038-54-4	Engineering polymer	L
Base & Casters	5-star base filler	Glass, oxide	65997-17-3	Mineral reinforcement	L
Base & Casters	5-star base pigment	Carbon black	1333-86-4	Pigment	H
Base & Casters	5-star base insert	Steel EN S235JR / DC01	—	Carbon steel	M
Casters	Wheel body	Polypropylene	9003-07-0	Polymer	L
Casters	Wheel body pigment	Carbon black	1333-86-4	Pigment	H
Casters	Wheel hub	POM	9002-81-7	Engineering polymer	M
Casters	Wheel hub (alt.)	POM copolymer	24969-26-4	Engineering polymer	M
Casters	Caster stem	Steel UNS G10080	—	Carbon steel	M
Casters	Caster stem plating	Zinc	7440-66-6	Metal plating	M
Gas Lift	Outer cylinder	Steel EN 10277	—	Carbon steel	M
Gas Lift	Outer cylinder coating	Carbon black	1333-86-4	Pigment	H
Gas Lift	Outer cylinder coating	Diiron trioxide	1309-37-1	Inorganic pigment	L
Gas Lift	Inner piston	Steel C45 / EN19	—	Alloy steel	M
Gas Lift	Piston plating	Nickel	7440-02-0	Metal	H
Gas Lift	Piston plating	Zinc	7440-66-6	Metal	M
Gas Lift	Seals	NBR	9003-18-3	Elastomer	M
Gas Lift	Seals	Silicone polymer	63148-53-8	Elastomer	L
Gas Lift	Lubricant	Hydrogenated decene polymer	68037-01-4	Lubricating oil	M
Gas Lift	Lubricant	Petroleum distillates	64742-54-7	Lubricating oil	M-H
Gas Lift	Lubricant additive	Zinc stearate	557-05-1	Additive	L
Seat Structure	Seat pan	Glass-filled polypropylene	9003-07-0	Polymer	L
Seat Structure	Seat pan filler	Glass, oxide	65997-17-3	Mineral	L
Seat Structure	Seat pan filler	Talc	14807-96-6	Mineral	M-H
Seat Structure	Seat pan pigment	Carbon black	1333-86-4	Pigment	H
Seat Structure	Support bracket	Steel EN S235JR / DC01	—	Carbon steel	M
Seat Structure	Hinge bushings	POM copolymer	24969-26-4	Engineering polymer	M
Seat Cushion	Foam core	Polyurethane foam	9009-54-5	Polymer (foam)	H
Seat Cushion	Foam component	Polyether polyol	9003-11-6	Polymer	M
Seat Cushion	Foam component	Polyether polyol	9082-00-2	Polymer	M
Seat Cushion	Isocyanate	pMDI	9016-87-9	Isocyanate	H
Seat Cushion	FR additive	T CPP	13674-84-5	Flame retardant	M
Seat Cushion	Foam additive	Zinc stearate	557-05-1	Additive	L
Backrest Structure	Back frame	Glass-filled Nylon 6	25038-54-4	Engineering polymer	L
Backrest Structure	Back frame filler	Glass, oxide	65997-17-3	Mineral	L
Backrest Structure	Connection bracket	Steel EN 10111 / S235JR	—	Carbon steel	M
Backrest Structure	Pivot bushings	POM	9002-81-7	Engineering polymer	M
Backrest Cushion / Mesh	Mesh fabric	Polyester fibre	113669-97-9	Textile polymer	L
Backrest Cushion / Mesh	Mesh fabric (alt.)	PET	25038-59-9	Textile polymer	L
Backrest Cushion / Mesh	Dye	Acid Black 2	8005-03-6	Dye	M-H
Backrest Cushion / Mesh	Dye (alt.)	Solvent Black 7	8005-02-5	Dye	M-H
Backrest Cushion / Mesh	Pigment	Carbon black	1333-86-4	Pigment	H

Armrests	Armrest frame	Steel C45 / EN19	—	Carbon steel	M
Armrests	Armrest frame (alt.)	Aluminum ADC12	—	Aluminum alloy	M
Armrests	Arm pad core	Polyurethane foam	9009-54-5	Foam	H
Armrests	Arm pad cover	TPEE	308079-71-2	TPE	L
Armrests	Arm pad cover (alt.)	Hydrogenated SBC	66070-58-4	Elastomer	L
Armrests	Arm pad pigment	Carbon black	1333-86-4	Pigment	H
Armrests	Fasteners	Steel UNS G10080	—	Carbon steel	M
Armrests	Fastener plating	Zinc	7440-66-6	Metal	M
Upholstery	Seat fabric	Polyester	113669-97-9	Textile polymer	L
Upholstery	Textile dye	Acid Black 2	8005-03-6	Dye	M-H
Upholstery	Textile dye (alt.)	Solvent Black 7	8005-02-5	Dye	M-H
Hardware	Screws and bolts	Steel G10080 / G10100	—	Carbon steel	M
Hardware	Screw and bolt plating	Zinc	7440-66-6	Metal	M
Hardware	Bushings	Bronze UNS S74100	—	Copper alloy	M
Adhesives & Coatings	Structural adhesive	Epoxy resin	25036-25-3	Thermoset resin	H
Adhesives & Coatings	Epoxy hardener	Polyamine hardener	63469-23-8	Hardener	H
Adhesives & Coatings	Coating resin	Phenol-formaldehyde resin	9003-35-4	Thermoset resin	M-H
Adhesives & Coatings	Powder coating	Polyester-based	—	Polymer coating	L-M
Adhesives & Coatings	Lubricant	Petroleum distillates	64742-54-7	Lubricating oil	M-H
Adhesives & Coatings	Antioxidant	Phosphite stabiliser	31570-04-4	Additive	M
Adhesives & Coatings	Plasticiser	Benzoate ester	68515-40-2	Plasticiser	M-H

3.4 Industry insights

3.4.1 Interview methodology

To understand how the office chair industry operates in practice, twenty semi-structured interviews were conducted with professionals working across different parts of the chair value chain. Semi-structured interviews were chosen because the complexity and variability of industry practice required open-ended exploration rather than fixed-response instruments. The flexibility of this format allowed interviewees to elaborate beyond the prepared questions, surfacing knowledge that a structured survey could not have captured.

Data was collected through two channels. The majority of interviews were conducted online, allowing access to professionals across different countries and company types. Additional participants were recruited and interviewed in person at the Amsterdam Furniture Fair, where informal observations about industry practice, sustainability claims, and emerging legislation were also made. Most participants were recruited via LinkedIn through direct outreach, a recruitment post, or referrals from previously interviewed experts.

All interviews were transcribed and analysed using inductive thematic analysis. Transcripts were read multiple times to identify recurring topics, and findings were grouped into themes based on the patterns that emerged. Three main themes were identified: industry structure, design process, and decision-making; chemical safety knowledge and practice; and circularity, end of life, and material challenges.

The interviews served three purposes across this thesis. In this chapter, they provide industry context: how the value chain operates, how design decisions are made, and what the current state of chemical safety and circularity practice looks like. In the analysis chapters, selected findings validate the lifecycle mapping and hotspot analysis developed in Steps 0 and 1.

During the design phase, expert feedback informed concept development and helped test whether proposed strategies are feasible within the constraints of real industry practice.

Table 3.4 summarises the twenty interviewees by professional role, company context, and experience level. The full interview overview including individual interview goals is provided in Appendix B.

Table 3.4. Interview participants by professional role, company context, and experience level.

Expert	Role	Company context	Experience
Expert 1	Partner, design agency	Design agency	35+ years
Expert 2	Design engineer	Large corporation	15+ years
Expert 3	Head of engineering	Mid-size corporation	12+ years
Expert 4	Junior designer/engineer	Mid-size corporation	2+ years
Expert 5	Partner, design agency	Design agency	20+ years
Expert 6	Freelance furniture designer	Designer	20+ years
Expert 7	Senior designer	Design agency	10+ years
Expert 8	Junior designer	Design agency	3+ years
Expert 9	Senior designer	Design agency	10+ years
Expert 10	Mid-level designer	Design agency	6+ years
Expert 11	Sustainability expert and industrial designer	Designer	15+ years
Expert 12	Owner, new chair company	Small corporation	25+ years
Expert 13	Textile expert	Designer	3+ years
Expert 14	Vice president of design	Large corporation	12+ years
Expert 15	Vice president of CMF	Large corporation	20+ years
Expert 16	Material scientist	Independent	15+ years
Expert 17	Sustainability expert	Large corporation	5+ years
Expert 18	Sustainability expert	Mid-size corporation	30+ years
Expert 19	Material innovation expert	Large corporation	30+ years
Expert 20	Retail and logistics expert	End-of-life sector	5+ years

The sample spans large corporations, mid-size companies, design agencies specialising in chair design, independent designers and freelancers, an independent material scientist, and an end-of-life specialist, providing a broad cross-section of the value chain. Interview goals varied across three categories:

- Understanding industry structure and design practice (Experts 1 to 10 and 12)
- Gaining specialist knowledge on materials, textiles and sustainability (Experts 11, 13, and 16)
- Validating the analysis conducted in Steps 0 and 1 (Experts 17, 18, 19, and 20).

3.4.2 Theme 1: Industry structure, design process, and decision-making

The office chair industry is relatively small and interconnected. Most professionals are familiar with one another or each other's work, and the majority of companies rely on the same original

equipment manufacturers (OEMs) for key components. Gas springs and star bases, for example, are sourced from no more than two or three suppliers worldwide.

The relationships between actors in the value chain are shown in Figure 3.6.

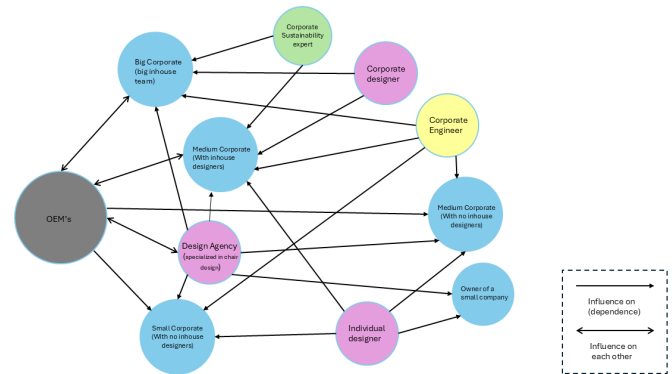


Figure 3.6. Relationships between actors in the office chair industry value chain.

The degree of dependency on OEMs varies with company size. Larger and medium-sized companies generally have greater control over their components and supply chain, whereas smaller companies are more constrained by what OEMs offer as standard. As Expert 6 noted: "As a consultant you can propose things, but unless the client has big purchasing power, the suppliers decide what is possible." This dependency directly limits what designers working within or for smaller companies can realistically implement.

Budget constraints represent a consistent limiting factor across the industry, operating in close relation to OEM dependency. Even when a designer identifies a preferable or safer material or manufacturing method, substitution is often not feasible within the allocated budget. The portion of a project budget dedicated to sustainability tends to be the smallest, and any material change requires additional cost and testing. This creates a structural barrier across all company sizes, though it is most acute for smaller organisations.

Design process: agency versus in-house. A clear distinction exists between how design is practised in external design agencies and within in-house corporate teams, and this distinction has direct implications for how material safety and sustainability can be addressed.

In design agencies, particularly those specialising in chair design, work is conducted on a billable-hour basis. Clients commission agencies primarily for their design skills and innovation capacity, and the hours allocated to a project are typically focused on form, ergonomics, and engineering rather than sustainability.

As several agency designers noted, it is difficult to sell additional hours for sustainability investigations or material safety improvements, because clients rarely include these in their brief. The agency's involvement is also time-limited: once the design is delivered, the agency has no further influence over engineering decisions, material selections, or manufacturing processes. In segments of the market where Chinese manufacturing is increasingly prevalent, the agency is typically engaged for the design phase only, after which all further decisions are made without their input.

In-house design teams operate differently. A project typically begins with designers, engineers, sustainability experts, and sometimes material scientists jointly defining the scope, target market, material guidelines, and safety parameters. These parameters are set early and are difficult to revise once the project progresses.

Figure 3.7 shows how design and engineering responsibilities are distributed across project phases prior to product launch

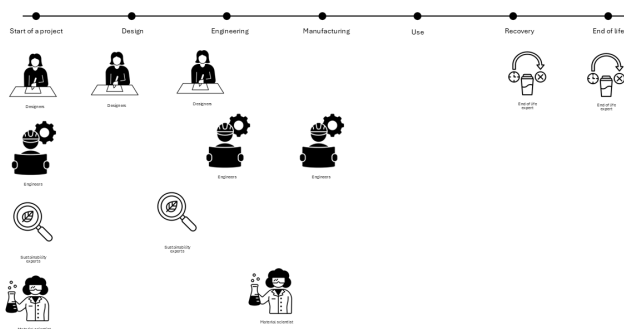


Figure 3.7. Distribution of design and engineering responsibilities across project phases prior to product launch.

After launch, product improvements are handled primarily by design engineers and manufacturers, with a focus on reducing manufacturing costs and addressing physical safety issues.

The window for meaningful intervention on material composition effectively closes once a product reaches the market. This means that even when problems are identified post-launch, the opportunity to address them through design is limited.

Figure 3.8 shows how responsibility shifts after launch, with designers re-engaged only at the start of a redesign.

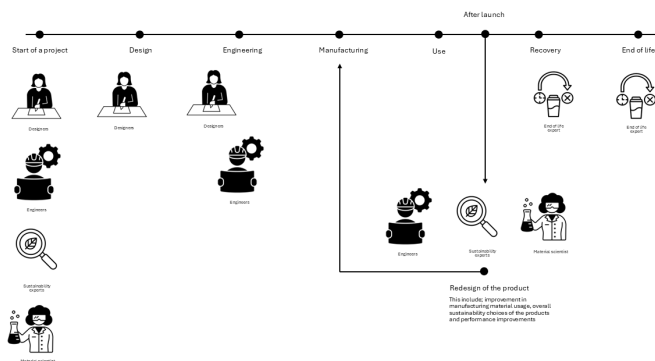


Figure 3.8. Distribution of design and engineering responsibilities following product launch, showing how responsibility shifts to engineers and specialists, with designers re-engaged only at the start of a redesign.

Larger corporations have access to dedicated specialists such as material scientists and sustainability experts, while at smaller companies designers often cover multiple roles simultaneously. This leads to knowledge gaps on topics such as chemical safety, where specialist expertise is required but not always available.

Design process and tool integration.

When the SCbD methodology and MAPSSS tool were discussed with interviewees, several consistent observations emerged. Designers noted that the topic of substances of concern is not well known within the profession and is difficult to

navigate without specialist support. For a tool like MAPSSS to be adopted in practice, it would need to be fast and straightforward to use, since time and budget constraints leave little room for methods that require extended investment.

Several agency designers identified a potential pathway for adoption through service offerings. If material safety analysis could be framed as a value-added service to clients, particularly given growing regulatory pressure and procurement incentives, it could be sold as part of a project scope rather than treated as overhead. This connects to an emerging development in the Dutch procurement context: government-related tenders increasingly use point systems that reward sustainability performance, meaning a more sustainably designed product can gain a competitive advantage in public procurement. This creates a direct commercial incentive for companies to engage with material safety, beyond regulatory compliance alone.

A related observation concerns the role of refurbished and reused chairs in sustainability accounting. In some contexts, refurbished office chairs do not count toward a building's embodied carbon, creating an incentive for architects and facility managers to specify them. However, this accounting benefit does not address the material safety of the reused product. If the chair being reused contains substances of concern, its extended life prolongs rather than resolves the exposure risk. This makes material safety a relevant consideration even within circular business models, and reinforces the need for tools that can assess the safety profile of existing products as well as new ones.

Interviewees also identified specific features that would make a tool like MAPSSS more practical: the ability to verify whether a lifecycle map and hotspot analysis are correct, access to open databases for substance information, and guided examples to support users unfamiliar with chemical safety concepts. The possibility of an AI-assisted component that could help designers navigate the process without requiring deep toxicological expertise was mentioned by several participants as a feature that could lower the barrier to adoption.

These findings are directly relevant to SQ2.1 and SQ2.3, addressing how the SCbD framework could improve designer workflows and what barriers exist to its implementation.

3.4.3 Theme 2: Chemical safety knowledge and practice

When it comes to chemical safety, a clear gap exists between what current research addresses, what regulation requires, and what experts in the chair industry actually do in practice.

Most interviewees indicated that material safety is considered primarily from a regulatory standpoint. Action is taken because a material has been banned and an alternative must be found, rather than out of voluntary initiative. As one interviewee noted: "Regulation is the main driver. Without EU pressure, a lot of companies would not move towards circular materials" (Expert 17, personal communication). Another stated: "Real change only happens when the EU or national standards force companies to do something. Without regulation, sustainability is optional" (Expert 18, personal communication).

Material safety is often treated as an afterthought rather than a design-phase consideration. Adjustments are typically made after a product has been launched, in response to the specific regulatory requirements of each market. Because regulatory requirements vary across countries, manufacturers tend to design a base product and adapt it for each market, resulting in multiple product variants. This also creates room for selective compliance, where certain variants are submitted for certification while others are not, allowing manufacturers to present a curated list of certified products without applying the same standards across their entire range.

A consistent finding was the lack of material transparency from suppliers, particularly when production occurs outside the company. Obtaining clear compositional data on materials such as plastics is extremely difficult. As one interviewee explained: "The different suppliers of the materials or the compounders are not willing to share what the mix of their products is" (Expert 19, personal communication). The same interviewee added: "There are 10 massive companies that control the market. If you do not order 1,000,000 kg they do not even look at you. The reseller will mix you a batch that can change every time to your needs." This variability in composition makes it nearly impossible to reliably track which substances are present in a given material batch. Chemical testing is conducted only periodically due to cost constraints, and inconsistent results have been found for the same materials across batches.

For companies that do conduct chemical analysis, interpreting the results presents a further challenge. As one interviewee described: "I get a report back of 12 pages, with chemicals and materials that are in the product, but I do not know what to do with it" (Expert 3, personal communication).

Figure 3.9 illustrates this pattern of inaction resulting from knowledge gaps.

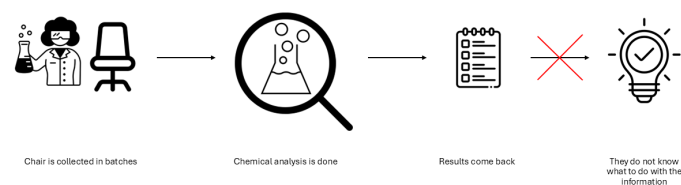


Figure 3.9. The knowledge gap cycle in the office chair industry: chemical analysis is conducted, results are returned, but companies lack the expertise to act on the findings

This problem is particularly acute for designers who cover multiple roles simultaneously, as chemical safety tends to compete with other responsibilities. Since there is no legal obligation to act on test results, the incentive to invest time in understanding them is limited.

The cost of testing and certifying new materials is a significant barrier to change. As one interviewee noted: "We tried several alternatives for nylon with glass fibre, and we found solutions that could work, but due to the cost of having to test everything and certify it, for now we left the idea" (Expert 14, personal communication). Designers consequently default to standard, well-tested materials whose performance is already verified, as shown in Figure 3.10.



Figure 3.10. Standard materials most commonly used in the construction of office task chairs, identified through expert interviews.

The broader priorities of most companies follow a consistent pattern: producing a chair that sells and meets ergonomic and physical safety requirements comes first, followed by reducing CO₂ emissions.

Material safety and chemical composition receive the least attention, not because companies are unaware of the issue, but because the structural incentives to act on it are largely absent. As one interviewee put it: "If you do not know what is in your product and your manufacturer will not tell you, how can you improve a product that you do not know needs improvement" (Expert 12, personal communication).

These findings directly address SQ1.1, SQ1.2, SQ1.3, and SQ3.3.

3.4.4 Theme 3: Chemical safety knowledge and practice

Several interviewees pointed to a distinction in the B2B market between the user and the customer.

The user prioritises comfort, ergonomics, and product quality, while the customer, typically a purchasing department, focuses primarily on price. This gap in priorities directly affects what sustainability and material safety requirements are placed on manufacturers, and reinforces the structural tendency to deprioritise chemical safety in procurement decisions.

End-of-life and product loss. Most B2B companies offer a take-back service, allowing customers to return chairs at the end of their lease or product life.

The two predominant business models in the industry, linear and take-back, are shown in Figure 3.11.

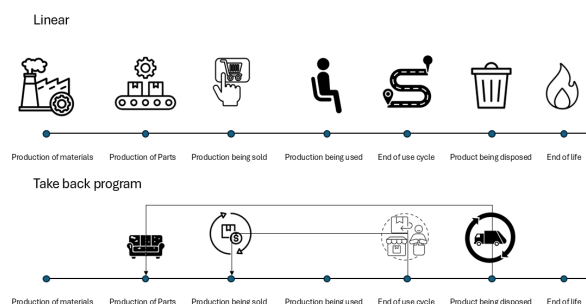


Figure 3.11 Business models in the office chair industry: the linear model and the take-back programme model.

Despite the existence of take-back programmes, around 50% of chairs are lost in the process, with many ending up in the secondary B2C market where refurbishment companies purchase them in bulk, repair and clean them, and resell them at lower prices.

The original manufacturer loses track of these products and can no longer recover parts or materials from them. While the chair receives an additional use cycle, which extends its life, this pathway also means that the safety profile of the product in its second life is unknown and unmanaged.

A recurring theme was the narrow focus on CO₂ metrics in current sustainability practice. Reducing carbon emissions has become a dominant priority, often at the expense of broader material and chemical considerations. This focus also creates space for misleading sustainability claims.

Figure 3.12 shows an example of a manufacturer claiming 100% circularity, a statement that is practically unachievable given the material complexity of task chairs.



Figure 3.12. Sustainability claims by an office chair manufacturer, illustrating the gap between marketed circularity and actual material complexity.

As Expert 20 noted, while metal components are typically recovered at end of life, the remaining materials are too time consuming to separate and are therefore incinerated for energy recovery, resulting in significant material value loss. This is consistent with Forrest et al. (2017), who argue that despite its considerable potential, the European furniture sector remains largely linear and structurally constrained in its ability to transition toward circularity.

Design for disassembly: repair versus shredding. A central tension that emerged across interviews concerns how products are designed for end of life, and the friction between two distinct disassembly objectives.

Design for disassembly for repair prioritises making components accessible and replaceable, supporting product longevity and circular loops through maintenance and part substitution.

Design for disassembly for shredding prioritises clean material separation at end of life, enabling efficient recovery of material streams. These two objectives are not always compatible: a construction optimised for repair may use modular connections and accessible interfaces that complicate shredding, while a construction optimised for material recovery may involve bonding or welding strategies that make component-level repair impossible.

The teardown findings confirmed that most current chairs are not optimised for either objective. Foam bonded to seat pans, textile stapled to plastic shells, and mechanisms that cannot be separated without destructive tools are construction choices that fail both repair and material recovery criteria simultaneously. As one interviewee stated: “Once the chair arrives here, in reality you can do very little with it. Since a lot of these products are assembled in such a way that you simply cannot separate the materials anymore” (Expert 20, personal communication). If disassembly takes more time than the recovered material is worth, the product goes into the shredder regardless of design intent.

This distinction is directly relevant to the design concepts developed in Step 2, where each strategy implies a different relationship with end of life.

Recycled materials and NIAS. The limited availability of high-quality recycled plastics suitable for use in new products presents a further barrier to circularity. Post-consumer recycled plastics frequently contain non-intentionally added substances, as documented by Horodytska et al. (2020), who found NIAS in post-consumer recycled polyolefin pellets derived from household waste. These arise because post-consumer plastics are blends of the same base material collected from different product applications, each carrying its own additives, degradation products, and contaminants.

One interviewee noted that their company addresses this by sourcing food-grade or medical-grade recycled materials, which are held to stricter safety standards, though NIAS remain a concern even at this level.

Packaging and logistical inefficiency were also raised across interviews as relevant sustainability challenges in this industry. These topics are considered out of scope for this research but are noted as areas warranting further investigation.

These findings address SQ4.1, SQ4.2, and SQ4.3.

3.4.5 Validation

A subset of interviews was conducted to validate the lifecycle mapping and hotspot analysis developed in Steps 0 and 1.

Experts 17, 18, 19, and 20 were consulted after the analysis was completed, and their responses were used to assess whether the findings reflected real industry conditions and to identify gaps or inaccuracies in the mapping.

One example of where expert input diverged from the theoretical baseline was in the characterisation of manufacturing safety: literature sources tend to describe manufacturing processes as controlled and safe, while several experts indicated that in practice, safety conditions are considerably more variable.

The findings from this validation round are discussed in detail in the Step 1 analysis chapter.

3.4.6 Conclusion from interviews

The twenty expert interviews reveal a consistent pattern across company sizes, roles, and market segments. Chemical safety and circularity are not simply overlooked in the office chair industry; they are structurally deprioritised by the conditions under which design decisions are made, which have a much stronger emphasis on physical safety and passing safety test.

OEM dependency limits what designers can specify. Budget constraints make material switching costly. Supplier opacity prevents companies from knowing what is in their products. The absence of strong regulatory pressure removes the incentive to act voluntarily.

The design process reinforces these conditions. Material safety decisions are rarely made during the design phase, where they would be most effective. Instead they are reactive, triggered by regulatory bans or market-specific compliance requirements, and addressed after the product has already been developed. Chemical safety knowledge is unevenly distributed and often siloed within specialist roles that are not consistently involved in early design work. Where knowledge exists, companies frequently lack the tools or incentives to act on it. The gap between what is known and what is done is therefore not primarily a knowledge gap but a structural one.

The circularity picture follows the same logic. Take-back programmes exist but lose approximately half of their product volume to the secondary market.

Products are not designed for disassembly, whether for repair or for material recovery, and recycled materials carry quality and contamination challenges that current practice is not equipped to address systematically.

These findings confirm and extend what Bolaños Arriola et al. (2023) identified as a core gap: substances of concern are addressed almost exclusively through a regulatory and chemical lens, while the product design perspective remains largely absent.

The interviews do not undermine the case for the SCbD methodology. They define the conditions under which it needs to operate, and point to where it can offer the most value: early in the design process, before material choices become fixed.

3.5 Conclusion

This chapter has established the product and industry context within which the SCbD methodology is applied in this research. It has done so across four areas.

The office task chair was introduced as a product category defined by prolonged daily use, complex multi-material construction, and a B2B procurement context in which material safety rarely features in purchasing decisions. Its component architecture, spanning seating, backrest, armrest, support and adjustment, and base systems, carries a layered substance of concern profile across multiple lifecycle stages.

This material complexity, combined with the product's use patterns, makes the task chair a demanding but representative case for safe and circular design.

The norms and certifications that govern the product were examined across two categories. Physical safety standards define the baseline performance envelope that every chair must meet.

Sustainability and chemical safety certifications go further by addressing material composition and chemical emissions, with BIFMA e3 and the Declare database offering the most direct route to identifying substances of concern at the ingredient level. The Declare database was used as the primary data source for constructing the median chair, providing a standardised material composition baseline across ten reference models.

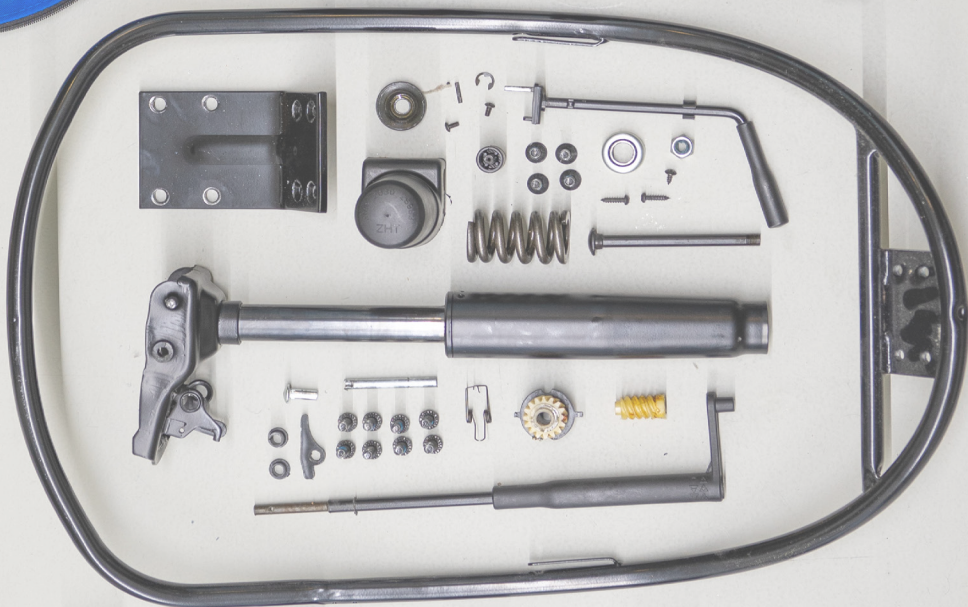
The median chair was constructed as the research object for this thesis, combining component evidence from a physical teardown of two second-hand chairs with material composition data from the Declare database. This process confirmed the material complexity of the product and established the component-material framework that underlies the lifecycle mapping in Step 0.

The industry insights gathered through twenty expert interviews revealed that chemical safety and circularity are structurally deprioritised across the value chain. Decision-making is fragmented between designers, engineers, OEMs, and sustainability specialists who rarely share the same information or work toward the same goals. Material safety is governed primarily by regulatory compliance rather than proactive design practice, and the knowledge and tools required to act on chemical risks are either unavailable, inaccessible, or left unacted upon even when they exist. The design process, whether in agencies or in-house teams, operates within constraints of time, budget, and standardised material specifications that make early-phase material safety intervention difficult to achieve without structural support.

These findings do not diminish the case for the SCbD methodology. They define the context in which it must operate and identify where it can make the greatest contribution: at the early design phase, before material choices become fixed, and through tools and methods that make chemical safety accessible to practitioners without specialist toxicological expertise.

The following chapters apply the SCbD methodology and MAPSSS tool to the median office task chair, beginning with the lifecycle mapping and substance identification of Step 0.

4



Chapter 4

SCbD Step 0: Identify

4.1 Introduction and Approach.....	40
4.2 Executing Step 0 Identify.....	40
4.3 Results.....	43

4.1 Introduction and approach

4.2 Results

This chapter presents the application of Step 0 (Identify) of the Safe and Circular by Design methodology to the median office task chair constructed in Chapter 3. The aim is to map the full lifecycle of the product, tracing the materials and substances present at each stage and establishing where substances of concern may arise or be released. The output is a complete lifecycle map that provides the foundation for the hotspot analysis in Step 1.

The lifecycle map was built using the MAPSSS tool, working through the product lifecycle stage by stage. Three data sources informed the mapping: the median chair bill of materials and component structure developed in Chapter 3, a grey literature review covering manufacturing processes, material properties, and end-of-life treatment relevant to each component, and insights from the expert interviews. The map is structured around the main components identified through the teardown: star base, castors, gas lift, seat structure, seat and backrest foam cushioning, backrest structure, mesh, armrests, and hardware. Packaging is included within scope. Chemical production upstream of material manufacturing is excluded, as establishing reliable process data at that level falls outside the capacity of this project.

For each component, the mapping records the raw materials and their upstream production processes, the manufacturing steps through which materials are combined into components, and the substances present at each stage. The standardised mapping elements introduced in Section 2.6.3 were used throughout to indicate known substances of concern and safety uncertainties. The individual component process maps are provided in Appendix C.

The application of Step 0 produced a complete lifecycle map of the median office task chair, covering the full lifecycle from raw material extraction through manufacturing, use, and end-of-life treatment.

The complete map is shown in Figure 4.1, spread across two pages.

Production phase

The production phase is the most materially complex phase of the lifecycle. Across the nine main components, the chair contains glass-fibre reinforced nylon, polypropylene, polyoxymethylene, multiple steel alloys, polyurethane foam, nylon mesh, thermoplastic polyester elastomer, and zinc-based surface coatings, among others. Several of these materials involve substances that carry known hazards or safety uncertainties, indicated in the component maps by the standardised SoC indicators.

The most notable is the flame retardant TCPP (tris(1-chloro-2-propyl) phosphate, CAS 13674-84-5), added to the polyurethane foam during production to meet fire safety requirements. The individual component process maps are provided in Appendix C.

Assembly, transport, and use phase

Following component manufacturing, the chair is assembled and packaged for transport to the client. The use phase is assumed to span ten years, in line with the BIFMA Product

Category Rule for seating (BIFMA, n.d.). During this phase, the chair undergoes gradual material degradation across its components. Physical examination of the disassembled chairs and expert interviews identified the foam cushioning, mesh, and armrest pads as the components showing the most visible deterioration. A worst-case scenario was included in the lifecycle map to account for the possibility of the product being destroyed by fire, representing complete material loss.

The use phase map is shown in Figure 4.2.

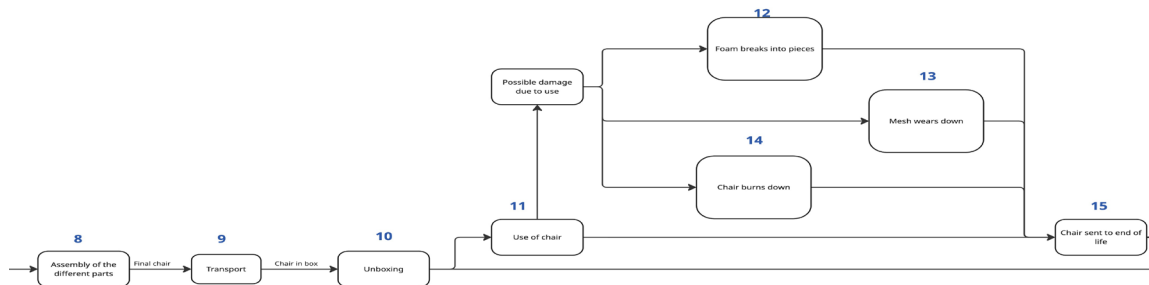


Figure 4.2. Lifecycle process map of the use phase, showing standard use and wear conditions alongside worst-case scenarios including foam degradation, mesh wear, and fire.

End-of-life phase

The end-of-life phase of a B2B task chair can follow several pathways depending on how the product is recovered. These pathways were mapped in consultation with an end-of-life specialist to reflect how this phase operates in practice.

A chair may be acquired by a refurbishment company and enter a second use cycle, returned to the manufacturer or a recycling facility for selective component recovery, or processed through shredding and incineration for energy recovery (Forrest et al., 2017). Where parts are recovered for reuse, some material flows remain within the system boundary. As discussed in Chapter 3, none of the interviewees had implemented a fully closed-loop recovery system in practice at the time of the interviews, and a fully closed system was therefore not modelled.

The end-of-life map is shown in Figure 4.3.

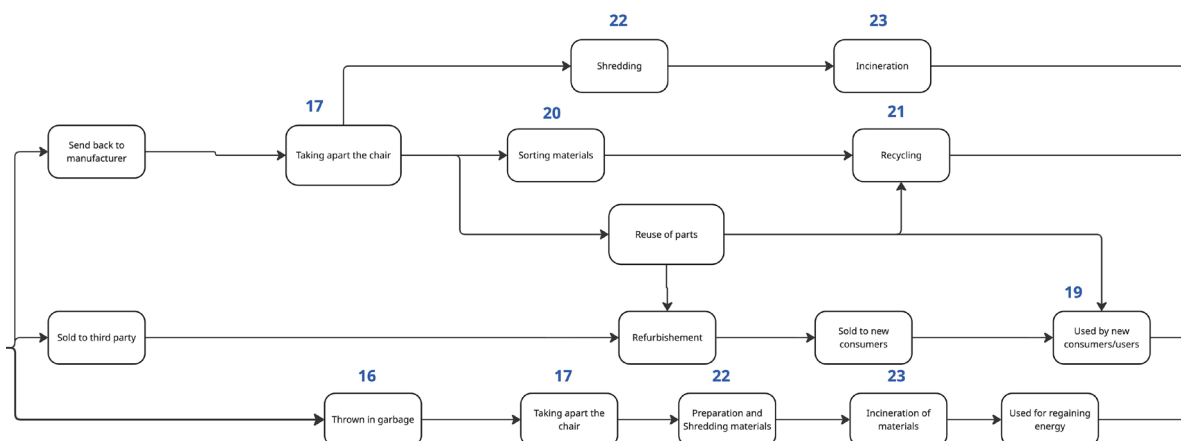


Figure 4.3. Lifecycle process map for the end-of-life phase, showing pathways including refurbishment, component recovery, recycling, shredding, and incineration.

Key observation: material complexity and integration

The lifecycle mapping reveals a structural feature of the product that has implications for everything that follows. The chair comprises many distinct materials distributed across numerous subcomponents, which are consolidated during manufacturing and remain combined throughout the use phase and end-of-life treatment.

The substances of concern identified in the map, indicated by the standardised SoC indicators in the component diagrams, are therefore not isolated within individual materials: they travel through the lifecycle inside an assembly that is unlikely to be separated before its constituent materials enter their respective end-of-life pathways. This observation frames the analysis in the chapters that follow.

4.3 Conclusion

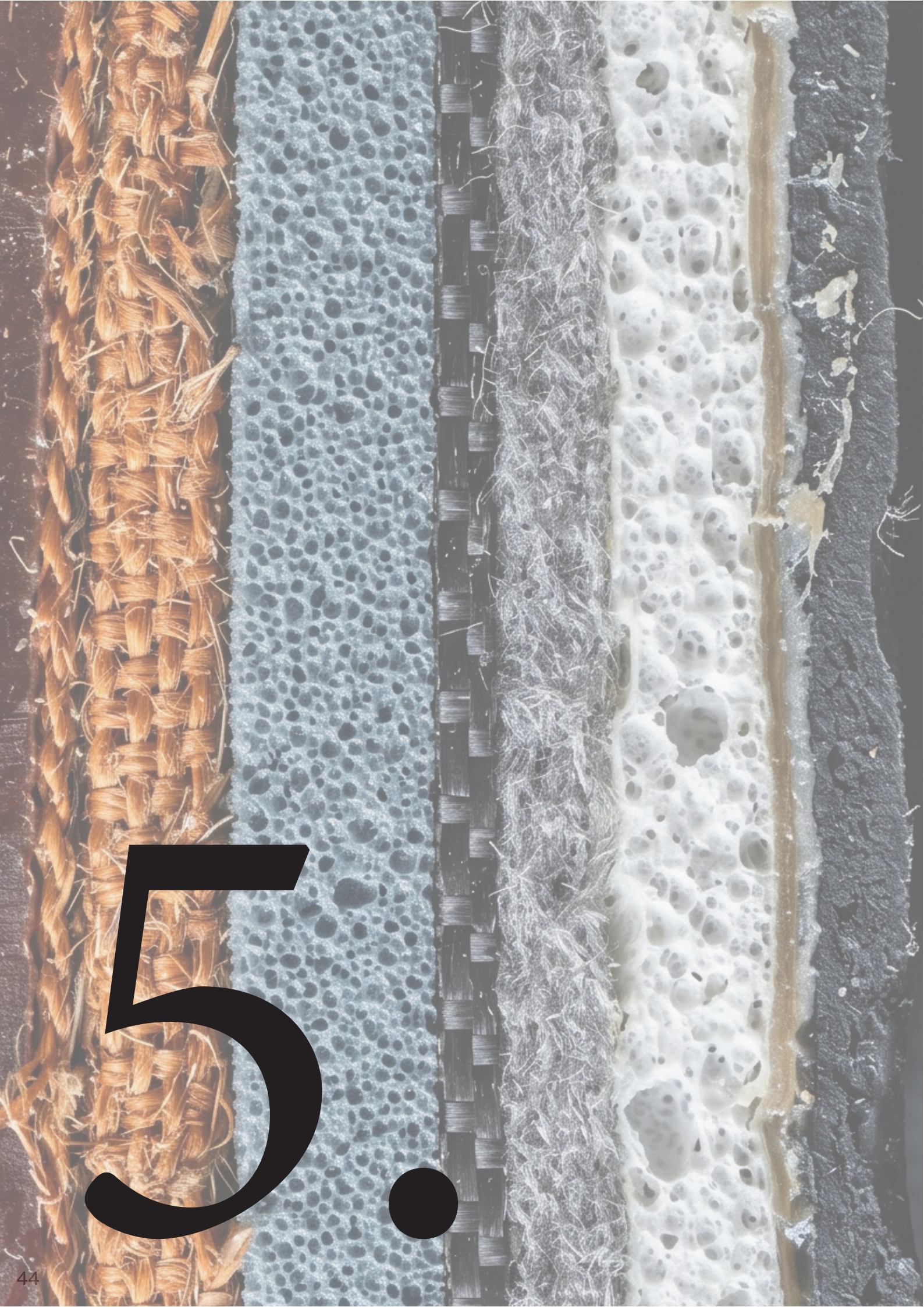
The lifecycle mapping in Step 0 produced a structured overview of the materials and processes present across the full lifecycle of the median office task chair.

The map confirms the material complexity of the product and identifies where substances of concern are present and how they move through the lifecycle.

The most significant finding is the presence of TCPP in the polyurethane foam seat and backrest cushioning, a flame retardant that cannot be separated from the foam without destroying the component.

This observation, combined with the foam's position as a high-contact component throughout the use phase, establishes it as the priority focus for the subsequent analysis.

The complete lifecycle map provides the foundation for Step 1 (Analyse), presented in Chapter 5, in which the MAPSSS hotspot calculator is applied to the exposure and emission scenarios identified here to determine which lifecycle stages and substances represent the greatest risk to human health and the environment.



5.

Chapter 5

SCbD Step 1: Analyse

5.1 Approach	46
5.2 Selection of the priority substance of concern	46
5.3 Physical teardown observations relevant to TCPP	48
5.4 Results: Hotspot assessment of TCPP across the lifecycle	50
5.5 Conclusion	53
5.6 Scope for the design solution	54

5.1 Introduction and approach

This chapter presents the application of Step 1 (Analyse) of the Safe and Circular by Design methodology to the median office task chair. Building on the lifecycle map established in Chapter 4, this step moves from mapping to evaluation, determining which substances and lifecycle stages represent the greatest risk to human health and the environment. The output is a structured hotspot assessment that identifies where design intervention should be concentrated in Step 2.

The analysis addresses three research sub-questions. SQ3.1 asks which chair components contain substances of concern and what hazards and emissions they pose across the product lifecycle. SQ3.2 asks which substances of concern are most impactful in terms of exposure risk and hazard severity. SQ3.3 asks why these substances remain present despite the availability of alternatives.

The analysis was carried out in two stages. The first stage involved selecting a priority substance of concern from the materials identified in the lifecycle map. This selection was based on a systematic evaluation of the substances present across the chair's main components, drawing on the physical teardown, the literature review, and expert interview insights. The scope was deliberately limited to the manufacturing of parts and onwards, reflecting the design perspective taken in this research. The upstream chemical production of individual substances falls largely outside the influence of a product designer and was therefore not included in the selection process. The one exception is the chemical production of TCPP, which was included once TCPP had been identified as the priority substance, to provide a complete picture of its presence across the lifecycle.

The second stage applied the MAPSSS hotspot calculator to the priority substance, evaluating each emission and exposure scenario across the lifecycle. Each scenario was assigned a concern score, an uncertainty rating, and an aggravation score. These scores were translated back into the Miro lifecycle map, producing a visual overview of the identified hotspots. The scoring scale used throughout this analysis is defined in Section 5.4 prior to the results.

5.2 Selection of the priority substance of concern

Although the lifecycle map produced in Step 0 identified substances across all components of the median chair, the analysis in this chapter focuses on one priority substance.

A systematic evaluation was conducted across the main material categories present in the chair, assessing each against four criteria: hazard profile, prevalence across lifecycle stages, relevance to circular economy considerations, and the degree to which a designer can meaningfully influence the associated risks. The evaluation was scoped to the manufacturing of parts and onwards, as explained in Section 5.1.

Table 5.1 summarises the substances and material categories evaluated and the rationale for their prioritisation or exclusion.

Table 5.1 Substances and material categories evaluated during the priority substance selection process.

Substance or material category	Hazard profile	Lifecycle prevalence	CE relevance	Designer influence	Outcome
Nylon 6 with glass fibre reinforcement	Low to moderate: short glass fibres may become airborne during processing or mechanical damage, but fibre diameters in structural components typically exceed 3 microns and are unlikely to reach the lower respiratory tract under normal use	Multiple structural components	Limits recyclability due to composite nature	Moderate: material selection	Not prioritised: hazard under normal use is limited
Microplastics from mesh textiles	Moderate: released through wear and mechanical degradation throughout use and end of life; detected in human tissue and environmental systems globally	Use and end of life	Restricts recyclability; subject to EU restriction under REACH Annex XVII	Moderate: material and construction choice	Noted as relevant; not selected as priority due to lower hazard severity compared to TCPP
Surface coatings on metal components	Low to moderate: historical reliance on heavy metalbased coatings; safer alternatives now widely available	Surface of multiple metal components	Metal components are generally well recovered at end of life	High: specification choice	Not prioritised: manageable through existing specification practices
PU foam reaction agents (isocyanates, polyols)	High during manufacturing: isocyanates are acutely toxic; residual unreacted isocyanates may persist in finished foam	Primarily manufacturing	Foam integration with other components limits recyclability	Low at design stage: controlled at process level	Not prioritised: exposure primarily at manufacturing, outside designer's direct influence
Formaldehyde	High: classified as a Group 1 carcinogen by IARC; causes irritation at low concentrations; linked to sick building syndrome	Byproduct during manufacturing and use phase off-gassing	Limited direct CE implication	Low to moderate	Not prioritised: TCPP presents a broader and more persistent hazard profile
TCPP in PU foam	High: neurotoxicity at higher doses, endocrine disruption, kidney and liver toxicity, persistent metabolite detected in human urine; detected in remote environmental systems	Manufacturing through use and end of life; highest concern in use and end of life	Foam integration limits recyclability; substances released during shredding and incineration	High: addressable through material substitution, product architecture, and business model	Selected as priority substance

The table makes visible the reasoning behind the selection. Several substances present genuine hazards, and microplastics in particular warrant attention in future research.

However, TCPP stands out across all four criteria. Its hazard profile extends across multiple organ systems and includes a persistent human metabolite. It is present not only during manufacturing but throughout the use phase and into end of life, where degraded foam releases particles carrying the substance into indoor environments and waste streams.

A designer has meaningful influence over TCPP's presence in the product: it can be addressed through material substitution, product architecture that contains or isolates the foam, or business models that support controlled end-of-life recovery. These characteristics make it the strongest candidate for design-led intervention within the SCbD framework.

TCPP: characterisation of the priority substance

Tris(1-chloro-2-propyl) phosphate (TCPP, CAS 13674-84-5) is a chlorinated organophosphate flame retardant added to polyurethane foam to meet fire safety requirements. It is not chemically bound to the foam matrix but remains as a physical additive, meaning it can migrate to the surface and be released over time (van der Veen & de Boer, 2012).

From a human health perspective, TCPP raises concerns across several toxicological endpoints. Animal studies have demonstrated interference with thyroid hormone pathways and reproductive hormone signalling, raising concerns about endocrine disruption under REACH (van der Veen & de Boer, 2012). Repeated exposure studies have shown kidney and liver toxicity at elevated doses, and neurotoxic effects at higher dose levels (van der Veen & de Boer, 2012). While TCPP is not currently classified as a carcinogen under EU CLP regulations, its structural similarity to TCEP, classified as a suspected carcinogen (Category 2) under REACH (ECHA, 2009), means it remains under regulatory scrutiny. Its primary human metabolite, BCIPHIPP, has been detected in urine across multiple biomonitoring studies and may be more toxic than the parent compound (van der Veen & de Boer, 2012).

From an environmental perspective, TCPP does not currently meet the formal PBT classification thresholds under REACH, but raises concerns regarding persistence and potential for bioaccumulation (van der Veen & de Boer, 2012; ECHA, 2018). It resists microbial biodegradation and has been detected in fish tissue, birds, and marine mammals, as well as in Arctic air and remote ocean water, indicating long-range environmental transport (van der Veen & de Boer, 2012). ECHA has identified risks from TCPP exposure via upholstered furniture and recommended a restriction proposal (ECHA, 2018).

The question of why TCPP remains in use despite these concerns is directly relevant to SQ3.3. Fire safety regulations in several European markets require upholstered furniture to meet specific flammability standards, and TCPP remains one of the most technically effective and cost-competitive flame retardants available for flexible polyurethane foam (van der Veen & de Boer, 2012). Safer alternatives exist, including non-halogenated phosphorus-based flame retardants and physical

barrier approaches, but these either carry their own unresolved hazard profiles, require significant changes to the foam formulation or product architecture, or come at higher cost. The combination of regulatory requirement, technical performance, and cost means TCPP has remained in widespread use despite growing evidence of its risks.

5.3 Physical teardown observations relevant to TCPP

The physical teardown conducted as part of Step 0 produced several observations directly relevant to TCPP and its behaviour across the chair lifecycle. These findings informed both the substance selection process and the hotspot assessment, providing physical evidence that complements the literature-based analysis.

The most significant observation concerned the condition of the foam components in both disassembled chairs. The seat foam had become brittle and was actively breaking down into dust particles during handling, as shown in Figure 5.1.

Fine particulate matter was visibly present within the upholstery layer before disassembly began, and the underlying foam dispersed into the surrounding environment upon removal of the mesh cover. This physical degradation confirms that aged polyurethane foam releases particles during handling, and that these particles carry associated substances of concern including TCPP into the immediate environment of anyone working with the material.



Figure 5.1 . Degradation of foam components in the disassembled task chair, showing (a) worn and chipped TPU armrest pad, (b) brittle and discoloured seat foam with visible particulate matter, and (c) detached foam fragment from the seat cushion.

The attachment methods used to fix the foam within the chair assembly created a second set of relevant observations. In both chairs, the foam was either stapled or adhesive-bonded to the underlying structural components, as shown in Figure 5.2.

In the first disassembled chair, the foam had been bonded directly to a wooden seat pan, a construction approach not representative of the median chair, which uses a glass-fibre reinforced nylon seat pan consistent with current industry practice.

The observation is nonetheless relevant, as it illustrates the broader problem of irreversible foam attachment methods across the product category, regardless of the substrate material. In both cases, separation is effectively impossible without mechanical tools and generates considerable dust during any attempt at removal, meaning the foam and the TCPP it contains enters shredding or incineration streams alongside other materials at end of life.



Figure 5.3 . Textile stapling practices observed during disassembly, showing (a) mesh stapled directly onto the structural seat pan, and (b) mesh stapled onto the nylon backrest structure



Figure 5.2 . Foam attachment methods observed during disassembly, showing (a) stapled foam attachment in the second chair, and (b) adhesive-bonded foam embedded in the structural seat pan of the first chair.

The textile upholstery showed the same pattern. In both chairs, the mesh was stapled directly onto the structural components rather than attached through a reversible connection, as shown in Figure 5.3.

In practice, end-of-life workers typically cut the mesh away rather than removing it staple by staple, leaving residual staples and mesh fragments embedded in the underlying components and reducing the purity and quality of the materials that can be recovered.

The mechanism assembly provided a further observation. All moving parts were lubricated with lubricants that had accumulated significant dust and particulate matter over the chair's service life, as shown in Figure 5.4.

During disassembly, this residue transferred readily to the hands and could not be fully removed after several washes with industrial soap. This points to a direct contact exposure scenario for both maintenance workers and end-of-life handlers who work with the mechanism without knowing what substances may be present in the accumulated particulate.



Figure 5.4 . Components of the task chair mechanism, showing (a) lubricated parts prior to disassembly, and (b) the underside of the chair, illustrating the complexity of the assembly and the difficulty of disassembly.

Taken together, these observations confirm three things relevant to the hotspot assessment.

First, foam degradation during use and end of life is not a theoretical risk but a physically observable process that generates airborne and surface-deposited particles carrying substances of concern.

Second, current assembly methods make material separation at end of life practically unachievable without generating additional exposure for workers.

Third, the information about what substances are present in the materials is not communicated to anyone handling the product after it leaves the manufacturer, meaning the exposure risks described above occur without awareness or protective measures in place.

5.4 Results: Hotspot assessment of TCPP across the lifecycle

This section presents the results of applying the MAPSSS hotspot calculator to TCPP across the lifecycle of the median office task chair. For each phase, the key exposure scenarios, concern scores, and aggravating conditions are described.

The scoring scale and visual indicators used throughout are defined in Table 5.2.

Table 5.2. Scoring scale and visual indicators used in the MAPSSS hotspot calculator.

Category	Level	Score Range	Icon
Human Health Concern Score	Low	0 – 22.5	▲
	Medium	22.5 – 45	▲
	High	45 – 67.5	▲
	Maximum	90	▲!
Human Health Uncertainty Rating	Low	0 – 34.6	▲
	Medium	34.6 – 57.8	▲
	High	57.8 – 88.1	▲

Environmental Concern Score	Low	0 – 90	▲
	Medium	90 – 180	▲
	High	180 – 270	▲
	Maximum	360	▲!
Environmental Uncertainty Rating	Low	0 – 13.5	▲
	Medium	13.5 – 27	▲
	High	27 – 40.5	▲
Aggravating Conditions	Low	–	*
	Medium	–	*
	High	–	*

5.4.1 Chemical production of TCPP

Where exposure prevention is fully in place during TCPP synthesis, the human health concern score reaches zero, as emissions are eliminated at the source. The environmental concern score is low, though it carries a medium uncertainty rating due to limited publicly available data on production-specific emissions.

Aggravating conditions may arise given that TCPP is unstable under elevated temperatures and high humidity (van der Veen & de Boer, 2012).

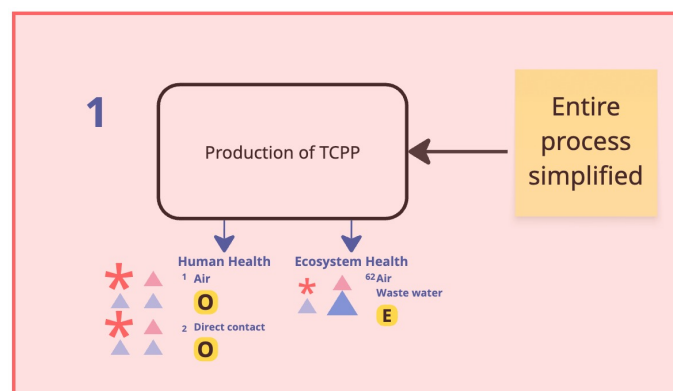


Figure 5.5. Lifecycle process map for the chemical production of TCPP.

5.4.2 Manufacturing phase

Human health concern scores for the manufacturing phase range from low to medium (11.25 to 22.5), reflecting the assumption that emission controls and safety measures are in place.

Environmental concern scores are medium to high (101.25 to 135), driven by air, dust, and wastewater release pathways across mixing, foaming, trimming, and storage operations.

The complete process map for the foam manufacturing phase is shown in Figure 5.6.

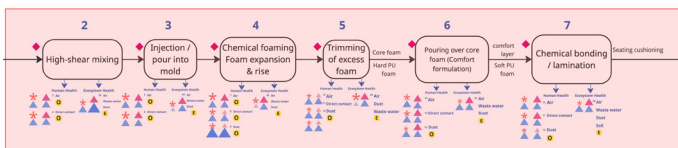


Figure 5.6. Lifecycle process map for the foam manufacturing phase, including identified exposure scenarios with concern scores, uncertainty ratings, and aggravating conditions.

The most significant aggravating condition at this stage is PPE compliance. Several interviewees with direct factory experience confirmed that PPE compliance varies considerably by production location, and that the absence of respiratory protection is more common than safety protocols would require.

This is reflected in the medium to high uncertainty ratings assigned to manufacturing scenarios throughout the calculator.

Figure 5.7 shows workers performing high-emission tasks during foam moulding and removal without respiratory protection.



Figure 5.7. Manufacturing process of polyurethane foam, showing (a) injection of the foam mixture into the mould, (b) closing of the mould during expansion and curing, and (c) removal of the cured foam by a worker without respiratory protective equipment.

A similar pattern is visible during the subsequent trimming step, where excess foam is removed from the moulded component (Figure 5.8).



Figure 5.8. Trimming of excess polyurethane foam following mould removal, showing a worker operating without respiratory protective equipment.

Following trimming, finished foam components enter a storage period representing the stage of highest VOC and substance of concern emissions in the production process, as the foam off-gasses at its peak rate immediately after manufacture (US EPA, 2020). This storage stage is illustrated in Figure 5.9.



Figure 5.9. Warehouse storage of finished polyurethane foam components during the peak off-gassing phase.

5.4.3 Logistics phase

The logistics phase scores low across both human health (13.5) and environmental pathways (45 to 67.5). The complete process map for this phase is shown in Figure 5.11.

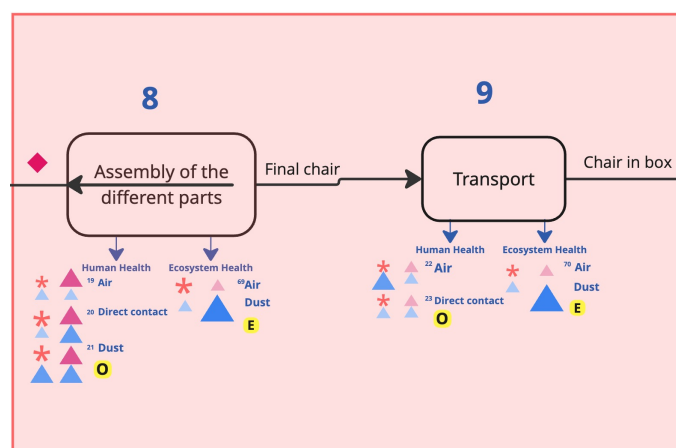


Figure 5.10. Lifecycle process map for the logistics phase, including assembly, packaging, and transport, with identified exposure scenarios.

During assembly the foam is enclosed behind the mesh, limiting direct worker exposure. Once packaged, TCPP continues to off-gas within the sealed box, and peak VOC release has been shown to occur in the first hours after unboxing, representing a distinct exposure scenario for the person opening the product (Schlittenbauer et al., 2019).

5.4.4 Use phase

The use phase carries the highest concern scores of any lifecycle stage across both human health and environmental pathways. No emission controls or protective measures exist for the user during this phase. The full annotated process map is shown in Figure 5.12.

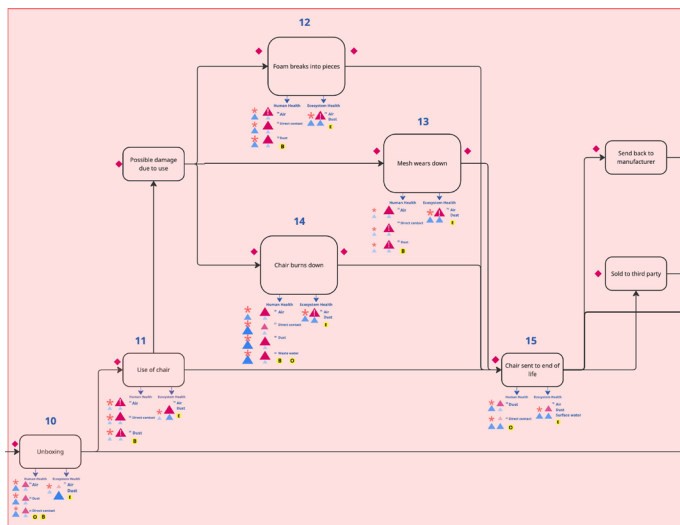


Figure 5.12. Lifecycle process map for the use phase, including normal use, wear and tear, and worst-case scenarios, with concern scores, uncertainty ratings, and aggravating conditions.

During normal use, the chair continuously emits TCPPE through off-gassing into the indoor environment via air, dust, and direct skin contact.

TCPPE emissions from upholstered office furniture persist at measurable levels with no detectable decline over monitoring periods exceeding 220 days (Plaisance et al., 2022; Plaisance et al., 2025).

Estimated daily inhalation exposure from a single upholstered office chair has been measured at 3,000 to 5,000 ng per day (Plaisance et al., 2022). The normal use scenario scores the maximum human health concern score of 90 and an environmental concern score of 202.5, driven by chronic exposure, no control mechanism, and aggravating conditions including elevated indoor temperatures.

The wear and tear scenarios produce the most critical scores in the entire analysis. As the foam breaks down and the mesh degrades, TCPPE is released simultaneously through air, dust, surface water, and soil. Both scenarios reach the maximum environmental concern score of 360. Physical degradation of the foam generates dust particles carrying flame retardants at concentrations orders of magnitude higher than settled dust in undisturbed environments (La Guardia & Hale, 2015). Replacing flame retardant-treated furniture has been shown to significantly reduce indoor dust concentrations of chlorinated organophosphate flame retardants within months (Rodgers et al., 2021).

In a fire scenario, thermal degradation produces toxic breakdown products including carbon monoxide, hydrogen cyanide, and isocyanates (McKenna & Hull, 2016). Flame retardant-treated furniture produces greater quantities of these gases than untreated equivalents (McKenna et al., 2018; Stec, 2017).

5.4.5 End-of-Life phase

The end-of-life phase produces the second-highest concern scores across the lifecycle, with human health scores ranging from medium to high (16.875 to 45) and environmental scores reaching 270. The full annotated process map is shown in Figure 5.13.

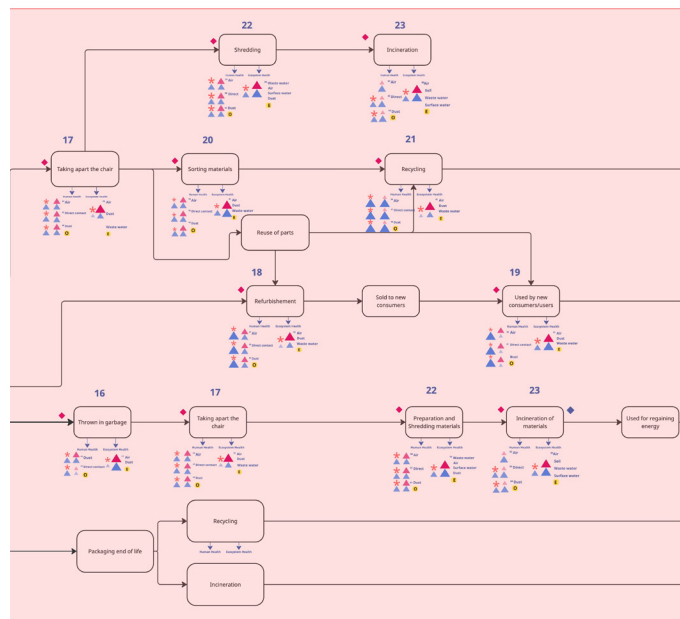


Figure 5.13. Lifecycle process map for the end-of-life phase, including refurbishment, disassembly, recycling, shredding, and incineration routes, with identified exposure scenarios.

A defining problem at this stage is the information gap. As Expert 20 noted: "If you do not know you are burning a certain material, or that material is not supposed to be there, there is a chance that there is no filtration installed for it, or not properly. Which means it can be released into the environment" (Expert 20, personal communication). This gap is reflected in the medium to high uncertainty ratings assigned throughout the end-of-life scenarios.

Disassembly and shredding operations score 270 on the environmental concern scale, driven by release across air, dust, wastewater, and surface water pathways.

Workers in dismantling industries have measurable organophosphate flame retardant concentrations in personal air samples, with TCPPE among the most frequently detected compounds (Estill et al., 2020). Incineration scenarios score 180 on the environmental scale, with high uncertainty reflecting the uncharacterised nature of TCPPE filtration in current waste treatment systems (Ma et al., 2021; Ma et al., 2022). TCPPE has been detected in surface waters and groundwater in multiple countries and is considered poorly biodegradable with an environmental half-life exceeding 60 days (Bester, 2004; van der Veen & de Boer, 2012).

5.4.5 End-of-Life phase

The application of Step 1 across all lifecycle phases produces a complete annotated lifecycle map of TCPPE concern scores for the median office task chair, shown in Figure 5.14.

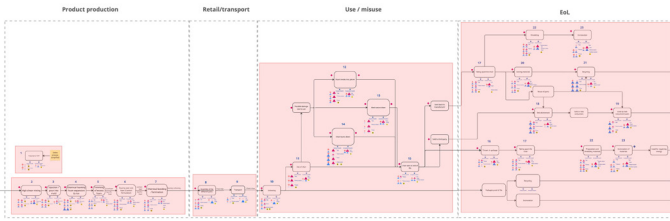


Figure 5.14. Complete Step 1 lifecycle map of the median office task chair, showing human health and environmental concern scores for TCPP across all lifecycle stages. Pink highlighted areas indicate the stages where TCPP is present.

The concern scores produced across the lifecycle are summarised in Table 5.3.

Figure 5.3. Table 5.3. Summary of TCPP concern scores by lifecycle phase.

Lifecycle phase	Human health concern	Environmental concern	Key driver
Chemical production	Zero to low (0)	Low (22.5)	Controlled process; exposure eliminated
Manufacturing	Low to medium (11.25–22.5)	Medium to high (101.25–135)	Air, dust, wastewater pathways; PPE uncertainty
Logistics	Low (13.5)	Low to medium (45–67.5)	Chair enclosed; limited exposure
Use – normal use	Maximum (90)	High (202.5)	Chronic unprotected exposure; no control mechanism
Use – wear and tear	Maximum (90)	Maximum (360)	Foam fragmentation; mesh degradation; multiple simultaneous release pathways
Use – fire scenario	High (54–90)	High (270)	Thermal breakdown products; uncontrolled release
End of life	Medium to high (16.875–45)	High (162–270)	Multiple release pathways; information gap; filtration uncertainty

A phase-by-phase comparison of these scores is shown in Figure 5.15.

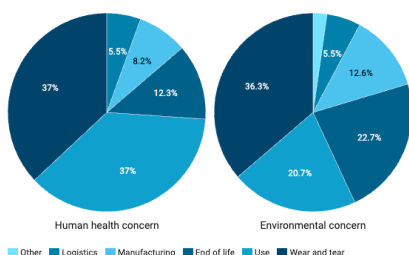


Figure 5.15. Pie chart of human health and environmental concern scores by lifecycle phase, showing the use-phase wear and tear scenario reaching the maximum environmental score of 360.

The use phase is confirmed as the most critical stage across both pathways.

The maximum human health score of 90 is reached by multiple normal use and wear scenarios. The maximum environmental score of 360 is reached by the wear and tear scenarios, where foam fragmentation and mesh degradation simultaneously release TCPP into multiple environmental matrices with no control mechanism in place. The end-of-life phase produces the second-highest environmental concern scores, particularly during disassembly and shredding.

The full Step 1 analysis was validated with Expert 19, who confirmed that the findings closely reflected their own experience in the industry, including the observation that manufacturing safety in practice is considerably more variable than literature sources suggest.

5.5 Conclusion

The hotspot assessment in Step 1 confirms that TCPP in the polyurethane foam seat and backrest cushioning represents the priority substance of concern across the lifecycle of the median office task chair.

Across both human health and environmental pathways, the use phase is the most critical stage, with multiple scenarios reaching the maximum possible concern scores. This is driven by the combination of chronic unprotected exposure over a ten-year product lifetime, the absence of any emission control mechanism for the user, and the progressive physical degradation of the foam that intensifies release over time.

The wear and tear scenarios, in which foam fragmentation and mesh degradation simultaneously release TCPP into air, dust, surface water, and soil, reach the maximum environmental concern score of 360, the highest score achievable in the calculator.

The end-of-life phase produces the second-highest environmental concern scores, particularly during disassembly, shredding, and incineration, where TCPP enters multiple environmental matrices through pathways that current filtration and recycling infrastructure is not designed to fully intercept.

The manufacturing phase scores moderately, reflecting the partial effectiveness of workplace controls, though the consistently medium to high uncertainty ratings indicate these controls are not reliably applied across all production contexts.

The analysis also highlights two structural problems that amplify concern across the lifecycle.

The first is the absence of any barrier between the user and the foam during the use phase: the current product architecture provides no mechanism to contain or reduce TCPP emissions at the point of greatest exposure.

The second is the information gap at end of life: the chemical content of the product is not communicated to the workers or facilities handling it, meaning that even where filtration or protective measures exist in principle, they are not applied to TCPP specifically. Both problems are design-addressable, and both define the scope of the intervention in Step 2.

5.6 Scope for the design solution

The scope for the design solution is defined by three converging sources: the hotspot assessment conducted in Step 1, the physical teardown observations described in Section 5.3, and the broader industry findings from Chapter 3.

The hotspot assessment establishes the use phase and end-of-life phase as the two stages requiring the most attention. The use phase is critical because TCPP emissions and particle release occur continuously and without protection over the product's full ten-year service life. The end-of-life phase is critical because degraded foam releases TCPP into multiple environmental pathways during disassembly and incineration, without the knowledge or filtration systems needed to intercept it.

The physical teardown confirms that the current product architecture creates structural barriers to addressing both problems. Foam is bonded or stapled to structural components, making separation at end of life practically unachievable without generating additional exposure. The mesh upholstery is fixed irreversibly, accelerating degradation and preventing replacement before the foam beneath is exposed. These assembly choices have been optimised for production speed and cost rather than for material safety or end-of-life performance.

The industry findings establish that these barriers are systemic rather than incidental. Designers operate within constraints of time, budget, and standardised material specifications that make early-phase material safety intervention difficult without structural support. At the same time, the interviews identified that a tool such as MAPSSS could support the business case for safer design, particularly in the context of growing regulatory pressure and procurement incentives such as government tender point systems that reward sustainability performance.

Together, these findings define a design scope structured around the three SCbD strategy categories. Each strategy addresses the same hotspot, TCPP in polyurethane foam, through a different mode of intervention, producing three distinct design directions developed in Step 2.

The Avoid strategy eliminates TCPP and where possible the polyurethane foam itself from the product, removing the hazard at its source. This may involve substituting the foam with an alternative material that does not require flame retardant treatment, or redesigning the seat system to deliver comfort and support through non-chemical means.

The Control strategy keeps TCPP within the foam but prevents emissions and particle release from reaching the user or the environment. This involves redesigning the product architecture to physically isolate the foam within a sealed or encapsulated component, preventing direct contact and limiting release pathways across the use phase and into end of life.

The Reduce strategy lowers the amount of TCPP in the foam and reduces the volume of emissions across the lifecycle. This may involve reducing the foam content in the product, designing for component replaceability to limit the accumulation of degraded material, or combining material reduction with extended product life through maintenance and take-back systems.

The three strategies are not mutually exclusive. As established in Section 2.5.5, strategies are frequently combined in practice, and the assessment in Step 3 will evaluate each concept against the baseline established in Step 1 to determine its effects on the identified concern scenarios, any new negative consequences, and its trade-offs. The development of these concepts is described in Chapter 6.



Chapter 6

Scbd Step 2: Select and Design

6.1 Introduction	58
6.2 Approach	58
6.3 Key Insights.....	59
6.4 List of requirements.....	59
6.5 Design process.....	61
6.6 Final Designs	62
6.7 Reflection on strategy application	65
6.8 Conclusion	66

6.1 Introduction

Step 1 identified TCPP in the polyurethane foam seat system as the priority substance of concern for the B2B office task chair, with the use phase and end-of-life phase carrying the highest concern scores across human health and environmental pathways. The use phase reaches the maximum human health score of 90 and the maximum environmental score of 360 in wear-and-tear scenarios, and the end-of-life phase reaches environmental scores up to 270. These hotspots, together with the design scope defined in Section 5.3 and the structural findings from the physical teardown, form the starting point for the work presented here.

This chapter covers Step 2 of the SCbD methodology, which moves from problem identification to design response (Bolaños Arriola et al., 2023). The teardown confirmed that the current product architecture creates structural barriers to both chemical safety and end-of-life material recovery, indicating that intervention at the component level is both necessary and feasible. The question for Step 2 is therefore not whether to redesign the product, but which of the three SCbD strategies (Avoid, Reduce, or Control) should guide that redesign, and what the resulting product would look like in each case.

Rather than commit to a single strategy at the outset, this chapter develops one concept per strategy, producing a product family of three resolved designs. This decision is deliberate. The three strategies are not interchangeable, and each carries different implications for the product, the user, and the surrounding service system. Developing one concept per strategy makes these differences visible and acknowledges that not every strategy is technically or commercially viable in every context. The product family therefore serves both as a design output and as a structured input to the assessment in Step 3, where each concept will be evaluated against the baseline established in Step 1 to compare its effects on the concern scenarios, its negative consequences, and its tradeoffs.

The chapter is organised as follows. Section 6.2 sets out the approach taken to move from hotspots to concepts. Section 6.3 synthesises the key insights from the preceding research that inform the design direction. Section 6.4 translates these insights into a list of requirements, with shared requirements applying to all three concepts and strategy-specific requirements defining what each concept must achieve. Section 6.5 presents the design process itself, from market analysis and brainstorming through to CAD. Section 6.6 presents the three final designs. Section 6.7 reflects on what the design exercise revealed, and Section 6.8 closes the chapter.

6.2 Approach

The approach taken in Step 2 moves from broad exploration to focused concept definition, with the three SCbD strategies (Avoid, Reduce, and Control) used as the organising principle throughout. The work began with a group brainstorming session at NPK Design involving two designers and a design engineer, structured around questions about how seating could be reimagined without the constraints of conventional task chair construction. This was followed by an individual ideation

phase that broadened the range of directions explored without committing to a specific concept. The full brainstorm output is presented in Appendix D.

A market analysis was conducted across task chair models from European, American, and emerging Asian brands. This served two purposes: to develop a working understanding of the product category and to identify reference models for the design concepts. The analysis revealed that meaningful design differentiation occurs above the mechanism, since spring mechanisms and several substructural components are sourced from a small number of OEM suppliers shared across brands.

From this foundation, one primary sub-strategy was selected within each of the three SCbD strategies, and three distinct design concepts were developed from these sub-strategies. The concepts were developed at the system level rather than as isolated products, considering how component-level decisions propagate through manufacture, use, and end of life. To ground the concepts in a realistic context, a target user profile and use environment were defined, and a set of design themes was established to provide a coherent visual and functional direction across the three concepts.

Initial directions were developed through sketching on paper, allowing rapid exploration of the design space. Selected directions were then taken into virtual reality using Gravity Sketch, where proportions and component relationships could be evaluated at full scale. The most resolved concepts were translated into CAD using Rhinoceros 3D, with Grasshopper used for the parametric geometry in the Avoid concept. CAD models were then used to produce the renders and visualisations presented in Section 6.6.

The emerging concepts were discussed with design experts in desk chair development, including the NPK Design team. Their input was used to evaluate the technical feasibility of the directions under consideration and to keep the concepts grounded in the realities of task chair development, which several experts noted typically spans a five-year cycle from initial concept to production. The goal within this thesis is not a production-ready design but to establish correct proportions and a coherent material language for each strategy, so the design intent remains legible to chair designers and the concepts can be assessed in Step 3.

The output of this process is a product family of three resolved concepts, one per SCbD strategy. The order in which they are presented in Section 6.6 (Avoid, Reduce, Control) follows the SCbD hierarchy and reflects the degree of departure from the current product architecture, from the most radical reformulation to the most architecturally conservative intervention.

6.3 Key insights

The literature review, expert interviews, physical teardown, and hotspot assessment in the preceding chapters point to a set of insights that inform the design direction for Step 2. These insights fall into three themes: product architecture and circularity, chemical safety and exposure, and industry conditions and opportunities.

Product architecture and circularity. Current task chair construction has been optimised for assembly efficiency and structural performance, but not for end-of-life recovery or material transparency. The teardown findings and lifecycle mapping together show that this is a design choice rather than a technical impossibility. The knowledge and means to design for disassembly already exist within the industry, demonstrated by individual components on existing models that show better practice. The gap is that these approaches have not been applied systematically across a single product.

The BIFMA e3-2024 certification reviewed in Chapter 3 operates through a tiered system in which higher tiers reflect greater progress towards sustainable and chemically responsible product design (see Figure 6.1). Each tier builds on the previous, moving from basic material identification and policy implementation at Tier 1 through to active substitution of harmful substances at Tier 4. This makes the certification a useful reference for positioning the design concepts developed in this project.

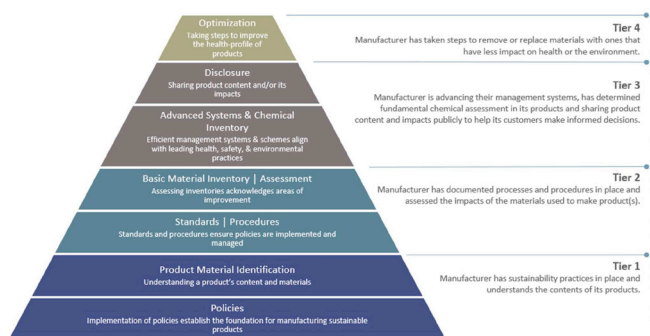


Figure 6.1. BIFMA e3 Sustainability Standard Tier Structure

The higher a product scores on material quality, recyclability, and chemical transparency, the greater its residual value when re-entering material streams. A chair built from cleaner, well-documented materials costs less to process at end of life and retains more recoverable value, creating a direct economic argument for safe and circular design that extends beyond regulatory compliance. Few manufacturers currently build their products around this logic.

Chemical safety and exposure. The hotspot assessment confirmed that chemical risk in the task chair is concentrated in components driven by a functional requirement that is itself context-dependent. Expert interviews added an important nuance: several markets do not mandate flame retardants in office task chairs, and manufacturers apply them across all product lines only to satisfy the most demanding market requirements.

This matters for design: Avoid is not categorically blocked by regulation, but available in most markets and product contexts. This project develops concepts applicable across all markets, including those with active flame retardancy requirements, because when a substance is restricted, manufacturers tend to substitute it with a chemically similar alternative carrying comparable hazard properties, which then faces a high probability of future restriction (Bumgardner & Nicholls, 2020). Designing around this substitution cycle, rather than within it, is the more durable response.

Industry conditions and opportunities. The expert interviews showed that the gaps in this industry are recognised but addressed only separately. Limited material transparency, inadequate take-back infrastructure, a narrow focus on carbon emissions, and the structural distance between design teams and chemical knowledge all exist as separate, partially addressed problems. Individual products on the market tackle one or two of these issues, but none currently address the full picture in an integrated way.

The opportunity identified through this research is that gap: a product designed from the outset to be chemically safer, easier to disassemble, and higher in retained material value, supported by a product service system that keeps materials in circulation.

6.4 List of requirements

The key insights translate into a set of design requirements that guide the development of the product family.

Requirements are divided into shared requirements, which apply to all three concepts and are listed in Table 6.1, and strategy-specific requirements, which define what each concept must achieve within its respective SCbD strategy category and are listed in Table 6.2.

Modal verbs follow **MoSCoW** conventions: **M** indicates a non-negotiable requirement, **S** a strong preference, **C** a desirable addition and **W** for a non-essential desire. Each requirement is traceable to a specific source in the preceding chapters, allowing the design choices made in Section 6.6 to be checked against the evidence base. Together, these requirements form the evaluative framework used in Step 3 to assess the performance of each concept against the baseline established in Step 1.

The shared requirements, presented in Table 6.1, establish the baseline that all three concepts must meet regardless of their SCbD strategy. They address use-phase exposure reduction, disassembly and material separability, and material transparency through supply chain documentation.

Table 6.1. Shared requirements applying to all three concepts.

ID	Requirement	Priority	Source
R1	Reduce the user's TCPP exposure during the use phase relative to the Section 5.5 baseline (human health score of 90 in the wear-and-tear scenario).	M	Ch. 5, hotspot assessment
R2	Address at least one of the three dominant exposure pathways: inhalation, dermal contact, or dust ingestion.	M	Davis et al. (2021); Ch. 3
R3	Allow main components (frame, mechanism, seat, backrest, armrests, base) to be separated with standard tools without destroying any component.	M	Ch. 4, teardown
R4	Avoid mixed-material assemblies that cannot be mechanically separated at end of life, particularly foam-textile-adhesive combinations.	M	Ch. 4, teardown
R5	Use the minimum number of material families necessary.	S	Ch. 3, Design for Disassembly
R6	Allow component-level replacement of consumable or wear-prone parts (textiles, filters, cushioning) without disassembling the structural frame.	S	Ch. 4, expert interviews
R7	Be supported by a product service system that facilitates take-back, refurbishment, and material recovery at end of life.	S	Ch. 5 (end-of-life scores up to 270); Ch. 4, expert interviews
R8	Use materials whose chemical composition is documentable through the supply chain to BIFMA e3-2024 Tier 2 or higher.	M	Ch. 3, literature review
R9	Not introduce REACH SVHC candidate list substances in components in direct or indirect user contact during normal use.	M	Ch. 3, literature review
R10	Carry a material passport or equivalent documentation accessible to end-of-life processors.	C	Ch. 4, expert interviews

Building on this shared baseline, Table 6.2 presents the strategy-specific requirements that distinguish the three concepts. The Avoid requirements (R11–R14) call for the complete elimination of TCPP and the demonstration that any substitutes do not carry comparable hazards.

The Reduce requirements (R15–R18) retain standard foam formulations but constrain its surface area in user contact and introduce a replaceable filtration pathway.

The Control requirements (R19–R23) target the conditions under which foam is allowed to remain in the product, including extended off-gassing before assembly and deployment in environments where complementary air quality measures are in place.

Table 6.2. Strategy-specific requirements defining what each concept must achieve within its SCbD category.

ID	Strategy	Requirement	Priority	Source
R11	Avoid	Contain no TCPP or other chlorinated organophosphate flame retardants in any component.	M	Ch. 5, hotspot assessment
R12	Avoid	Contain no polyurethane foam in components where the foam's only function is cushioning.	M	Ch. 4–5
R13	Avoid	Achieve BS 5852 ignition sources 0 and 1 (or equivalent) through material substitution, inherent flame resistance, or barrier systems that introduce no new substances of concern.	M	Ch. 3; Ch. 4, expert interviews
R14	Avoid	Demonstrate that substitutes do not carry comparable or greater hazards than TCPP-treated foam.	M	Bumgardner & Nicholls (2020); Ch. 3
R15	Reduce	Demonstrably reduce the surface area of foam in user contact relative to the teardown baseline.	M	Ch. 4, teardown
R16	Reduce	Retain standard industry polyurethane foam formulations, so reduction is achieved architecturally rather than chemically.	M	Section 5.3, design scope
R17	Reduce	Intercept TCPP migration from retained foam through a defined and replaceable filtration pathway.	M	Ch. 5; Davis et al. (2021); Ch. 3
R18	Reduce	Provide a service touchpoint for filter replacement aligned with the foam's emission profile over its service life.	S	Ch. 4, expert interviews
R19	Control	Reduce the total mass of TCPP-containing foam by eliminating foam from components where it is not functionally necessary.	M	Ch. 4, teardown
R20	Control	Incorporate inherently flame-resistant materials, selected to be REACH-compliant in their finished form, in components where foam has been removed.	M	Ch. 3, literature review
R21	Control	Allow extended off-gassing of foam components in a controlled industrial environment before assembly.	M	Ch. 3, VOC literature

R22	Control	Be deployable in office environments where engineered air filtration or biophilic design provides a complementary contribution to indoor air quality.	M	Cummings & Waring (2020); Wang et al. (2021); Hong et al. (2017); Ch. 3
R23	Control	Carry labelling that communicates foam chemical content and recommended unboxing conditions to end users and end-of-life processors.	C	Ch. 4, expert interviews

The themes that emerged covered substances of concern, improved logistics, business models, and design for disassembly.

These were consolidated into five guiding design themes: Soft and hard material contrast, functional disassembly and modularity, primitive shape-based design, transparency as material communication, and playfulness and self-expression. The full brainstorm output and inspiration moodboards are provided in Appendix D.

6.5.3 Target user and context of use

The design is aimed at a young professional for whom sustainability and personal health are primary rather than secondary priorities. This generation is more likely to factor environmental consequences into purchasing decisions than older cohorts focused on cost (Deloitte, 2024), and the target user is willing to express these values visibly through their workspace. The persona profile of the target user is shown in Figure 6.3.

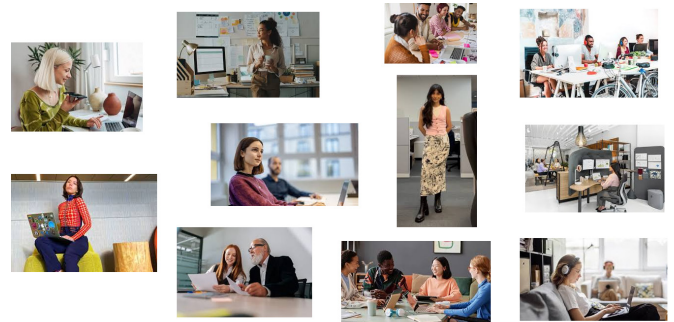


Figure 6.3. Persona profile

The design is intended for use across a broad range of office environments. For the Control strategy specifically, the focus is on offices that apply biophilic design principles.

Such offices tend to incorporate more indoor greenery, which is relevant here: living plants have been shown to contribute to the removal of volatile organic compounds from indoor air (Claudio, 2011; Hong et al., 2017; Yang et al., 2009), and ornamental houseplants have been identified as potential biosamplers for organophosphate flame retardants including TCPP (Pan et al., 2020; Wang et al., 2021), although the extent of this effect under real-world conditions remains debated (Cummings & Waring, 2020). This creates a use case in which the surrounding environment supports the control of chemical exposure. The target office environment is illustrated in Figure 6.4.

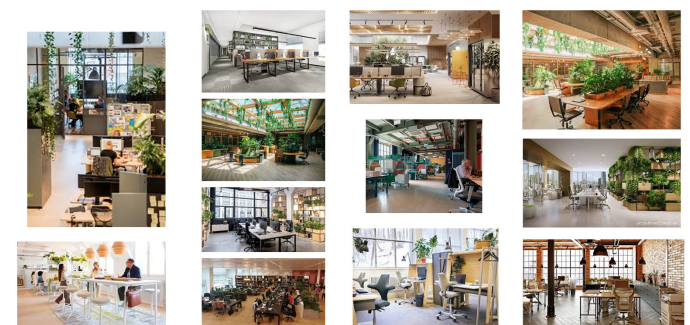


Figure 6.4. Target office environment.

6.5 Design approach

6.5.1 Market research

A market analysis was conducted across task chair models from European, American, and emerging Asian brands (Figure 6,2). Most models share similar mechanisms and substructural components sourced from a small number of OEM suppliers, with meaningful design differentiation beginning above the mechanism.

Models were clustered by appearance and by component-level design features to identify references that aligned with the emerging design scope (see Appendix D for the full clustering).

The selected references share a common design language: formal simplicity, basic geometric shapes, and restrained material use. A full task chair design process typically spans five years, so the priority within this project is correct proportions and a coherent visual language rather than a finalised design.



Figure 6.2. Market overview of office task chair models

6.5.2 Brainstorm and design themes

A group brainstorm at NPK Design with two designers and a design engineer explored how seating could be reimagined when freed from conventional assumptions, followed by an individual brainstorm structured around why the problem occurs, what a solution would look like, and how it could be realised.

6.5.4 Ideation per strategy

Sketching was structured around the three SCbD strategies, using the TCPP exposure scenarios from Step 1 as the reference (Figure 6.5). For each strategy, opportunities for intervention were mapped and a primary sub-strategy was selected.

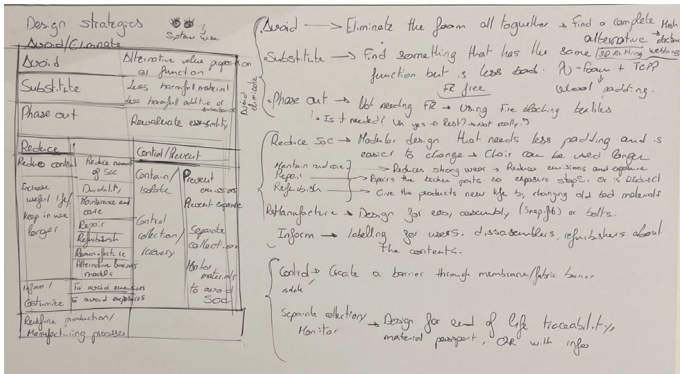


Figure 6.5. Design opportunities mapped per SCbD strategy.

For Avoid, the exploration focused on a chair that does not rely on foam, flame retardants, or textile components. The direction that emerged centred on selective laser sintering (SLS), which fuses material layer by layer to produce complex geometries unachievable through injection moulding (Lupone et al., 2022). SLS is already applied to nylon, one of the most widely used materials in the task chair industry. Combined with computational design (Tang et al., 2024), the approach integrates frame, seat, and cushioning function into a single component, removing the need for separate foam or textile layers.

For Reduce, the focus was on lowering the total mass of TCPP-containing foam in the product without introducing a new product-level mechanism. The direction that emerged centred on removing foam from the backrest, where it is not functionally necessary, and substituting inherently flame-resistant aramid textile. The residual exposure from the retained seat foam is supplemented by biophilic filtration in the deployment environment, where living plants contribute passively to indoor air quality.

For Control, the strategy was approached at the product level. The direction that emerged centred on an integrated active carbon filter system in the backrest and seat, intercepting TCPP emissions at source through a controlled pathway within the chair itself rather than relying on the surrounding environment. The reasoning for this intervention is developed in Section 6.6.3 alongside the resolved concept.

The full sketch exploration is presented in Appendix D. The three concepts were translated into CAD to establish proportions, material relationships, and component breakdowns at a level sufficient for assessment in Step 3.

6.6 Final Designs

This section presents the three resolved concepts: Avoid, Reduce, and Control. Each is grounded in one of the SCbD strategies and addresses the TCPP exposure problem through a different design logic.

They are not competing options for a single final design, but three coherent answers to the same problem under different SCbD framings. Together they illustrate how the choice of strategy shapes the resulting product, the user interaction, and the surrounding service system.

6.6.1 Avoid

The Avoid concept (Figure 6.6) is built around a single dominant polymer family, nylon, combined with steel parts for the mechanism. By concentrating the material composition into one polymer, the design removes TCPP-treated polyurethane foam from the product entirely and eliminates the substance of concern at source.



Figure 6.6. Avoid strategy chair.

The seat, backrest, and armrest pads are produced through selective laser sintering, allowing frame, support, and cushioning function to be integrated into single components. Computational design distributes material only where structural demands require it, producing a lattice geometry lighter and chemically simpler than current constructions.

The chair is modular: components can be disassembled, repaired, exchanged, or upgraded with standard tools, and at end of life the nylon components separate from the steel mechanism into their respective recycling streams.

The supporting product service system is built on leasing and manufacturer ownership. Worn components are returned and replaced rather than discarded, and because the product contains no hazardous content, the end-of-life loop is clean.

The concept was developed in two colourways to test how the design reads across different market segments. The first uses a bold palette inspired by the Studio Memphis references in the design themes moodboard. Since the chair already breaks from traditional task chair construction through its single-material architecture and computational geometry, a bold colourway suits an early-adopter audience drawn to visible design innovation (Figure 6.7).



Figure 6.7. Avoid concept, bold colourway.

The market analysis showed that muted colours, particularly black and grey, still dominate the B2B office chair segment. A second treatment in a neutral palette tests whether the same design reads as a viable mainstream option once the bold colourway is removed (Figure 6.8).



Figure 6.8. Avoid concept, neutral colourway.

6.6.2 Reduce

The Reduce concept (Figure 6.9) addresses TCPP exposure by reducing the total mass of foam-containing material in the product and supplementing this with biophilic elements in the surrounding office environment. Rather than altering the standard foam formulation or introducing a new filtration mechanism, the strategy accepts the presence of TCPP in the seat but reduces the volume of material from which it can migrate, and introduces living plants as a complementary passive filter in the deployment environment.



Figure 6.9. Reduce strategy chair.

The backrest uses an aramid textile suspended on a structural frame, removing foam from the component where it is not functionally necessary. Foam is retained only in the seat, where its cushioning function cannot be replicated through textile alone. Aramid was selected because it is inherently flame resistant without chemical treatment, removing the need for TCPP in the backrest while satisfying fire safety requirements. The fibre is REACH-compliant in its finished form, although its production uses NMP, a REACH SVHC reproductive toxicant. Compared with TCPP-treated foam this represents a meaningful reduction in user-phase exposure, since the hazard is contained within the manufacturing facility rather than migrating from the product. End of life remains constrained: aramid is difficult to recycle and material recovery typically takes the form of mechanical downcycling.

The deployment environment supplements the in-product reduction. Offices applying biophilic design principles incorporate living plants at sufficient density to contribute to indoor air quality. Ornamental houseplants have been identified as potential biosamplers for organophosphate flame retardants including TCPP (Pan et al., 2020; Wang et al., 2021), and living plants have been shown to contribute to the removal of volatile organic compounds from indoor air (Hong et al., 2017; Yang et al., 2009). Plant-based VOC removal alone is insufficient as a primary control measure (Cummings & Waring, 2020), but in combination with the in-product foam reduction, the layered approach produces a lower overall exposure than either intervention achieves alone. Figure 6.10 shows the concept in its intended office context.



Figure 6.10. Reduce concept in office context

The supporting product service system is built on leasing and manufacturer ownership. At end of life, textile components are returned for processing through their respective recovery streams, and the foam seat, containing a smaller volume of TCPP than the reference chair, is returned to the manufacturer for controlled disposal.

6.6.3 Control

The Control concept (Figure 6.11) keeps the existing foam-based construction and standard polyurethane formulations, but reorganises the product architecture around an integrated filtering system in the backrest and seat. Rather than reducing the volume of TCPP in the product or relying on the surrounding environment, the strategy intercepts emissions at source through a controlled pathway within the chair itself.



Figure 6.11. Control strategy chair.

Each cushioned component consists of a moulded shell housing the foam, with a felt mesh wrapping the foam itself. The filter sits at a single defined opening in the shell. The shell and the felt mesh prevent migration through the rest of the surface, so air can only enter and exit through the filter, eliminating dermal contact with the foam and routing airborne emissions through the active carbon filter before they reach the surrounding air. Figure 6.12 shows the assembly in exploded view.



Figure 6.12. Exploded view of the Control backrest.

The filter is replaceable, and this exchange forms the basis of the supporting product service system, modelled on a printer ink subscription. Loading data from returned filters indicates foam degradation over time, informing replacement schedules and eventual retirement of the chair. At end of life, the encapsulated foam can be returned in its sealed shell, reducing exposure for workers handling disassembly. Figure 6.13 shows the concept in its intended office context.



Figure 6.13. Control concept in office context.

End-of-life communication is addressed through a material passport embedded in the product. A QR code fixed to the underside of the seat shell links end-of-life processors directly to the chemical content of the foam, the filter loading history, and the recommended handling procedure.

This approach aligns with the Digital Product Passport framework scheduled for furniture under the EU Ecodesign for Sustainable Products Regulation (European Parliament and Council, 2024), and ensures that the information gap identified in the expert interviews, where end-of-life workers handle TCPP-containing foam without knowing what is in it, is addressed through a traceable and updateable data record.

The supporting product service system is built on leasing with maintenance included. Returned filters and sealed foam shells are processed through manufacturer-controlled routes rather than entering general waste streams.

6.7 Reflection on strategy per application

Developing one concept per strategy made visible something the SCbD framework anticipates but that only becomes concrete through design. The three strategies are not interchangeable, and they rarely operate in isolation.

The clearest overlap is between Reduce and Control. The Control concept intercepts migration at source through an integrated filter, which is also a form of reduction in that it limits what reaches the user. The Reduce concept removes foam where it is not functionally necessary and supplements with environmental filtration, which is also a form of control over the exposure pathway. The distinction is one of emphasis rather than category: Control keeps the standard architecture and adds an interception layer, while Reduce changes the architecture and supplements the result with environmental and procedural measures. Both acknowledge that the substance is present and design around that presence.

Avoid sits more clearly on its own, since the elimination of TCPP and foam is categorical rather than gradient. Even here, however, the strategy is not pure: the substitute materials carry their own production-phase hazards. Avoid in this project escapes the substitution cycle described by Bumgardner and Nicholls (2020) by changing the functional logic of the product rather than swapping one flame retardant for another, but the broader principle holds. There is no design that introduces no new burdens.

This connects to the position taken in Bolaños Arriola et al. (2023, 2025). The SCbD framework is explicit that strategies form a hierarchy with Avoid preferred over Control and Control preferred over Reduce, but the same work emphasises that the strategies are tools to be applied where they fit, not a ladder to be climbed regardless of context. Avoid is preferable in principle, but its viability depends on the market accepting a different-looking product and on the existence of SLS production capacity at scale. Reduce and Control are less preferable in the hierarchy but more accessible to manufacturers working within existing production lines and customer expectations.

In all three concepts, the product service system is integral to the strategy rather than a separate layer. Avoid depends on take-back to close the material loop. Control depends on filter subscription to maintain its function over time. Reduce depends on lease-with-maintenance and controlled end-of-life routing to handle the partially-retained foam. This reinforces a point Bolaños Arriola et al. (2025) make: design decisions propagate through the broader value chain, and the strategy is only as strong as the supporting infrastructure.

The product family is therefore best read not as three competing options but as three reference points on a continuum. In practice, a real product would combine elements of more than one strategy, positioned on the continuum by what is technically, commercially, and contextually viable.

6.8 Conclusion

Step 2 translated the hotspots identified in Step 1 into three resolved design concepts, one per SCbD strategy.

The Avoid concept removes TCPP and polyurethane foam from the product entirely through an SLS-printed nylon construction with integrated cushioning function.

The Reduce concept lowers the total mass of TCPP-containing foam by removing it from the backrest and substituting aramid textile, supplementing the in-product reduction with biophilic filtration in the deployment environment.

The Control concept retains the standard foam-based architecture but reorganises it around an integrated active carbon filter system in the seat and backrest, intercepting TCPP emissions at source before they reach the user. Each concept is supported by a product service system aligned with its strategy.

The chapter also produced a set of design requirements traceable to the evidence base in the preceding chapters, structured as shared requirements applying to all three concepts and strategy-specific requirements defining what each concept must achieve. These requirements form the evaluative framework for the assessment that follows.

The reflection in Section 6.7 made visible that the three strategies overlap in practice and that a real product would likely combine elements of more than one. The product family is therefore best read as three reference points showing the range of design responses within the SCbD methodology, rather than as three competing options for a final product.

Chapter 7 takes the three concepts into Step 3, Assess, where each is evaluated against the Step 1 baseline to compare effects on the concern scenarios, negative consequences, and tradeoffs.



Chapter 7

SCbD Step 3: Asses

7.1 Introduction	70
7.2 Approach	70
7.3 Assesment per concept.....	70
7.4 Comparative results.....	71
7.5 Reflection on trade-offs	72
7.6 Conclusion	73

7.1 Introduction

Step 3 assesses the three concepts developed in Chapter 6 against the reference chair from Step 1. The aim is not to identify a best concept, but to make visible how each SCbD strategy shifts the hazard profile across the lifecycle and what tradeoffs each shift introduces (Bolaños Arriola et al., 2023).

The reference chair carries its highest concern during the use phase, where TCPP migrates from the foam to the user without engineered control. End of life ranks second, since the chair enters waste streams without reliable chemical information. Manufacturing ranks lowest, since occupational exposure is managed through ventilation, PPE, and process controls absent from the other phases.

The three concepts intervene at different points in this profile. Avoid removes TCPP and foam at source, shifting the burden to SLS manufacturing. Reduce removes foam from components where it is not functionally necessary, substitutes aramid textile, and supplements with biophilic filtration in the deployment environment, distributing the reduction across the product and its context. Control retains the foam but intercepts emissions through an integrated active carbon filter, moving part of the burden to end of life where the saturated filter requires controlled disposal.

Section 7.2 sets out the assessment approach. Section 7.3 assesses each concept against the reference. Section 7.4 presents the comparative results. Section 7.5 reflects on what the assessment reveals about the SCbD framework. Section 7.6 closes the chapter.

7.2 Approach

The assessment uses the same MAPSSS dimensions applied to the reference chair in Step 1: hazard categories, exposure pathways, and aggravating conditions across the manufacturing, use, and end-of-life phases. Two adaptations are made relative to Step 1.

First, the assessment operates at lifecycle phase granularity rather than at scenario granularity. The reference chair was scored across 23 individual scenarios within the three phases. The three concepts developed in Chapter 6 each carry different product architectures, so a scenario-by-scenario comparison is not always meaningful: some scenarios in the reference chair do not exist in the Avoid concept (the foam-related scenarios), and the Reduce and Control concepts introduce new scenarios that have no equivalent in the reference. Working at phase level keeps the comparison consistent across all four products and focuses on the relative shift in concern within each phase rather than on absolute scenario-level scores.

Second, the comparison is qualitative-relative rather than quantitative. Both the reference chair and the three concepts are conceptual rather than physically tested products, so the assessment expresses concern in terms of higher, comparable, or lower relative to the reference baseline within each phase. Where a concept introduces a new pathway that has no

equivalent in the reference (such as SLS particulate exposure in Avoid or aramid production hazards in Reduce), the new pathway is added so the comparison reflects the full hazard profile of the new design rather than only the changes from the reference.

The assessment proceeds in three steps for each concept. The first step identifies which lifecycle phases the strategy targets and which it leaves untouched. The second step rescores those phases against the reference, marking improvements, deteriorations, and unchanged conditions. The third step identifies the new pathways introduced by the strategy and the negative consequences and tradeoffs they carry, in line with the questions specified by Bolaños Arriola et al. (2023) for Step 3. Alongside the MAPSSS-based hazard assessment, each concept is also considered against the implementation conditions on which its delivery depends, since the lifecycle hazard profile alone does not capture whether a strategy is viable in practice.

The results are summarised in two formats. Each concept assessment in Section 7.3 closes with a phase-by-phase summary indicating direction of change relative to the reference. Section 7.4 presents the comparative results across all three concepts and the reference, supported by a visual comparison of the phase-level hazard profiles.

7.3 Assessment per concept

This section assesses each concept against the reference chair in turn, identifying which phases the strategy targets, marking the direction of change relative to the reference, and identifying the new pathways the strategy introduces.

7.3.1 Avoid

The Avoid concept eliminates TCPP and polyurethane foam from the product through an SLS-printed nylon construction with integrated cushioning function. Because the substance of concern is removed at source, the reductions distribute across the full lifecycle rather than concentrating at a single phase.

In manufacturing, the foam-pouring and TCPP-treatment steps are removed entirely, but SLS introduces a new pathway in their place: nylon particulate generation during printing and post-processing, requiring enclosed handling and respiratory protection for operators. The relative concern is comparable to the reference but in a different hazard category. In the use phase, the strategy makes its strongest improvement: TCPP migration is removed entirely, dermal contact, inhalation, and dust ingestion pathways from foam are eliminated, and the microplastic generation pathway associated with textile wear is removed since the chair has no textile components. At end of life, the single-material architecture supports clean separation, with nylon components routing into a single recovery stream and emerging chemical recycling processes potentially returning glass-fibre-reinforced nylon to clean polymer feedstock.

Phase-level summary relative to reference: manufacturing comparable (different hazard category); use substantially lower; end of life substantially lower.

The principal tradeoff is not in the hazard profile but in the implementation barrier. The strategy requires changes to materials, manufacturing processes, and supply chains that the industry has not yet made at scale. The hazard profile is the cleanest of the three concepts, but the path to market is the longest, and several experts noted that the absence of established large-scale SLS production is a primary reason manufacturers continue to use foam.

7.3.2 Reduce

The Reduce concept lowers the total mass of TCPP-containing foam in the product by removing it from the backrest, where it is not functionally necessary, and substituting aramid textile. Foam is retained only in the seat. The strategy supplements this in-product reduction with biophilic elements in the deployment environment, where living plants contribute passively to indoor air quality.

In manufacturing, the aramid textile introduces a new concern: aramid production uses NMP, a REACH SVHC reproductive toxicant. The finished fibre is REACH-compliant, but the production-phase hazard is higher than in the reference. The seat foam manufacturing process is unchanged. In the use phase, the reduced foam mass means less TCPP is available to migrate over the product's service life. The biophilic supplementation contributes to indoor air quality, although plant-based VOC removal is not well-quantified for SVOCs such as TCPP (Cummings & Waring, 2020; Wang et al., 2021), and its effectiveness depends on the actual plant density and species in the deployment environment. At end of life, the aramid textile is difficult to recycle and typically downcycled mechanically. The seat foam still carries TCPP, though in a smaller volume than the reference chair.

Phase-level summary relative to reference: manufacturing higher for textile components (NMP production hazard); use lower (reduced foam mass, conditional biophilic supplementation); end of life comparable to slightly worse depending on textile fraction.

The principal tradeoff is uncertainty and conditionality. The in-product reduction is real and unconditional, but the biophilic supplementation depends on the deployment environment delivering sufficient plant density and species selection to contribute meaningfully. The concept is best suited to offices that already apply biophilic design principles, and less suited to standard open-plan offices where plant density is incidental rather than deliberate

7.3.3 Control

The Control concept retains the existing foam-based construction and standard polyurethane formulations, but reorganises the product architecture around an integrated active carbon filter system in the backrest and seat. Rather than reducing the volume of TCPP in the product, the strategy intercepts its migration at source through a controlled pathway within the chair itself.

Manufacturing is essentially unchanged from the reference, with the additional components (shell, felt mesh, filter media) introducing no novel hazards. In the use phase, the shell and felt mesh prevent TCPP migration through the rest of the foam surface, leaving the filter as the only pathway through which air can enter and exit. Airborne TCPP, formaldehyde from foam degradation, and other VOCs are captured in the filter rather than reaching the user, and dermal contact and dust ingestion are reduced by the sealed shell. At end of life, the saturated filter holds accumulated TCPP in concentrated form, and the foam still contains its original chemical loading. The assessment assumes a functioning product service system that routes returned filters and chairs through manufacturer-controlled processing. Without that assumption, the Control concept performs worse than the reference at end of life, since the same contamination is now both concentrated and uncontained. A material passport embedded in the product, accessible via QR code, communicates the chemical content of the foam to end-of-life processors, addressing the information gap identified in the expert interviews.

Phase-level summary relative to reference: manufacturing unchanged; use substantially lower; end of life higher in absolute hazard but contained within a controlled service loop, conditional on a functioning PSS.

The principal tradeoff is the dependence of the assessment on the supporting service system. The architectural change to the chair itself is small, making the concept accessible to manufacturers working within existing production lines, but the realised SCbD outcome is determined as much by the take-back infrastructure as by the product itself. User acceptance of subscription-based filter replacement in the office furniture category is a further open question that would need to be tested with the intended customer base.

7.4 Comparative results

Each of the three concepts shifts the hazard profile of the reference chair, but in different ways and at different points along the lifecycle. This section presents the comparison across all four products.

Table 7.1 summarises the direction of change relative to the reference for each concept across the three lifecycle phases. The reference chair carries its highest concern in use, second-highest at end of life, and lowest in manufacturing, as established in Step 1.

Table 7.1. Direction of change relative to the reference chair across lifecycle phases.

Phase	Reference	Avoid	Reduce	Control
Manufacturing	Lowest	Comparable (different hazard category)	Higher (aramid NMP)	Unchanged
Use	Highest	Substantially lower	Lower (conditional on biophilic deployment)	Substantially lower
End of life	Second-highest	Substantially lower	Comparable to slightly worse (aramid textile fraction)	Higher (concentrated in filter, contained by PSS)

The phase-level comparison across all four products is visualised in Figure 64, showing the relative concern across manufacturing, use, and end of life for the reference chair and each of the three concepts.

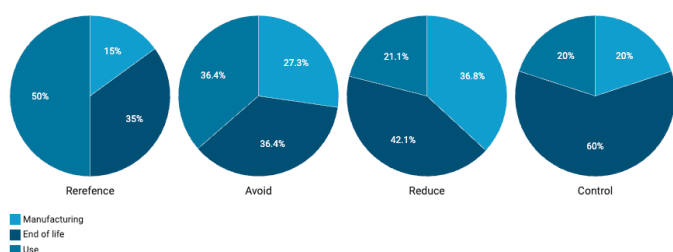


Figure 7.1. Phase-level hazard profile comparison across the reference chair and the three concepts.

Reading across the table and figure, three patterns emerge.

Avoid produces the cleanest hazard profile across the lifecycle, with reductions in both the use phase and end of life and no significant deterioration in manufacturing once the SLS hazards are properly contained.

This is consistent with the SCbD framework’s preference for Avoid in its strategy hierarchy. The hazard profile, however, does not capture the implementation barrier, which is the principal constraint on this concept. Several experts identified the lack of large-scale SLS production capacity as the main reason manufacturers continue to use foam, indicating that the R&D and OEM adaptation costs required to bring an Avoid concept to market are the dominant practical tradeoff.

Reduce and Control both improve the use phase relative to the reference, but through different mechanisms and with different secondary effects.

Reduce distributes the reduction across the product and its context by lowering the foam mass and supplementing with biophilic filtration, but pays for this in manufacturing through the aramid production hazard and in the use phase through conditionality on the deployment environment.

Control concentrates the reduction in the use phase through a single intercepting mechanism and pays for that reduction at end of life, where the captured contaminants now sit in

concentrated form. Neither concept produces a uniformly better profile than the other: Reduce is more architecturally varied and more dependent on the surrounding office environment, while Control is more architecturally conservative and more dependent on the supporting service system.

No concept removes all hazards across the lifecycle. Each improves the profile in some phases and worsens it in others, and each depends on conditions outside the product itself to deliver its intended reduction. Avoid depends on the existence of SLS production at scale and on clean material recovery infrastructure. Reduce depends on the deployment environment providing biophilic supplementation. Control depends on the take-back service system. The product-level decision is therefore inseparable from the value-chain decisions surrounding it.

Table 7.2 summarises the principal improvements and drawbacks for each concept.

Table 7.2. Principal improvements and drawbacks per concept.

Concept	Principal improvement	Principal drawback
Avoid	Removes TCPP and foam at source; clean profile across all phases	High implementation barrier; SLS not yet at production scale
Reduce	Reduces TCPP-containing foam mass; no new product-level mechanisms required	Biophilic effectiveness conditional on deployment; aramid production hazard; end-of-life constrained
Control	Addresses use-phase exposure directly within the product; architecturally conservative	Shifts burden to end of life; effectiveness depends on PSS; filter concentration risk without take-back

The choice between concepts depends less on the hazard profile in isolation than on the operating context in which the chair will be produced, sold, and used. A manufacturer with R&D capacity and a willingness to invest in new production methods is best positioned for Avoid.

A manufacturer with access to inherently flame-resistant material supply and customers operating in well-equipped biophilic office environments is best positioned for Reduce.

A manufacturer working within existing foam-based production lines, with a customer base willing to engage with a service subscription, is best positioned for Control.

7.5 Reflection on trade-offs

The assessment surfaces three observations about the SCbD framework itself, beyond the specific findings for the TCPP case.

The first is that the strategy hierarchy holds in principle but underdetermines design choice in practice. Avoid produces the cleanest hazard profile, consistent with its position at the top of the SCbD hierarchy (Bolaños Arriola et al., 2023), but the assessment shows that this advantage is purchased at the cost of an implementation barrier that the other two concepts

do not face. The hierarchy expresses what is preferable when implementation is unconstrained; the design decision is made under specific constraints of production capacity, supply chain readiness, and customer expectations.

The second is that the strategies shift hazard rather than removing it. Avoid shifts hazard out of the use phase but introduces SLS particulate generation in manufacturing. Reduce distributes the reduction across the product and its context, but introduces aramid production hazards and depends on the deployment environment. Control shifts hazard from use to end of life, where captured contaminants sit concentrated in the saturated filter. This is consistent with the observation in Bolaños Arriola et al. (2025) that strategies for dealing with substances of concern operate on a continuum, with each move carrying its own consequences. There is no design that introduces no new burdens.

The third is that the product-level decision is inseparable from the value chain surrounding it. Each concept depends on conditions outside the product itself to deliver its intended reduction: Avoid on SLS production at scale and clean recovery infrastructure, Reduce on the deployment environment, and Control on the take-back service system. The same product evaluated in different value-chain contexts will produce different SCbD outcomes. A Reduce chair deployed in a standard office without biophilic elements loses most of its use-phase advantage; a Control chair outside its return loop produces a worse profile than the reference. The SCbD strategy is therefore not a property of the product alone but of the product together with its value chain.

Taken together, these observations support reading the SCbD framework as a structured way of making tradeoffs visible rather than a procedure for arriving at a single correct answer. Its value lies in forcing evaluation of hazard across the full lifecycle and across substitution effects, rather than focusing on the substance of concern in isolation.

7.6 Conclusion

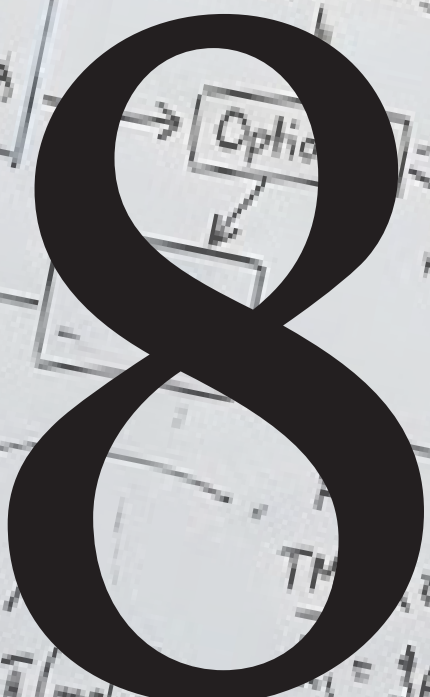
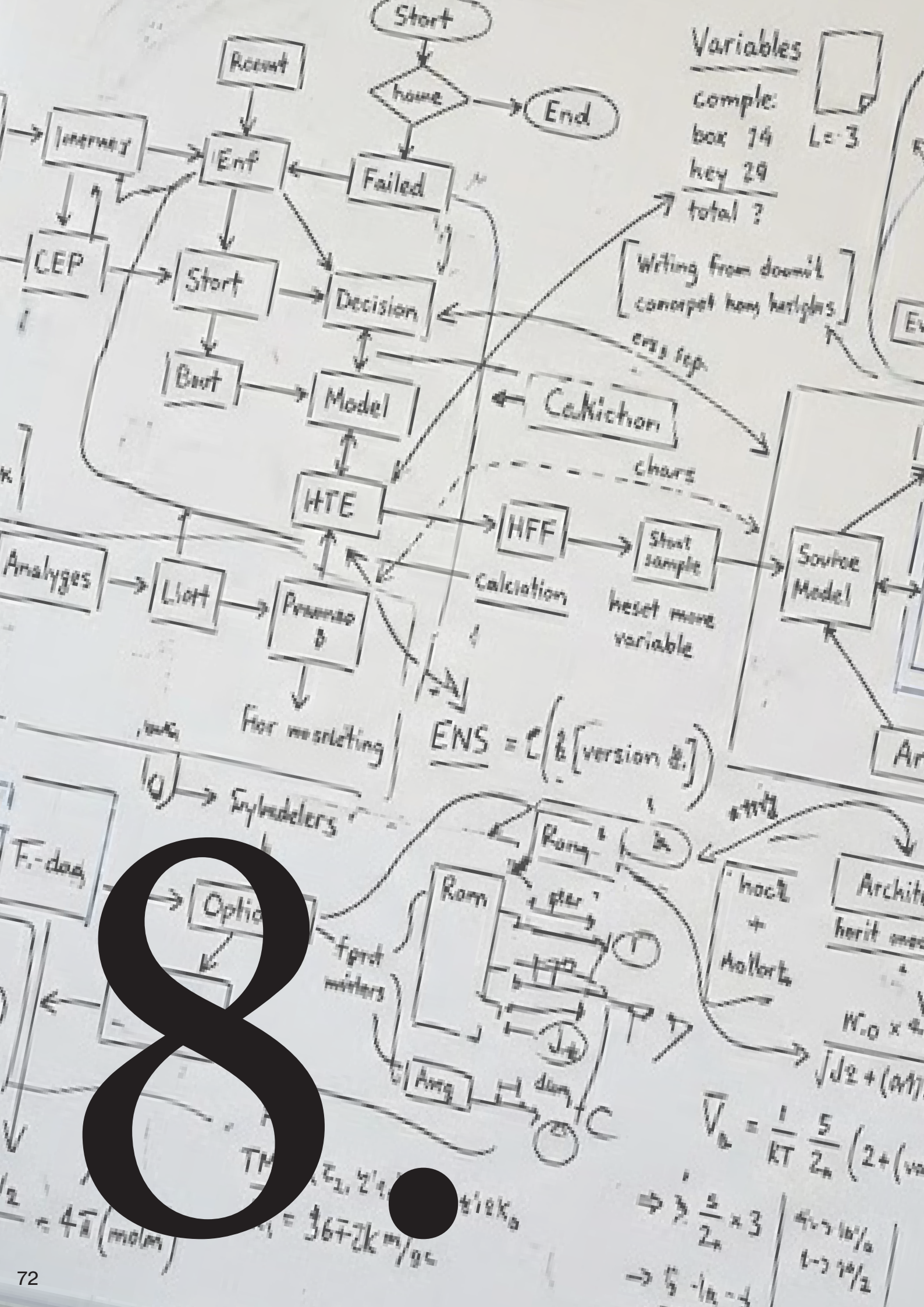
Step 3 assessed the three concepts developed in Chapter 6 against the reference chair from Step 1, focusing on how each SCbD strategy shifts the hazard profile across the manufacturing, use, and end-of-life phases.

The Avoid concept produces the cleanest profile by removing TCPP and foam at source, with the principal tradeoff being the implementation barrier. The Reduce concept lowers the total mass of TCPP-containing foam and supplements with biophilic filtration in the deployment environment, with the principal tradeoffs being the aramid production hazard and the conditionality of the biophilic contribution. The Control concept addresses use-phase exposure directly through an integrated filter pathway, with the burden shifting to end of life and the strategy depending on the supporting service system.

No concept removes all hazards across the lifecycle. Each improves the profile in some phases and worsens it in others, and each depends on conditions outside the product itself to deliver its intended reduction. The three concepts therefore do not compete as alternative final designs but illustrate three

coherent responses to the same problem under different SCbD framings, each suited to a different operating context.

The implications of these findings for design practice and for the wider B2B office task chair industry are discussed in Chapter 8.



Chapter 8

Discussion

8.1 Introduction	78
8.2 Answering the reseach questions	78
8.3 The SCbD methodology from a designer's perspective	79
8.4 Uncertainty and validation.....	81
8.5 What the three concepts together reveal	81
8.6 Industry implications and recommendations	82
8.7 Recommendations for the SCbD methodology and MAPSSS tool	83

8.1 Introduction

This chapter reflects on the work presented in the preceding chapters and draws out what the case study reveals about both the SCbD methodology and the office task chair industry. It does so across six sections.

Section 8.2 answers the four research questions set out in Chapter 1, drawing on evidence from across the thesis. Section 8.3 reflects on the SCbD methodology and the MAPSSS tool from a designer's perspective, working through each step in turn and identifying where the methodology supports design work and where it strains against the realities of design practice. Section 8.4 addresses the question of uncertainty and validation, which surfaced repeatedly throughout the analysis and the expert feedback. Section 8.5 considers what the three concepts together reveal about the relationship between material safety and circularity, and about how the SCbD strategy hierarchy behaves when applied. Section 8.6 turns outward to the office task chair industry, examining the structural conditions that shape current practice and the conditions under which safer and more circular design becomes viable. Section 8.7 closes with recommendations for the further development of the SCbD methodology and MAPSSS tool, drawn from the case study and from feedback gathered throughout the project.

The chapter draws on three sources of evidence: the analytical work conducted in Chapters 4 through 7, the twenty expert interviews described in Chapter 3, and a feedback session with NPK Design held during the project. The personal reflection on the project as a whole is held until Chapter 9, where it sits alongside the conclusion, limitations, and future work.

8.2 Answering Research questions

This section answers each of the four research questions set out in Chapter 1, drawing on evidence from across the thesis.

8.2.1 RQ1: How are substances of concern currently identified and managed in desk chair design and production?

Substances of concern are addressed primarily through reactive regulatory compliance rather than proactive design practice. Identification typically happens after a substance has been restricted in a target market, at which point the manufacturer searches for an alternative. Material safety is rarely a design-phase consideration: the dominant priorities are ergonomics, mechanical performance, certification, and cost, with chemical composition addressed downstream by engineers or sustainability specialists.

The methods and tools available are oriented towards chemical and material developers rather than designers. Restricted substance lists, REACH procedures, and certifications such as BIFMA e3 and Declare offer transparency at the ingredient level, but their use sits in compliance and procurement functions rather than design teams. Key material decisions are made early,

often before studio designers are engaged, and they are difficult to revise once a product reaches engineering.

Communication across the value chain is fragmented. OEMs supply standardised components whose composition is treated as commercially confidential, manufacturers integrate these without full visibility of their chemical content, and end-of-life processors receive products without reliable information on what they contain. The result is a value chain in which substances of concern travel from production to disposal largely unmanaged at the design level.

8.2.2 RQ2: How can the Safe and Circular by Design methodology be applied effectively to support safer desk chair design?

The case study shows that the SCbD methodology adds a complementary lens rather than competing with existing practice. Current sustainability work in the industry is dominated by carbon reduction, and SCbD introduces a substance-of-concern dimension that is currently under-represented in standard design briefs. The methodology surfaces intervention points at the component level and at the lifecycle stage where they matter, making upstream design decisions visible at the start of the process rather than at the end.

The methodology relates to existing certifications in principle: BIFMA e3 and the Declare label provide the ingredient-level transparency that Step 0 requires. In practice the integration is one-directional, since the certifications do not yet recognise SCbD-style design reasoning. Three implementation barriers stand out. The methodology requires chemistry and toxicology knowledge that sits outside typical designer training, particularly in Steps 0 and 1. The data infrastructure required to complete Step 0 reliably is not yet accessible to designers in routine practice. And the methodology has no built-in validation mechanism at the chemistry level, meaning a designer working without expert support has no way to verify whether the assessment is correct.

Despite these barriers, the methodology offers benefits to both manufacturers and users. For manufacturers, it provides a way to anticipate regulatory developments, make substance-of-concern decisions traceable, and position products for emerging procurement incentives such as government tender point systems. For users, it supports products with lower exposure during the use phase, where exposure is most prolonged and least controlled.

8.2.3 RQ3: What are the main substances of concern in desk chairs, and what risks do they pose to human and environmental health?

The lifecycle mapping in Chapter 4 identified substances of concern across multiple components, including flame retardants in polyurethane foam, microplastics from mesh textiles, surface coatings on metal components, and non-intentionally added substances in recycled plastics. The hotspot assessment in Chapter 5 identified TCPP in polyurethane foam as the priority substance.

TCPP carries hazards across multiple endpoints: thyroid and reproductive hormone interference raising endocrine disruption concerns, kidney and liver toxicity at elevated

doses, and neurotoxic effects at higher dose levels. Its primary human metabolite has been detected in urine across multiple biomonitoring studies. Environmentally, it resists biodegradation and has been detected in remote ecosystems including Arctic air and ocean water, indicating long-range transport.

Exposure risk varies across the lifecycle. The use phase carries the highest concern: TCPP is not chemically bound to the foam and migrates continuously through inhalation, dermal contact, and dust ingestion over the chair's ten-year service life, with no engineered control between the substance and the user. End of life carries the second-highest concern, with TCPP entering waste streams through handling environments that lack the information to manage it specifically.

These substances remain in use because the conditions for substitution are not currently met. TCPP remains technically effective and cost-competitive, regulatory bans have not been enforced in all major markets, and the substitution cycle described by Bumgardner and Nicholls (2020) means restricted substances are typically replaced with chemically similar alternatives carrying comparable hazards.

8.2.4 RQ4: What challenges arise when substituting or managing substances of concern in desk chairs?

The three concepts developed in Chapter 6 and assessed in Chapter 7 surface a consistent pattern: every intervention against TCPP introduces tradeoffs that must be managed rather than removed. Avoid eliminates TCPP at source but introduces new hazards in manufacturing and depends on production infrastructure not yet established at scale. Reduce intercepts emissions through an integrated filter but shifts the burden to end of life, where captured contaminants require a functioning take-back system to contain them. Control distributes the reduction across phases but introduces production-phase hazards through substitute materials and depends on the deployment environment to deliver its full effect.

These technical tradeoffs are amplified by organisational and supply chain challenges. OEM dependency means substitution requires either accepting what the OEM offers or absorbing the cost of custom production. Supply chain opacity means companies often cannot verify the chemical composition of components they purchase, even when they want to. The cost of testing and certifying alternative materials is the most consistently cited reason organisations continue to use standard, well-tested materials despite identifying preferable alternatives.

The pressures shaping material decisions are predominantly regulatory and economic rather than consumer-driven. Material safety becomes a priority when an EU directive forces it, when a client tender includes a sustainability point system, or when a manufacturer anticipates upcoming legislation. The discrepancy between user and customer in the B2B market reinforces the structural deprioritisation of chemical safety: the actor who experiences the exposure is not the actor making the purchasing decision.

8.3 The SCbD methodology from a designer's perspective

The SCbD methodology introduces a way of thinking that does not currently feature in standard chair design practice. In studio work, design has centred on ergonomics, mechanical performance, certification testing, and form, with safe and circular considerations rarely surfacing as primary drivers. Designers in the interviews reported that sustainability and circularity are typically among the last topics clients raise, and substance-of-concern questions are largely absent from briefs.

The process is demanding in the early stages because of the chemistry knowledge it requires and the unfamiliar lifecycle framing. Once the underlying logic is understood, the tool becomes straightforward to apply. The most significant obstacle, raised consistently across interviews, was the lack of transparency in the value chain: information on material composition, additives, and the chemical content of supplied parts is difficult or impossible to obtain, whether the designer works in a studio or in-house.

The tool performs well at making intervention points visible at the component level without displacing the sustainability concerns designers already work with. Current practice is dominated by carbon reduction, and SCbD adds a complementary lens rather than competing with that framing. Its relevance is likely to grow as product liability expands beyond the point of sale, more substances are regulated, and material composition data becomes more available and more expected.

The remainder of this section reflects on each step in turn.

8.3.1 Step 0: Identify

Step 0 was the most difficult step to complete reliably. A significant portion of the research phase went to identifying a suitable data source for material composition, eventually arriving at the Declare Living Future database through industry consultation. Even then, materials are listed at the product level rather than linked to specific components, requiring substantial additional research to resolve. Companies generally do not share bill of materials data, so accessibility varies considerably depending on the designer's position and existing industry relationships. Several interviewees noted that even within their own organisations, accurate knowledge of product composition is limited.

The accuracy of Step 0 has consequences across the rest of the methodology, since Steps 1 to 3 rely on the lifecycle map and material inventory generated here. Any gap propagates through the hazard assessment, the design phase, and the comparative evaluation. This makes Step 0 the methodological weakest link in practice, not because the step is poorly designed, but because the underlying data infrastructure does not yet exist in an accessible form. The median reference chair developed in this project was a workaround that should not be necessary if component-level material data were directly available.

The same point was raised consistently during expert validation: the need for a structured and accessible database where material compositions and component specifications can be consulted directly. A digital product passport (DPP) was identified as a promising solution, since it could provide the chemical transparency of the Declare database while linking materials to their corresponding components, similar to how material information is organised in CAD software (Awan et al., 2024). This is especially relevant given that under the EU Ecodesign for Sustainable Products Regulation, furniture is among the first product categories for which DPP implementation is scheduled, with delegated acts expected by 2028 (European Parliament and Council, 2024).

8.3.2 Step 1: Analyse

Step 1 is the most demanding step for a designer working without direct access to a materials scientist. The chemical assessment was a steep learning curve even with an industrial design engineering background. Identifying the right substances of concern, selecting appropriate exposure scenarios, and interpreting toxicological and regulatory data required significant time and iteration. The choice of substance shapes the rest of the analysis, and several wrong directions were explored before landing on TCPP.

A related challenge is the trade-off between depth and breadth. A real chair contains dozens of components, multiple materials per component, and a range of additives and finishes. The designer must make scoping decisions about which substances to assess in detail and which to acknowledge but not pursue, and this scoping is currently left to judgement.

The Excel-based template offers good visibility on each exposure scenario, but a separate file is required for each substance, which becomes inefficient when multiple substances need to be assessed in parallel. Starting from the manufacturing stage of each component worked well in this project, since the chemicals required there tend to produce the worst-case scenarios, making it easier to prioritise effort.

The most significant limitation is validation. The tool does not include a built-in mechanism for verifying that an exposure scenario has been correctly assessed. The lifecycle map can be validated against industry expertise, but the chemistry-level reasoning within Step 1 requires specialist knowledge that even most industry interviewees may not have. The NPK feedback session reinforced this point: without validation built into the method, the designer can only verify the assessment by waiting until the product has been launched and reached end of life, which defeats the purpose of an upstream design tool.

Several improvements could make Step 1 more accessible: an integrated chemistry knowledge resource focused on exposure scenarios for common building product chemicals, better integration with existing hazard databases such as PubChem, ECHA, or GreenScreen, and a guided version with default assumptions for common manufacturing processes that the designer can adjust to their specific case.

Steps 0 and 1 together ask designers to operate at the boundary between design and material science. This is where substance-of-concern questions need to be addressed, but it is also where most designers will need additional support to work effectively.

8.3.3 Step 2: Select and Design

Step 2 aligns most closely with established design practice. Once Steps 0 and 1 are complete, the designer moves from chemical analysis into ideation and concept development, which uses familiar tools and ways of working. The three SCbD strategies function effectively as creative constraints, channeling ideation in different directions and producing a broader range of concepts than an open brief would.

Two limitations apply. Step 2 inherits the quality of Step 1: if the substance scoping was incomplete, the resulting concepts may address only part of the actual hazard profile. The NPK feedback also raised that the strategy definitions can be broad enough to be misinterpreted, particularly the distinction between Reduce and Control, which the design exercise in Chapter 6 confirmed to be more porous than the framework's hierarchy suggests.

8.3.4 Step 3: Assess

Step 3 returns to the analytical reasoning of Step 1, applied to concepts rather than to an existing product. Technical execution is faster once the tool is familiar, but the cognitive shift is non-trivial: Step 1 evaluates a product whose composition can be measured, while Step 3 evaluates concepts whose composition is assumed. The assessment is therefore more speculative, and any conclusion is bounded by the accuracy of those assumptions.

In this project both the reference chair and the three concepts were conceptual rather than physically tested products, so the assessment remained qualitative and relative rather than quantitative. This is structural rather than methodological, but it constrains how confidently any concept can be claimed as superior to another. Only after a concept is produced and tested in real scenarios can its performance against the baseline be verified.

8.4 Uncertainty and validation

Uncertainty surfaced as a structural feature of the analysis rather than a peripheral concern. The hotspot assessment in Chapter 5 carried medium-to-high uncertainty ratings across most lifecycle stages, particularly in manufacturing and end of life, and the expert validation in Section 3.5.5 confirmed that this reflects real industry conditions rather than gaps specific to this project. Uncertainty is built into the SCbD method because it asks designers to assess substances whose behaviour across the lifecycle is often incompletely characterised, in industrial contexts where conditions vary considerably between sites and over time.

Three sources of uncertainty are particularly relevant to interpreting the results of this thesis.

The first is data uncertainty at the component level. The median chair was constructed from aggregated Declare database entries rather than from a verified bill of materials, and the Declare database itself reflects manufacturers who have undergone rigorous transparency reporting and therefore represents better

practice rather than the industry average.

The actual median chair on the market likely contains a more concerning material composition than the one analysed here. The conclusions of Chapter 5 should therefore be read as a lower bound on the hazard profile of the typical B2B office task chair.

The second is condition uncertainty in the lifecycle. Manufacturing safety, PPE compliance, end-of-life filtration, and take-back recovery rates all vary considerably between sites and operators. The literature tends to describe manufacturing processes as controlled and end-of-life processes as managed, while several experts indicated that in practice these conditions are far more variable. This is reflected in the medium-to-high uncertainty ratings assigned across the manufacturing and end-of-life scenarios in Chapter 5, but it also means that the absolute concern scores produced by the MAPSSS calculator are best read as indicative rather than precise.

The third is assumption uncertainty in the assessment of the concepts in Chapter 7. The three concepts are conceptual rather than physically tested, and several of their projected benefits depend on conditions outside the product itself: SLS production at scale for Avoid, a functioning take-back system for Reduce, and a supportive deployment environment for Control. Where these conditions hold, the assessment in Chapter 7 reflects the strategy's likely performance. Where they do not, the realised SCbD outcome may diverge significantly from the assessed one. This is acknowledged in Chapter 7 but is worth restating here, since it shapes how confidently the comparative results in Section 7.4 can be acted on.

Validation is the structural response to uncertainty, and the methodology in its current form does not yet provide it. The lifecycle map can be validated against industry expertise, as was done in this project through the four validation interviews described in Section 3.5.5. The chemistry-level reasoning within Step 1 is harder to verify, since it requires specialist knowledge that most industry contacts do not hold. The NPK feedback session identified this as the central methodological gap: without validation built into the method, the designer can only verify the assessment after the product has been launched and reached end of life, which defeats the purpose of an upstream design tool.

Three forms of validation would strengthen the methodology. The first is peer validation, in which a second designer or chemist reviews the assessment for consistency. This is the form of validation most easily added to current practice, requiring only a structured review protocol.

The second is automated validation, in which integrated chemistry databases and exposure scenario libraries flag inconsistencies or omissions as the designer works. This is more demanding to build but would scale further.

The third is empirical validation, in which design decisions made through the methodology are tested against measured outcomes in produced and deployed products. This is the most powerful form of validation but the slowest to operationalise, since it requires the methodology to have been applied long enough for produced products to reach maturity in the market.

None of these is available in the methodology as it currently exists. The single highest-value improvement to the SCbD method, drawn from this case study and consistently raised

in expert feedback, would be the addition of validation points between the steps and within Step 1 in particular.

This recommendation is developed further in Section 8.7.

8.5 What the three concepts together reveal

Developing one concept per SCbD strategy made visible something the framework anticipates but that only becomes concrete through design: the strategies are not interchangeable, and they rarely operate in isolation. Three observations from the design exercise are worth drawing out.

The first is that the strategy hierarchy holds in principle but underdetermines design choice in practice. Avoid produces the cleanest hazard profile across the lifecycle, consistent with its position at the top of the hierarchy (Bolaños Arriola et al., 2023). But the hierarchy expresses what is preferable when implementation is unconstrained; the design decision is made under specific constraints of production capacity, supply chain readiness, and customer expectations. Avoid in this case study requires SLS production at scale, which the industry has not yet developed, and several experts identified this as the main reason manufacturers continue to use foam. The framework is not wrong to prefer Avoid, but the preference is a starting point rather than a conclusion.

The second is that the strategies shift hazard rather than removing it. Avoid shifts hazard out of the use phase but introduces SLS particulate generation in manufacturing. Reduce distributes the reduction across the product and its context, lowering foam mass and supplementing with biophilic filtration, but introduces aramid production hazards and depends on the deployment environment. Control shifts hazard from use to end of life, where captured contaminants sit concentrated in the saturated filter. This is consistent with the observation in Bolaños Arriola et al. (2025) that strategies for dealing with substances of concern operate on a continuum, with each move carrying its own consequences. There is no design that introduces no new burdens, which means the evaluation of an SCbD strategy must always include the burdens it introduces alongside the burdens it removes.

The third is that the product-level decision is inseparable from the value chain surrounding it. Each concept depends on conditions outside the product itself to deliver its intended reduction: Avoid on SLS production at scale and clean recovery infrastructure, Reduce on the deployment environment providing biophilic supplementation, and Control on the take-back service system. The same product evaluated in different value-chain contexts will produce different SCbD outcomes. A Control chair outside its return loop produces a worse profile than the reference; a Reduce chair deployed in a standard office without biophilic elements loses most of its use-phase advantage. The SCbD strategy is therefore not a property of the product alone but of the product together with its value chain.

These three observations point to a wider conclusion about how safety and circularity interact. Circular strategies extend a product's life and bring its materials back into circulation, but they also extend the time over which any substances of concern in those materials remain in use. A Control chair that successfully intercepts TCPP during its first life still carries the substance into any second life unless the take-back loop is closed and the contaminated foam is properly handled. A Reduce chair removes a significant portion of this tension by lowering the foam mass and relying on an inherently safe backrest material, but its viability depends on the deployment environment and the end-of-life handling of the retained seat foam. Avoid removes the tension at source, but its viability depends on the development of new production infrastructure.

This is the practical meaning of the tension between safety and circularity introduced in Chapter 2: a product cannot be considered genuinely circular if keeping it in circulation prolongs exposure to harmful substances, and the longer the loop, the more carefully the substance question must be answered upstream. The three concepts illustrate this in different ways, and together they suggest that the most durable SCbD response combines product-level design with value-chain conditions that match the strategy chosen.

The framing supported by this case study is therefore not "which concept wins" but "which concept fits which context." A manufacturer with R&D capacity and a willingness to invest in new production methods is best positioned for Avoid. A manufacturer with access to inherently flame-resistant material supply and customers operating in well-equipped biophilic offices is best positioned for Reduce. A manufacturer working within existing foam-based production lines, with a customer base willing to engage with a service subscription, is best positioned for Control. Reading the SCbD framework as a way of making tradeoffs visible, rather than as a procedure for arriving at a single answer, is what the design exercise in this thesis most clearly supports.

8.6 Industry implications and recommendations

The office task chair industry is small and tightly interconnected, but this does not translate into rapid innovation around safe and circular design. Several structural factors slow the introduction of new sustainable solutions in this segment, and the SCbD methodology only delivers value if it is read against these conditions.

The first factor is part standardisation. Mechanisms, gas lifts, casters, and many structural components are sourced from a limited number of OEM suppliers, keeping costs predictable but making it expensive to deviate from the standard architecture. Without significant capital, manufacturers and design studios have limited room to experiment with alternative materials or product systems.

The second is the position of sustainability within the design brief. Multiple interviewees noted that these topics tend to surface late, after ergonomics, mechanical performance, certification,

and cost have already shaped the main product decisions. Within the broader sustainability conversation, carbon footprint reduction dominates, leaving substance-of-concern questions and circular material flows under-addressed.

The third is the discrepancy between user and customer in the B2B market. The user prioritises comfort and ergonomics; the customer, typically a purchasing department, focuses primarily on price. Material safety rarely features in either conversation, even though users spend hours per day in contact with the product over its full service life.

The industry has nevertheless seen real innovation in recent years, particularly in mesh constructions, foam-free designs in high-tier chairs, and take-back programmes. The pace of change remains slow, but the direction is set. Three external developments are likely to accelerate the transition.

The first is regulatory pressure. The EU Ecodesign for Sustainable Products Regulation, the upcoming Digital Product Passport requirements for furniture, and the gradual expansion of REACH restrictions all create a regulatory environment in which substance-of-concern questions cannot be deferred indefinitely. Several interviewees were explicit that regulation, rather than voluntary initiative, is the dominant driver of material change in the industry. The MAPSSS tool aligns with this direction because it surfaces the questions that regulation is increasingly asking, and at the design phase rather than after product launch.

The second is advances in data infrastructure. The Digital Product Passport, if implemented at component level and including additives, would resolve the most significant practical barrier to applying Step 0. Better integration with existing chemical hazard databases such as PubChem, ECHA, and GreenScreen would reduce the time investment required for Step 1. Several interviewees raised the possibility of AI-assisted components that could help designers navigate the methodology without requiring deep toxicological expertise, a plausible direction for future development.

The third is advances in manufacturing technology. SLS at production scale, foam-free construction approaches, and the wider availability of inherently flame-resistant materials would all reduce the cost of departing from standardised architectures. None of these is mature in the chair industry yet, but each is moving in a direction that makes alternative product architectures more viable.

Recommendations for NPK Design

The methodology has clear potential value for NPK Design and its project portfolio.

The tool is industry-agnostic in its underlying logic, meaning it can be applied across the wide range of product categories that NPK works in. The agency's existing project relationships are a particular advantage: many NPK projects have been developed in-house over extended periods, meaning material composition data, manufacturing details, and supplier relationships are already accessible internally. This significantly lowers the barrier to applying Step 0.

The feedback gathered from NPK during the project raised concerns that were independently echoed by several other design agency experts across the twenty interviews, which strengthens their significance.

The most consistent point was that selling sustainability work to clients is already difficult, and selling a methodology that

requires significant time investment per material is harder still. Several agency designers and the NPK team both noted that clients are generally not willing to pay for work that diverges too far from core design and manufacturing tasks, and that sustainability analysis tends to be treated as overhead rather than as a billable deliverable. For the tool to be commercially viable within a design agency, it would need to be considerably faster to apply than it currently is.

A related point raised by both NPK and several other interviewees was the difficulty of obtaining reliable material information, whether approaching suppliers as an external designer or attempting to access it within a client organisation. Even within companies, internal knowledge of product composition is often fragmented, and suppliers are rarely willing to disclose formulation details. This is consistent with what Expert 19 described regarding the opacity of large material compounders and what Expert 3 described regarding the inability to act on chemical analysis results even when they exist. The transparency problem is structural across the value chain, and any tool that depends on this information needs to account for the conditions under which it will be sought.

Both NPK and other interviewees also raised the need for the tool to include validation points within the process rather than only at the end. The gaps between the steps were identified as places where the method currently leaves the designer without guidance on whether what they have done is correct. This validation gap was independently identified by NPK and by several other experts as the single most significant practical limitation of the methodology, and it is developed further in Section 8.7.

For NPK specifically, applying the tool offers a way to deliver more complete design solutions: not only solving the original brief, but surfacing the next-life implications of the materials used and identifying where small upstream decisions can prevent downstream problems. The growing use of sustainability point systems in Dutch public procurement, where more sustainably designed products gain a competitive advantage in tenders, creates a commercial incentive that could support positioning the methodology as a differentiating service offering. The thesis case study illustrates how this can work in practice, and similar applications would be feasible across other product categories in the portfolio.

8.7 Recommendations for the SCbD methodology and MAPSSS tool

The case study and the expert feedback together point to a set of concrete recommendations for the further development of the SCbD methodology and MAPSSS tool. These are organised around the four steps of the methodology and the cross-cutting issue of validation.

Improve data accessibility for Step 0.

The most significant practical barrier to applying Step 0 is the absence of a structured, accessible database that links material composition to specific components.

The Declare database provides ingredient-level transparency but not at the component level, and company bill of materials data is rarely accessible to external designers.

The Digital Product Passport, as it is implemented under the EU Ecodesign for Sustainable Products Regulation, has the potential to resolve this if it is designed to include additive-level detail and component-level material linkage.

The SCbD research project should engage with the development of the DPP standard for furniture to ensure it serves the data needs of Step 0. In the interim, a curated library of typical material compositions for common product categories, structured at the component level and including commonly used additives, would substantially reduce the time investment required to complete Step 0 reliably.

Reduce the chemistry barrier in Step 1.

The distinction between Reduce and Control was identified both in this case study and in the NPK feedback as more porous than the framework's hierarchy suggests.

The strategy definitions are currently broad enough to be misinterpreted, which risks producing concepts that conflate the two approaches or that apply a lower-priority strategy where a higher one was feasible.

Clearer worked examples, ideally drawn from real design projects, would help designers distinguish the strategies in practice. The inclusion of a decision tree or structured prompt set that guides the designer from the hotspot findings in Step 1 to the most appropriate strategy category in Step 2 would also improve the consistency of strategy selection across different users and project contexts.

Address the validation gap across all steps.

The single most consistently raised limitation across this case study and the expert feedback is the absence of built-in validation mechanisms across the methodology.

The lifecycle map can be validated against industry expertise, but there is no structured way to verify the chemistry-level reasoning in Step 1, no check on whether the strategy selection in Step 2 follows logically from the hotspot findings, and no mechanism to confirm that the comparative assessment in Step 3 is correctly structured.

Three forms of validation are recommended.

Peer validation, in which a second designer or chemist reviews the assessment at defined checkpoints between steps, is the form most easily added to current practice and requires only a structured review protocol.

Automated validation, in which integrated chemistry databases and exposure scenario libraries flag inconsistencies or omissions as the designer works, would scale further and is a natural companion to the database improvements recommended above.

Empirical validation, in which design decisions made through the methodology are tested against measured outcomes in produced and deployed products, is the most powerful form but the slowest to operationalise.

Together these three forms would address the feedback from NPK and other experts that the methodology currently asks designers to trust their own judgement in areas where they have limited expertise and no external check.

Improve usability and integration into design workflows.

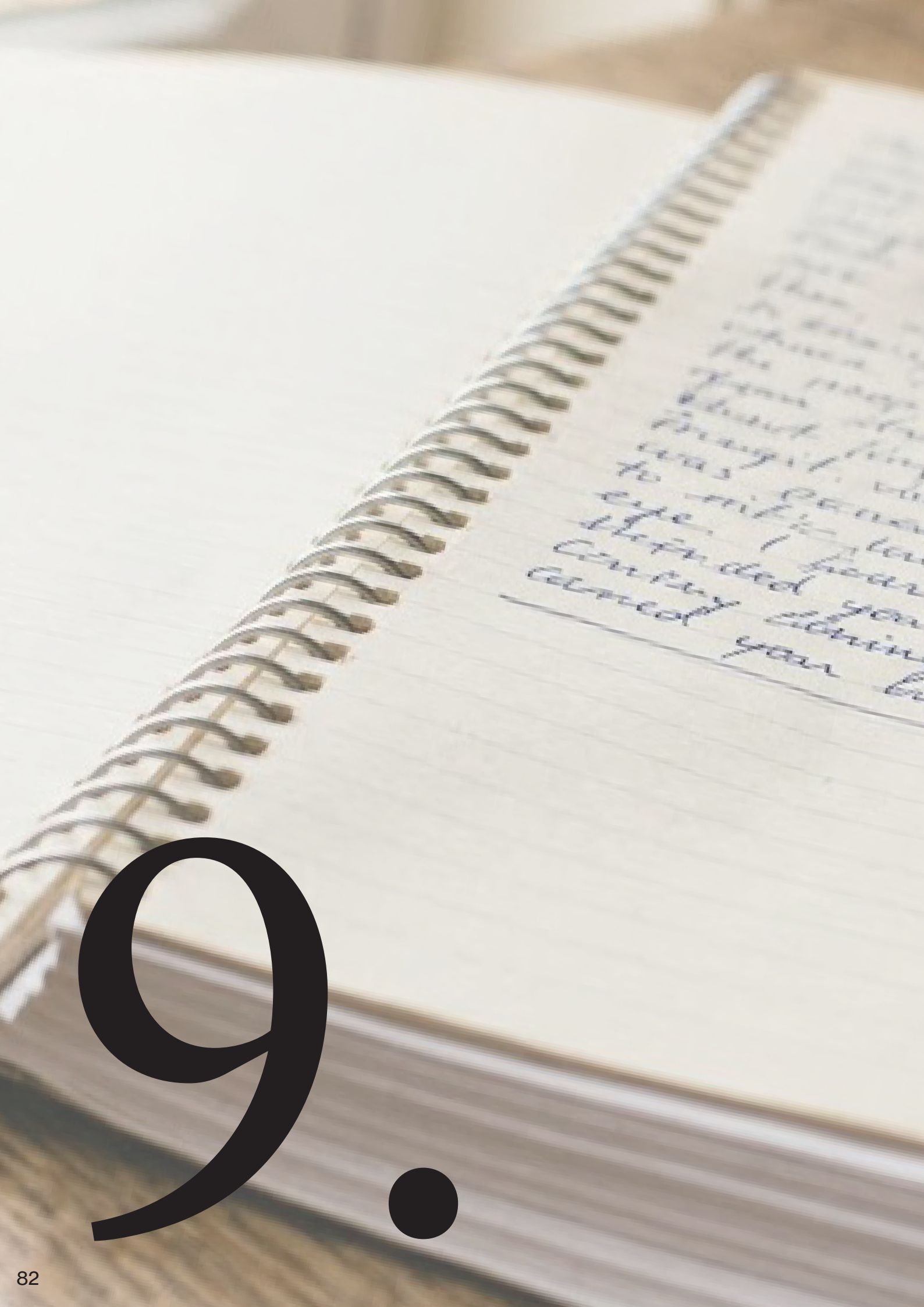
Several interviewees, including the NPK team and multiple agency designers, raised the need for the tool to be faster and more user-friendly if it is to be commercially viable in studio practice.

The current format, in which the Miro lifecycle map and the Excel hotspot calculator operate as separate tools requiring manual data transfer, creates friction that slows the process and introduces transcription errors.

A more integrated digital tool, in which the lifecycle map and the scoring calculator are linked and update in real time, would reduce this friction.

The double diamond framing used in the SCbD explanation pages was noted as a useful context for positioning the methodology within a familiar design process structure, and this framing could be developed further to make the relationships between the steps and the rest of a design project more explicit.

The methodology would also benefit from positioning guidance that helps design studios frame substance-of-concern analysis as a value-added service offering to clients, particularly in the context of growing regulatory pressure and public procurement incentives, rather than as an overhead cost that competes with billable design hours.



[Handwritten text in cursive, mostly illegible due to blur]

9.

Chapter 9

Conclusion

9.1 Conclusion	84
9.2 Limitations	84
9.3 Future work	85
9.4 Personal reflection	85

9.1 Conclusion

This thesis applied the Safe and Circular by Design methodology and the MAPSSS tool to a real product in a real industry context, demonstrating that the methodology does what it is designed to do: it makes substance-of-concern questions visible at the design phase, structures the analysis of hazard and exposure across the full lifecycle, and produces design directions that address the identified hotspots in materially different ways

The hotspot assessment confirmed TCPP in polyurethane foam as the priority substance of concern in the B2B office task chair, with the use phase carrying the highest concern and end of life the second highest. The physical teardown confirmed that the current product architecture reinforces these concerns: foam is bonded or stapled to structural components in ways that make separation at end of life practically unachievable, and the chemical content of the product is not communicated to anyone handling it after it leaves the manufacturer.

The three design concepts demonstrate that the choice of SCbD strategy shapes not only the product but the user interaction and the surrounding service system. No concept removes all hazards across the lifecycle. Each shifts the burden to a different phase and depends on conditions outside the product to deliver its intended reduction. Read together, the three concepts suggest that the most durable SCbD response combines product-level design with value-chain conditions that match the strategy chosen.

The methodology faces real adoption barriers in design practice, particularly the chemistry knowledge required in Steps 0 and 1, the absence of accessible component-level material data, and the lack of built-in validation mechanisms. These barriers define the conditions under which the methodology can and cannot currently be applied, and point directly to where further development is most needed. The SCbD methodology, applied here to a single product and a single substance, offers a transferable framework for addressing substance-of-concern problems wherever they arise, with its value lying in making tradeoffs visible early, at the design phase where they are still possible to address.

9.2 Limitations

Several limitations affected the application of the methodology in this project. The MAPSSS tool is still in an early stage of development, and applying it for the first time in a real industry context meant working without established precedents or reference applications to draw on. This made the learning curve steeper than it would be for a more mature method, and contributed to errors during the early stages of the analysis that required revisiting later.

The most significant practical limitation was access to reliable material composition data. A substantial portion of the research phase was spent identifying data sources of sufficient quality to complete Step 0. The Declare Living Future database and the BIFMA e3 certification were identified through expert referral rather than through the methodology itself, and much of the most relevant technical literature on chemical safety and toxicology sits behind paywalls. The quality of the analysis in Steps 0 and 1 is directly dependent on the quality of the input data, and the workarounds required here, particularly the construction of a median reference chair from aggregated database entries, introduce uncertainties that propagate through the rest of the assessment.

Access to expert knowledge was a further limiting factor. The twenty interviews conducted for this project provided a strong foundation for the industry analysis, but access to this breadth of expertise was partly a function of the research context. Industry professionals may be more willing to engage with a student researcher than with a competitor or commercial consultant, and a designer applying the methodology in practice may find it harder to access the same depth of specialist knowledge. Similarly, the project was conducted individually, which increased the likelihood of errors in the chemical assessment and limited the possibility of internal peer review during the analysis.

Finally, the scope of this thesis was limited to a single substance of concern, TCPP, across a single product category. The office chair contains many other substances that warranted further investigation, and the methodology has not been tested here against the full complexity of a multi-substance assessment. These limitations do not undermine the findings of the thesis, but they define the boundaries within which they should be read.

9.3 Future work

Several directions follow naturally from this thesis.

The most immediate is the further development of the three design concepts. The concepts produced here establish proportions, material logic, and service system direction, but each would need to progress through detailed engineering, physical prototyping, and real-world testing before its SCbD performance could be verified empirically. Producing a physical prototype of one or more concepts and measuring actual TCPP emission levels against the reference chair would replace the qualitative-relative assessment in Chapter 7 with measured outcomes, significantly strengthening the evidence base for the strategy comparison.

The methodology and tool would also benefit from further development. The most needed addition is validation mechanisms between the steps, as identified in Chapter 8. A structured review protocol between Steps 0 and 1, and between Steps 1 and 2, would allow designers to verify the quality of their assessment before carrying errors forward. Alongside this, a more integrated digital tool that links the Miro lifecycle map and the Excel hotspot calculator in real time would reduce the friction and transcription errors that currently slow the process.

Reducing the time investment required to apply the methodology is a further priority, particularly for adoption in design studio practice. Two directions are promising. A curated component-level material database, structured around common product categories and including typical additives and processing aids, would substantially reduce the data-gathering burden in Step 0. An AI-assisted interface that helps designers identify relevant substances, locate hazard data, and populate exposure scenarios without requiring deep toxicological expertise would lower the barrier in Step 1. Both developments would make the methodology faster and more accessible to practitioners working without specialist chemical support.

Finally, extending the methodology to other product categories and to multi-substance assessments within the same product would broaden the evidence base for the SCbD approach. The office chair contains many substances beyond TCPP that warranted investigation but fell outside the scope of this thesis. Applying the full methodology to a second substance within the same product, or to a comparable product in a different category, would test how well the method transfers and identify where further calibration is needed.

9.4 Personal reflection

This project was more demanding than anticipated, for reasons that turned out to be directly relevant to the thesis itself.

The topic of substances of concern sits at the intersection of chemistry, toxicology, product design, and regulation, and properly understanding it took considerably longer than expected.

The MAPSSS tool, being new and without established precedents in real design practice, offered little guidance on what correct application looked like. Several times the analysis moved in the wrong direction before being corrected, which cost time and created pressure on the rest of the project. Getting lost and finding the way back is itself a finding: if a designer with an engineering background and dedicated research time struggles to navigate the methodology, the barrier for a practitioner working under commercial time pressure is considerably higher.

A pattern that emerged repeatedly, and that the expert interviews confirmed, was the pull of conventional design thinking. Even with the SCbD framework as an explicit organising principle, the ideation phase repeatedly gravitated toward questions of aesthetics, form, and manufacturing rather than toward the substance-of-concern problem the strategy was meant to address. Recognising this in oneself, and then observing the same pattern in experienced designers during interviews, made clear that this is not a personal failing but a structural one. The way designers are trained and the way design briefs are written make it difficult to keep chemical safety at the centre of the work. The SCbD methodology needs to be fast and compelling enough to resist this pull, not merely correct in principle.

What made the project possible was the generosity of the people who participated in it. The twenty experts who gave their time, answered follow-up questions, and shared knowledge they had no obligation to share brought the industry to life in ways that no database could. Their willingness to engage, and in several cases to actively encourage the project, gave this thesis a connection to real industry practice that a purely literature-based study would not have had.

The project has been an education in materials, substances, the office chair industry, and the gap between how design is taught and how it needs to work if chemical safety is to become a genuine design concern rather than a compliance afterthought.

References

- Allchairparts. (2022, November 7). Different materials of plastic office chairs — factory tells. <https://allchairparts.com/the-different-materials-of-plastic-office-chairs/>
- Apel, C., Kümmerer, K., Sudheshwar, A., Nowack, B., Som, C., Colin, C., Walter, L., Breukelaar, J., Meeus, M., Ildefonso, B., Petrovykh, D., Elyahmadi, C., Huttunen-Saarivirta, E., Dierckx, A., Devic, A. C., Valsami-Jones, E., Brennan, M., Rocca, C., Scheper, J., Strömberg, E., & Soeteman-Hernández, L. G. (2024). Safe-and-sustainable-by-design: State of the art approaches and lessons learned from value chain perspectives. *Current Opinion in Green and Sustainable Chemistry*, 45, 100876. <https://doi.org/10.1016/j.cogsc.2023.100876>
- Awan, U. (2024). Digital product passport for sustainable and circular supply chain management: A structured review of use cases. *International Journal of Logistics Research and Applications*. <https://doi.org/10.1080/13675567.2024.2374256>
- Baas, L., Metselaar, S., & Klaassen, P. (2022). Circles of care for safety: A care ethics approach to safe-by-design. *NanoEthics*, 16(2), 167–179.
- Beekman, M., Bakker, J. C., Bodar, C. W. M., van Leeuwen, L. C., Waaijers-van der Loop, S. L., Zijp, M. C., & Verhoeven, J. K. (2020). Coping with substances of concern in a circular economy (RIVM Letter Report 2020-0049). National Institute for Public Health and the Environment (RIVM). <https://www.rivm.nl/bibliotheek/rapporten/2020-0049.pdf>
- Bester, K. (2004). Retention characteristics and balance assessment for two organophosphorus flame retardants in a typical German sewage treatment plant. *Science of the Total Environment*, 327(1–3), 277–286. <https://doi.org/10.1016/j.scitotenv.2004.01.006>
- Bettoni, A., Giorgi, S., & Lavagna, M. (2024). Enhancing circular economy practices in the furniture industry through circular design strategies. *Sustainability*, 16(15), 6544. <https://doi.org/10.3390/su16156544>
- BEUC — The European Consumer Organisation. (2023). Ubiquitous but preventable: Harmful chemicals in everyday consumer products. <https://europa.eu/eurobarometer/surveys/detail/2156>
- BIFMA. (2024). BIFMA e3-2024: Furniture sustainability standard. Business and Institutional Furniture Manufacturers Association.
- Bolaños Arriola, J., Aghaeian, S., Bakker, C., & Balkenende, R. (2025). Strategies for dealing with substances of concern in product design — a review of five cases. *Circular Economy and Sustainability*, 5(2), 1369–1388.
- Bolaños Arriola, J., Subramanian, V., Bakker, C. A., & Balkenende, R. (2023). Safe and circular design: A design method for dealing with substances of concern in products. In K. Niinimäki & K. Cura (Eds.), *Proceedings of the 5th PLATE Conference* (pp. 60–70). Aalto University.
- Brandolini, A. J., & Hills, D. D. (2000). *NMR spectra of polymers and polymer additives*. Marcel Dekker.
- Bumgardner, M. S., & Nicholls, D. L. (2020). Sustainable practices in furniture design: A literature study on customization, biomimicry, competitiveness and product communication. *Forests*, 11(12), 1277. <https://doi.org/10.3390/f11121277>
- Buro Seating. (n.d.). Ergonomic office chair parts explained: Castors, bases and more. <https://buroseating.com/ergonomic-office-chair-parts-explained-castors-bases-and-more>
- Costa, F., Prendeville, S., Beverley, K., Teso, G., & Brooker, C. (2015). Sustainable product-service systems for an office furniture manufacturer: How insights from a pilot study can inform PSS design. *Procedia CIRP*, 30, 66–71.
- Cradle to Cradle Products Innovation Institute. (2021). *Cradle to Cradle Certified® Product Standard (Version 4.0)*. <https://www.c2ccertified.org/>
- Czerczak, S. (2025). Occupational exposure to volatile organic compounds in polyurethane foam production — concentration, variability and health risk assessment. *Molecules*, 31(1), 145. <https://doi.org/10.3390/molecules31010145>
- Davis, E. (2021). Chemical exposures from upholstered furniture with various flame retardant technologies. *Indoor Air*, 31(5). <https://doi.org/10.1111/ina.12805>
- Deloitte Global. (2024). The Deloitte Global 2024 Gen Z and Millennial Survey. <https://www.deloitte.com/global/en/issues/work/content/genz-millennialsurvey.html>
- Dreher, M., Wiesemann, N., Schramm, E., Raps, D., Pfaff, A., Heuberger, M., & Mülhaupt, R. (2024). The emission and physicochemical properties of airborne microplastics and nanoplastics generated during the mechanical recycling of plastic via shredding. *Scientific Reports*, 14, 24632. <https://doi.org/10.1038/s41598-024-73775-0>

- Ellen MacArthur Foundation. (n.d.). Design and the circular economy. <https://www.ellenmacarthurfoundation.org/articles/design-and-the-circular-economy>
- Estill, C. F., Slone, J., Mayer, A., Chen, I.-C., & La Guardia, M. J. (2020). Worker exposure to flame retardants in manufacturing, construction and service industries. *Environment International*, 135, 105349. <https://doi.org/10.1016/j.envint.2019.105349>
- European Chemicals Agency. (2009). European Union risk assessment report: Tris(2-chloroethyl) phosphate (TCEP). <https://echa.europa.eu/documents/10162/2663989d-1795-44a1-8f50-153a81133258>
- European Chemicals Agency. (2018). Screening report: An assessment of whether the use of TCEP, TCPP and TDCP in articles should be restricted. https://echa.europa.eu/documents/10162/13641/screening_report_tcep_tcpp_tdcp_en.pdf
- European Chemicals Agency. (2023). Microplastics restriction (Commission Regulation (EU) 2023/2055). <https://echa.europa.eu/hot-topics/microplastics>
- European Commission. (2003, September 22). Indoor air pollution: New EU research reveals higher risks than previously thought (IP/03/1278) [Press release]. https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_03_1278/IP_03_1278_EN.pdf
- European Commission. (n.d.). Revision of EU Ecolabel criteria for furniture products: Final technical report. https://ec.europa.eu/environment/ecolabel/documents/technical_report_furniture.pdf
- European Parliament and Council. (2024). *Regulation (EU) 2024/1781 of the European Parliament and of the Council establishing a framework for the setting of ecodesign requirements for sustainable products (ESPR)*. <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024R1781>
- FEMB. (n.d.). FEMB Level — Furniture Environmental Marketing & Benchmarking. Furniture EPD Management Group. <https://www.femb.info/>
- Forrest, A., Hilton, M., Ballinger, A., & Whittaker, D. (2017). Circular economy opportunities in the furniture sector. European Environment Bureau. <https://eeb.org/wp-content/uploads/2019/05/Report-on-the-Circular-Economy-in-the-Furniture-Sector.pdf>
- Ghaffarianhoseini, A., AlWaer, H., Omrany, H., Ghaffarianhoseini, A., Alalouch, C., Clements-Croome, D., & Tookey, J. (2018). Sick building syndrome: Are we doing enough? *Architectural Science Review*, 61(3), 99–121. <https://doi.org/10.1080/00038628.2018.1461060>
- Glass Fibre Europe. (2021). Continuous filament glass fibre and human health [Report]. https://glassfibreeurope.eu/wp-content/uploads/2022/10/GFE_leaflet-Human-Health-November2021.pdf
- Governa, M., Amati, M., Valentino, M., Visonà, I., Fubini, B., Botta, G. C., & Mollo, F. (2003). Changes induced by exposure of the human lung to glass fiber-reinforced plastic. *Environmental Health Perspectives*, 111(16), 1927–1933. <https://doi.org/10.1289/ehp.6555>
- Government of Canada. (2021). Updated draft screening assessment: TCPP and TDCPP. <https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/updated-draft-screening-assessment-organic-flame-retardants-substance-grouping-tcptdcp.html>
- Government of the Netherlands. (2024). Research: Ecodesign for furniture. Ministry of Infrastructure and Water Management. <https://www.government.nl/binaries/government/documenten/reports/2024/01/31/research-ecodesignfor-furniture/Research%2BEcodesign%2Bfor%2Bfurniture.pdf>
- GS-LCIE. (2012). Certification rules GS mark by LCIE (8th ed.) [Report]. <https://www.lcie.fr>
- Guillaume, E. (2020). An overview and experimental analysis of furniture fire safety regulations in Europe. *Fire and Materials*. <https://doi.org/10.1002/fam.2826>
- Horodytska, O., Cabanes, A., & Fullana, A. (2020). Non-intentionally added substances (NIAS) in recycled plastics. *Chemosphere*, 251, 126373. <https://doi.org/10.1016/j.chemosphere.2020.126373>
- International Living Future Institute. (2023). Declare product database. <https://declare.living-future.org/> Lahl, U., & Zeschmar-Lahl, B. (2024). Material recycling of plastics — a challenge for sustainability. *Sustainability*, 16(15), 6630. <https://doi.org/10.3390/su16156630>

- Ma, Y., Stubbings, W. A., Abdallah, M. A., Cline-Cole, R., & Harrad, S. (2022). Formal waste treatment facilities as a source of halogenated flame retardants and organophosphate esters to the environment: A critical review with particular focus on outdoor air and soil. *Science of the Total Environment*, 806, 150494. <https://doi.org/10.1016/j.scitotenv.2021.150494>
- Ma, Z., Chen, H., Zhu, L., & Huang, Y. (2021). Spatiotemporal distribution and analysis of organophosphate flame retardants in the environmental systems: A review. *Molecules*, 27(2), 573. <https://doi.org/10.3390/molecules27020573>
- Maeder, M., & Fröhling, M. (2024). Conceptualizing circular economy policy instruments: The case of recycled content standards. *Sustainable Production and Consumption*, 52, 333–346. <https://doi.org/10.1016/j.spc.2024.11.009>
- Market Reports World. (n.d.). Polyamide or nylon waste recycling market size, growth | Report [2034]. <https://www.marketreportsworld.com/market-reports/polyamide-or-nylon-waste-recycling-market14722588>
- Monclús, L., Arp, H. P. H., Groh, K. J., Faltynkova, A., Løseth, M. E., Muncke, J., Wang, Z., Wolf, R., Zimmermann, L., & Wagner, M. (2025). Mapping the chemical complexity of plastics. *Nature*, 643, 349–359. <https://doi.org/10.1038/s41586-025-09184-8>
- National Business Furniture. (n.d.). 16 types of office chairs: A guide to every seat, style, and solution. <https://www.nationalbusinessfurniture.com/blog/types-of-office-chairs>
- NEN. (2018). *NEN-EN 1335-2:2018 en — Office furniture — Office work chair — Part 2: Safety requirements*. Nederlands Normalisatie-instituut.
- NEN. (2020). *NEN-EN 1335-1:2020 en — Office furniture — Office work chair — Part 1: Dimensions — Determination of dimensions*. Nederlands Normalisatie-instituut.
- Periyasamy, A. P., & Tehrani-Bagha, A. (2022). A review on microplastic emission from textile materials and its reduction techniques. *Polymer Degradation and Stability*, 199, 109901. <https://doi.org/10.1016/j.polymdegradstab.2022.109901>
- REACH Regulation. (n.d.). Environment. European Commission. https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en
- Salthammer, T., Mentese, S., & Marutzky, R. (2010). Formaldehyde in the indoor environment. *Chemical Reviews*, 110(4), 2536–2572.
- Schlittenbauer, L., Waldmann, T., Wack, M., & Heußner, C. (2019). Emissions of VOCs from polymer-based consumer products: From emission data of real samples to the assessment of inhalation exposure. *Frontiers in Public Health*, 7, 202. <https://doi.org/10.3389/fpubh.2019.00202>
- Slunge, D., Andersson, I., & Sterner, T. (2022). REACH authorisation and the substitution of hazardous chemicals: The case of trichloroethylene. *Journal of Cleaner Production*, 364, 132637. <https://doi.org/10.1016/j.jclepro.2022.132637>
- Strong, A. B. (2006). *Plastics: Materials and processing*. Pearson Prentice Hall.
- Substances of Concern. (2018, November 28). Board for the Authorisation of Plant Protection Products and Biocides. <https://english.ctgb.nl/biocidal-products/application-active-substance/substances-of-concern>
- ToxFree LIFE for All. (2025). *The sound of contamination: All analysed headphones on the Central European market found to contain hormone-disrupting chemicals*. Arnika. <https://arnika.org/en/publications/thesound-of-contamination>
- UL LLC. (2013). GREENGUARD certification criteria: CAS numbers and maximum allowable predicted concentrations [Technical document]. UL Solutions. https://www.ul.com/sites/g/files/qbfbpbp306/files/2019-05/GG_VOC_tables.pdf
- Ulker, O. C., Ulker, O., & Hizirolu, S. (2021). Volatile organic compounds (VOCs) emitted from coated furniture units. *Coatings*, 11(7), 806. <https://doi.org/10.3390/coatings11070806>
- US Environmental Protection Agency. (2020). Chemicals and production of spray polyurethane foam: Why it matters. <https://archive.epa.gov/epa/saferchoice/chemicals-and-production-spray-polyurethane-foamwhy-it-matters.html>
- Van der Veen, I., & de Boer, J. (2012). Phosphorus flame retardants: Properties, production, environmental occurrence, toxicity and analysis. *Chemosphere*, 88(10), 1119–1153. <https://doi.org/10.1016/j.chemosphere.2012.03.067>
- Vanegas, P. (2022). Challenges to the circular economy: Recovering wastes from simple versus complex products. *Sustainability*, 14(5), 2576. <https://doi.org/10.3390/su14052576>
- Wiesinger, H., Shalin, A., Huang, X., Siegrist, A., Plinke, N., Hellweg, S., & Wang, Z. (2024). LitChemPlast: An open database of chemicals measured in plastics. *Environmental Science and Technology Letters*, 11(11), 1147–1160.
- Wiesinger, H., Wang, Z., & Hellweg, S. (2021). Deep dive into plastic monomers, additives, and processing aids. *Environmental Science and Technology*, 55(13), 9339–9351.
- Wormuth, M., Scheringer, M., Vollenweider, M., & Hungerbühler, K. (2006). What are the sources of exposure to eight frequently used phthalic acid esters in Europeans? *Risk Analysis*, 26(3), 803–824.

Appendix

Appendix A. Median chair

Appendix A.1 Chairs from the Declare Diving futures database.

Chair 1:

Component	Subcomponent	Material name	CAS number	Material subcategory
Base & Casters	5-star base	Nylon 6	25038-54-4	Engineering thermoplastic
Base & Casters	5-star base filler	Glass, oxide, chemicals	65997-17-3	Mineral reinforcement
Base & Casters	Base pigment	Carbon black	1333-86-4	Pigment
Base & Casters	Caster wheels	Ethene, polymer with 1-propene	9010-79-1	Polyolefin copolymer
Base & Casters	Caster wheels	Polyethylene	9002-88-4	Polyolefin
Base & Casters	Caster hub	Poly(oxymethylene)	9002-81-7	Engineering thermoplastic
Base & Casters	Caster stem	Carbon steel	12597-69-2	Carbon steel
Base & Casters	Caster stem alloying	Manganese	7439-96-5	Alloying element
Base & Casters	Caster stem coating	Zinc	7440-66-6	Corrosion-protection metal
Gas Lift	Outer cylinder	SAE 1008 steel	UNS G10080	Low-carbon steel
Gas Lift	Inner piston	SAE 1022 steel	UNS G10220	Medium-carbon steel
Gas Lift	Inner piston	SAE 1035 steel	UNS G10350	Medium-carbon steel
Gas Lift	Inner piston	SAE 1050 steel	UNS G10500	Medium-high carbon steel
Gas Lift	Inner piston	AISI 1215 steel	UNS G12150	Free-machining steel
Gas Lift	Structural metal	Iron	7439-89-6	Base metal
Gas Lift	Alloying element	Chromium	7440-47-3	Alloying element
Gas Lift	Alloying element	Nickel (metallic)	7440-02-0	Alloying element
Gas Lift	Alloying element	Silicon	7440-21-3	Alloying / deoxidizer
Gas Lift	Solid lubricant	Graphite	7440-44-0	Solid lubricant
Seat Structure	Seat pan	Polypropylene	9003-07-0	Commodity thermoplastic
Seat Structure	Seat pan filler	Kieselguhr (diatomaceous earth)	68855-54-9	Mineral filler
Seat Structure	Seat pan filler	Amorphous precipitated silica	112926-00-8	Mineral filler
Seat Structure	Seat pan stabilizer	Phenolic phosphite antioxidant	31570-04-4	Polymer stabilizer
Seat Structure	Seat support bracket	Carbon steel	12597-69-2	Carbon steel
Seat Cushion	Foam core	Polyurethane foams	9009-54-5	Polymer foam
Seat Cushion	Foam additive	Sulfur (elemental)	7704-34-9	Processing additive
Seat Cushion	Foam additive	Phosphorus	7723-14-0	Flame-retardant element
Seat Cushion	Foam additive	Fatty acids, sodium salts	67701-11-5	Surfactant / processing aid
Seat Cushion	Foam additive	Zinc	7440-66-6	Catalyst / additive
Backrest Structure	Back frame	Aluminum alloy A380	No CAS	Cast aluminum alloy
Backrest Structure	Structural polymer	Polyamide 66	32131-17-2	Engineering thermoplastic
Backrest Structure	Back pivot bushings	Poly(oxymethylene)	9002-81-7	Engineering thermoplastic
Backrest Cushion / Mesh	Textile	Polyethylene terephthalate (PET)	25038-59-9	Polyester fiber
Backrest Cushion / Mesh	Elastomer	Rubber, synthetic, acrylic	67254-76-6	Acrylic elastomer
Armrests	Arm pad foam	Polyurethane foams	9009-54-5	Polymer foam
Armrests	Arm pad skin	Saturated polyester resin	61926-16-7	Thermoset resin
Armrests	Arm structure	Carbon steel	12597-69-2	Carbon steel
Mechanisms	Gear / cam	POM copolymer (trioxane polymer)	24969-26-4	Engineering thermoplastic
Mechanisms	Seal / elastomer	Benzenamine reaction products	68411-46-1	Rubber antioxidant
Coatings & Adhesives	Structural adhesive	Epoxy resin (DGEBA)	25036-25-3	Epoxy thermoset
Coatings & Adhesives	Plasticizer	Hexanedioic acid ester	141-17-3	Plasticizer
Coatings & Adhesives	Solvent	2-Butoxyethanol	111-76-2	Glycol ether solvent
Lubricants	Hydraulic oil	Fatty acid pentaerythritol esters	91050-82-7	Synthetic lubricant
Lubricants	Oil additive	Silicic acid, sodium salt	1344-09-8	Anti-caking additive
Manufacturing Residues	Process chemicals	Steel manufacture, chemicals	65997-19-5	Process mixture
Miscellaneous	Proprietary ingredients	Proprietary / undisclosed	N/A	Confidential mixture

Chair 2:

Component	Subcomponent	Material name	CAS number	Material subcategory
Base & Casters	5-star base	Nylon 6	25038-54-4	Engineering thermoplastic
Base & Casters	5-star base filler	Glass, oxide, chemicals	65997-17-3	Mineral reinforcement
Base & Casters	Base structure	Carbon steel	12597-69-2	Carbon steel
Base & Casters	Base frame (alt.)	Cast aluminum alloy A380	No CAS	Cast aluminum alloy
Base & Casters	Base coating / pigment	Carbon black	1333-86-4	Pigment
Casters	Wheel body	Polypropylene	9003-07-0	Commodity thermoplastic
Casters	Wheel body	Ethene, polymer with 1-propene	9010-79-1	Polyolefin copolymer
Casters	Wheel tread	Thermoplastic elastomer (TPE)	308079-71-2	Thermoplastic elastomer
Casters	Wheel hub	Poly(oxymethylene)	24969-26-4	Engineering thermoplastic
Seat Structure	Seat pan	Polypropylene	9003-07-0	Commodity thermoplastic
Seat Structure	Seat pan filler	Talc	14807-96-6	Mineral filler
Seat Structure	Seat pan filler	Calcium carbonate	471-34-1	Mineral filler
Seat Structure	Seat pan filler	Glass, oxide, chemicals	65997-17-3	Mineral reinforcement
Seat Structure	Seat pan pigment	Carbon black	1333-86-4	Pigment
Seat Structure	Structural bracket	Carbon steel	12597-69-2	Carbon steel
Seat Cushion	Foam core	Polyurethane foams	9009-54-5	Polymer foam
Seat Cushion	Foam component	Polyester polyol	9078-71-1	Polyester polyol
Seat Cushion	Foam component	Polyurethane prepolymer	9018-04-6	Polyurethane prepolymer
Seat Cushion	Foam additive	Antioxidant (benzenepropanoic acid derivative)	6683-19-8	Antioxidant
Backrest Structure	Back frame	Polyamide 66	32131-17-2	Engineering thermoplastic
Backrest Structure	Back pivot bushings	Poly(oxymethylene)	24969-26-4	Engineering thermoplastic
Backrest Structure	Back frame (alt.)	Aluminum alloy ASTM A401	No CAS	Aluminum alloy
Backrest Cushion / Mesh	Textile	Polyethylene terephthalate (PET)	25038-59-9	Polyester fiber
Backrest Cushion / Mesh	Colorant	C.I. Pigment Yellow 119	68187-51-9	Organic pigment
Backrest Cushion / Mesh	Pigment	Titanium dioxide	13463-67-7	Inorganic pigment
Backrest Cushion / Mesh	Pigment	Diiron trioxide	1309-37-1	Inorganic pigment
Armrests	Arm pad foam	Polyurethane foams	9009-54-5	Polymer foam
Armrests	Arm pad skin	Saturated polyester resin	61926-16-7	Thermoset resin
Armrests	Arm pad elastomer	Thermoplastic elastomer (TPE)	308079-71-2	Thermoplastic elastomer
Mechanisms	Gear / cam	POM copolymer	24969-26-4	Engineering thermoplastic
Mechanisms	Sliding element	Polyamide polymer	25750-23-6	Engineering thermoplastic
Mechanisms	Bearing / wear surface	Rubber dust	9006-04-6	Elastomeric material
Hardware	Fasteners	Carbon steel	12597-69-2	Carbon steel
Hardware	Fastener coating	Zinc	7440-66-6	Corrosion-protection metal
Hardware	Surface treatment	Copper iodide (CuI)	7681-65-4	Inorganic salt
Coatings & Adhesives	Structural adhesive	Epoxy resin (DGEBA)	25036-25-3	Epoxy thermoset
Coatings & Adhesives	Process solvent	2-Butoxyethanol	111-76-2	Glycol ether solvent
Manufacturing / Processing	Process mixture	Steel manufacture, chemicals	65997-19-5	Process mixture
Miscellaneous	Proprietary ingredients	Proprietary / undisclosed	N/A	Confidential mixture

Chair 3:

Component	Subcomponent	Material name	CAS number	Material subcategory
Base & Casters	5-star base	SAE 1008 steel	UNS G10080	Low-carbon steel
Base & Casters	5-star base (alt.)	SAE 1010 steel	UNS G10100	Low-carbon steel
Base & Casters	5-star base (alt.)	C1065 steel	UNS G10650	High-carbon steel
Base & Casters	Base insert / reinforcement	Carbon steel	12597-69-2	Carbon steel
Base & Casters	Alloying element	Manganese	7439-96-5	Alloying element
Base & Casters	Alloying element	Chromium	7440-47-3	Alloying element
Base & Casters	Alloying element	Nickel (metallic)	7440-02-0	Alloying element
Base & Casters	Surface coating / pigment	Diiron trioxide	1309-37-1	Inorganic pigment
Casters	Wheel body	Polypropylene (1-propene homopolymer)	9003-07-0	Commodity thermoplastic
Casters	Wheel body	Ethene, polymer with 1-propene	9010-79-1	Polyolefin copolymer
Casters	Wheel tread	1-Butene, polymer with 1-propene	29160-13-2	Polyolefin elastomer
Casters	Wheel tread	1-Butene, polymer with ethene and 1-propene	25895-47-0	Polyolefin elastomer
Casters	Wheel tread (alt.)	1-Butene, polymer with ethene	25087-34-7	Polyolefin elastomer
Casters	Wheel hub	Poly(oxymethylene)	9002-81-7	Engineering thermoplastic
Casters	Solid lubricant	Graphite	7440-44-0	Solid lubricant
Gas Lift	Outer cylinder	SAE 1022 steel	UNS G10220	Medium-carbon steel
Gas Lift	Inner piston	SAE 1035 steel	UNS G10350	Medium-carbon steel
Gas Lift	Structural metal	Iron	7439-89-6	Base metal
Gas Lift	Piston coating	Zinc	7440-66-6	Corrosion-protection metal
Seat Structure	Seat pan	Nylon 6	25038-54-4	Engineering thermoplastic
Seat Structure	Seat pan filler	Glass, oxide, chemicals	65997-17-3	Mineral reinforcement
Seat Structure	Seat pan filler	Calcium carbonate	1317-65-3	Mineral filler
Seat Structure	Seat pan pigment	Carbon black	1333-86-4	Pigment
Seat Cushion	Foam core	Polyurethane foams	9009-54-5	Polymer foam
Seat Cushion	Foam precursor	Polyester polyol (terephthalate-based)	9078-71-1	Polyester polyol
Backrest Structure	Back frame	Polyamide 66	32131-17-2	Engineering thermoplastic
Backrest Structure	Back pivot bushings	POM copolymer (trioxane polymer)	24969-26-4	Engineering thermoplastic
Backrest Cushion / Mesh	Textile	Polyethylene terephthalate (PET)	25038-59-9	Polyester fiber
Armrests	Arm pad foam	Polyurethane foams	9009-54-5	Polymer foam
Armrests	Arm pad skin	Acrylonitrile-Butadiene-Styrene copolymer	9003-56-9	Engineering thermoplastic
Mechanisms	Sliding elements	Polyethylene	9002-88-4	Commodity thermoplastic
Mechanisms	Structural polymer	Polyamide polymer	25750-23-6	Engineering thermoplastic
Mechanisms	Damping element	Siloxanes and silicones, di-Me	63148-62-9	Silicone elastomer
Miscellaneous	Additive	Carbon black	1333-86-4	Pigment

Chair 4:

Main Component	Subcomponent	Material Name	CAS Number	Material Subcategory
Base	Star base	Carbon steel	12597-69-2	Ferrous metal
Base	Star base	Aluminum Alloy A380	No CAS RN	Aluminum alloy
Base	Star base	Zinc Alloy Zamak 5	No CAS RN	Zinc alloy
Base	Surface coating	Poly(bisphenol A-co-epichlorohydrin), glycidyl	25036-25-3	Thermoset epoxy resin
Base	Surface coating	Carbon black	1333-86-4	Pigment / filler
Base	Corrosion protection	Zinc	7440-66-6	Metallic coating
Gas lift	Cylinder housing	Carbon steel	12597-69-2	Ferrous metal
Gas lift	Internal parts	Diiron trioxide	1309-37-1	Inorganic oxide
Gas lift	Seals	Poly(oxymethylene)	9002-81-7	Engineering thermoplastic
Gas lift	Lubricant carrier	2-oxohexamethylenimine	105-60-2	Lactam / polymer precursor
Seat	Structural shell	Nylon 6	25038-54-4	Engineering thermoplastic
Seat	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Seat	Foam padding	Polyurethane foams	9009-54-5	Thermoset foam
Seat	Upholstery fabric	Polyethylene terephthalate	25038-59-9	Polyester thermoplastic
Seat	Upholstery resin	Saturated polyester resin	61926-16-7	Thermoset polyester
Seat	Additive	Amorphous precipitated silica	112926-00-8	Filler / rheology modifier
Backrest	Structural shell	Acrylonitrile-Butadiene-Styrene	9003-56-9	Engineering thermoplastic
Backrest	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Backrest	Foam padding	Polyurethane foams	9009-54-5	Thermoset foam
Backrest	Upholstery fabric	Polyethylene terephthalate	25038-59-9	Polyester thermoplastic
Armrests	Armrest frame	Nylon 6	25038-54-4	Engineering thermoplastic
Armrests	Armrest pads	Polyurethane foams	9009-54-5	Thermoset foam
Armrests	Armrest covers	1-propene, homopolymer	9003-07-0	Polyolefin thermoplastic
Mechanism	Tilt housing	Carbon steel	12597-69-2	Ferrous metal
Mechanism	Lever & knobs	Ethene, polymer with 1-propene	9010-79-1	Polyolefin copolymer
Mechanism	Internal gears	Poly[imino(1,6-dioxo-1,6-hexanediy)]imino-1,6-hexanediy]	32131-17-2	Engineering thermoplastic
Mechanism	Bushings	Poly(oxymethylene)	9002-81-7	Engineering thermoplastic
Fasteners	Screws & bolts	Carbon steel	12597-69-2	Ferrous metal
Fasteners	Surface coating	Zinc	7440-66-6	Metallic coating
Adhesives & binders	Foam bonding	1,3,5-Trioxane, polymer with 1,3-dioxolane	24969-26-4	Polycetal resin
Adhesives & binders	Composite bonding	1,3-Benzenedicarboxylic acid polymer with 1,4-benzenedicarboxylic acid and 1,6-hexanediamine	25750-23-6	Polyamide copolymer
Miscellaneous	Additives	Proprietary ingredients	N/A	Additives / stabilizers

Chair 5:

Component	Subcomponent	Material Name	CAS Number	Material Subcategory
Seat / Backrest	Structural shell	Nylon 6 (PA6)	25038-54-4	Engineering thermoplastic
Seat / Backrest	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Seat / Backrest	Plastic parts	Polypropylene (PP)	9010-79-1	Polyolefin thermoplastic
Seat / Backrest	Foam padding	Polyurethane foams	9009-54-5	Thermoset foam
Seat / Backrest	Upholstery fabric	Polyester	113669-97-9	Polyester thermoplastic
Seat / Backrest	Elastomer parts	Thermoplastic polyester elastomer (TPE-E)	308079-71-2	Thermoplastic elastomer
Base	Star base	Aluminium alloy EN-AC 46500	No CAS RN	Aluminum alloy
Base	Star base	Steel EN 10149	No CAS RN	Structural steel
Base	Star base	Steel EN S235JR	No CAS RN	Structural steel
Base	Star base	Steel EN DC01	No CAS RN	Cold-rolled steel
Base	Surface coating	Zinc	7440-66-6	Metallic coating
Mechanism	Tilt housing	Steel EN C45	No CAS RN	Carbon steel
Mechanism	Shafts & pins	Steel EN 1.0718	No CAS RN	Free-cutting steel
Mechanism	Shafts & pins	Steel EN 10277	No CAS RN	Bright steel
Mechanism	Plates	Steel EN 10111	No CAS RN	Hot-rolled steel
Mechanism	Springs	Steel EN 10270-I DH	No CAS RN	Spring steel
Mechanism	Springs	Steel EN 10270-1	No CAS RN	Spring steel
Mechanism	Gears / bushings	Poly(oxymethylene) (POM)	9002-81-7	Engineering thermoplastic
Mechanism	Gears	Polyamide 66 (PA66)	32131-17-2	Engineering thermoplastic
Gas lift	Cylinder	Steel EN C50	No CAS RN	Carbon steel
Gas lift	Cylinder	Steel EN C45E	No CAS RN	Carbon steel
Gas lift	Piston rod	Steel EN 1.0398	No CAS RN	Carbon steel
Gas lift	Springs	Steel EN 65Mn	No CAS RN	Manganese spring steel
Gas lift	Springs	Steel EN C75S	No CAS RN	High-carbon steel
Gas lift	Housing	Steel EN C25	No CAS RN	Carbon steel
Gas lift	Housing	Steel EN C17E2C	No CAS RN	Low-carbon steel
Gas lift	Formed parts	Steel EN 10263-4	No CAS RN	Cold-heading steel
Armrests	Structural core	Polypropylene (PP)	9010-79-1	Polyolefin thermoplastic
Armrests	Soft pads	Polyurethane foams	9009-54-5	Thermoset foam
Armrests	Surface finish	Thermoplastic polyester elastomer (TPE-E)	308079-71-2	Thermoplastic elastomer
Additives / Fillers	Plastic filler	Talc	14807-96-6	Mineral filler
Additives / Fillers	Plastic filler	Carbon black	1333-86-4	Pigment / filler
Additives / Fillers	Pigment	C.I. Solvent Black 7	8005-02-5	Dye / pigment
Additives / Fillers	Stabilizer	Phenol, 2,4-bis(1,1-dimethylethyl)-, phosphite (3:1)	31570-04-4	Antioxidant
Additives / Fillers	Stabilizer	Benzenepropanamide, N,N'-1,6-hexanediybis	23128-74-7	Polymer stabilizer
Additives / Fillers	Plasticizer	Phosphoric acid, triethyl ester	78-40-0	Phosphate ester
Additives / Fillers	Processing aid	Octadecanoic acid, calcium salt	1592-23-0	Lubricant / stabilizer
Adhesives	Foam bonding	1,3,5-Trioxane, polymer with 1,3-dioxolane	24969-26-4	Polyacetal resin
Adhesives	Structural adhesive	Hexanedioic acid polymer with 1,4-butanediol and MDI	26375-23-5	Polyurethane resin
Minor plastic parts	Covers & caps	Polyethylene (PE)	9002-88-4	Polyolefin thermoplastic
Minor plastic parts	Rubber-like parts	2-Propenenitrile, polymer with 1,3-butadiene (NBR)	9003-18-3	Synthetic rubber
Upholstery	Fiber content	Cellulose	9004-34-6	Natural polymer
Manufacturing	Solvent	N,N-Dimethylacetamide	127-19-5	Organic solvent
Miscellaneous	Additives	Undisclosed	N/A	Proprietary additives

Chair 6:

Component	Subcomponent	Material Name	CAS Number / I	Material Subcategory
Base	Star base	A380 Aluminum	UNS A13800	Aluminum alloy (die-cast)
Base	Star base	ADC12 Aluminum	UNS A03840	Aluminum alloy (die-cast)
Base	Structural parts	6063-T5 Aluminum	UNS A96063	Aluminum alloy (extruded)
Base	Bearing insert	SAE 841 Oilite Bronze	UNS C84400	Sintered bronze
Base	Surface coating	Chromium	7440-47-3	Metallic coating
Base	Surface coating	Trivalent Chromium Compound	57693-14-8	Conversion coating
Gas Lift	Cylinder / tube	JIS STKM12B Carbon Steel	UNS G10080	Carbon steel
Gas Lift	Cylinder / tube	JIS SPCC Carbon Steel	UNS G10080	Cold-rolled carbon steel
Gas Lift	Piston rod	SAE 1008 Carbon Steel	UNS G10080	Low-carbon steel
Gas Lift	Piston rod	AISI 1018 Carbon Steel	UNS G10180	Low-carbon steel
Gas Lift	Springs	ASTM A228 Steel	UNS K08500	Spring steel
Gas Lift	Springs	AISI 1065 Carbon Steel	UNS G10650	High-carbon steel
Gas Lift	Structural parts	10B21 Steel	UNS G10210	Boron steel
Gas Lift	Oxide layer	Diiron Trioxide	1309-37-1	Iron oxide
Gas Lift	Oxide layer	Ferrum Dioxide	1332-37-2	Iron oxide
Mechanism	Plates & levers	11L41 CRS / #45 Carbon Steel	UNS G11410	Carbon steel
Mechanism	Shafts & pins	AISI 12L14 Carbon Steel	UNS G12144	Free-machining steel
Mechanism	Shafts & pins	AISI 1008 Carbon Steel	UNS G10080	Low-carbon steel
Mechanism	Structural parts	JIS G4053 SCM435 Steel	UNS G41350	Alloy steel
Mechanism	Bushings	Poly(oxyethylene) (POM)	9002-81-7	Engineering thermoplastic
Mechanism	Bushings	POM (copolymer)	24969-26-4	Engineering thermoplastic
Seat / Backrest	Structural shell	Nylon 6 (PA6)	25038-54-4	Engineering thermoplastic
Seat / Backrest	Structural shell	Nylon 66 (PA66)	32131-17-2	Engineering thermoplastic
Seat / Backrest	Structural shell	Polyamide PA6	24993-04-2	Engineering thermoplastic
Seat / Backrest	Structural shell	ABS	9003-56-9	Engineering thermoplastic
Seat / Backrest	Reinforcement	Glass/Mineral Fiber	65997-17-3	Glass fiber
Seat / Backrest	Foam padding	Polyurethane	9009-54-5	Thermoset foam
Seat / Backrest	Upholstery	Polyethylene Terephthalate (PET)	25038-59-9	Polyester thermoplastic
Armrests	Structural core	Polypropylene	9003-07-0	Polyolefin thermoplastic
Armrests	Structural core	1-Propene, polymer with ethene	9010-79-1	Polyolefin copolymer
Armrests	Soft cover	1-Butene, polymer with ethene	25087-34-7	Polyolefin elastomer
Armrests	Soft cover	EVA	108-05-4	Copolymer elastomer
Plastics (general)	Fillers	Talc filler	14807-96-6	Mineral filler
Plastics (general)	Fillers	Calcium Carbonate	1317-65-3	Mineral filler
Plastics (general)	Pigment	Titanium dioxide	13463-67-7	Inorganic pigment
Plastics (general)	Pigment	Carbon Black	1333-86-4	Pigment / filler
Plastics (general)	Lubricant	Zinc Stearate	557-05-1	Processing lubricant
Additives	Antioxidant	Hindered phenol antioxidant	6683-19-8	Antioxidant
Additives	Stabilizer	HALS stabilizer	42774-15-2	UV stabilizer
Additives	Processing aid	Caprolactam	105-60-2	Processing aid
Lubricants	Oil	White mineral oil (petroleum)	8042-47-5	Mineral oil
Miscellaneous	Additives	Undisclosed	N/A	Proprietary additives

Chair 7:

Component	Subcomponent	Material Name	CAS Number / U	Material Subcategory
Mechanism	Bushings / gears	1,3,5-Trioxane, polymer with 1,3-dioxolane (POM copolymer)	24969-26-4	Engineering thermoplastic
Seat / Backrest	Structural shell	Nylon 6 (PA6)	25038-54-4	Engineering thermoplastic
Base	Star base	Aluminum ADC12 (A384.0)	UNS A03840	Aluminum alloy (die-cast)
Base	Star base	A380 Aluminum Alloy	UNS A03800	Aluminum alloy (die-cast)
Seat / Backrest	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Mechanism / Frame	Structural metal	Iron	7439-89-6	Ferrous metal
Seat / Backrest	Upholstery resin	Polyester copolymer (terephthalate-based)	9086-55-9	Thermoplastic polyester
Mechanism / Frame	Structural metal	UNS G10080 Steel	UNS G10080	Carbon steel
Mechanism	Structural parts	UNS K06501 Steel Alloy	UNS K06501	Alloy steel
Adhesives / Coatings	Binder	Poly(propylene oxide)	9003-11-6	Polyether polymer
Fasteners	Screws / bolts	Small steel hardware	N/A	Carbon steel
Mechanism / Frame	Structural metal	UNS G10100 Steel Alloy	UNS G10100	Carbon steel
Plastics (general)	Plastic parts	1-Propene, polymer with ethene	9010-79-1	Polyolefin copolymer
Upholstery	Fabric / yarn	Polyethylene terephthalate (PET)	25038-59-9	Polyester thermoplastic
Mechanism	Pins / shafts	UNS G12150 Steel Alloy	UNS G12150	Free-machining steel
Adhesives / Coatings	Crosslinker	Polyether polyol (epoxy-modified)	9082-00-2	Polyether resin
Plastics (general)	Plastic parts	Polypropylene (PP)	9003-07-0	Polyolefin thermoplastic
Seat / Backrest	Foam padding	Polyurethane foams	9009-54-5	Thermoset foam
Miscellaneous	Additives	Undisclosed	N/A	Proprietary additives
Mechanism	Structural parts	UNS S21900 Steel Alloy	UNS S21900	Stainless steel
Fasteners	Screws / bolts	UNS S30400 Steel Alloy	UNS S30400	Stainless steel
Plastics (general)	Elastomer parts	1-Octene, polymer with ethene	26221-73-8	Polyolefin elastomer
Adhesives / Coatings	Catalyst / additive	2-Propanol, 1,1'-[[3-(dimethylamino)propyl]imino]bis-	63469-23-8	Amine compound
Plastics (general)	Pigment	Carbon black	1333-86-4	Pigment / filler
Seat / Backrest	Foam chemistry	Polymethylene polyphenyl isocyanate (pMDI)	9016-87-9	Isocyanate
Manufacturing	Process medium	Water	7732-18-5	Inorganic compound
Plastics (general)	Elastomer parts	Hydrogenated styrene-butadiene copolymer	66070-58-4	Synthetic rubber
Coatings	Colorant	C.I. Acid Black 2	8005-03-6	Organic dye
Base	Structural metal	Aluminum	7429-90-5	Aluminum metal
Mechanism / Frame	Alloying element	Manganese	7439-96-5	Alloying element
Mechanism	Structural parts	UNS K02403 Steel Alloy	UNS K02403	Alloy steel
Plastics (general)	Surface additive	Siloxanes and silicones	63148-53-8	Silicone polymer
Base	Bearing insert	UNS S74100 Bronze Alloy	UNS S74100	Bronze alloy
Plastics (general)	Elastomer parts	2-Propenenitrile, polymer with 1,3-butadiene (NBR)	9003-18-3	Synthetic rubber
Plastics (general)	Flame retardant	Antimony oxide (antimony trioxide)	1309-64-4	Inorganic flame retardant
Mechanism / Frame	Oxide layer	Diiron Trioxide	1309-37-1	Iron oxide
Adhesives / Coatings	Binder	Phenol, polymer with formaldehyde	9003-35-4	Phenolic resin
Mechanism	Pins / shafts	UNS G10180 Steel Alloy	UNS G10180	Carbon steel
Plastics (general)	Processing aid	1-Decene, homopolymer, hydrogenated	68037-01-4	Polyolefin wax
Plastics (general)	Filler	Barium sulfate	7727-43-7	Mineral filler
Lubricants	Oil	Distillates (petroleum), hydrotreated heavy paraffinic	64742-54-7	Mineral oil
Plastics (general)	Filler / lubricant	Graphite	7440-44-0	Carbon filler
Plastics (general)	Processing aid	Octadecanoic acid, zinc salt	557-05-1	Metal soap
Plastics (general)	Structural polymer	Polyamide 66 (PA66)	32131-17-2	Engineering thermoplastic
Plastics (general)	Additive	Silicon	7440-21-3	Metalloid additive
Plastics (general)	Surface additive	Vinyl silicone polymer	68083-19-2	Silicone polymer

Chair 8:

Component	Subcomponent	Material Name	CAS Number	Material Subcategory
Seat / Backrest	Structural shell	Nylon	63428-83-1	Engineering thermoplastic
Frame / Mechanism	Structural metal	Steel	12597-69-2	Ferrous metal
Armrests / Covers	Plastic parts	Polypropylene	9003-07-0	Polyolefin thermoplastic
Base	Star base	Aluminum	7429-90-5	Aluminum metal
Seat / Backrest	Foam padding	Polyurethane foams	9009-54-5	Thermoset foam
Mechanism	Bushings / gears	1,3,5-Trioxane, polymer with 1,3-dioxolane	24969-26-4	Engineering thermoplastic (POM)
Plastics (general)	Monomer content	Styrene	100-42-5	Aromatic monomer
Adhesives / Coatings	Binder resin	Ethane, 1,1-dioxy-, homopolymer	30846-29-8	Polycetal resin
Upholstery	Fabric / yarn	Polyethylene terephthalate (PET)	25038-59-9	Polyester thermoplastic
Minor plastic parts	Covers & caps	Polyethylene	9002-88-4	Polyolefin thermoplastic
Additives	Binder / thickener	17,19-Dinoratis-15-ene-4,13,14-tricarboxylic acid polymer (ammonium salt)	105583-82-2	Polymeric additive
Lubricants	Grease	Grease	68153-81-1	Lubricant

Chair 9:

Component	Subcomponent	Material Name	CAS Number	Material Subcategory
Frame / Mechanism	Structural metal	Steel (G10150)	G10150	Carbon steel
Seat / Backrest	Structural shell	Nylon 6 (33% glass-filled)	25038-54-4	Glass-fiber reinforced thermoplastic
Seat / Backrest	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Seat / Backrest	Structural shell	Nylon 6 (30% glass-filled)	25038-54-4	Glass-fiber reinforced thermoplastic
Seat / Backrest	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Seat / Backrest	Foam padding	Polyurethane foams	9009-54-5	Thermoset foam
Armrests / Covers	Plastic parts	Polypropylene	9003-07-0	Polyolefin thermoplastic
Plastics (general)	Filler	Talc	14807-96-6	Mineral filler
Plastics (general)	Pigment	Titanium dioxide	13463-67-7	Inorganic pigment
Armrests / Covers	Elastomer modifier	1-Butene, polymer with ethene	25087-34-7	Polyolefin elastomer
Armrests / Covers	Plastic parts	Polypropylene (PP 511MK40T)	9003-07-0	Polyolefin thermoplastic
Upholstery	Fabric	Polyethylene terephthalate (PET)	25038-59-9	Polyester thermoplastic
Armrests / Covers	Soft-touch layer	Thermoplastic polyurethane (TPU)	9009-54-5	Thermoplastic elastomer
Seat / Backrest	Plastic parts	ABS (styrenic polymer)	107-13-1	Engineering thermoplastic
Plastics (general)	Pigment	Carbon black	1333-86-4	Pigment / filler
Plastics (general)	Monomer residue	Styrene	100-42-5	Aromatic monomer
Plastics (general)	Pigment	Titanium dioxide	13463-67-7	Inorganic pigment
Plastics (general)	Flame retardant	Triphenyl phosphate	115-86-6	Organophosphate FR
Base / Frame	Surface coating	Powder coat (epoxy-based)	25036-25-3	Thermoset epoxy coating
Plastics (general)	Filler	Calcium carbonate	1317-65-3	Mineral filler
Plastics (general)	Polyester additive	Terephthalate-based polyester copolymer	126191-59-1	Thermoplastic polyester
Plastics (general)	Pigment	Titanium dioxide	13463-67-7	Inorganic pigment
Minor plastic parts	Covers / caps	Polyethylene (LDPE / HDPE)	9002-88-4	Polyolefin thermoplastic
Mechanism	Bushings / gears	Polyoxymethylene (POM)	30846-29-8	Engineering thermoplastic
Seat / Backrest	Structural shell	Nylon 6 (50% glass-filled)	25038-54-4	Glass-fiber reinforced thermoplastic
Seat / Backrest	Reinforcement	Glass, oxide, chemicals	65997-17-3	Glass fiber
Seat / Backrest	Structural shell	Nylon 6	25038-54-4	Engineering thermoplastic
Feet / Pads	Anti-slip element	Rubber dust	9006-04-6	Elastomer
Minor plastic parts	Small molded parts	Nylon 6	25038-54-4	Engineering thermoplastic

Appendix A.2 The median chair

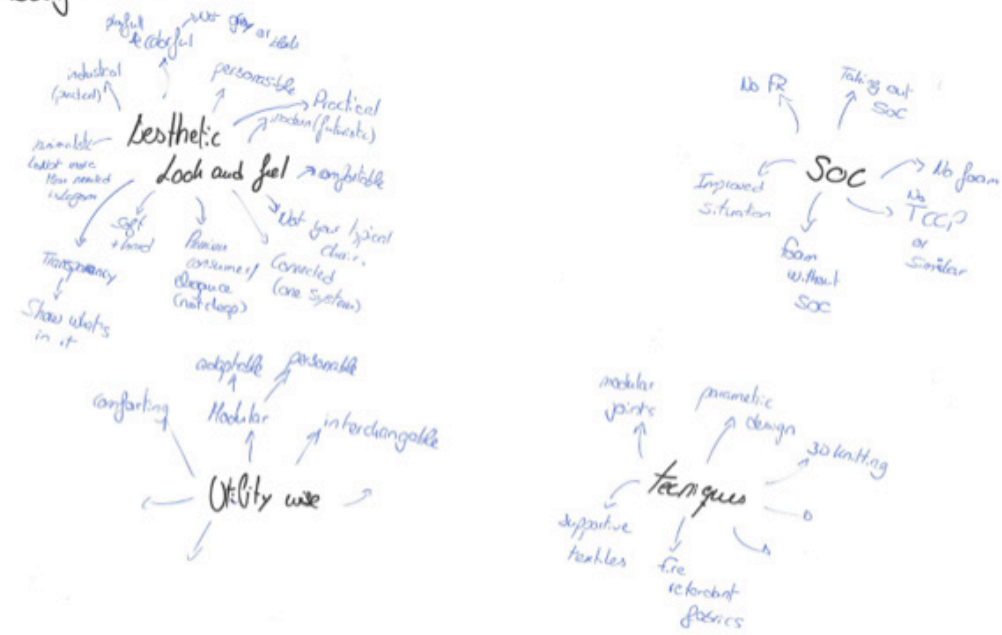
Component	Subcomponent	Material	CAS	Material Category	Risk	Compliance Notes
Base & Casters	5-star base	Nylon 6 (glass-filled)	25038-54-4	Engineering polymer	L	Standard polymer; microplastics & fumes
Base & Casters	5-star base filler	Glass, oxide	65997-17-3	Mineral reinforcement	L	Inert; dust irritation only
Base & Casters	5-star base pigment	Carbon black	1333-86-4	Pigment	H	IARC 2B carcinogen via dust inhalation; control dust
Base & Casters	5-star base insert	Steel EN S235JR / DC01	—	Carbon steel	M	Welding fumes (Fe, Mn); manage with LEV
Casters	Wheel body	Polypropylene	9003-07-0	Polymer	L	Low toxicity; microplastics at EoL
Casters	Wheel body pigment	Carbon black	1333-86-4	Pigment	H	Same concern: inhalable dust in production
Casters	Wheel hub	POM	9002-81-7	Engineering polymer	M	Formaldehyde release when overheated/lubricated
Casters	Wheel hub (alt.)	POM copolymer	24969-26-4	Engineering polymer	M	Same as POM: control processing temperature
Casters	Caster stem	Steel UNS G10080	—	Carbon steel	M	Welding/cutting fumes; low risk in finished product
Casters	Caster stem plating	Zinc	7440-66-6	Metal plating	M	Fume fever in hot work; aquatic toxicity if released
Gas Lift	Outer cylinder	Steel EN 10277	—	Carbon steel	M	Welding/pressure vessel fabrication risks
Gas Lift	Outer cylinder coating	Carbon black	1333-86-4	Pigment	H	Powder handling risk; bound in coating in finished product
Gas Lift	Outer cylinder coating	Diiron trioxide	1309-37-1	Inorganic pigment	L	Low toxicity; dust irritation
Gas Lift	Inner piston	Steel C45 / EN19	—	Alloy steel	M	Welding/heat-treatment fumes; low article risk
Gas Lift	Piston plating	Nickel	7440-02-0	Metal	H	Carcinogenic in fumes; skin sensitizer; Amersfoort
Gas Lift	Piston plating	Zinc	7440-66-6	Metal	M	See above; manage wastewater & fumes
Gas Lift	Seals	NBR	9003-18-3	Elastomer	M	Monomers CMR; finished rubber low risk; control dust
Gas Lift	Seals	Silicone polymer	63148-53-8	Elastomer	L	Very low toxicity; persistent elastomer
Gas Lift	Lubricant	Hydrogenated decene polyolefin	68037-01-4	Lubricating oil	M	Manage spills; check PAH content; aquatic toxicity
Gas Lift	Lubricant	Petroleum distillates	64742-54-7	Lubricating oil	M-H	Dependent on refining; aquatic toxicity; control dust
Gas Lift	Lubricant additive	Zinc stearate	557-05-1	Additive	L	Common plastic/lube additive; low concern
Seat Structure	Seat pan	Glass-filled polypropylene	9003-07-0	Polymer	L	As PP; glass fibers/dust in processing
Seat Structure	Seat pan filler	Glass, oxide	65997-17-3	Mineral	L	Dust irritation only
Seat Structure	Seat pan filler	Talc	14807-96-6	Mineral	M-H	Respirable talc dust: probable carcinogen; control dust
Seat Structure	Seat pan pigment	Carbon black	1333-86-4	Pigment	H	Priority for dust control in compounding
Seat Structure	Support bracket	Steel EN S235JR / DC01	—	Carbon steel	M	Welding/grinding fumes; low article risk
Seat Structure	Hinge bushings	POM copolymer	24969-26-4	Engineering polymer	M	Formaldehyde at high temperature; control dust
Seat Cushion	Foam core	Polyurethane foam	9009-54-5	Polymer (foam)	H	Foam production, fumes & fire toxicity; isocyanate
Seat Cushion	Foam component	Polyether polyol	9003-11-6	Polymer	M	Irritant; PU precursor; low concern once reacted
Seat Cushion	Foam component	Polyether polyol	9082-00-2	Polymer	M	As above
Seat Cushion	Isocyanate	pMDI	9016-87-9	Isocyanate	H	Strong respiratory sensitizer; major workplace hazard
Seat Cushion	FR additive	Tris(1-chloro-2-propyl) phosphite	13674-84-5	Flame retardant	M	harmful if ingested; suspected carcinogen
Seat Cushion	Foam additive	Zinc stearate	557-05-1	Additive	L	Lubricant/stabilizer; low hazard
Backrest S	Back frame	Glass-filled Nylon 6	25038-54-4	Engineering polymer	L	As Nylon 6; processing dust/fumes only
Backrest S	Back frame filler	Glass, oxide	65997-17-3	Mineral	L	Inert; dust irritation
Backrest S	Connection bracket	Steel EN 10111 / S235JR	—	Carbon steel	M	Welding/grinding fumes; low article risk
Backrest S	Pivot bushings	POM	9002-81-7	Engineering polymer	M	Formaldehyde at high temp; machining fumes
Backrest C	Mesh fabric	Polyester fiber	113669-97-9	Textile polymer	L	Low toxicity; microfibre shedding
Backrest C	Mesh fabric (alt.)	PET	25038-59-9	Textile polymer	L	As above
Backrest C	Dye	Acid Black 2	8005-03-6	Dye	M-H	Azo-type dye; check RSL; aquatic toxicity
Backrest C	Dye (alt.)	Solvent Black 7	8005-02-5	Dye	M-H	Possible PAH concerns; wastewater exposure
Backrest C	Pigment	Carbon black	1333-86-4	Pigment	H	Same concern as above for dust
Armrests	Armrest frame	Steel C45 / EN19	—	Carbon steel	M	Welding/heat-treatment fumes; low article risk
Armrests	Armrest frame (alt.)	Aluminum ADC12	—	Aluminum alloy	M	Casting fume/dust; low use-phase hazard
Armrests	Arm pad core	Polyurethane foam	9009-54-5	Foam	H	Same PU risks as seat foam in production
Armrests	Arm pad cover	TPEE	308079-71-2	TPE	L	Low toxicity; microplastic shedding
Armrests	Arm pad cover (alt.)	Hydrogenated SBC	66070-58-4	Elastomer	L	Low toxicity; microplastic shedding
Armrests	Arm pad pigment	Carbon black	1333-86-4	Pigment	H	In compounding; low risk in article
Armrests	Fasteners	Steel UNS G10080	—	Carbon steel	M	Welding/grinding; low article hazard
Armrests	Fastener plating	Zinc	7440-66-6	Metal	M	Environmental concern in wastewater
Upholster	Seat fabric	Polyester	113669-97-9	Textile polymer	L	Low toxicity; microfibre shedding
Upholster	Textile dye	Acid Black 2	8005-03-6	Dye	M-H	Azo dye; check restricted amines
Upholster	Textile dye (alt.)	Solvent Black 7	8005-02-5	Dye	M-H	Check MRSL; wastewater hazard
Hardware	Screws/bolts	Steel G10080 / G10100	—	Carbon steel	M	Welding/heat-treatment fumes at supplier
Hardware	Screw/bolt plating	Zinc	7440-66-6	Metal	M	Environmental concern in wastewater
Hardware	Bushings	Bronze UNS S74100	—	Copper alloy	M	Cu/Zn release in waste streams
Adhesives	Structural adhesive	Epoxy resin	25036-25-3	Thermoset resin	H	BPA-based; sensitizer; CMR concerns
Adhesives	Epoxy hardener	Polyamine hardener	63469-23-8	Hardener	H	Strong irritant/sensitizer; worker exposure
Adhesives	Coating resin	Phenol-formaldehyde resin	9003-35-4	Thermoset resin	M-H	Formaldehyde/phenol fumes during curing
Adhesives	Powder coating	Polyester-based	—	Polymer coating	L-M	Low in article; ensure TGIC-free/BPA-free
Adhesives	Lubricant	Petroleum distillates	64742-54-7	Lubricating oil	M-H	Aquatic hazard; ensure highly-refined grade
Adhesives	Antioxidant	Phosphite stabilizer	31570-04-4	Additive	M	Low use risk; document classification
Adhesives	Plasticizer	Benzoate ester	68515-40-2	Plasticizer	M-H	Check vs SVHC/RSL lists

Expert	Role	Experience	
Expert 1	Partner of design agency	35+ years of experience; has designed chairs for big corporations and designed a more 'sustainable' chair	
Expert 2	Design Engineer of a big corporation	15+ years at the company	
Expert 3	Head of Engineering of a mid-size corporation	12+ years of experience in the industry	
Expert 4	Junior Designer/Design Engineer of a mid-size corporation	2+ years of experience in the industry	
Expert 5	Partner of design agency, expert in desk chair design	20+ years of expertise in the field	
Expert 6	Freelance furniture designer	20+ years of experience designing and manufacturing furniture	
Expert 7	Designer at a design agency focused on desk chairs	Senior designer, 10+ years of experience designing chairs	
Expert 8	Designer at a design agency focused on desk chairs	Junior designer, 3+ years designing chairs	
Expert 9	Designer at a design agency focused on desk chairs	Senior designer, 10+ years designing chairs	
Expert 10	Designer at a design agency focused on desk chairs	Mid-level designer, 6+ years of experience designing chairs	
Expert 11	Sustainability expert and industrial designer	15+ years in the industry; 20+ years as an industrial designer; has written a book on sustainable furniture design	
Expert 12	Owner of a new desk chair company	25+ years of experience in the industry	
Expert 13	Textile expert	3+ years of experience with textiles and new knitting technologies	
Expert 14	Vice President of Design at a big corporation	12+ years of experience in the industry	
Expert 15	Vice President of CMF at a big corporation	20+ years of experience in the industry	
Expert 16	Material scientist of medical products	15+ years working as a material scientist	
Expert 17	Sustainability expert at a big corporation	5+ years of experience in the industry	
Expert 18	Sustainability expert at a medium-size corporation	30+ years of experience in the industry	
Expert 19	Material innovation expert at a big corporation	30+ years with the company; 15+ years in this role	
Expert 20	Retail and logistics expert in product end-of-life	5+ years working in the end-of-life industry	

	Interview Purpose
	To understand the design and development process of the chair, including key challenges encountered and discoveries made during its creation, and how it differed from designing a traditional chair.
	To understand their work processes, their role in the process, their approach to material selection and handling of SoCs/VoCs, and how a large corporation's perspective and action plan differs from smaller companies.
	To understand their design process, material selection approach regarding SoCs/VoCs, how a mid-sized company's perspective and decision-making differs from larger corporations, and when they initiate product improvements.
	To understand their design process and material selection approach (as with Experts 2 and 3), explore how recent university sustainability education influences junior designers, and examine how their dual designer-engineer role affects lifecycle decisions. Additionally, to identify what drives different design choices in the industry and how sustainability is integrated into the development process.
	To gain insights into broader industry dynamics and the role of traditional design agencies that focus on design and pre-engineering before client handoff. To explore how sustainability affects client relationships, whether material safety and SoCs are discussed in their work, and whether they have observed recent industry changes.
	To understand their operational approach as a one-person company working with larger clients, what influence they have over design decisions, how they navigate various constraints, and how they implement safe and circular design principles in their solutions.
	Same focus as Expert 5, but examining the industry from a different country's perspective. To explore how safe and circular design is practiced in their daily work and understand their decision-making processes.
	This expert worked with Experts 7 and 9 at an influential industry agency. To understand how they operated within the industry and how they drove innovation in office chair design.
	Same as Experts 7 and 8.
	To understand their role as a traditional designer focused on shape and form rather than engineering and manufacturing, and explore how a tool like the one used in this thesis could help designers improve their practice.
	To gain knowledge on materials in office chairs that pose the greatest risk to people throughout the lifecycle. Given their expertise in sustainable design, to understand the current state of safe and circular design practices, whether companies are actively working on this topic, and to validate the approach taken in Chapter 4.
	To understand their vision for their new brand, what they mean by circularity and sustainability in practice, and to explore the role of OEMs within the industry.
	To understand different 3D knitting techniques and explore how this technology could replace materials that perform poorly across the lifecycle.
	To analyse and compare information from previous experts, gain insights into their processes as a large corporation in the industry, and understand how they manage innovation and implement changes that set examples for other businesses.
	Same as Expert 14.
	To gain a better understanding of materials that emerged as hotspots in the analysis section, understand their effects, and identify other materials and processes that warrant investigation.
	To validate the identification and analysis process, gain insights from a sustainability expert at a large corporation, understand their safe and circular design practices, and explore how they handle SoCs. Additionally, to learn what they are currently working on and how regulatory changes drive new solutions for safety and sustainability challenges.
	To validate the identification and analysis process, gain insights from a sustainability expert at a mid-sized corporation, understand their safe and circular design practices, and explore how they handle SoCs.
	To validate the entire process in Chapter 4.1 and understand the complete product lifecycle from idea to end-of-life within a large corporation with take-back programmes. To explore their processes, decision-making criteria, what factors they consider, how the tool could help them, and how different roles contribute to the lifecycle.
	To understand the end-of-life stage of office chairs, what problems they encounter and how they address them. To discuss different end-of-life pathways and understand how these challenges create major barriers to circularity.

Design themes.

Design themes.



Personal brainstorm session

Soc → Fire retardants

Ideas: How to avoid:

- Avoid
- Substitute
- Phase out
- without a different bad material

recreate effect

focus areas

foams

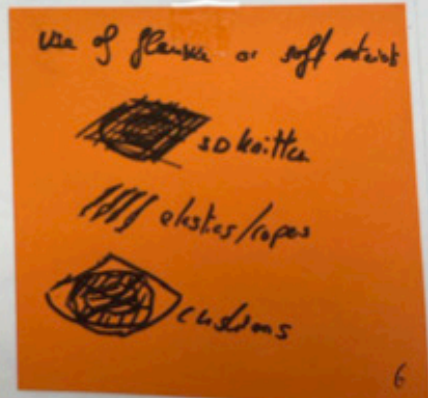
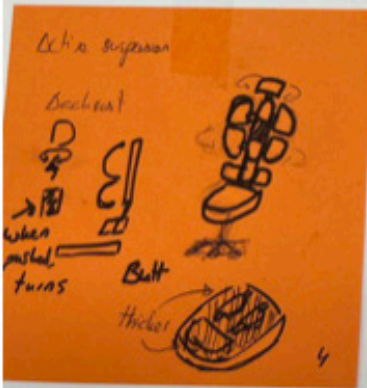
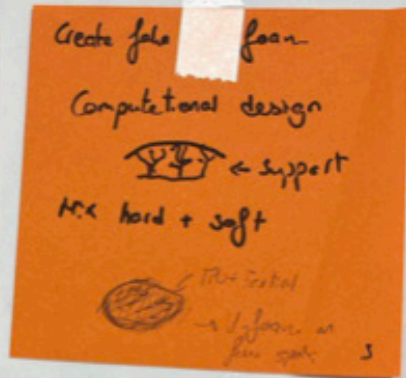
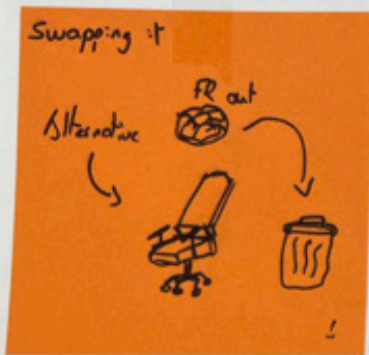
- Headrest
- Backrest
- Seat rest
- Seating

Why does it happen?

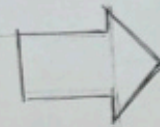
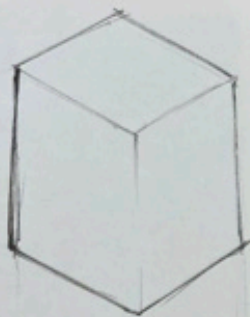
Ideas: Post-its:

1. Taking out the foam. What happens?
2. Enclose the foam. Laminize so that it can't breathe. Encase it!
3. No foam as resting material. Use a rigid material. Create a pattern suspension.
4. Soft material. Active suspension seating.
5. No chair. In sitting work slowly straight.
6. No foam as resting material. Substitute (support) that offers better and different forms.

How would it work?



Packaging → Logistic nightmare → High CO₂



Big packaging



Full size
vs
flat pack

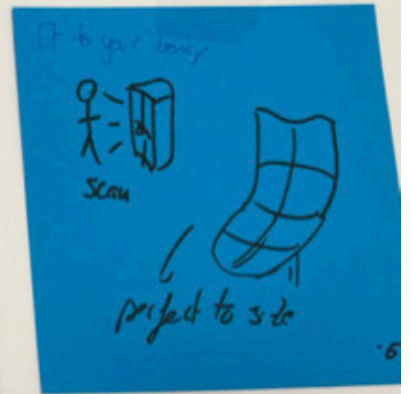
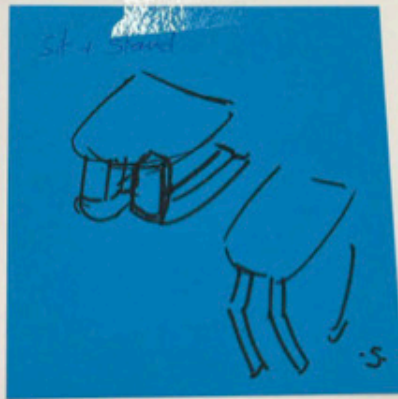
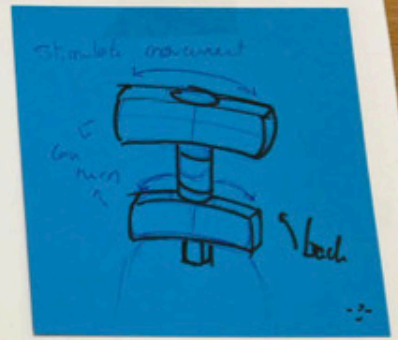
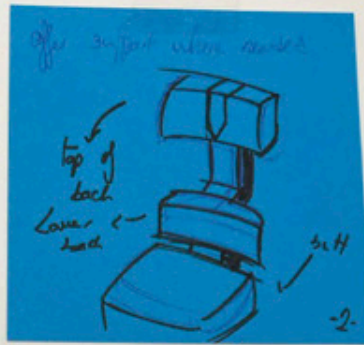
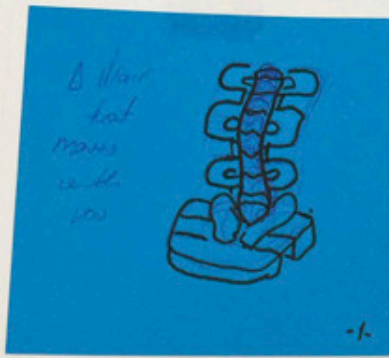


Disassembled

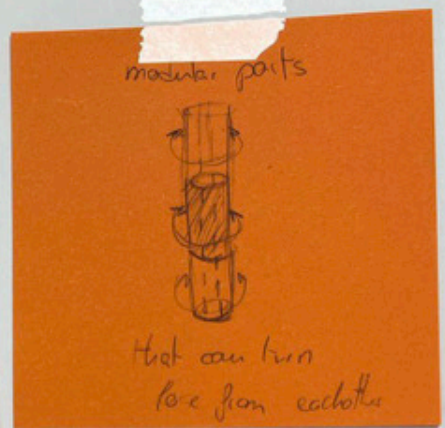
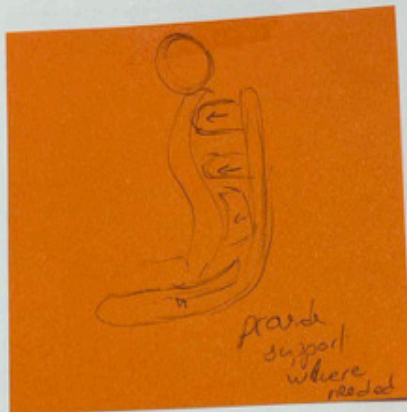
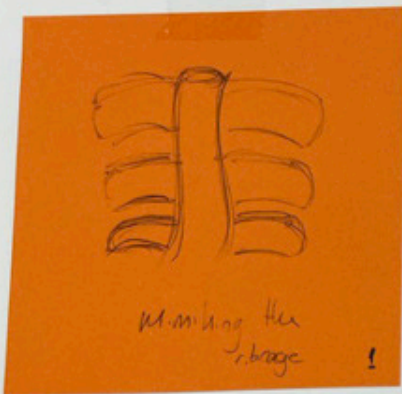
(Ease of use)



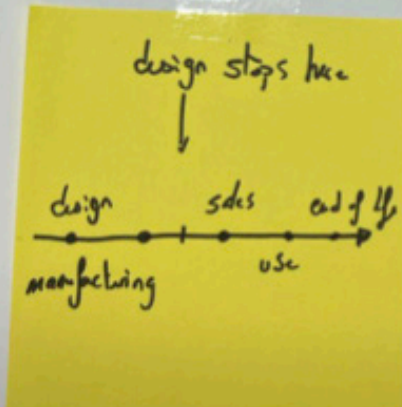
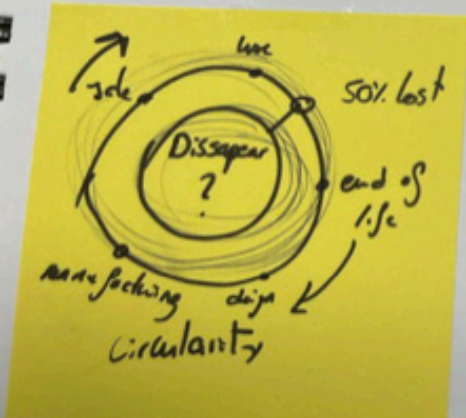
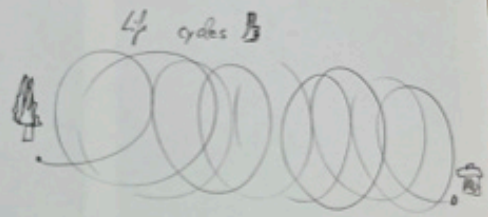
Possible solutions →



How would it be done?



Improved business models

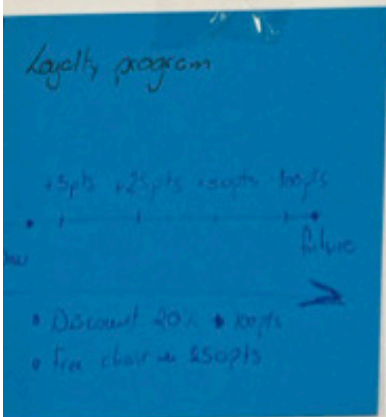
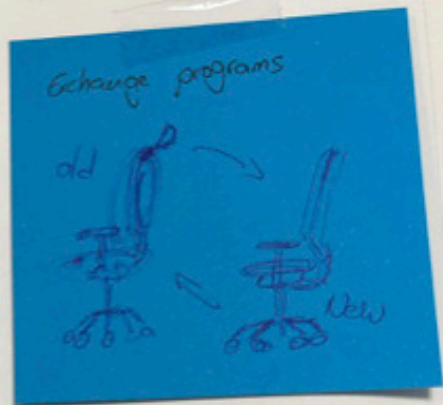
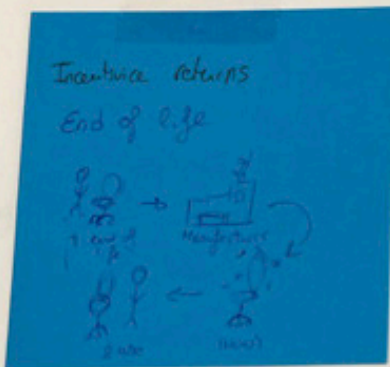


How to make it attractive for:

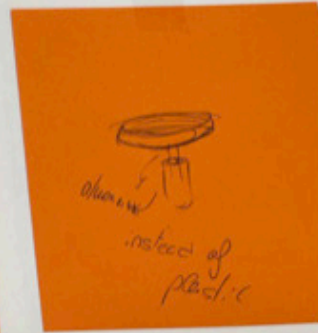
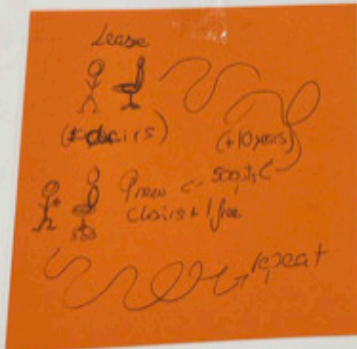
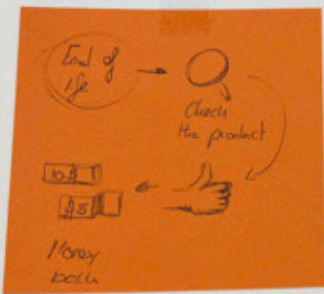
Consumer: - Treat the product
- Give it back

Manufacturer: - Give it another use
- Recycle it properly

How could it be improved?



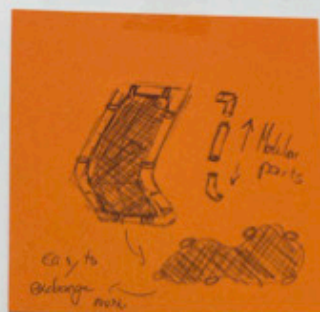
How would that work?



Assembly - Repairability



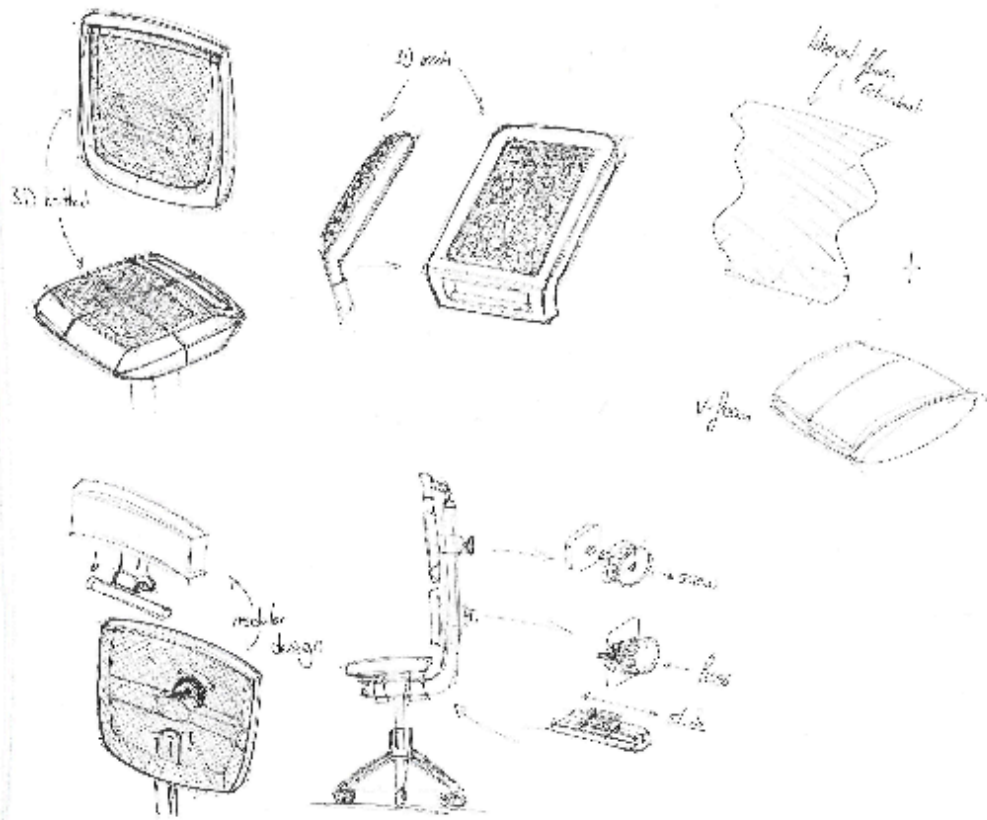
Possible solutions



Ideation phase – Sketches

Form

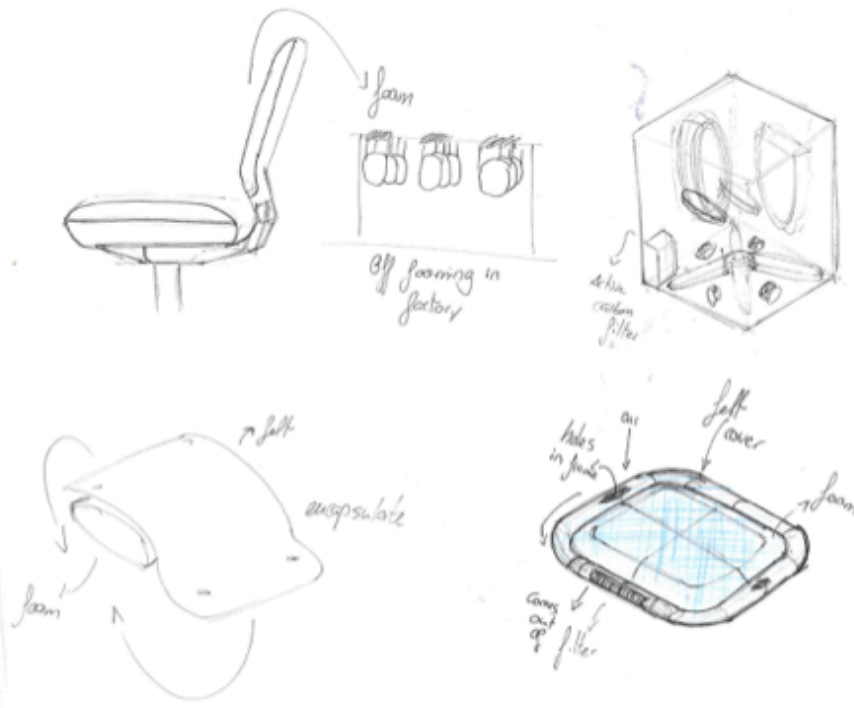
- 3D foam with 3D
 - 3D foam
 - 3D foam with dots
 - 3D mesh
 - 3D printing
 - 3D printed lattice
 - 3D foam
 - 3D printing
 - 3D printing
 - 3D printing
- Goal is to control offgassing of the foam and VOC.



Control

- Goal is to control the offgassing
- Encapsulate with a better layer
- Put into it (before dipping)
- Water blown foam
- Avoid out-gas packaging
- Use water barriers around foam
- Active carbon or zeolite layers

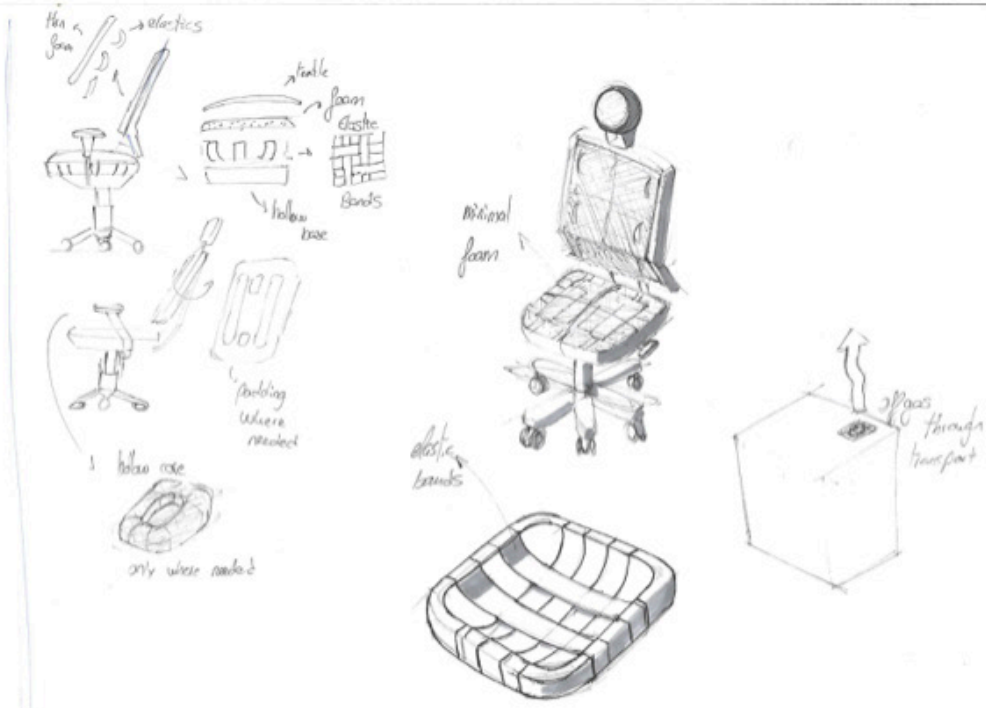
Control offgas



Reduce

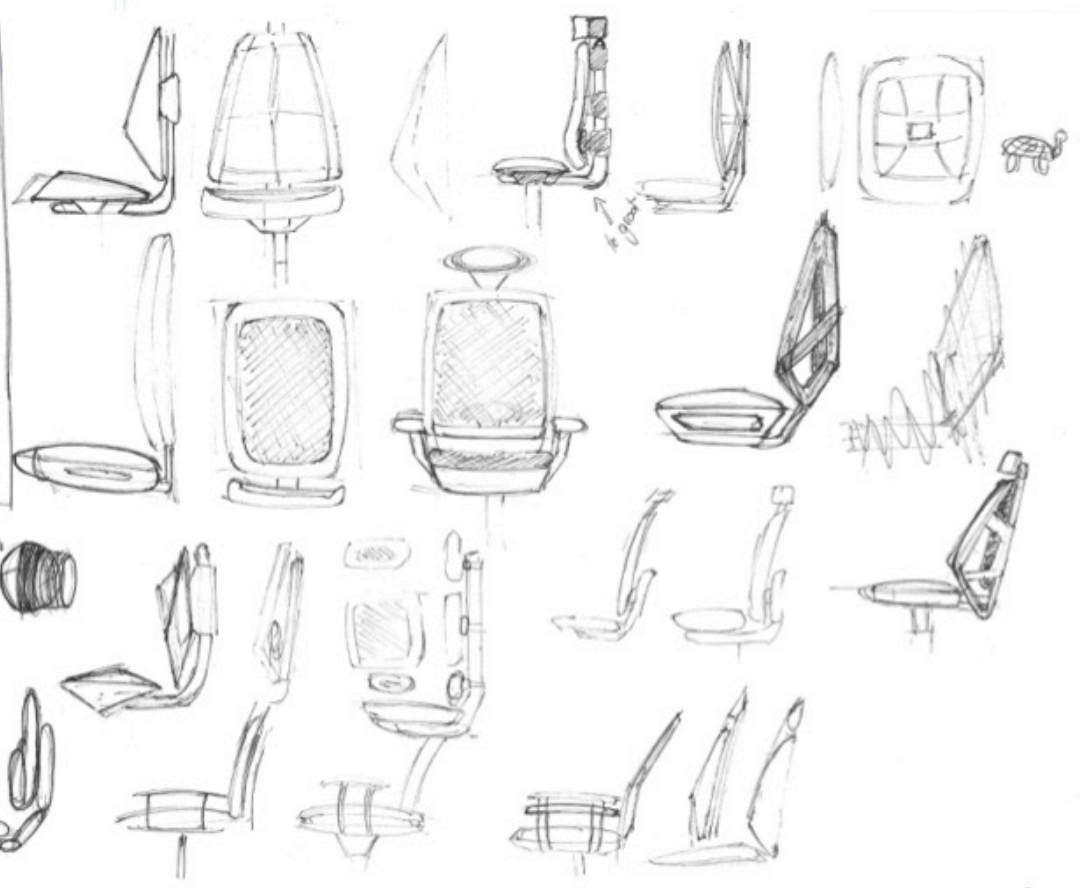
- Goal is to reduce the offering
- Optimized foam structures (hollow cores)
- Hybridize mechanical systems:
 - Elastic webbing / air foam
 - Head rails

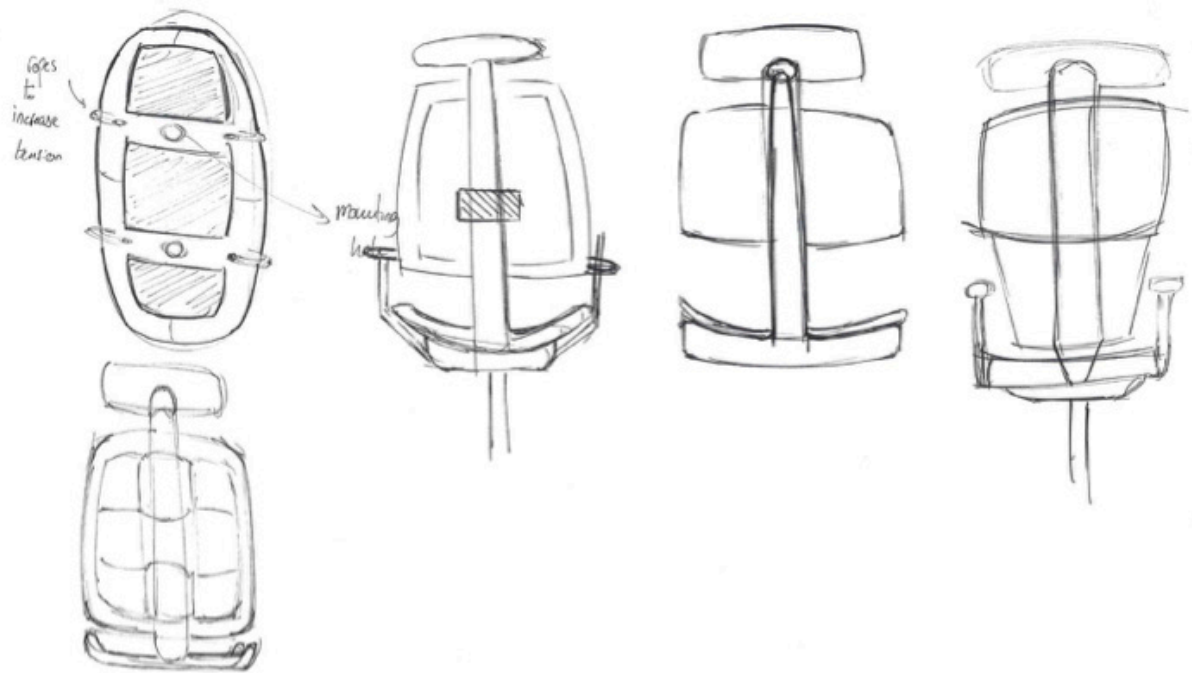
• Reduce just offers and total



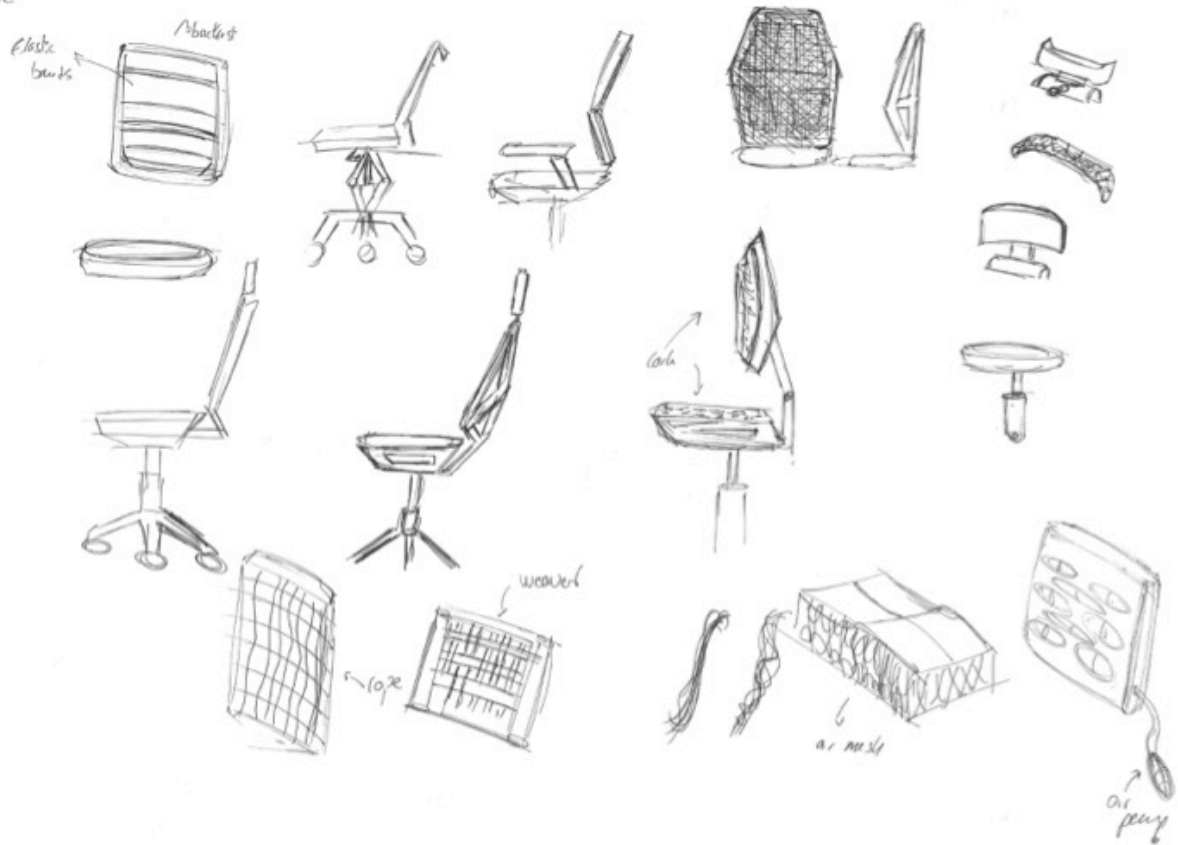
Concepting

- Side / front view back
- Cool, better, best
- Small, medium, big
 corporate / executive
- Important
 to Base → skeleton
 to Connecting parts (hollow)
 to Base (5 str)
 to arm rest
 to head rest

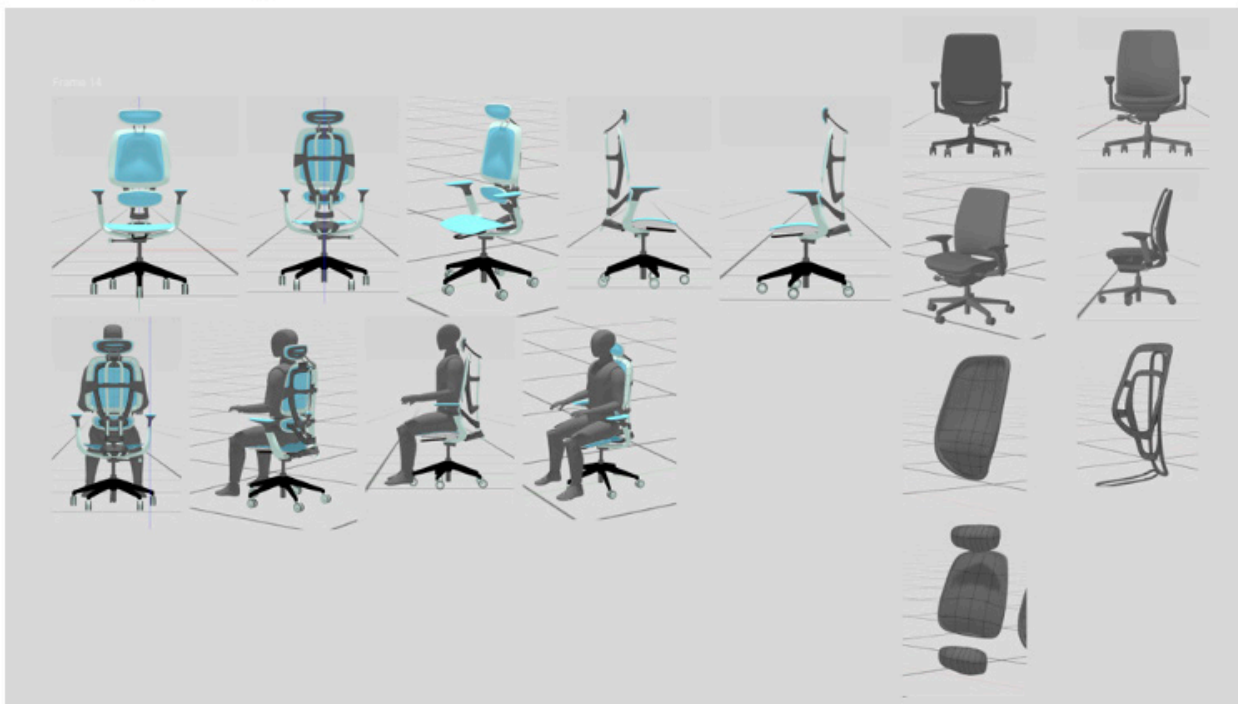




Duoid



Gravity sketch exploration



Designer feedback and inspiration

Modular design - No foam

No foam - Just textile

Behance sketching

Old school chairs - Wilkhahn neos - Flexible body sitting

3D knitting - Haworth Cardigan Lounge

Futuristic design - against conventions Kukoyo IngCloud

Japanese design IngLife

Design that plays with transparency Circ design G2 chair

Only textile nice design HM - Cosm

Monomaterial foam and textile

Shrinking over something textiles - Kroll roth

Behance new chair - 250 design 5 degree chair

Modular chair - Form us with love - Savo

Backwards compatibility. Designed for both sides other sides - Citroen Ami

3D printing foam okamura

Feedback from their side:

What if you create a soft element of the chair that can go to different places. That you can create a better modular design.

If you create designs that are all different. Where do you move apart from your own manufacturing and printing capabilities as a designer.

Look at new textiles and new chairs and see how they do it. Your vision is interesting, it is hard to be done separately but not together because of safety considerations. Try to combine these things together.

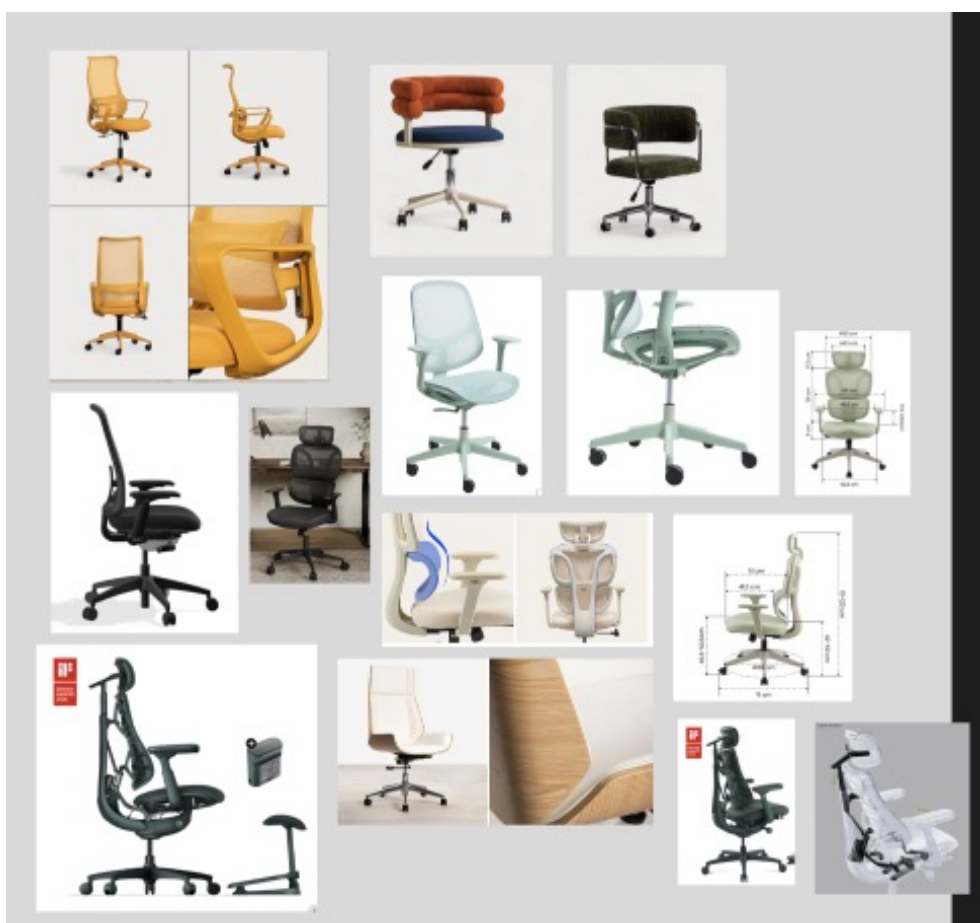
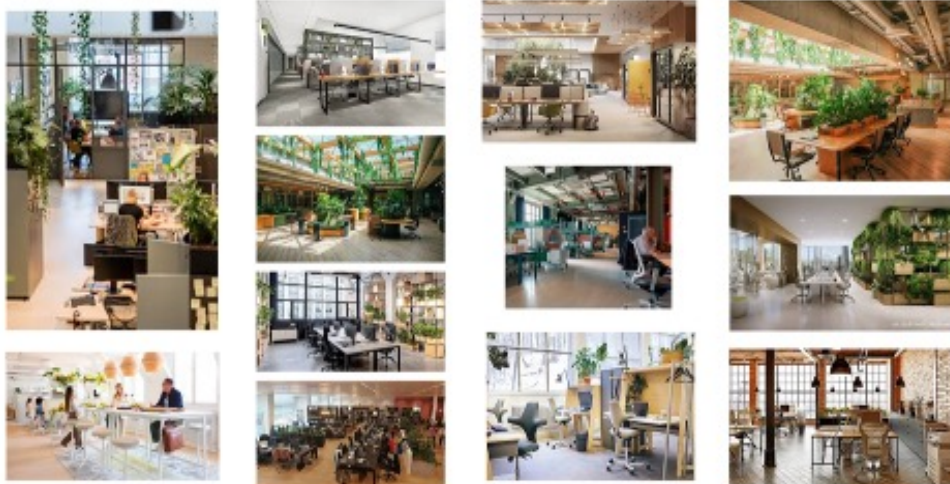
So crazy with the design.

Show of that transparency in a nice way that you can communicate to the user what they see and what they want.

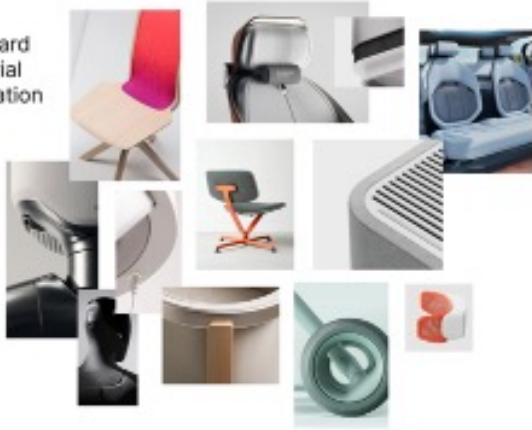
Fig. 1: 3D model of the chair and design over it to fit the proportions.

Textile is the best point, there are the flexible it becomes. 3D model should be better.

There is double-curved mesh (3D-knit) like the user defines 3 layers of seat. Support chair is 3D-knit as support.



Soft/Hard
Material
combination



Functional
design



Transparency
(Material
communication)



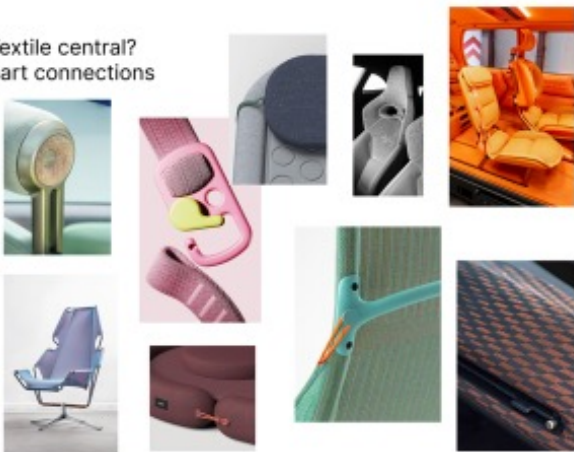
Playfulness
(Studio Memphis)



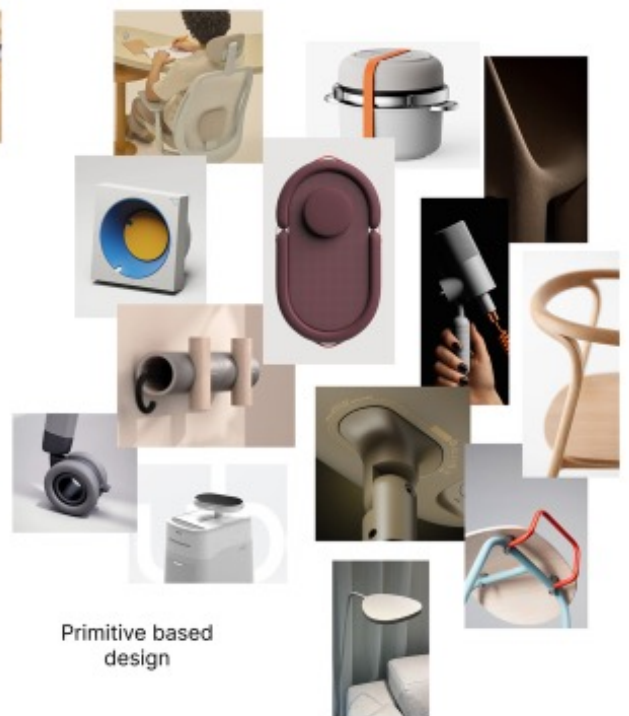
Futuristic
experience
(elegance)

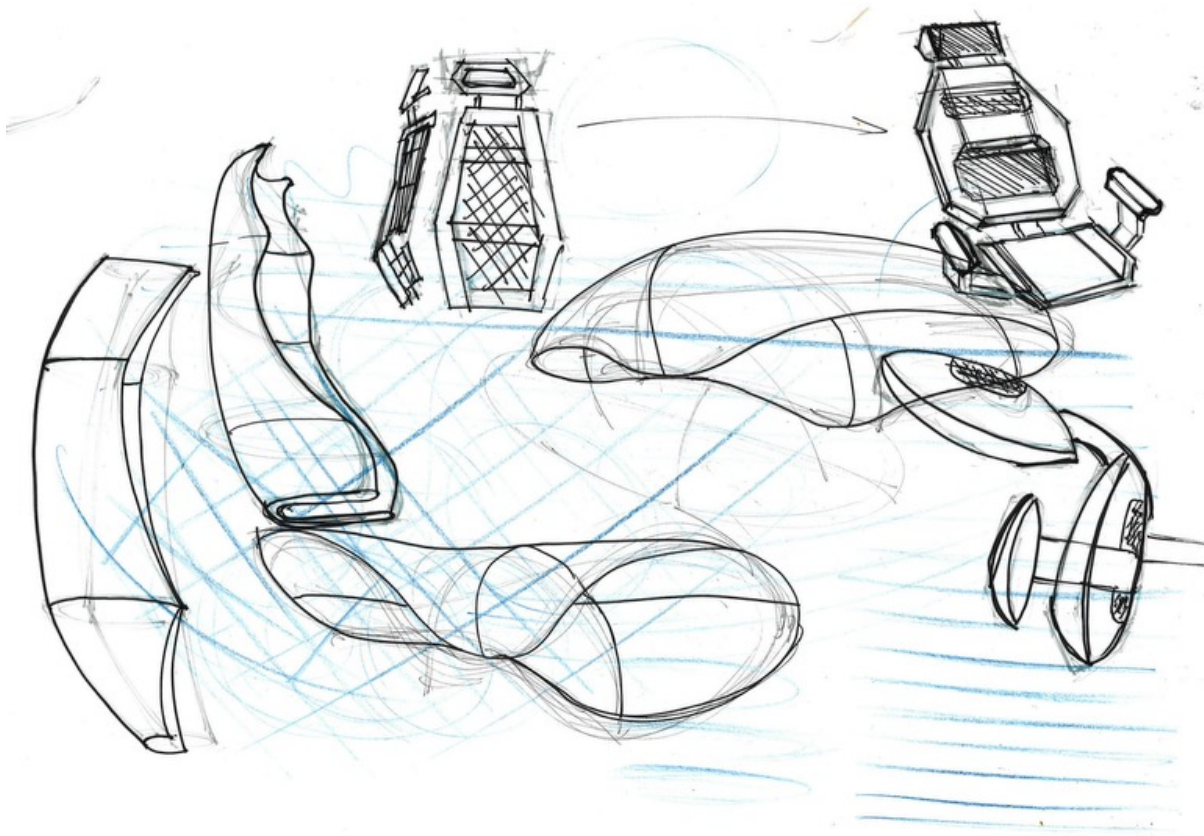


Textile central?
Smart connections



Primitive based
design





Personal Project Brief – IDE Master Graduation Project

Name student Fabian Hoogendijk

Student number 4547357

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Design safe and circular office furniture by researching substances of concern and industry practices.

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This graduation project takes place within the domain of circular product design, with a specific focus on material safety in recycled office furniture, through the tool created by Maaïke Weber and Ruud Balkenende. The central issue is the presence of substances of concern, such as flame retardants and plasticizers, that may remain in recycled materials like plastics, textiles, and foams. These substances can pose health risks during a product's lifecycle, in this case office furniture, since these are used intensively for long periods the materials can be damaged exposing these substances to users or recyclers.

The project is carried out in collaboration with NPK design. NPK has developed a circular office chair using pure recycled plastics. However, the safety of its recyclability, particularly when made from recycled foam or textiles, remains uncertain. This project builds upon their existing work by investigating the presence and impact of substances of concern throughout the tool of the TU Delft and the practices of the industry.

The main stakeholders in this project are NPK design, office furniture manufacturers, material suppliers, office workers as end-users, and researchers from TU Delft like Maaïke Weber and Ruud Balkenende. Their interests include product performance, user health and comfort, environmental responsibility, and compliance with circular economic principles.

The project offers opportunities to address these interests by redesigning materials or components to reduce health risks, improving disassembly for easier recycling, and integrating transparent information about material safety. At the same time, limitations include the unknown composition of some recycled materials, the constraints of existing product architectures, and the absence of standardized methods to assess chemical safety in circular design.

introduction (continued): space for images



image / figure 1 **Recycled foam**



image / figure 2 **Sustainable chair from NPK**

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.

(max 200 words)

The problem is the uncertainty surrounding the presence and risks of substances of concern (SoCs) in office furniture, particularly in recycled plastics, textiles, and foams. Current circular furniture solutions often lack a thorough chemical safety assessment, posing potential health risks and undermining trust in recycled materials. I will identify the most relevant SoCs in office furniture, map where and how they occur, and determine the key decision points and stakeholders influencing their use. This will involve speaking with designers and companies in the industry to understand current practices and supply chain flows also at the end of life of a product. Using the preliminary design tool developed by TU Delft, combined with lifecycle analysis, I will assess several chair models. The findings will be translated into a redesigned component or feature for a circular chair that reduces SoC risks while maintaining circularity and cost-effectiveness. The added value lies in delivering both a tangible outcome, a well-designed, safe, and sustainable chair. And a refined, designer-friendly tool accessible to professionals without a deep scientific background. This will strengthen NPK's leadership in sustainable design, validate TU Delft's tool in real-world conditions, and offer the wider furniture industry a credible blueprint for safer circular products.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for.

Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)

As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Design a circular and safe office chair that enhances understanding of substances of concern in furniture design, while advancing circular design practices through the application and further development of the tool provided by TU Delft.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

I will approach this project using a traditional design process and through the method developed by Ruud and Maaïke. Starting with research and exploration. This includes literature research, interviews with experts and professionals from NPK, and other furniture companies, and studying and further developing the TU Delft design tool. I will collect various office chair models to perform material analyses and lifecycle assessments, identifying substances of concern and critical decision points.

Insights from this research will guide the design phase, where I will iterate from sketches and rough prototypes to a final concept. And further developing the tool of the TU. The design will be developed into a functional prototype, accompanied by CAD models, renders, and animations to communicate the concept effectively. Finally, I aim to create a digital showcase demonstrating the practical application of the TU Delft tool, providing designers with an example of how to integrate material and chemical safety into circular furniture projects.

